AP® Physics 1: Algebra-Based 2015 Free-Response Questions

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AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant, $k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9$ N•m^2/C^2
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Speed of light, $c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2

UNIT SYMBOLS	meter,	m	kelvin,	K	watt,	W	degree Celsius, °C
	kilogram,	kg	hertz,	Hz	coulomb,	C	
	second,	s	newton,	N	volt,	V	
	ampere,	A	joule,	J	ohm,	Ω	

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$|\vec{F}_f| \le \mu |\vec{F}_n|$

$a_c = \frac{v^2}{r}$

$\vec{p} = m\vec{v}$

$\Delta \vec{p} = \vec{F} \Delta t$

$K = \frac{1}{2} m v^2$

$\Delta E = W = F_{\|} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(2\pi f t)$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp} F = r F \sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$|\vec{F}_s| = k|\vec{x}|$

$U_s = \frac{1}{2} k x^2$

$\rho = \frac{m}{V}$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$\Delta U_g = mg\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$|\vec{F}_g| = G\frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY

$|\vec{F}_E| = k\left|\frac{q_1 q_2}{r^2}\right|$

$I = \frac{\Delta q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$I = \frac{\Delta V}{R}$

$P = I\,\Delta V$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

A = area
F = force
I = current
ℓ = length
P = power
q = charge
R = resistance
r = separation
t = time
V = electric potential
ρ = resistivity

WAVES

$\lambda = \frac{v}{f}$

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2} bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

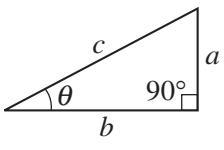
Rectangular solid
$V = \ell w h$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r \ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

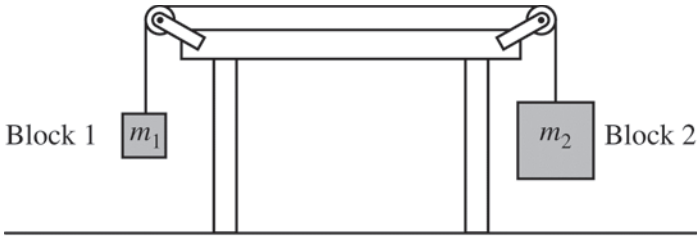
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



PHYSICS 1
Section II
5 Questions
Time—90 minutes

Directions: Questions 1, 4 and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

   Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

   (a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.

   Block 1 Block 2

   (b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

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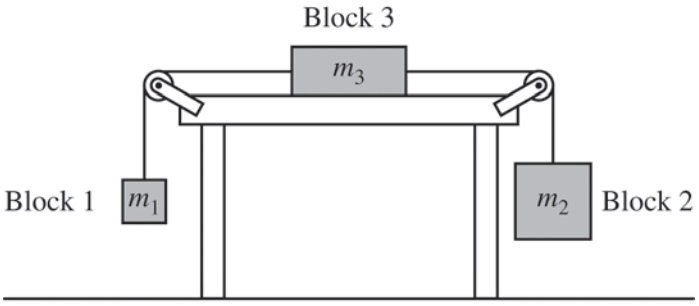
Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

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2. (12 points, suggested time 25 minutes)

Some students want to know what gets used up in an incandescent lightbulb when it is in series with a resistor: current, energy, or both. They come up with the following two questions.

(1) In one second, do fewer electrons leave the bulb than enter the bulb?
(2) Does the electric potential energy of electrons change while inside the bulb?

The students have an adjustable power source, insulated wire, lightbulbs, resistors, switches, voltmeters, ammeters, and other standard lab equipment. Assume that the power supply and voltmeters are marked in 0.1 V increments and the ammeters are marked in 0.01 A increments.

(a) Describe an experimental procedure that could be used to answer questions (1) and (2) above. In your description, state the measurements you would make and how you would use the equipment to make them. Include a neat, labeled diagram of your setup.

(b)
i. Explain how data from the experiment you described can be used to answer question (1) above.
ii. Explain how data from the experiment you described can be used to answer question (2) above.

A lightbulb is nonohmic if its resistance changes as a function of current. Your setup from part (a) is to be used or modified to determine whether the lightbulb is nonohmic.

(c)
i. How, if at all, does the setup need to be modified?
ii. What additional data, if any, would need to be collected?

(d) How would you analyze the data to determine whether the bulb is nonohmic? Include a discussion of how the uncertainties in the voltmeters and ammeters would affect your argument for concluding whether the resistor is nonohmic.

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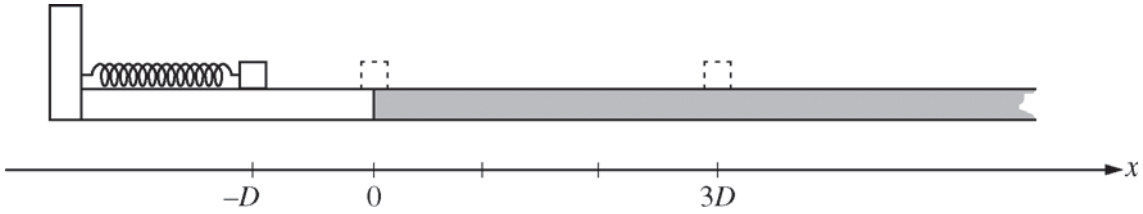


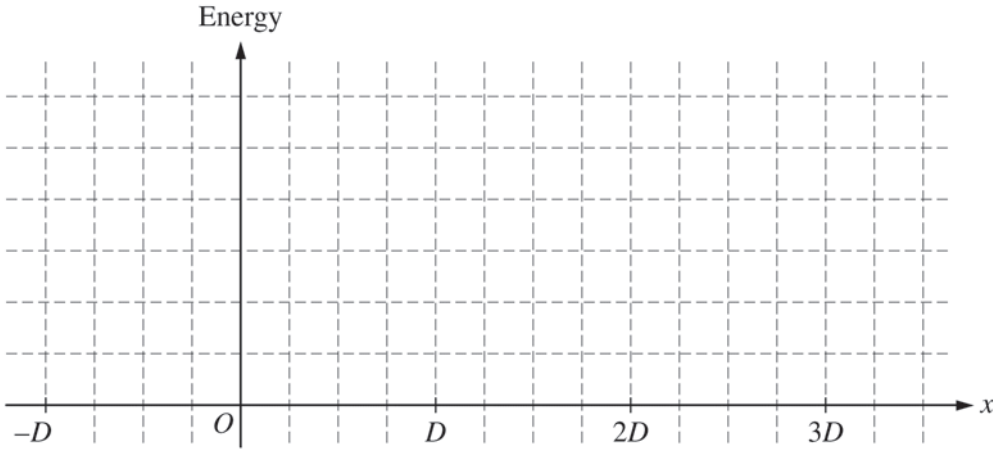
3. (12 points, suggested time 25 minutes)

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

ii. The potential energy U of the block-spring system



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The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

(b)

i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.

ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.

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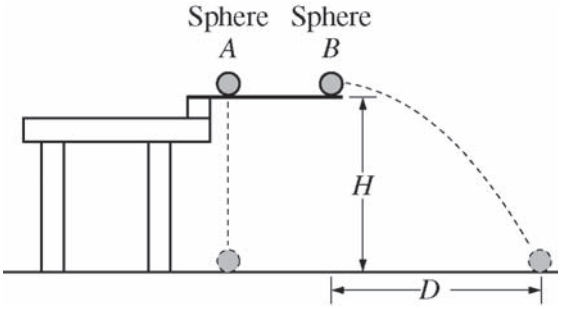
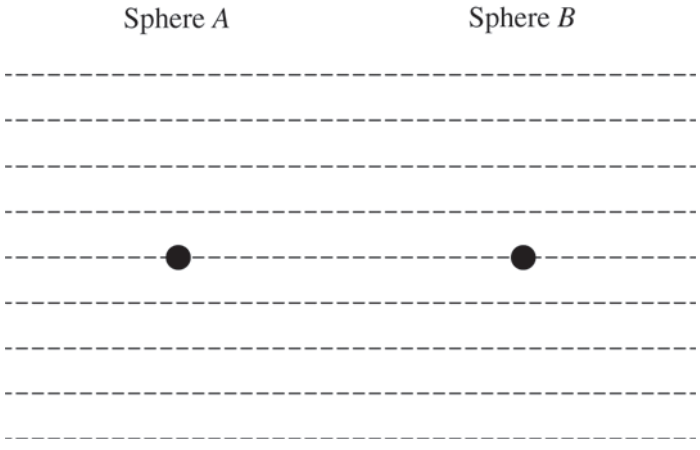


4. (7 points, suggested time 13 minutes)

Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.



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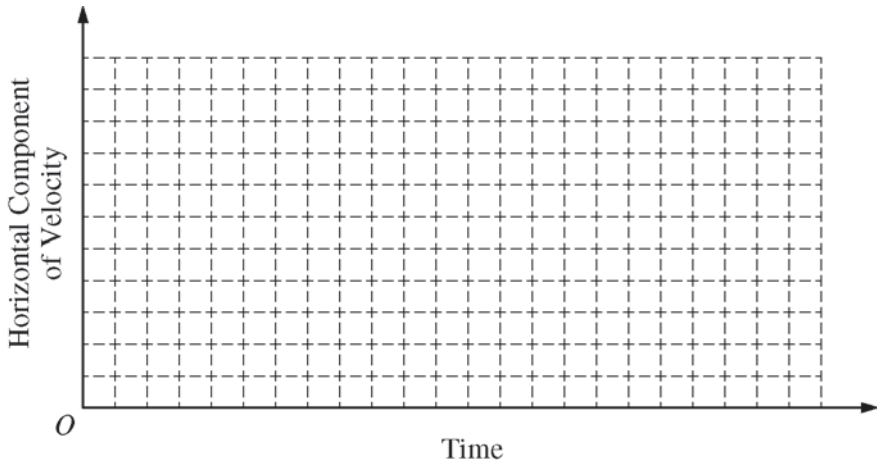
(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.



(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

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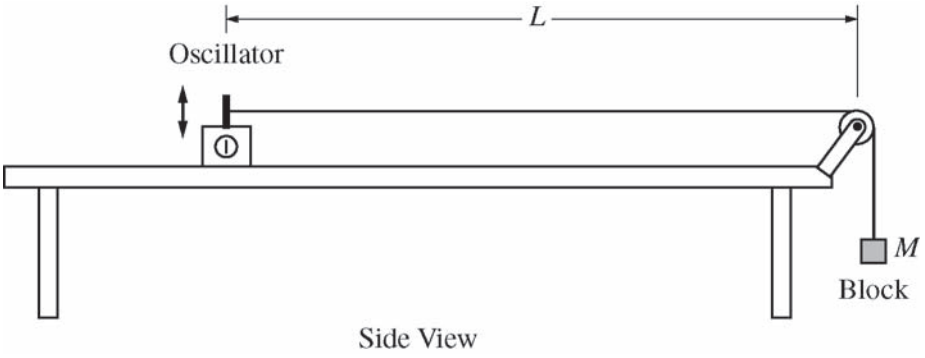
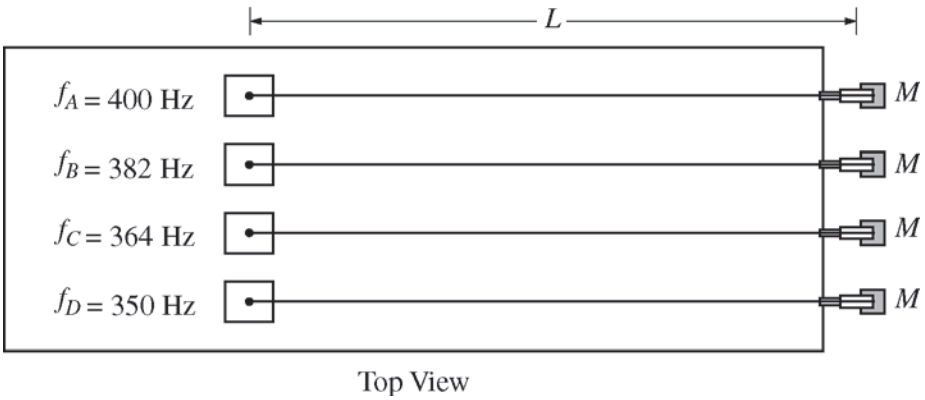


5. (7 points, suggested time 13 minutes)

The figure above shows a string with one end attached to an oscillator and the other end attached to a block. The string passes over a massless pulley that turns with negligible friction. Four such strings, A, B, C, and D, are set up side by side, as shown in the diagram below. Each oscillator is adjusted to vibrate the string at its fundamental frequency f. The distance between each oscillator and pulley L is the same, and the mass M of each block is the same. However, the fundamental frequency of each string is different.



The equation for the velocity v of a wave on a string is $v = \sqrt{\frac{F_T}{m/L}}$, where F_T is the tension of the string and m/L is the mass per unit length (linear mass density) of the string.

(a) What is different about the four strings shown above that would result in their having different fundamental frequencies? Explain how you arrived at your answer.

(b) A student graphs frequency as a function of the inverse of the linear mass density. Will the graph be linear? Explain how you arrived at your answer.

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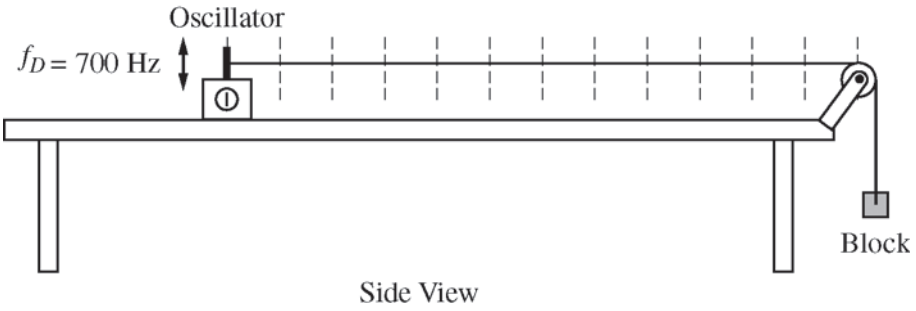
(c) The frequency of the oscillator connected to string D is changed so that the string vibrates in its second harmonic. On the side view of string D below, mark and label the points on the string that have the greatest average vertical speed.



STOP

END OF EXAM

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AP® Physics 1
2015 Scoring Guidelines

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AP® PHYSICS 1
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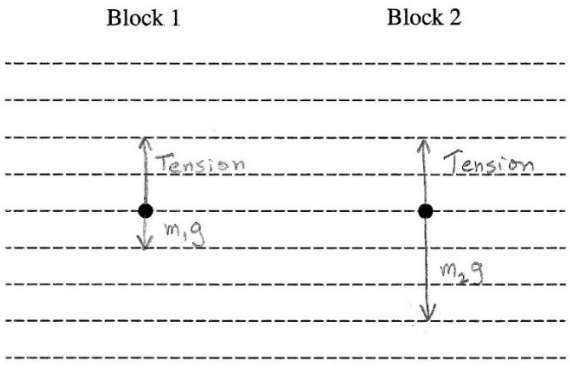
Question 1

7 points total **Distribution of points**

(a) 2 points



For drawing two vectors starting on the dots that point upward, have the same length and are labeled as the tension force — 1 point

For drawing two vectors starting on the dots that point downward, where the vector for block 1 is smaller than the vector for block 2 and both are labeled as the gravitational force — 1 point

One earned point is deducted for drawing any extraneous vectors.

One earned point is deducted for vector lengths that do not allow the system to accelerate in the proper direction.

(b) 3 points

For writing an equation for Newton's second law for block 1 — 1 point

$m_1a = T - m_1g$

For writing an equation for Newton's second law for block 2 — 1 point

$m_2a = m_2g - T$

For eliminating T to obtain an equation that can be solved for the acceleration — 1 point

$T = m_1a + m_1g$

$m_2a = m_2g - m_1a - m_1g$

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

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Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution — *Alternate points*

The system of two blocks must move as a unit, so the acceleration of the system is the acceleration of block 2.

For writing an equation showing that the net force acting on the system is the difference in masses times the acceleration of gravity — *1 point*

$F_{net} = (m_2 - m_1)g$

For writing an equation that relates the net force to the sum of the masses and the acceleration of the system — *1 point*

$F_{net} = (m_2 + m_1)a$

For writing an equation that can be solved for the acceleration in terms of the variables used in the summation of forces equations — *1 point*

$(m_2 + m_1)a = (m_2 - m_1)g$

$a = (m_2 - m_1)g/(m_2 + m_1)$

(c) 2 points

The acceleration of the new system, and thus of block 2, is smaller.

For indicating that the mass of the system is larger — 1 point

For a clear indication that the tension on block 2 is greater — 1 point

Alternate solution — *Alternate points*

For indicating that the mass of the system is larger — *1 point*

For indicating that the net force exerted on the system stays the same — *1 point*

Notes:

No points are earned for a correct prediction without a reasonable attempt at an explanation.

No points are earned for an incorrect prediction, regardless of the explanation.

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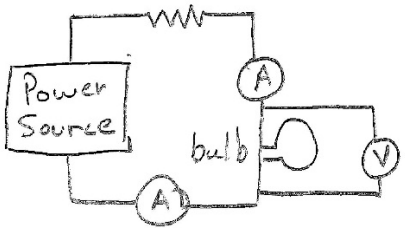
Question 2

12 points total **Distribution of points**

(a) 5 points



For drawing a circuit in which the power source, resistor, and bulb are wired in series — 1 point

For connecting at least one ammeter in series with the bulb — 1 point

For connecting the voltmeter across the bulb in parallel — 1 point

For describing measurements that can plausibly be used to answer question 1 — 1 point

Example: Measure the current entering and leaving the bulb with ammeters connected in series on either side of the bulb.

For describing measurements that can plausibly be used to answer question 2 — 1 point

Example: Measure the potential difference across the bulb with a voltmeter connected in parallel with the bulb.

The response does not need to mention multiple measurements.

(b)

(i) 1 point

For describing an analytical method of using the data, and explaining how that analytical method can be used to answer question 1 — 1 point

Example: If the current is the same on both sides of the bulb, then the number of electrons per second entering and leaving the bulb is the same.

(ii) 1 point

For describing an analytical method of using the data, and explaining how that analytical approach can be used to answer question 2 — 1 point

Example: If the potential difference across the bulb is not zero, then electrons that leave the bulb have different electric potential energy than electrons that enter it.

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Question 2 (continued)

Distribution of points

(c)

(i) 1 point

For any of the following: 1 point
- Describing any changes to the circuit needed to have a setup that can plausibly be used to determine whether the bulb's resistance is constant as a function of current.
- Describing changes to a circuit that are not needed but do not impair the ability to determine whether the bulb's resistance is constant as a function of current.
- Correctly indicating that no changes are needed.

Example based on circuit diagram in part (a): Remove one of the ammeters.

(ii) 1 point

For describing any additional measurements needed to determine whether current varies linearly as a function of voltage, or indicating that none are needed if the appropriate multiple measurements are mentioned in part (a) or (c)(i) 1 point

Example: Measure the current through the bulb and the potential difference across the bulb for multiple settings of the power source.

(d) 3 points

For describing an analytical method in which data are represented or manipulated in some way that can plausibly be used to determine whether current varies linearly as a function of potential difference 1 point

Examples:
- Graphing measurements of current as a function of potential difference
- Calculating the ratio of current to potential difference for multiple settings of the power source

For identifying that linearity is the relevant feature for determining whether the bulb is ohmic 1 point

Examples:
- Evaluating whether a plot of current as a function of voltage is linear
- Evaluating whether the ratio of current to potential difference is constant

For describing a strategy for evaluating whether the conclusion of linearity is valid for a given data set taking into account the meter uncertainties 1 point

Examples:
- Drawing error boxes that represent the uncertainties of the meters around each point and evaluating whether a straight line can be drawn that goes through all the error boxes.
- Indicating that small differences in the ratios could be due to uncertainty in the meters and would not discount the conclusion that the bulb is ohmic

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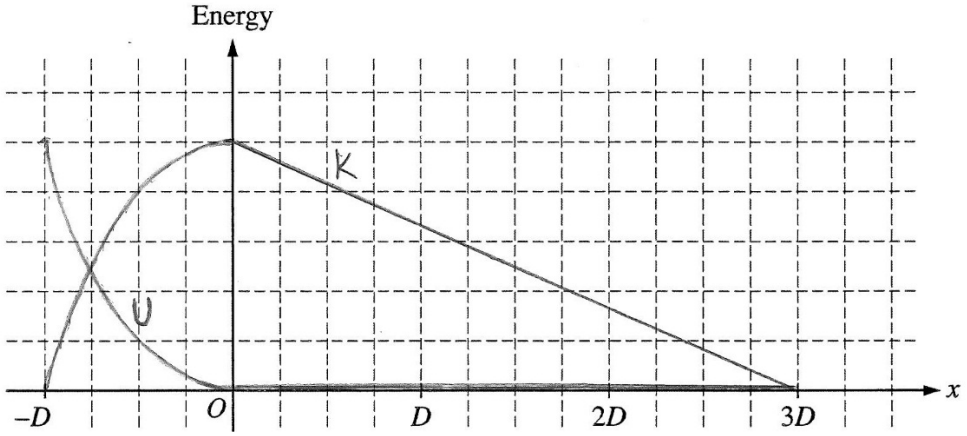
Question 3

12 points total **Distribution of points**

(a) 4 points



For sketching either energy curve with a reasonably correct shape between $x = -D$ and $x = 0$, with zero and maximum values at the correct locations — 1 point

For sketching two curves from $x = -D$ to $x = 0$ with shapes and values such that the total energy is constant (even if the curves are incorrect) — 1 point

For sketching potential energy equal to zero from $x = 0$ to $x = 3D$ — 1 point

For sketching kinetic energy as a linear function from its maximum value at $x = 0$ to zero at $x = 3D$ — 1 point

(b)

(i) 1 point

For identifying that the student is correct that the block will have more energy when it leaves the spring — 1 point

(ii) 1 point

For identifying that the student is incorrect about the new final position of the block because the spring's energy does not scale linearly with its compression — 1 point

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Question 3 (continued)

Distribution of points

(c) 3 points

For indicating that the final energy in the spring (which becomes the mechanical energy of the block as it reaches the rough track) is four times the original energy in the spring — 1 point

For indicating that the frictional force remains the same — 1 point

For equating the initial energy in the spring to an expression that shows that the energy dissipated by friction is proportional to the distance the block slides down the rough track — 1 point

Example:

$U_1 = \frac{1}{2}kD^2$ and $U_2 = \frac{1}{2}k(2D)^2$ so $U_2 = 4U_1$

$W_1 = \mu mg(3D)$ and $W_2 = \mu mg\Delta x_2$

$W_1 = U_1$ and $W_2 = U_2 = 4U_1 = 4W_1$

$\mu mg\Delta x_2 = 4(\mu mg(3D))$

$\Delta x_2 = 4(3D) = 12D$

(d) 3 points

For indicating that the student's correct reasoning that the block has more energy in the second situation is expressed by the calculations comparing the initial energy in the spring — 1 point

For indicating that the student's correct reasoning that the block will slide farther is expressed by an equation that indicates that the work done by friction to stop the block in the second situation is some factor greater than the work done in the first situation — 1 point

For indicating that the student's incorrect reasoning that energy scales linearly with the spring's compression is corrected by the expression for the initial energy of the spring — 1 point

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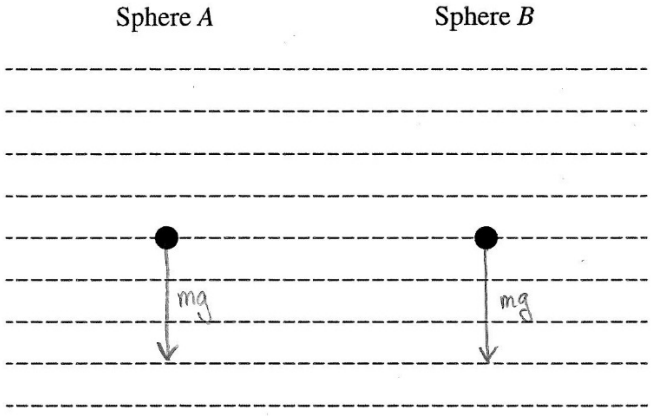
AP® PHYSICS 1
2015 SCORING GUIDELINES

Question 4

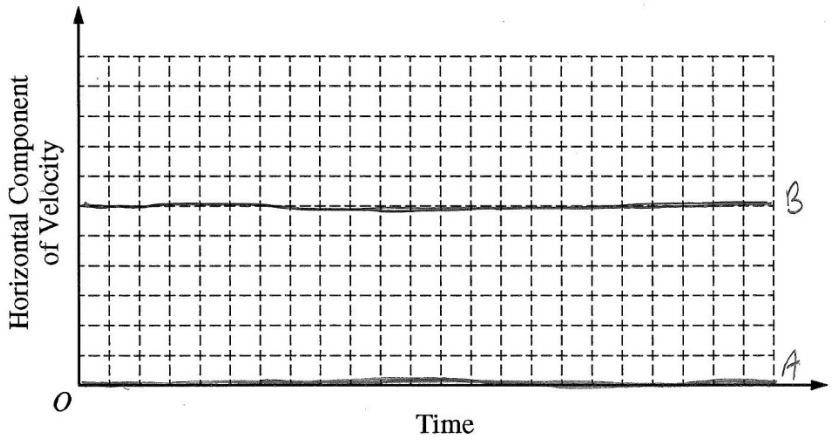
7 points total **Distribution of points**

(a) 1 point



For sketching only one force pointing straight down from each sphere and indicating that this force represents the force of gravity — 1 point

(b) 1 point



For sketching a horizontal line at zero velocity for sphere *A*, and sketching a horizontal line at some non-zero velocity for sphere *B* — 1 point

(c) 5 points

For indicating that the difference in horizontal motion does not affect the vertical motion of the spheres — 1 point
For indicating that both spheres start with the same vertical velocity — 1 point
For indicating that both spheres have the same vertical acceleration — 1 point
For indicating that falling the same height would take the same time — 1 point
For no incorrect or irrelevant statements — 1 point

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2015 SCORING GUIDELINES

Question 5

7 points total **Distribution of points**

(a) 3 points

For reasoning that since the strings all have the same length, and since the wavelength of the fundamental depends on the length, all four waves have the same wavelength (e.g., $\lambda_1 = 2L$) — 1 point

For reasoning that since the wavelengths are all the same, different frequencies correspond to different velocities of the waves on the strings — 1 point

For reasoning that all the string tensions are the same due to the same mass M of each block, and therefore the linear mass densities must be different for different velocities since $v = \sqrt{F_T/(m/L)}$ (or since the vertical component of the tension will result in different vertical accelerations for strings with different masses) — 1 point

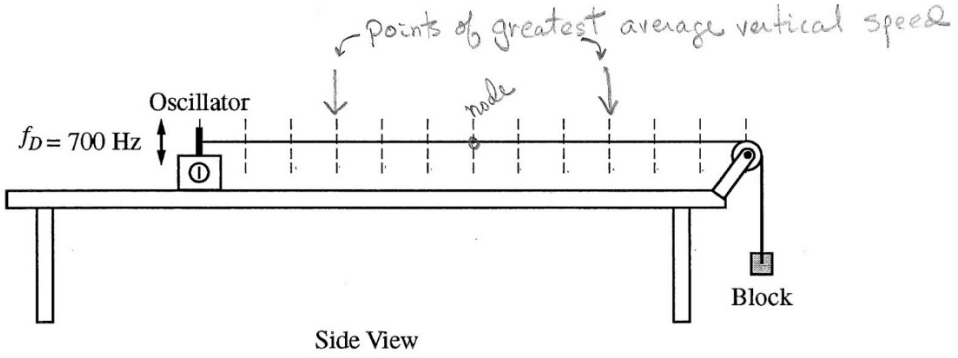
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(b) 2 points

For combining $v = f\lambda$ with $v = \sqrt{F_T/(m/L)}$ (or referring to such an equation written in part (a)) — 1 point

For indicating how the equation leads to the conclusion that frequency would not be proportional to the inverse of the linear mass density — 1 point

(c) 2 points



For any indication of the second harmonic on the string, or a wave drawn such that $\lambda_2 = L$. — 1 point

For points which are at the antinodes of the second harmonic, or at the antinodes of any standing wave drawn on the string — 1 point

Notes:

Full credit is earned for having two points that are located one fourth the length of the string and three fourths the length of the string from the oscillator.

One earned point is deducted for each incorrect point marked on the figure

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AP® Physics 2
2015 Scoring Guidelines

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AP® PHYSICS 2
2015 SCORING GUIDELINES

Question 1

10 points total | **Distribution of points**

(a) 5 points

For explaining that the light that results in spot X reflects at the glass-liquid interface — 1 point

For explaining that the light that results in spot Y is refracted both as it leaves the glass and reenters the glass (direction of refraction need not be correct) — 1 point

For explaining that the light that results in spot Y is reflected at the liquid-air interface — 1 point

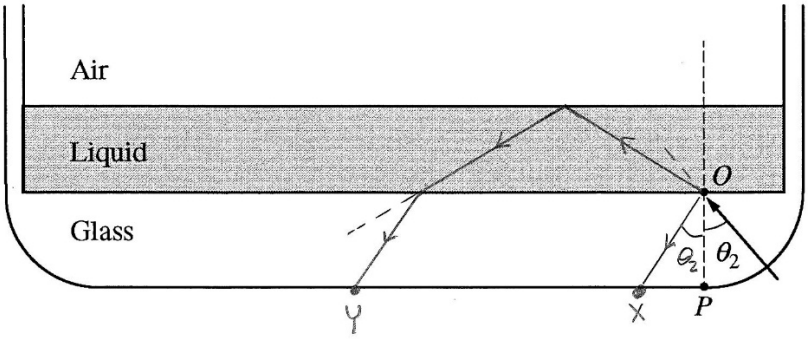
For explaining that Y is farther from P than X in terms of the geometry of the path — 1 point

For explaining that at each interface the brightness is affected by reflection, and by transmission and/or refraction as appropriate — 1 point

Students may reference a diagram to support the reasoning, but it cannot supplant the written reasoning.

(b)

i) 2 points



For drawing a reasonably accurate path for the rays that form spot X — 1 point

For drawing a reasonably accurate path for the rays that form spot Y, including correct directions of refraction, with no rays in the air — 1 point

ii) 1 point

For indicating that Y becomes brighter in terms of the distribution of energy with and without total internal reflection — 1 point

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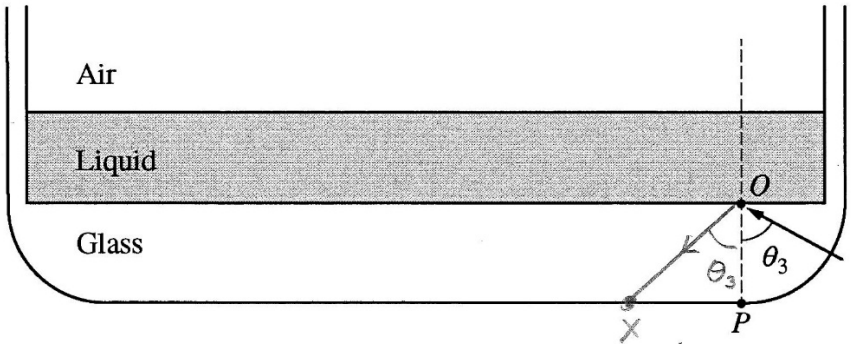
Question 1 (continued)

Distribution of points

(c)

i) 1 point



For drawing rays to show reflection at the glass-liquid interface — 1 point
One point will be deducted for drawing any rays above the glass-liquid interface.

ii) 1 point

For indicating that Y disappears and indicating that total internal reflection takes place at the glass-liquid interface — 1 point

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AP® PHYSICS 2
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Question 2

12 points total | **Distribution of points**

(a)

i) 3 points

For indicating that R_{eq} of the entire circuit or the combination of bulbs 2 and 3 decreases — 1 point

For indicating a change in I_{tot} or the potential difference across bulb 1 consistent with Ohm's law and the change in R_{eq} stated in the response — 1 point

For indicating a change in brightness consistent with the current or potential difference change stated in the response — 1 point

ii) 3 points

For indicating that $P_1 = \frac{1}{4}\left(\mathcal{E}^2/R\right)$ — 1 point

For indicating that the new equivalent resistance of the circuit is $R_{eq,new} = (3/2)R$ — 1 point

Note: Credit is earned if calculation is done in part (i) and used here.

For manipulating equations to show that the power expended by bulb 1 is $P_{new} = \frac{16}{9}P_1$ — 1 point

iii) 1 point

For using or referring to the expression from part (a)(ii) to support the claim made in (a)(i) regarding the brightness of bulb 1: e.g., $16/9 > 1$, and indicating an understanding that brightness is related to power consumption — 1 point

(b)

i) 1 point

For explaining that the brightness of bulb 2 decreases after the switch is closed because it expends less power (or the current through bulb 2 decreases, or the potential difference across bulb 2 decreases) — 1 point

ii) 1 point

For a calculation that supports the reasoning in part i — 1 point

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Question 2 (continued)

Distribution of points

(c) 3 points

For indicating in either part (c)i or part (c)ii that brightness is dependent on potential difference across the bulb OR on current through the bulb — 1 point

i)

For a reasonable explanation for why bulb 1 is brighter than bulb 2 — 1 point
Example: Immediately after the switch is closed, the potential difference across the capacitor will be zero (like a short in the circuit), so the current through bulb 2 would be zero, which is less than the current through bulb 1.
Note: No points will be awarded for indicating that bulb1 is brighter than bulb 2 with no justification.

ii)

For a reasonable explanation for why bulb 1 is the same brightness as bulb 2 — 1 point
Example: The current through bulb 2 increases as the potential difference across the capacitor increases (becomes like an open circuit), so a long time after the switch is closed, the current through bulb 2 will be equal to the full current through bulb 1.
Note: No points will be awarded for indicating that bulb 1 is the same brightness as bulb 2 without a justification.

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AP® PHYSICS 2
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Question 3

12 points total **Distribution of points**

(a) 2 points

For indicating that the ideal gas law ($PV = nRT$ or $PV = NkT$) gives the relevant relationship between pressure and temperature of a gas and attempting to use it to support some reasoning — 1 point

For indicating that the volume and number of moles (or particles) of gas are held constant — 1 point

Note: The student will not be penalized for not specifying that pressure and temperature are only directly proportional when the temperature is measured in Kelvin.

Alternate Solution *Alternate Points*

For indicating that the density of a sample of gas increases as its temperature decreases (if the pressure and number of moles or molecules of gas are held constant), and a sample of denser gas will sink below samples of gas that are less dense — *1 point*

For indicating that the gas near the North Pole is not a closed system and its pressure will increase as additional sinking gas molecules are added to it — *1 point*

(b) 4 points

For selecting one of the cylinders and indicating or implying that volume is held constant — 1 point

For selecting all the equipment described in the procedure and no extraneous equipment — 1 point

For describing a method of measuring the temperature of the enclosed gas — 1 point

For describing a method for measuring the pressure at more than just two temperatures — 1 point

Example: Insert the thermometer and pressure sensor in the gasket to measure the gas temperature and pressure. Place the cylinder in the bath with hot (cold) water. Take measurements periodically as the bath water cools (heats) over time.

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Question 3 (continued)

Distribution of points

(c) 2 points

For selecting a set of trials in which volume is held constant and explaining that the volume must be held constant to test the relationship between pressure and temperature — 1 point

For selecting trials in which volume is $5.0\ \text{cm}^3$, and explaining that there are the most trials for this volume, and the most trials will result in the most reliable test — 1 point

Alternate Solution — *Alternate points*

For selecting the full set of trials and explaining that the effect of changing volume on the relationship between pressure and temperature can be taken into account by multiplying pressure by volume (or plotting P/T as a function of $1/V$, etc.) — *1 point*

For explaining that selecting the most trials will result in the most reliable test OR that selecting the widest range of pressure values will result in the most precise determination of the proportionality constant relating pressure and temperature — *1 point*

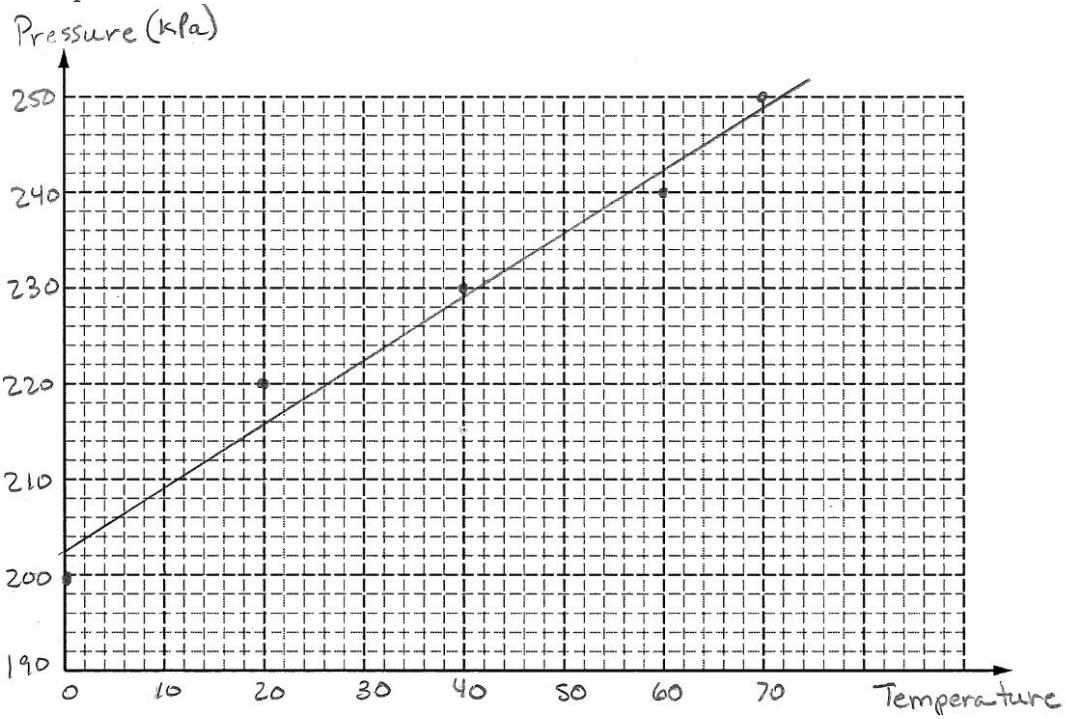
(d) 3 points

For plotting P as a function of T (or T as a function of $1/P$, etc.) OR plotting PV as a function of T (or P as a function of V/T, etc.) for each trial selected in part (c) — 1 point

For appropriate axis labels with units and appropriate scales — 1 point

For drawing an appropriate best-fit line or curve — 1 point

Example:



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Question 3 (continued)

Distribution of points

(e) 1 point

For correctly describing the relationship depicted in part (d) 1 point
Examples:

The relationship between P and T is linear.

The relationship between P and V/T is hyperbolic.

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AP® PHYSICS 2
2015 SCORING GUIDELINES

Question 4

10 points total **Distribution of points**

(a) 2 points

The top plate is negative.
For relating the direction of force or acceleration to the direction of the field 1 point
For relating the direction of the electric field to the sign of the charge on the top plate 1 point
No points are awarded for identifying that the top plate is negative with no attempt to explain why.

(b) 4 points

For using an appropriate kinematic relation to determine the acceleration of the electron while it is between the plates 1 point

$a = (v_f - v_i)/t$

For using Newton's second law to determine an expression for the magnitude of the force needed to give the electron the calculated acceleration 1 point

$F = ma = m(v_f - v_i)/t$

For setting eE equal to the force calculated from Newton's second law 1 point
For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units 1 point

$E = m(v_f - v_i)/et$

$$E = \frac{(9.11 \times 10^{-31}\ \text{kg})(8.02 \times 10^{6}\ \text{m/s} - 5.40 \times 10^{6}\ \text{m/s})}{(1.6 \times 10^{-19}\ \text{C})(1.49 \times 10^{-9}\text{s})} = 10{,}000\ \text{N/C}$$

Alternate Solution *Alternate Points*

For applying conservation of energy for the time the electron is between the plates *1 point*

$\Delta K = \Delta U$

For using the correct relationship between potential energy and potential difference *1 point*

$\Delta U = e\,\Delta V$

$$\frac{1}{2}m_e(v_f^2 - v_i^2) = e\,\Delta V$$

For using the relation between potential difference, electric field, and plate separation *1 point*

$\Delta V = Ed$

$$\frac{1}{2}m_e(v_f^2 - v_i^2) = eEd$$

For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units *1 point*

$E = m_e(v_f^2 - v_i^2)/2ed$

$$E = \frac{(9.11 \times 10^{-31})\left((8.02 \times 10^{6}\ \text{m/s})^2 - (5.40 \times 10^{6}\ \text{m/s})^2\right)}{2(1.6 \times 10^{-19}\ \text{C})(0.010\ \text{m})} = 10{,}000\ \text{N/C}$$

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Question 4 (continued)

Distribution of points

(c) 1 point

$E = Q/\varepsilon_0 A$

$Q = \varepsilon_0 AE$

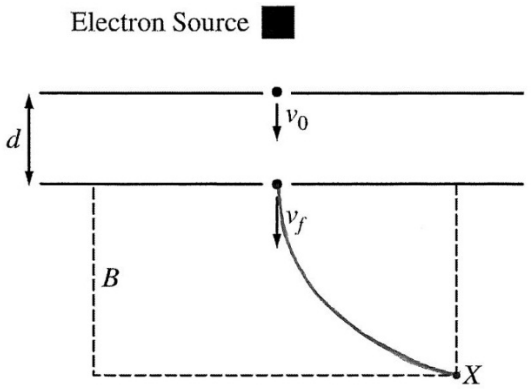
For correct substitution of values into the equation to calculate the magnitude of charge on each parallel plate — 1 point

$Q = \left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(0.25\ \text{m}^2\right)(10{,}000\ \text{N/C})$

$Q = 2.2 \times 10^{-8}\ \text{C}$

(d)

i. 2 points



Note: Figure not drawn to scale.

For drawing a reasonably circular path from the point where the electrons leave the bottom plate to point X — 1 point

Note: There is no penalty for starting the path at the tip of the arrow.

For explaining that the field is always perpendicular to the velocity, so the force is also always perpendicular to the velocity which creates a curved (circular) path — 1 point

ii. 1 point

In order for the electron to reach point X, the magnetic field must exert a centripetal force on the electron toward the top right corner of the dashed box.

For using the right hand rule and reasoning that the force on a negatively charged object is in the opposite direction from the force exerted on a positively charged object (or using the "left hand rule") to conclude that the direction of the magnetic field is directed out of the page — 1 point

Notes:

No points are awarded for identifying that the direction of the magnetic field is out of the page without explaining why.

Credit can be earned for a correct analysis at any individual point on the path.

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AP® Physics 2: Algebra-Based 2015 Free-Response Questions

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AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. In all situations, positive work is defined as work done on a system.
III. The direction of current is conventional current: the direction in which positive charge would drift.
IV. Assume all batteries and meters are ideal unless otherwise stated.
V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.
VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object

AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$

$a_c = \frac{v^2}{r}$

$\vec{p} = m\vec{v}$

$\Delta \vec{p} = \vec{F}\,\Delta t$

$K = \frac{1}{2} m v^2$

$\Delta E = W = F_{\|} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_\perp F = rF\sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$\left|\vec{F}_s\right| = k|\vec{x}|$

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

$U_s = \frac{1}{2} k x^2$

$\Delta U_g = mg\,\Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$\left|\vec{E}\right| = \left|\frac{\Delta V}{\Delta r}\right|$

$\Delta V = \frac{Q}{C}$

$C = \kappa\varepsilon_0 \frac{A}{d}$

$E = \frac{Q}{\varepsilon_0 A}$

$U_C = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$

$I = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho \ell}{A}$

$P = I\,\Delta V$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

$\vec{F}_M = q\vec{v} \times \vec{B}$

$\left|\vec{F}_M\right| = |q\vec{v}||\sin\theta|\left|\vec{B}\right|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$\left|\vec{F}_M\right| = \left|I\vec{\ell}\right||\sin\theta|\left|\vec{B}\right|$

$\Phi_B = \vec{B} \bullet \vec{A}$

$\Phi_B = \left|\vec{B}\right|\cos\theta\left|\vec{A}\right|$

$\mathcal{E} = -\frac{\Delta \Phi_B}{\Delta t}$

$\mathcal{E} = B\ell v$

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = \frac{m}{V}$

$P = \frac{F}{A}$

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho {v_1}^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho {v_2}^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

MODERN PHYSICS

$E = hf$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\lambda = \frac{v}{f}$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

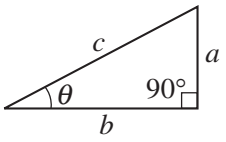
Rectangular solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

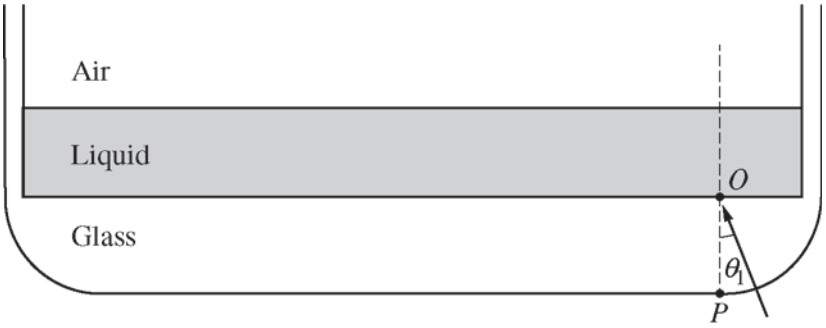
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



PHYSICS 2
Section II
4 Questions
Time—90 minutes

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (10 points - suggested time 20 minutes)

   The figure above shows a cross section of a drinking glass (index of refraction 1.52) filled with a thin layer of liquid (index of refraction 1.33). The bottom corners of the glass are circular arcs, with the bottom right arc centered at point O. A monochromatic light source placed to the right of point P shines a beam aimed at point O at an angle of incidence θ. The flat bottom surface of the glass containing point P is frosted so that bright spots appear where light from the beam strikes the bottom surface and does not reflect. When $\theta = \theta_1$, two bright spots appear on the bottom surface of the glass. The spot closer to point P will be referred to as X; the spot farther from P will be referred to as Y. The location of spot X and that of spot Y both change as θ is increased.

   (a) In a coherent paragraph-length answer, describe the processes involved in the formation of spots X and Y when $\theta = \theta_1$. Include an explanation of why spot Y is located farther from point P than spot X is and what factors affect the brightness of the spots.

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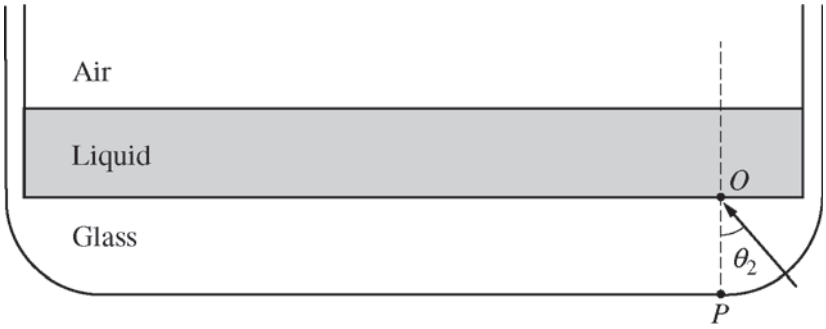
(b) When θ is increased to θ_2, one of the spots becomes brighter than it was before, due to total internal reflection.

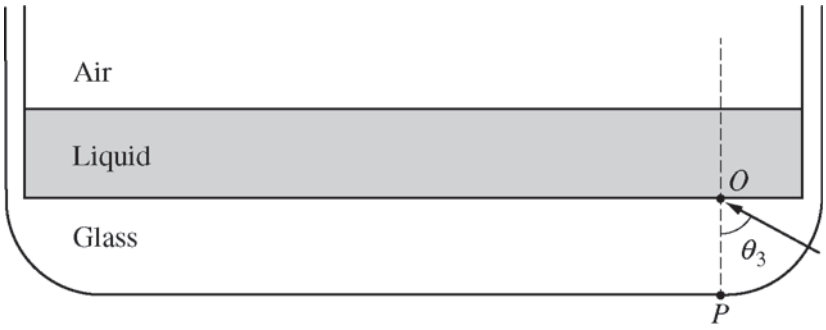
i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of spots X and Y when $\theta = \theta_2$.



ii. Which spot, X or Y, becomes brighter than it was before due to total internal reflection? Explain your reasoning.

(c) When θ is further increased to θ_3, one of the spots disappears entirely.

i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of the remaining spot, X or Y, when $\theta = \theta_3$.



ii. Indicate which spot, X or Y, disappears. Explain your reasoning in terms of total internal reflection.

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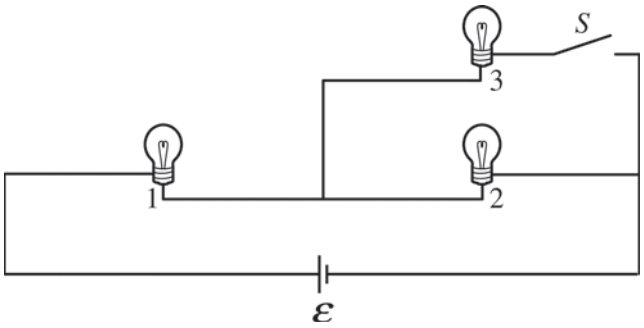

2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

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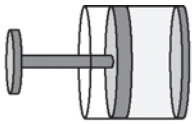
3. (12 points, suggested time 25 minutes)

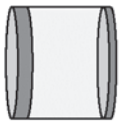
Students are watching a science program about the North Pole. The narrator says that cold air sinking near the North Pole causes high air pressure. Based on the narrator's statement, a student makes the following claim: "Since cold air near the North Pole is at high pressure, temperature and pressure must be inversely related."

(a) Do you agree or disagree with the student's claim about the relationship between pressure and temperature? Justify your answer.

After hearing the student's hypothesis, you want to design an experiment to investigate the relationship between temperature and pressure for a fixed amount of gas. The following equipment is available.



Cylinder with Movable Piston



Cylinder with Fixed Lid

___ A cylinder with a movable piston, shown above on the left
___ A cylinder with a fixed lid, shown above on the right
Note: The two cylinders have gaskets through which measurement instruments can be inserted without gas escaping.
___ A pressure sensor
___ A basin that is large enough to hold either cylinder with a lot of extra room
___ A source of hot water
___ A source of mixed ice and water
___ A meterstick
___ A thermometer
___ A stopwatch

(b) Put a check in the blank next to each of the items above that you would need for your investigation. Outline the experimental procedure you would use to gather the necessary data. Make sure the outline contains sufficient detail so that another student could follow your procedure.

The table below shows data from a different experiment in which the volume, temperature, and pressure of a sample of gas are varied.

Trial Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Volume $\left(\text{cm}^3\right)$	10.0	5.0	4.0	3.0	5.0	4.0	10.0	5.0	3.0	4.0	5.0	10.0	3.0	5.0
Pressure (kPa)	100	200	250	330	220	270	110	230	380	290	240	120	420	250
Temperature (°C)	0	0	0	0	20	20	20	40	40	40	60	60	70	70

(c) What subset of the experimental trials would be most useful in creating a graph to determine the relationship between temperature and pressure for a fixed amount of gas? Explain why the trials you selected are most useful.

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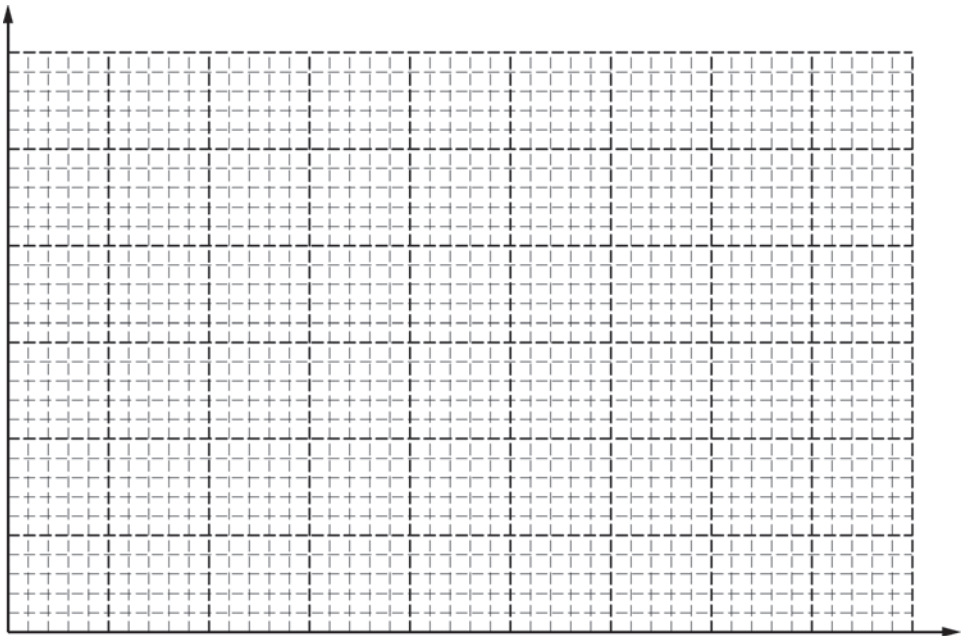
(d) Plot the subset of data chosen in part (c) on the axes below. Be sure to label the axes appropriately. Draw a curve or line that best represents the relationship between the variables.



(e) What can be concluded from your curve or line about the relationship between temperature and pressure?

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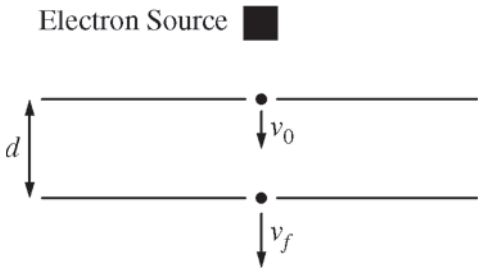

Note: Figure not drawn to scale.

4. (10 points - suggested time 20 minutes)

The apparatus shown in the figure above consists of two oppositely charged parallel conducting plates, each with area $A = 0.25\ \text{m}^2$, separated by a distance $d = 0.010\ \text{m}$. Each plate has a hole at its center through which electrons can pass. High velocity electrons produced by an electron source enter the top plate with speed $v_0 = 5.40 \times 10^6\ \text{m/s}$, take $1.49\ \text{ns}$ to travel between the plates, and leave the bottom plate with speed $v_f = 8.02 \times 10^6\ \text{m/s}$.

(a) Which of the plates, top or bottom, is negatively charged? Support your answer with a reference to the direction of the electric field between the plates.

(b) Calculate the magnitude of the electric field between the plates.

(c) Calculate the magnitude of the charge on each plate.

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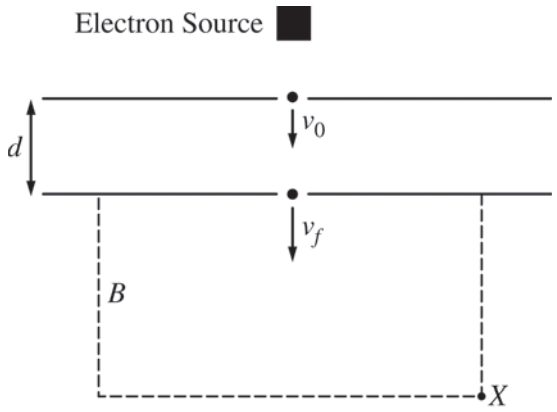
(d) The electrons leave the bottom plate and enter the region inside the dashed box shown below, which contains a uniform magnetic field of magnitude B that is perpendicular to the page. The electrons then leave the magnetic field at point X.



Note: Figure not drawn to scale.

i. On the figure above, sketch the path of the electrons from the bottom plate to point X. Explain why the path has the shape that you sketched.

ii. Indicate whether the magnetic field is directed into the page or out of the page. Briefly explain your choice.

STOP

END OF EXAM

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AP® Physics B
2014 Free-Response Questions

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TABLE OF INFORMATION, EFFECTIVE 2012

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS, EFFECTIVE 2012

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{kq_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{kq_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + ...\right)$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + ...$

$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$

$R_s = R_1 + R_2 + R_3 + ...$

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA \cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS, EFFECTIVE 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

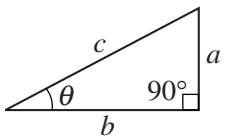
$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Rectangular Solid
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

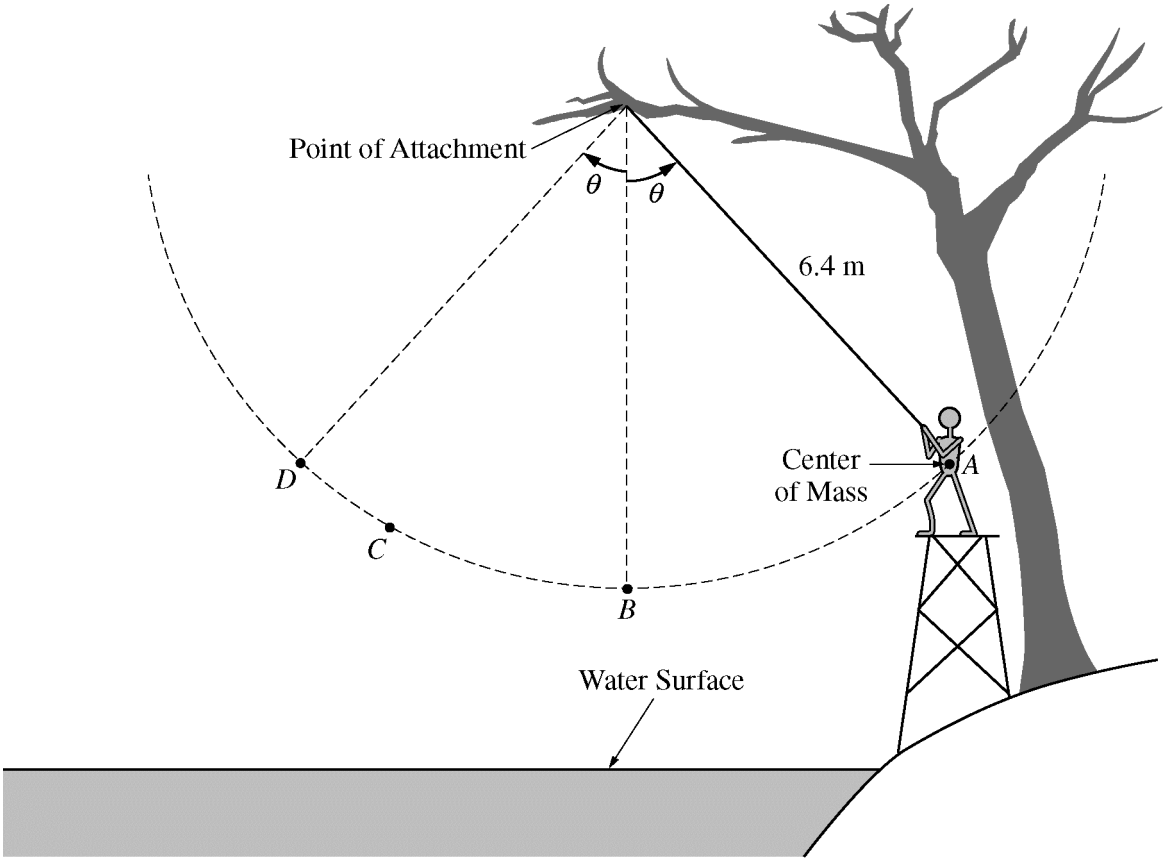
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1 and 5, and about 11 minutes for answering each of Questions 2-4 and 6-7. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. (15 points)

Starting from rest at point *A*, a 50 kg person swings along a circular arc from a rope attached to a tree branch over a lake, as shown in the figure above. Point *D* is at the same height as point *A*. The distance from the point of attachment to the center of mass of the person is 6.4 m. Ignore air resistance and the mass and elasticity of the rope.

(a) The person swings two times, each time letting go of the rope at a different point.

i. On the first swing, the person lets go of the rope when first arriving at point *C*. Draw a <u>solid</u> line to represent the trajectory of the center of mass after the person releases the rope.

ii. A second time, the person lets go of the rope at point *D*. Draw a <u>dashed</u> line to represent the trajectory of the center of mass after the person releases the rope.

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(b) The center of mass of the person standing on the platform is at point *A*, 4.1 m above the surface of the water. Calculate the gravitational potential energy when the person is at point *A* relative to when the person is at the surface of the water.

(c) The center of mass of the person at point *B*, the lowest point along the arc, is 2.4 m above the surface of the water. Calculate the person's speed at point *B*.

(d) Suppose that the person swings from the rope a third time, letting go of the rope at point *B*. Calculate *R*, the horizontal distance moved from where the person releases the rope at point *B* to where the person hits the water.

(e) If the person does not let go of the rope, how does the magnitude of the person's momentum p_C at point *C* compare with the magnitude of the person's momentum p_B at point *B* ?

____ $p_C > p_B$ ____ $p_C < p_B$ ____ $p_C = p_B$

Provide a physical explanation to justify your answer.

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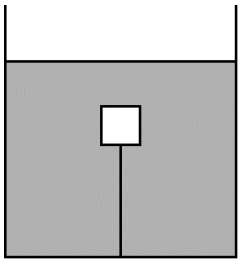

2. (10 points)

A cube of mass m and side length L is completely submerged in a tank of water and is attached to the bottom of the tank by a string, as shown in the figure above. The tension in the string is 0.25 times the weight of the cube. The density of water is 1000 kg/m^3.

(a) On the dot below that represents the cube, draw and label the forces (not components) that act on the cube while it is attached to the string. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(b) Calculate the density of the cube.

(c) The string is now cut. Calculate the magnitude of the acceleration of the cube immediately after the string is cut. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

(d) Indicate whether the magnitude of the buoyant force on the cube increases, decreases, or remains the same while the cube is rising, but before it reaches the surface.

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

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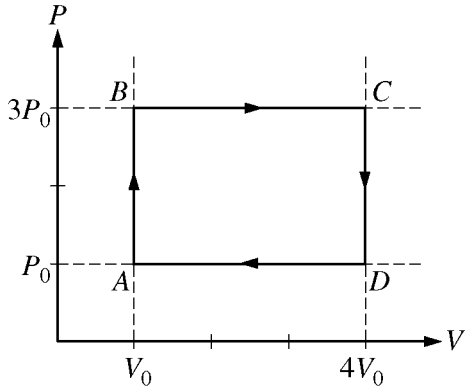

3. (10 points)

A sample containing three moles of an ideal gas is taken through a series of equilibrium states, as represented by the closed path *ABCDA* in the diagram above.

(a)

i. Rank the temperatures at the 4 labeled points from least to greatest, using 1 for the lowest temperature. If two or more points have the same temperature, give them the same ranking.

____ *A* ____ *B* ____ *C* ____ *D*

ii. Determine the temperature T_D at point *D* in terms of P_0, V_0, and fundamental constants, as appropriate.

(b) Indicate all segments of the path *ABCDA*, if any, for which the work done <u>by</u> the gas is positive. If the work done by the gas is not positive for any of the segments, then check "None".

____ *AB* ____ *BC* ____ *CD* ____ *DA* ____ None

Justify your answer.

(c) In process *AB*, is the energy transferred to the gas by heating positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

(d) Derive an expression for the net work done <u>on</u> the gas during the entire process *ABCDA*. Express your answer in terms of P_0, V_0, and fundamental constants, as appropriate.

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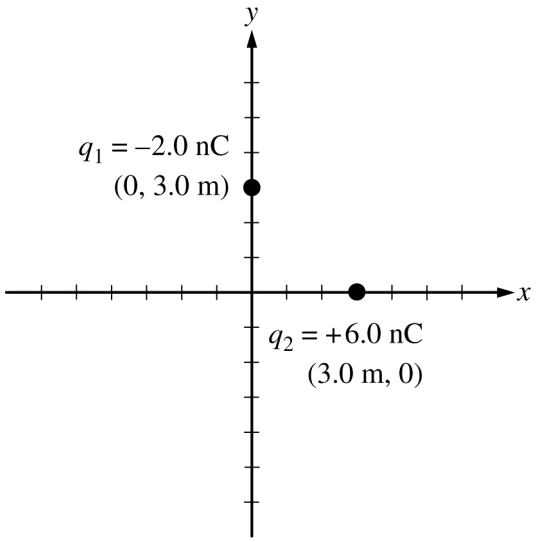
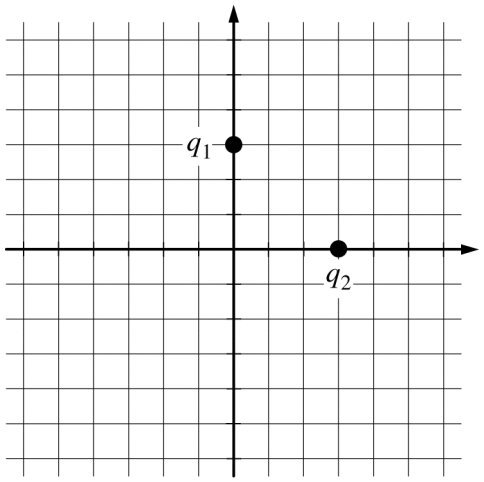


4. (10 points)

Two point charges are fixed at the coordinates shown in the diagram above. The charges are $q_1 = -2.0$ nC and $q_2 = +6.0$ nC.

(a) Calculate the magnitudes of the x and y components of the net electric field at the origin (0, 0).

(b) On the diagram below, draw a single vector (not components) originating at the origin (0,0) to represent the direction of the net electric field at that point.



(c) Calculate the electric potential at the origin (0, 0).

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A third charge, $q_3 = +3.0$ nC, is moved by an external force from very far away to the origin. The third charge has the same speed at the start and end of the motion.

(d) Indicate whether the total work done by the external force is positive, negative, or zero.

____ Positive ____ Negative ____ Zero

Justify your answer.

(e) Calculate the magnitude of the net force on q_3 due to the other two charges when q_3 is at the origin.

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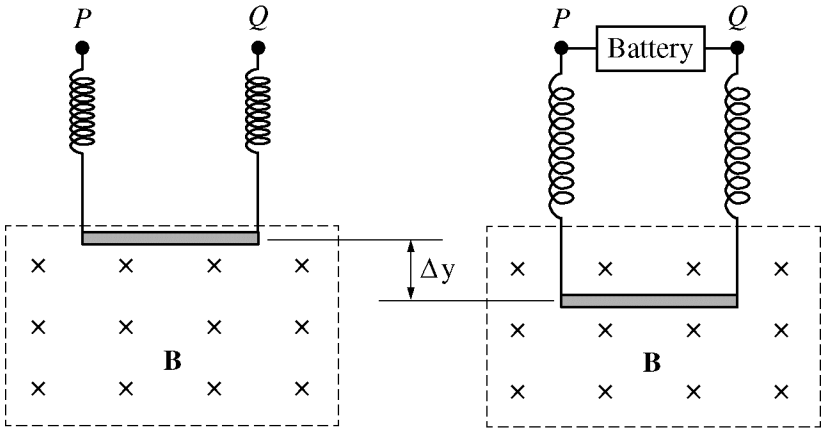

5. (15 points)

A conducting rod of mass m and length L hangs at rest from two identical conducting springs, each with spring constant k, as shown in the figure at left above. The upper ends of the springs are fixed at points P and Q, and the rod is in a uniform magnetic field **B** directed into the page. A battery is then connected between points P and Q, as shown in the figure at right above, resulting in a current I in the rod. The rod is displaced downward, eventually reaching a new equilibrium position with the springs stretched an additional distance Δy.

(a) Which point, P or Q, is connected to the positive terminal of the battery?

____ P ____ Q

Justify your answer.

(b) On the dot below that represents the rod, draw and label the forces (not components) that act on the rod in its new equilibrium position. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

(c) Derive an expression for Δy in terms of k, m, L, I, the magnetic field strength B, and fundamental constants, as appropriate.

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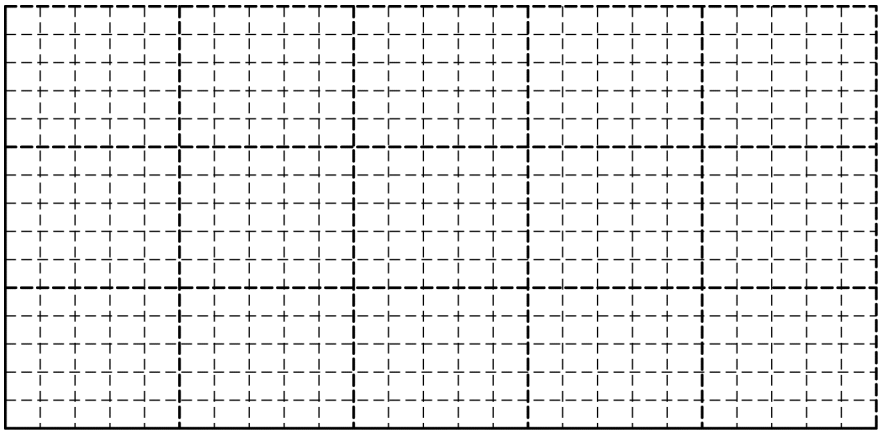
An experiment is conducted with batteries of different emf connected between points P and Q. The current I in the rod and the stretch of the springs Δy are measured and recorded in the table below.

I (amperes)	Δy (meters)
1.0	0.0028
2.0	0.0050
3.0	0.0084
4.0	0.0119
5.0	0.0140

(d) On the grid below, plot the data points for Δy as a function of I. Be sure to label your axes with variables, units, and scale. Draw a straight line that best represents the data.



(e) Using the straight line you drew in part (d), calculate the value B for the magnetic field if m is 0.019 kg, L is 0.35 m, and k is 25 N/m.

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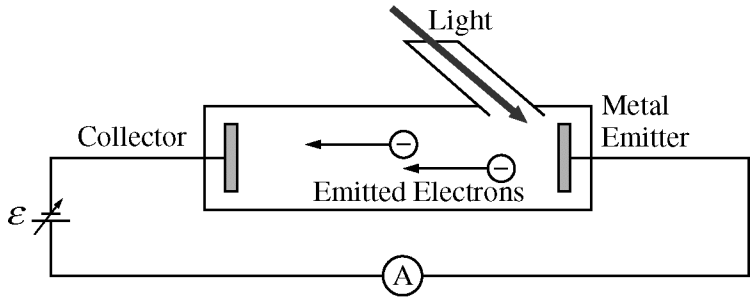

6. (10 points)

The apparatus shown above is used in determining the work function of a particular metal using the photoelectric effect. The experiment is set up with an ammeter A and a variable power supply. A light source that emits photons of frequency 7.5×10^{14} Hz is used. The emf $\mathcal{E}$ provided by the power supply is slowly increased from zero until the ammeter shows that the current between the collector and metal emitter is zero. The magnitude of the emf is 0.65 V when the current becomes zero.

(a) Determine the wavelength of the incident photons.

(b) Calculate the work function of the metal.

(c) Calculate the minimum frequency of light at which electrons would be emitted.

(d) If the power per unit area (intensity) of the incident light is increased and the wavelength stays the same, does the magnitude of the emf needed to stop the current increase, decrease, or remain the same?

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

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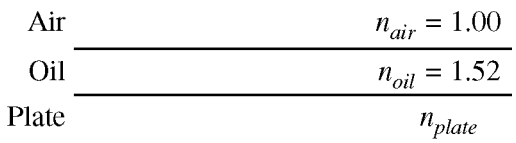

Note: Figure not drawn to scale.

7. (10 points)

A thin layer of transparent oil is placed on top of a transparent plate. The oil film is then illuminated by white light shining onto the oil's surface, as shown in the figure above. To an observer standing right next to the light source and looking straight down on the oil film, the oil film appears green, corresponding to a wavelength of 520 nm in air. The oil has an index of refraction of 1.52.

(a) Determine the frequency of the green light in the air.

(b) Determine the frequency of the green light in the oil film.

(c) Calculate the wavelength of the green light in the oil film.

(d) The oil film thickness is half of the wavelength you found in part (c). Is the index of refraction of the plate greater than, less than, or equal to that of the oil?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

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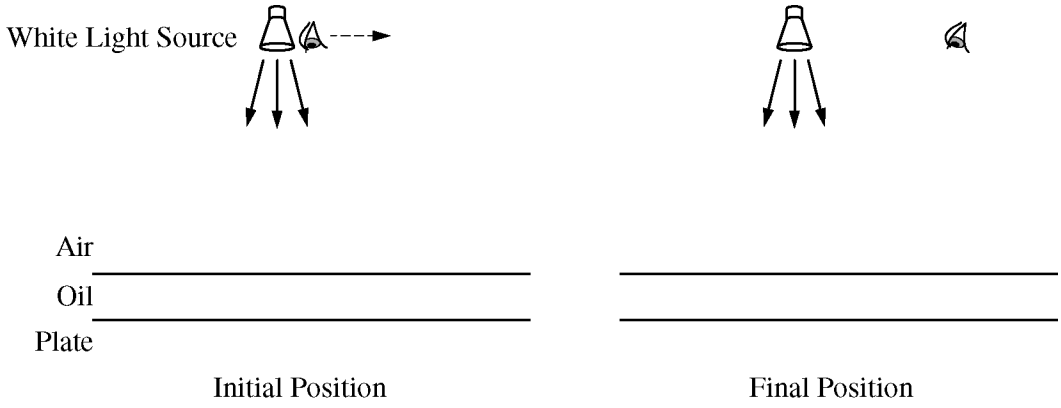

Note: Figure not drawn to scale.

(e) As the observer starts moving to the right away from the light source, as shown in the figures above, the film appears to change color. Describe the color change and give an explanation for this phenomenon.

STOP

END OF EXAM

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AP® Physics B
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AP® PHYSICS B
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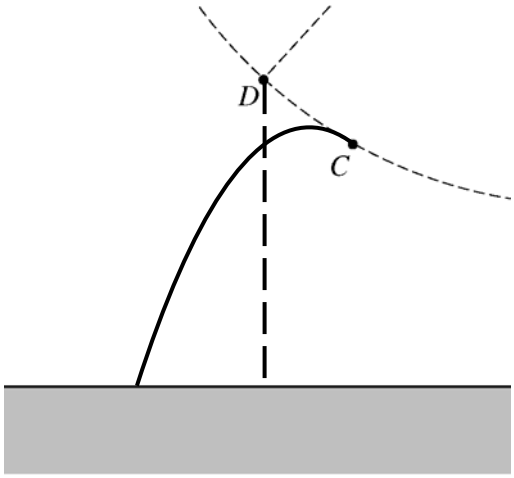
Question 1

15 points total **Distribution of points**

(a) 3 points



For showing a parabolic path from point C that is tangent to the arc at C 1 point
For a maximum height of the parabolic path that is lower than point D 1 point
For showing the person traveling straight downward from point D 1 point
Note: the two paths may, but need not, cross each other.

(b) 2 points

For using the gravitational potential energy equation 1 point

$\Delta U_g = mgh = (50\text{ kg})\left(9.8\text{ m/s}^2\right)(4.1\text{ m})$

For a correct answer 1 point

$\Delta U_g = 2010\text{ J}$ (or 2050 J using $g = 10\text{ m/s}^2$)

(c) 3 points

For using an expression of conservation of energy 1 point

$U_{g1} = U_{g2} + K_2$

$mgh_1 = mgh_2 + \frac{1}{2}mv^2$

For correctly substituting values 1 point

$gh_1 = gh_2 + \frac{1}{2}v^2$

$v = \sqrt{2g(h_1 - h_2)}$

$v = \sqrt{2\left(9.8\text{ m/s}^2\right)(4.1\text{ m} - 2.4\text{ m})}$

For a correct answer 1 point

$v = 5.8\text{ m/s}$

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Question 1 (continued)

Distribution of points

(d) 3 points

For using a correct expression to solve for the time of fall 1 point

$\Delta y = v_0 t + \frac{1}{2} a t^2$

For correctly solving for the time of fall 1 point

$\Delta y = \frac{1}{2} a t^2$

$t = \sqrt{\frac{2\Delta y}{a}}$

$t = \sqrt{\frac{2(2.4\text{ m})}{(9.8\text{ m/s}^2)}}$

$t = 0.70\text{ s}$ (or 0.69 s using $g = 10\text{ m/s}^2$)

In the horizontal direction, the acceleration is zero.

$R = v_x t$

For substituting the speed from part (c) into the constant-velocity equation for horizontal motion 1 point

$R = (5.8\text{ m/s})(0.70\text{ s})$

$R = 4.1\text{ m}$ (or 4.0 m using either unrounded speed of 5.77 m/s or $g = 10\text{ m/s}^2$)

Units 1 point

For correct units in the calculated answers to parts (b), (c), and (d) 1 point

(e) 3 points

For selecting "$p_C < p_B$" 1 point

For any indication that the speed at C is less than the speed at B 1 point

For an explanation of why the speed decreases from B to C, which includes the following or equivalent statements: 1 point

by conservation of energy: U increases as the person moves from B to C, therefore K decreases, resulting in a decrease in speed
OR
gravitational force opposes motion as the person moves from B to C, which results in a negative acceleration and a decrease in speed
OR
by the impulse-momentum theorem: momentum decreases because the force of gravity provides impulse opposing the motion of the person

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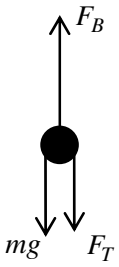
Question 2

10 points total **Distribution of points**

(a) 2 points



For showing the three force vectors for buoyancy, weight (gravity), and tension 1 point
For showing all the forces labeled and in the correct direction 1 point
One point is deducted if either or both of the following occur:

- Any other forces are indicated
- Any vector does not both touch and point away from the dot

(b) 3 points

For using Newton's second law to sum the forces in the vertical direction 1 point

$F_B - F_T - F_g = 0$

$F_B = F_g + F_T$

For equating the buoyant force with the weight of displaced water, and expressing this weight in terms of density, volume, and g 1 point

$F_B = F_g + 0.25F_g = 1.25F_g$

$\rho_W V_{\text{cube}} g = 1.25mg$

$\left(1000\ \text{kg}/\text{m}^3\right)V_{\text{cube}} = 1.25m$

For solving the equation to get a correct answer with units 1 point

$\left(1000\ \text{kg}/\text{m}^3\right)/1.25 = m/V_{\text{cube}}$

$800\ \text{kg}/\text{m}^3 = \rho_{\text{cube}}$

Alternate solution *Alternate Points*

Answer based on direct comparison of densities of water and the cube: since the buoyant force on the cube only depends on the density of water, and the net downward force only depends on the density of the cube, the ratio of densities can be determined.

For correctly substituting density and mass and determining the ratio of densities *2 points*

$\rho_W V g = mg + 0.25mg$

$\rho_W V = 1.25m$

$\rho_W = 1.25\rho_{\text{cube}}$

Note: 2 points will be awarded for correctly writing down the ratio of the densities even without showing any work

For the correct answer *1 point*

$\rho_{\text{cube}} = \rho_W/1.25 = \left(1000\ \text{kg}/\text{m}^3\right)/1.25 = 800\ \text{kg}/\text{m}^3$

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Question 2 (continued)

Distribution of points

(c) 3 points

For any use of Newton's second law to sum the forces in the vertical direction 1 point

$F_{net} = ma = F_B - F_g$

For correct substitution 1 point

$ma = 1.25F_g - F_g = 0.25mg$

$a = 0.25g$

OR

$F_B = \rho_W g V = \rho_W g\left(\frac{m}{\rho_{\text{cube}}}\right)$

$F_B = \left(1000 \text{ kg/m}^3\right)(g)\left(\frac{m}{800 \text{ kg/m}^3}\right)$, or ρ_{cube} consistent with answer from (b)

$$a = \frac{F_B - F_g}{m} = \frac{\left(1000 \text{ kg/m}^3\right)(g)\left(\frac{m}{800 \text{ kg/m}^3}\right) - mg}{m} = \left(\frac{1000}{800}\right)g - g$$

For calculating a correct answer, with units 1 point

$a = 2.5 \text{ m/s}^2$

(d) 2 points

For selecting "Remains the same" 1 point

For providing a correct explanation 1 point

Example:

F_B relates to density, volume, and g, none of which change.

Note: If the wrong choice is selected, the explanation is not considered and no points are awarded.

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Question 3

10 points total **Distribution of points**

(a)

i. 2 points

For correctly ranking all 4 labeled points 2 points

$\underline{1}\,A \quad \underline{2}\,B \quad \underline{4}\,C \quad \underline{3}\,D$

Note: one point is earned for a ranking that identifies A and C as having the lowest and highest temperatures, respectively, but incorrectly ranks B and D. For example:

$\underline{1}\,A \quad \underline{3}\,B \quad \underline{4}\,C \quad \underline{2}\,D$ or $\underline{1}\,A \quad \underline{2}\,B \quad \underline{3}\,C \quad \underline{2}\,D$

A and C cannot have the same ranking as other points (e.g., $\underline{1}\,A \quad \underline{1}\,B \quad \underline{2}\,C \quad \underline{2}\,D$)

ii. 1 point

For using the ideal gas law with correct substitutions for P, V, and n to get the correct answer 1 point

$PV = nRT$

$T = \dfrac{PV}{nR}$

$T_D = \dfrac{P_0(4V_0)}{3R} = \dfrac{4P_0V_0}{3R}$ or $\dfrac{4P_0V_0}{(3\text{ mol})\bullet R}$

Note: mole units need not be explicitly stated

(b) 2 points

For selecting "BC" only 1 point

For providing a correct explanation 1 point

Examples:

- For the gas to do positive work on its surroundings (or for work done on the gas to be negative), $P\Delta V$ must be positive so ΔV must be positive.
- An expanding gas exerts a force in the direction of motion, doing positive work.

(c) 2 points

"Positive" is the only box checked for which the Justify section will be read

For a correct explanation that mentions internal energy increases with the temperature increase. 1 point

For a correct explanation that mentions the work is zero 1 point

Example:

The volume does not change in process AB, hence the work done is zero. The temperature increase in AB means the internal energy increases. Since the work done is zero, the positive change in internal energy must be provided by heating.

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Question 3 (continued)

	Distribution of points
(d) 3 points	
For a correct expression of net work done on the gas from segments *BC* and *DA* of the graph $W_{net} = -(P\Delta V)_{BC} - (P\Delta V)_{DA}$	1 point
For correctly substituting the values of *P* and ΔV into the above equation $W_{net} = -(3P_0)(3V_0) - (P_0)(-3V_0) = -9P_0V_0 + 3P_0V_0 = -6P_0V_0$	1 point
For having a final answer that is negative	1 point
Alternate Solution	*Alternate points*
For a correct expression or statement that the net work done on the gas is given by the area enclosed by the entire path $W_{net} = -(\Delta P \bullet \Delta V)$	*1 point*
For correctly substituting the values of P and ΔV *into the above equation* $W_{net} = -(3P_0 - P_0)\bullet(4V_0 - V_0) = -2P_0 \bullet 3V_0 = -6P_0V_0$	*1 point*
For having a negative answer	*1 point*

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Question 4

10 points total **Distribution of points**

(a) 2 points

For using and substituting values into the equation for the electric field magnitude due to a point charge, for both the *x* and *y* components 1 point

$$E = \frac{kq}{r^2} \quad \text{or} \quad \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$

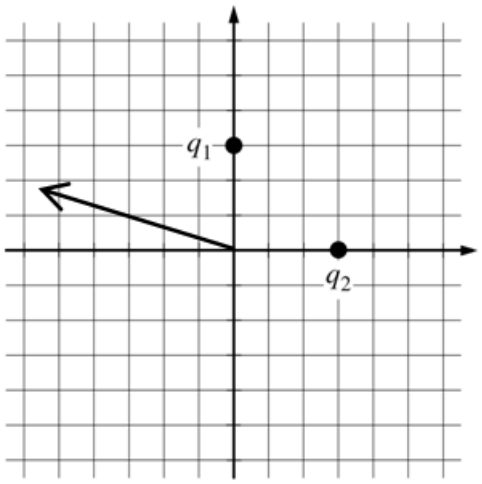
For correctly calculating the x and y component values with units 1 point

$$|E_x| = \frac{\left(9 \times 10^9 \ \text{N•m}^2/\text{C}^2\right)\left(6 \times 10^{-9} \ \text{C}\right)}{(3 \ \text{m})^2} = 6.0 \ \text{N/C} \quad (\text{or V/m})$$

$$|E_y| = \frac{\left(9 \times 10^9 \ \text{N•m}^2/\text{C}^2\right)\left(2 \times 10^{-9} \ \text{C}\right)}{(3 \ \text{m})^2} = 2.0 \ \text{N/C} \quad (\text{or V/m})$$

Note: No points were deducted for omitting absolute-value symbols or showing incorrect signs, since direction is assessed in part (b)

(b) 2 points



For showing the direction of the net electric field in quadrant II 1 point

For showing a direction of the net electric field consistent with the answers to part (a) 1 point

(closer to the *x*-axis than to the *y*-axis if part (a) correctly has $|E_x| > |E_y|$,

or closer to the *y*-axis than to the *x*-axis if part (a) has $|E_y| > |E_x|$,

or at 45 degrees if part (a) has $|E_x| = |E_y|$

Note: The second point could be earned even if the vector was drawn in the wrong quadrant.

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Question 4 (continued)

Distribution of points

(c) 2 points

For using a correct expression for the potential at the origin as a scalar sum — 1 point

$$V = \frac{kq_1}{r_1} + \frac{kq_2}{r_2}$$

$$V = \left(9 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left[\frac{\left(-2 \times 10^{-9} \text{ C}\right)}{(3 \text{ m})} + \frac{\left(6 \times 10^{-9} \text{ C}\right)}{(3 \text{ m})}\right]$$

$$= \left(9 \text{ N•m}^2/\text{C}^2\right)(4 \text{ C})/(3 \text{ m})$$

For correctly calculating the potential, with units — 1 point

$V = 12 \text{ N•m/C}$ (or J/C or V)

(d) 2 points

For selecting "Positive" — 1 point

For providing a correct explanation — 1 point

Example: Since $W = q\Delta V$ and both the charge and potential difference are positive, it takes positive work to move charge q_3 to the origin.

(e) 2 points

For using Coulomb's law for the forces exerted on q_3 due to charges q_1 and q_2
OR — 1 point
For stating the relation between force and electric field components

$F_x = \frac{k|q_2 q_3|}{r^2}$ and $F_y = \frac{k|q_1 q_3|}{r^2}$ OR $F_x = q_3 E_x$ and $F_y = q_3 E_y$

Calculate the components of **F**

$$F_x = \frac{\left(9 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left(6 \times 10^{-9} \text{ C}\right)\left(3 \times 10^{-9} \text{ C}\right)}{3^2 \text{ m}^2} = 18 \times 10^{-9} \text{ N} = 1.8 \times 10^{-8} \text{ N}$$

$$F_y = \frac{\left(9 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left(2 \times 10^{-9} \text{ C}\right)\left(3 \times 10^{-9} \text{ C}\right)}{3^2 \text{ m}^2} = 6.0 \times 10^{-9} \text{ N}$$

OR

$$F_x = q_3 E_x = (6.0 \text{ N/C})\left(3 \times 10^{-9} \text{ C}\right) = 1.8 \times 10^{-8} \text{ N}$$

$$F_y = q_3 E_y = (2.0 \text{ N/C})\left(3 \times 10^{-9} \text{ C}\right) = 6.0 \times 10^{-9} \text{ N}$$

For substituting the calculated components into an expression for the magnitude of **F** — 1 point

$$F = \sqrt{F_x^{\,2} + F_y^{\,2}} = \sqrt{\left(1.8 \times 10^{-8} \text{ N}\right)^2 + \left(6.0 \times 10^{-9} \text{ N}\right)^2}$$

$$= 1.9 \times 10^{-8} \text{ N}$$

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Question 4 (continued)

Distribution of points

(e) (continued)

Alternate Solution *Alternate Points*

For calculating the net electric field as a vector sum of the components calculated in part (a) *1 point*

$$E_{\text{net}} = \sqrt{E_x^{\,2} + E_y^{\,2}} = \sqrt{(6\ \text{N/C})^2 + (2\ \text{N/C})^2} = 6.2\ \text{N/C}$$

For substituting into the relationship between force and electric field and using the value of charge q_3 *1 point*

$$F_{net} = qE_{net} = q_3E = \left(3 \times 10^{-9}\ \text{C}\right)(6.32\ \text{N/C}) = 1.9 \times 10^{-8}\ \text{N}$$

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Question 5

15 points total **Distribution of points**

(a) 2 points

The correct choice is *"Q"*.

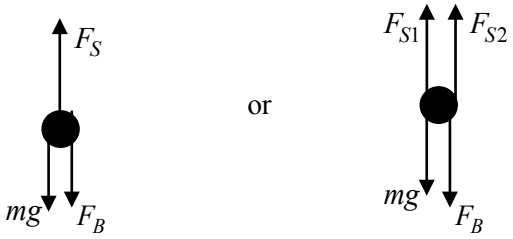
Note: Selecting *"Q"* earned no points, but was required in order to earn credit for a correct justification.

For recognizing that the current must be to the left in the rod (or clockwise in the circuit) 1 point

For a complete explanation with no incorrect statements 1 point

Example: In order to stretch the springs, the magnetic force must be downward. According to the right hand rule, this requires a current to the left in the rod. Therefore, the positive terminal of the battery must be connected to point Q.

(b) 2 points



Note: The spring force may be represented either as a single combined force or as two separate forces due to the two springs.

For the spring force (or forces) drawn upward and properly labeled (with no additional upward forces) 1 point

For the magnetic and gravitational forces drawn downward and properly labeled (with no additional downward forces) 1 point

One earned point is deducted for any of the following:

- Any horizontal forces
- Any vector that is not distinct and/or does not both touch and point away from the dot
- The vectors are not reasonably straight and reasonably vertical

(c) 4 points

For using a correct expression for Newton's second law 1 point

Using a single spring force: $F_S - mg - F_B = 0$ or $F_S = mg + F_B$

Using two spring forces : $F_{S1} + F_{S2} - mg - F_B = 0$ or $F_{S1} + F_{S2} = mg + F_B$

For any recognition, implicit or explicit, that mg is balanced by the original stretch in the springs and ultimately not part of this calculation 1 point

The spring force is $2k\Delta y$. It is not necessary to explicitly show how the original spring force is canceled by mg.

$2k\Delta y = F_B$

For correctly substituting BIL for the magnetic force 1 point

$2k\Delta y = BIL$

For solving for Δy to get a correct answer 1 point

$\Delta y = BIL/2k$

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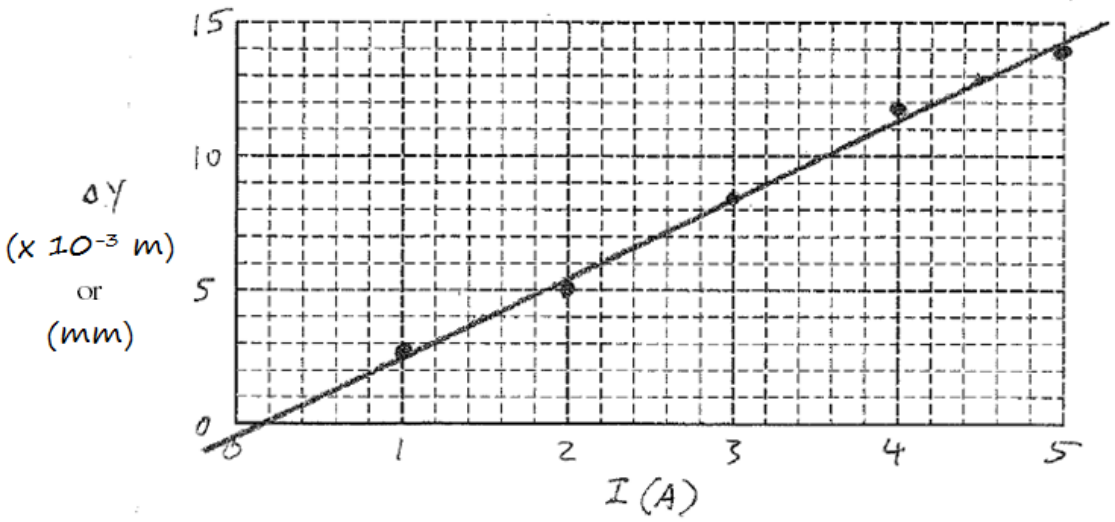
Question 5 (continued)

Distribution of points

(d) 4 points



For correctly labeling both axes with variables and units — 1 point
Note: This point is not earned if axes are labeled with I as a function of Δy.

For using an appropriate linear scale on both axes — 1 point

For correctly plotting the points — 1 point

For drawing a reasonable and straight best fit line for the data — 1 point

Note: The point (0, 0) may be included in the plot without penalty since it is also a data point, though unmeasured and unrecorded.

(e) 3 points

For obtaining a relationship between the slope and the magnetic field B consistent with part (c). — 1 point

From part (c): $\Delta y = \dfrac{BIL}{2k} = \dfrac{BL}{2k} I$

$\text{slope} = \dfrac{BL}{2k}$ so $B = \dfrac{2k \bullet \text{slope}}{L}$

For calculating a slope using *two* points on the line drawn in part (d), including data points *only* if they are on that line — 1 point

Example: Using the two points (5.0 A, 14.2 mm) and (1.2 A, 3.0 mm) that are on the line in the graph above.

$$\text{slope} = \left(\frac{14.2 - 3.0}{5.0 - 1.2}\right) \bullet \frac{10^{-3}\ \text{m}}{\text{A}} = \frac{11.2}{3.8} \times 10^{-3}\ \frac{\text{m}}{\text{A}} = 2.95 \times 10^{-3}\ \frac{\text{m}}{\text{A}}$$

For a substitution of values into the expression for the magnetic field B consistent with part (c) and the calculated slope — 1 point

$$B = \frac{2 \bullet (25\ \text{N/m}) \bullet (2.95 \times 10^{-3}\ \text{m/A})}{0.35\ \text{m}} = 0.42\ \text{N/A} \bullet \text{m} \text{ or } 0.42\ \text{T}$$

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AP® PHYSICS B
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Question 6

10 points total **Distribution of points**

(a) 1 point

For correctly calculating the wavelength, with units 1 point

$c = \lambda f$

$\lambda = \dfrac{c}{f} = \dfrac{\left(3.00 \times 10^{8}\ \text{m/s}\right)}{\left(7.5 \times 10^{14}\ \text{Hz}\right)}$

$\lambda = 4.0 \times 10^{-7}\ \text{m} \quad \text{or} \quad 400\ \text{nm}$

(b) 3 points

For using a correct expression relating frequency f, work function ϕ, and maximum electron kinetic energy $K_{\max}$ 1 point

$K_{\max} = hf - \phi \quad \text{or} \quad \phi = hf - K_{\max}$

For recognizing that the maximum electron kinetic energy is equal to $e\mathcal{E}$. 1 point

$\phi = hf - e\mathcal{E}$

For correctly calculating the answer (with or without the correct units) 1 point

$\phi = \left(4.14 \times 10^{-15}\ \text{eV•s}\right)\left(7.5 \times 10^{14}\ \text{Hz}\right) - e\text{•}(0.65\ \text{V}) = 3.10\ \text{eV} - 0.65\ \text{eV}$

$\phi = 2.45\ \text{eV} \quad \left(\text{or } 3.92 \times 10^{-19}\ \text{J}\right)$

Note: ϕ can also be calculated using $f = c\lambda$ and $hc = 1240\ \text{eV•nm}$

$\phi = hf - K_{\max} = hc/\lambda - K_{\max}$

$= (1240\ \text{eV•nm})/(400\ \text{nm}) - 0.65\ \text{eV}$ (or use wavelength obtained in part (a))

$= 3.10\ \text{eV} - 0.65\ \text{eV}$

$\phi = 2.45\ \text{eV} \quad \left(\text{or } 3.92 \times 10^{-19}\text{J}\right)$

(c) 2 points

For an expression or statement that $K_{\max}$ is zero at the threshold frequency 1 point

$K_{\max} = 0 = hf_0 - \phi$

For correctly substituting the answer from part (b) into a correct expression to calculate the threshold frequency 1 point

$f_0 = \phi/h = (2.45\ \text{eV})/\left(4.14 \times 10^{-15}\ \text{eV•s}\right) \quad \text{or} \quad \left(3.92 \times 10^{-19}\ \text{J}\right)/\left(6.63 \times 10^{-34}\ \text{J•s}\right)$

$f_0 = 5.92 \times 10^{14}\ \text{Hz}$

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Question 6 (continued)

Distribution of points

(c) continued

Alternate solution — *Alternate points*

For using a correct expression containing the threshold frequency — *1 point*

$K_{\max} = h(f - f_0)$

$f_0 = f - (K_{\max}/h)$

Converting from eV to joules and substituting values

$K_{\max} = (0.65 \text{ eV})\left(1.60 \times 10^{-19} \text{ J/eV}\right) = 1.04 \times 10^{-19} \text{ J}$

$f_0 = 7.5 \times 10^{14} \text{ Hz} - \left(1.04 \times 10^{-19} \text{ J} / 6.63 \times 10^{-34} \text{ J•s}\right)$

For a correct answer with units — *1 point*

$f_0 = 5.93 \times 10^{14} \text{ Hz}$

Note: The conversion to joules is shown for illustrative purposes and not required.

(d) 2 points

The correct choice is "Remains the same". Selecting it earned no points, but was required in order to earn credit for the justification.

For indicating that the energy of the photons (and hence the zero-current emf) depends on frequency or wavelength — 1 point

For indicating that the intensity does NOT change the energy of the photons or photoelectrons (it only affects the number of photoelectrons produced) so it does not affect the zero-current emf (stopping potential) — 1 point

Example: The maximum kinetic energy of emitted electrons, and therefore the emf to stop the current, depends on the frequency (or wavelength) of the light source and the metal's work function. It does not depend on the intensity of the light.

(e) 2 points

The correct choice is "Decreases". Selecting it earned no points, but was required in order to earn credit for the justification.

For indicating that shorter wavelength (or higher frequency) photons have more energy — 1 point

For indicating that (since the photons have more energy and the intensity stays the same) there must be fewer photons; therefore fewer electrons are emitted — 1 point

Example: As the wavelength of the light source decreases, the frequency and energy of each photon increases and therefore fewer photons are incident on the metal to maintain a constant intensity. Fewer photons result in fewer photoelectrons.

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AP® PHYSICS B
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Question 7

10 points total **Distribution of points**

(a) 1 point

The wavelength and frequency are related by $c = \lambda f$

$$f = \frac{c}{\lambda} = \frac{\left(3 \times 10^{8}\ \text{m/s}\right)}{\left(520 \times 10^{-9}\ \text{m}\right)}$$

For a correct answer 1 point

$f = 5.77 \times 10^{14}\ \text{Hz}$

(b) 1 point

The frequency does not change when light travels in a different medium

For an answer that is consistent with part (a) 1 point

$f = 5.77 \times 10^{14}\ \text{Hz}$

(c) 2 points

For using a correct expression for the wavelength in oil 1 point

$\lambda_{\text{oil}} = \frac{\lambda_{\text{air}}}{n}$ or $\lambda = \frac{v_{\text{oil}}}{f}$

The second equation can be manipulated to obtain the first equation:

$$\lambda_{oil} = \frac{v}{f} = \frac{c/n}{f} = \frac{c}{f}\frac{1}{n} = \frac{\lambda_{air}}{n}$$

$$\lambda_{oil} = \frac{(520\ \text{nm})}{1.52}$$

For a correct numerical answer 1 point

$\lambda_{oil} = 342\ \text{nm}$

Units 1 point

For correct units in two of the calculated responses in parts (a), (b), and (c) 1 point

(d) 3 points

For selecting "Greater than" 1 point

For mentioning that there must be a phase shift upon reflection at both interfaces 1 point

For mentioning interference 1 point

Example: There is constructive interference for the observed light. In the oil, the light traverses the oil thickness two times: $2 \times 171\ \text{nm} = 342\ \text{nm}$, or one wavelength in the oil. For constructive interference, reflections at the two interfaces must then have the same phase shift. Since the refractive index increases at the air-to-oil surface, it must also increase at the oil-to-plate surface, so $n_{\text{plate}} > n_{\text{oil}}$.

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Question 7 (continued)

Distribution of points

(e) 2 points

For mentioning that the color shifts toward the red end of the visible spectrum — 1 point
For mentioning that the light's path length in the oil increases — 1 point
Example:
As the observer views the film from a larger angle, the light must travel a greater distance in the film. This creates constructive interference for a longer wavelength of light and causes the apparent film color to shift toward the red end of the visible spectrum.

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AP® Physics B
2013 Free-Response Questions

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TABLE OF INFORMATION DEVELOPED FOR 2012

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, 1 eV $= 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{kq_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{kq_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + ...\right)$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + ...$

$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$

$R_s = R_1 + R_2 + R_3 + ...$

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA \cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

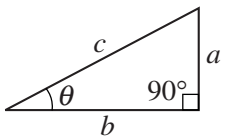
Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular Solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

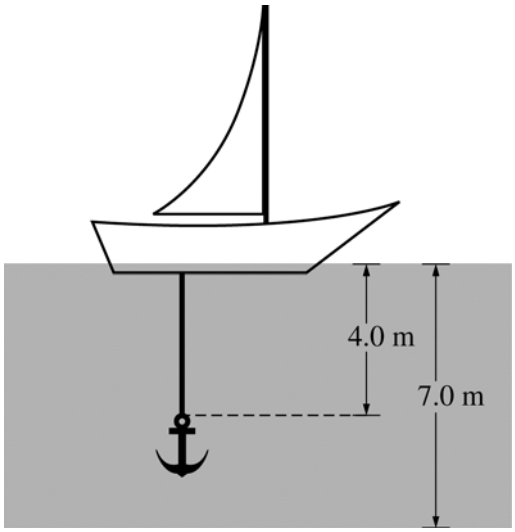
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering each of Questions 1, 3-5 and 7 and about 17 minutes for answering each of Questions 2 and 6. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. (10 points)

   A sailboat at rest on a calm lake has its anchor dropped a distance of 4.0 m below the surface of the water. The anchor is suspended by a rope of negligible mass and volume. The mass of the anchor is 50 kg, and its volume is 6.25×10^{-3} m^3. The density of water is 1000 kg/m^3.

   (a) On the dot below that represents the anchor, draw and label the forces (not components) that act on the anchor.

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(b) Calculate the magnitude of the buoyant force acting on the anchor. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. DO NOT add anything to the figure in part (a).

(c) Calculate the tension in the rope. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. DO NOT add anything to the figure in part (a).

(d) The bottom of the boat is at a depth d below the surface of the water. Suppose the anchor is lifted back into the boat so that the bottom of the boat is at a new depth d' below the surface of the water. How does d' compare to d ?

____ $d' < d$ ____ $d' = d$ ____ $d' > d$

Justify your answer.

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2. (15 points)

A 20 kg box on a horizontal frictionless surface is moving to the right at a speed of 4.0 m/s . The box hits and remains attached to one end of a spring of negligible mass whose other end is attached to a wall. As a result, the spring compresses a maximum distance of 0.50 m, and the box then oscillates back and forth.

(a)

i. The spring does work on the box from the moment the box first hits the spring to the moment the spring first reaches its maximum compression. Indicate whether the work done by the spring is positive, negative, or zero.

____ Positive ____ Negative ____ Zero

Justify your answer.

ii. Calculate the magnitude of the work described in part i.

(b) Calculate the spring constant of the spring.

(c) Calculate the magnitude of the maximum acceleration of the box.

(d) Calculate the frequency of the oscillation of the box.

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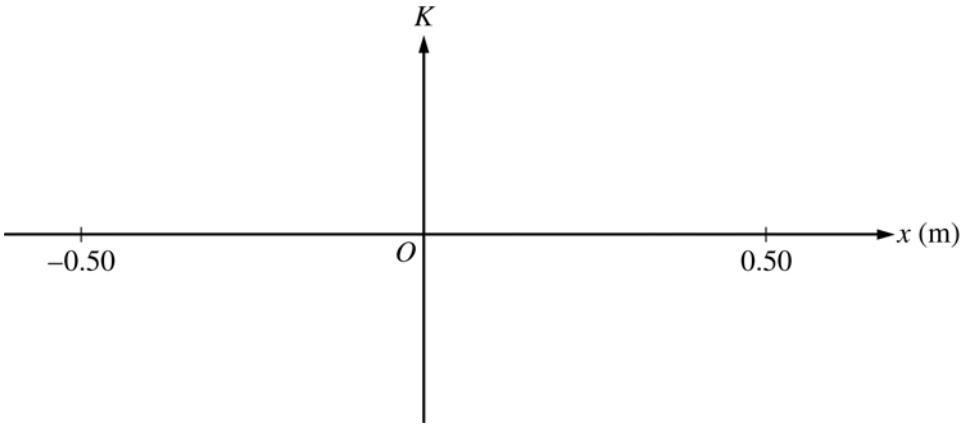
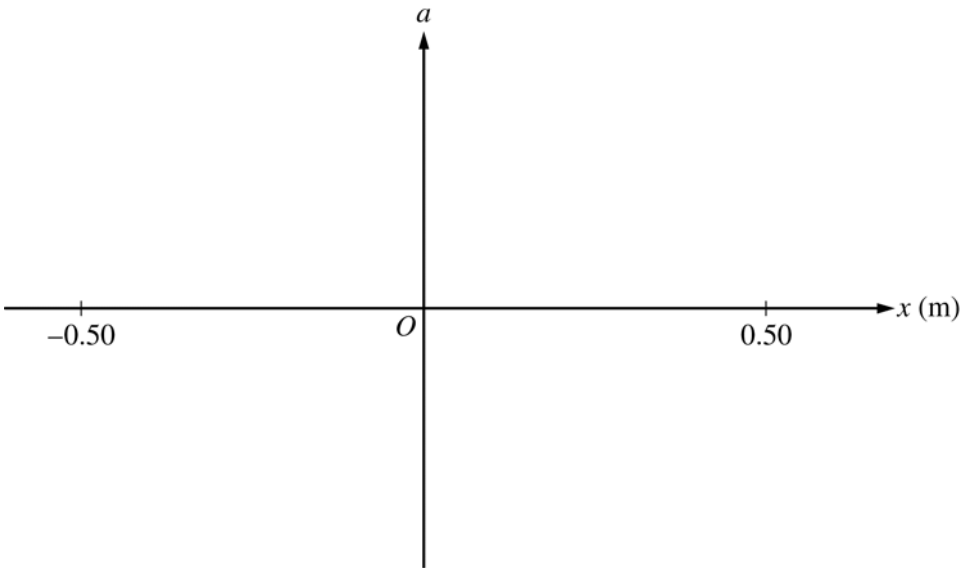
(e) Let $x = 0$ be the point where the box makes contact with the spring, with positive x directed toward the right.

i. On the axes below, sketch the kinetic energy K of the oscillating box as a function of position x for the range $x = -0.50$ m to $x = +0.50$ m.



ii. On the axes below, sketch the acceleration a of the oscillating box as a function of position x for the range $x = -0.50$ m to $x = +0.50$ m.



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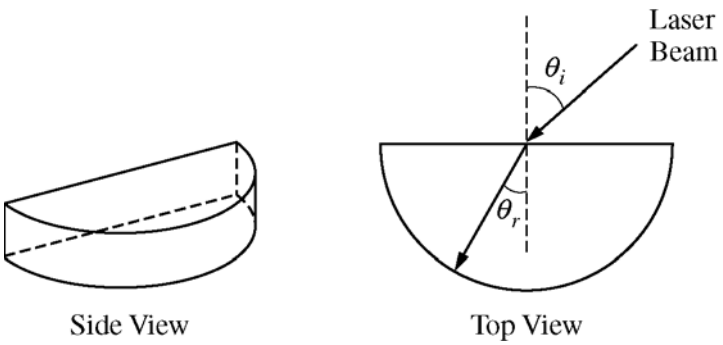

3. (10 points)

A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength $\lambda = 632$ nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly. The student uses a protractor to aim the laser at several different angles of incidence θ_i between $0°$ and $90°$ and to measure the angles of refraction θ_r. The student's data are given in the table below.

θ_i	0°	15°	30°	45°	60°	75°
θ_r	0°	10°	21°	30°	37°	44°
$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

(a) On the grid below, plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.

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(b) On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.

(c) The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.

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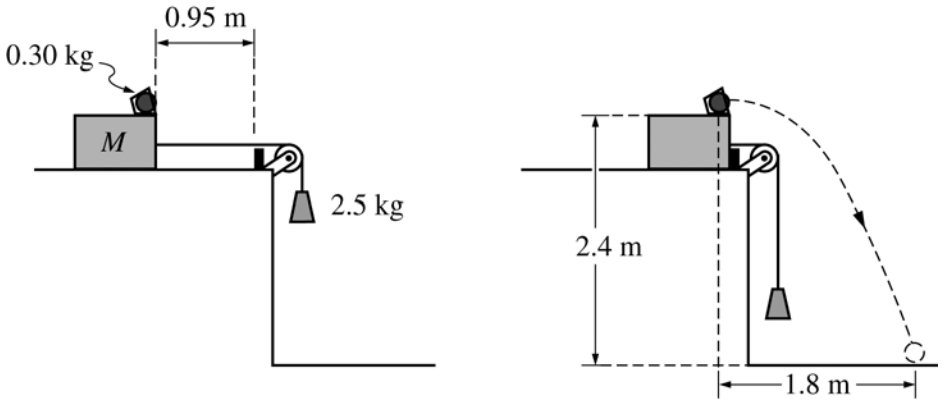

4. (10 points)

A 0.30 kg ball is in a cup of negligible mass attached to a block of mass M that is on a table. A string passing over a light pulley connects the block to a 2.5 kg object, as shown above. The system is released from rest, the block accelerates to the right, and after moving 0.95 m the block collides with a bumper near the end of the table. The ball continues to move and lands on the floor at a position 2.4 m below and 1.8 m horizontally from where it leaves the cup. Assume all friction is negligible.

(a) Calculate the speed of the ball just after the block hits the bumper and the ball leaves the cup.

(b) Calculate the magnitude of the acceleration of the block as it moves across the table.

(c) Calculate the mass M of the block.

(d) If the mass of the ball is increased, the horizontal distance it travels before hitting the floor will decrease. Explain why this will happen.

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5. (10 points)

In a certain process, 3200 J of energy is added to an ideal gas by heating. During the same process, 2100 J of work is done on the gas.

(a) Determine the change in the internal energy of the gas.

(b) Indicate whether each of the following properties of the gas increases, decreases, or remains the same during the process.

i. Volume

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

ii. Temperature

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

iii. Pressure

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

Suppose that in a different process 1800 joules of work is done on the ideal gas at a constant temperature.

(c) Determine the change in internal energy of the gas during the process.

(d) Which of the following correctly describes the energy transfer by heating, if any, between the gas and its surroundings?

____ Energy is transferred into the gas. ____ Energy is transferred out of the gas.

____ There is no energy transfer by heating.

Justify your answer.

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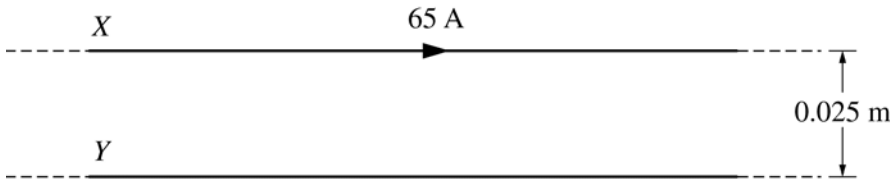

Side View

6. (15 points)

Two long, straight horizontal wires are near each other and parallel, with one directly above the other as shown in the figure. Wire *X* is fixed in place and connected to a battery (not shown) so that it carries a current of 65 A. Wire *Y*, which is part of a second circuit, is free to move vertically and is suspended at rest by the magnetic force between the wires. The mass per length of wire *Y* is 5.6×10^{-3} kg/m . Neglect effects from the parts of the circuits that are not shown.

(a) Calculate the magnitude of the magnetic field produced by wire *X* at the position of wire *Y*.

(b)
i. Calculate the magnitude of the current in wire *Y*.
ii. Indicate the direction of the current in wire *Y*.

____ To the left ____ To the right ____ Neither left nor right, since there is no current

(c) Now wire *Y* is moved to a new position that is closer to wire *X*, but wire *Y* is still below wire *X* and is still carrying the same current as determined in part (b). Wire *Y* is released from rest. Describe the initial motion of wire *Y*. Justify your answer.

(d) Suppose wire *Y* is moved to a position 0.025 m above wire *X*. What changes in current, if any, must occur to maintain equilibrium?

(e) With wire *Y* still above wire *X*, the circuit connected to wire *Y* is removed. Wire *Y*, which is 1.2 m long, is then moved vertically up and away from wire *X* at a constant speed of 3.0 m/s.

i. Calculate the magnitude of the induced emf in wire *Y* when the wires are 0.050 m apart.

ii. Indicate which end of wire *Y* is at a higher electric potential.

____ The left end ____ The right end
____ Neither end, since they are at the same electric potential
Justify your answer.

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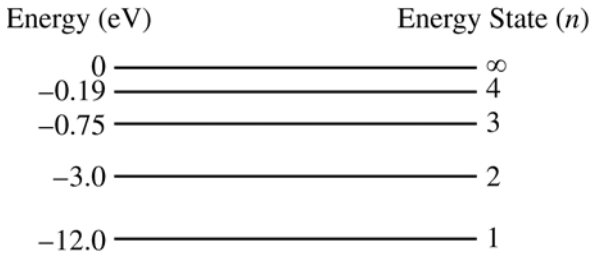

Note: Figure not drawn to scale.

7. (10 points)

The energy-level diagram for an isolated hypothetical atom is shown above.

(a) A collection of such atoms with electrons in the $n = 3$ state undergo transitions in which the atoms only emit photons, and the electrons eventually end in the $n = 1$ state. On the diagram above, draw arrows to indicate all possible transitions, given the starting and ending states for the electrons.

(b) Calculate the longest wavelength of photons that the atom can emit during the transitions identified in part (a).

(c) What is the ionization energy of an atom in the ground state?

(d) Photons of energy 11.0 eV are incident on the atom. What effect can this have on an electron in the $n = 1$ state? Justify your answer.

(e) Photons of energy 14.0 eV are incident on the atom. What effect can this have on an electron in the $n = 1$ state? Justify your answer.

STOP

END OF EXAM

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AP® Physics B
2013 Scoring Guidelines

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AP® PHYSICS B
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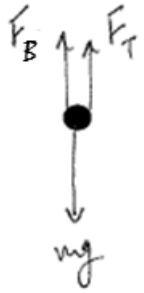
Question 1

10 points total **Distribution of points**

(a) 3 points



For showing the buoyant force in the correct direction and labeling it — 1 point
For showing the tension in the correct direction and labeling it — 1 point
For showing the gravitational force in the correct direction and labeling it — 1 point
One earned point was deducted for any extraneous forces.

(b) 2 points

For use of the correct expression for the buoyant force — 1 point

$F_B = \rho V g$

Substitute correct values

$F_B = \left(1000 \text{ kg/m}^3\right)\left(6.25 \times 10^{-3} \text{ m}^3\right)\left(9.8 \text{ m/s}^2\right)$

For a correct answer, with units — 1 point

$F_B = 61.3 \text{ N}$ (62.5 N if using $g = 10 \text{ m/s}^2$)

(c) 3 points

For a correct expression of Newton's second law when the anchor is at equilibrium — 1 point

$F_T + F_B = mg$

For substituting a value consistent with the buoyant force from part (b) — 1 point

For substituting correct values for calculation of the gravitational force — 1 point

$F_T = (50 \text{ kg})\left(9.8 \text{ m/s}^2\right) - (61.3 \text{ N})$

$F_T = 429 \text{ N}$ (438 N if using $g = 10 \text{ m/s}^2$)

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Question 1 (continued)

Distribution of points

(d) 2 points

For selecting $d' > d$ 1 point
For a correct justification 1 point

Example
When the anchor is lifted onto the boat, the buoyant force on the boat must now support the weight of both the boat and the anchor. This will increase the buoyant force, which requires a greater volume of water, which means the boat will reach a greater depth into the water.

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Question 2

15 points total **Distribution of points**

(a)

i. 2 points

For selecting "Negative" 1 point
For a correct justification 1 point

Examples

- The spring pushes on the box in a direction opposite to the box's motion, therefore the work done is negative.
- The box slows down, so its kinetic energy decreases. Therefore the work done is negative.

ii. 3 points

For a correct expression relating work to change in kinetic energy 1 point

$W = \Delta K$

$W = \frac{1}{2}m\left(v_2^2 - v_1^2\right) = -\frac{1}{2}mv_1^2$

For substituting the correct values 1 point

$W = -\left(\frac{1}{2}\right)(20\text{ kg})(4.0\text{ m/s})^2$

For a correct answer 1 point

$W = 160\text{ J}$ (either positive or negative value acceptable)

(b) 2 points

For a correct expression of conservation of energy 1 point

$K_1 = U_2$

$\frac{1}{2}mv_1^2 = \frac{1}{2}kx_2^2$

For correct substitution of values consistent with the answer from part (a) ii 1 point

$(160\text{ J}) = \left(\frac{1}{2}\right)k(0.50\text{ m})^2$

$k = 1280\text{ N/m}$

(c) 2 points

For a correct expression of the maximum acceleration 1 point

$a = F_{\max}/m = kx_{\max}/m$

For correct substitution consistent with the answer from part (b) 1 point

$a = (1280\text{ N/m})(0.50\text{ m})/(20\text{ kg})$

$a = 32\text{ m/s}^2$

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Question 2 (continued)

Distribution of points

(d) 2 points

For a correct expression of the frequency 1 point

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

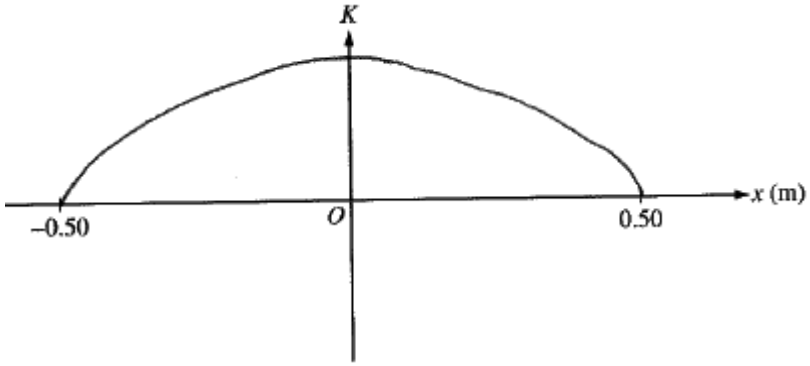
For correct substitution consistent with the answer from part (b) 1 point

$$f = \left(\frac{1}{2\pi}\right)\sqrt{\frac{(1280\ \text{N/m})}{(20\ \text{kg})}}$$

$$f = 1.27\ \text{Hz}$$

(e)

i. 2 points



For a graph that shows positive kinetic energy values and zero kinetic energy at −0.50 m and +0.50 m 1 point

For a smooth curve that is concave down 1 point

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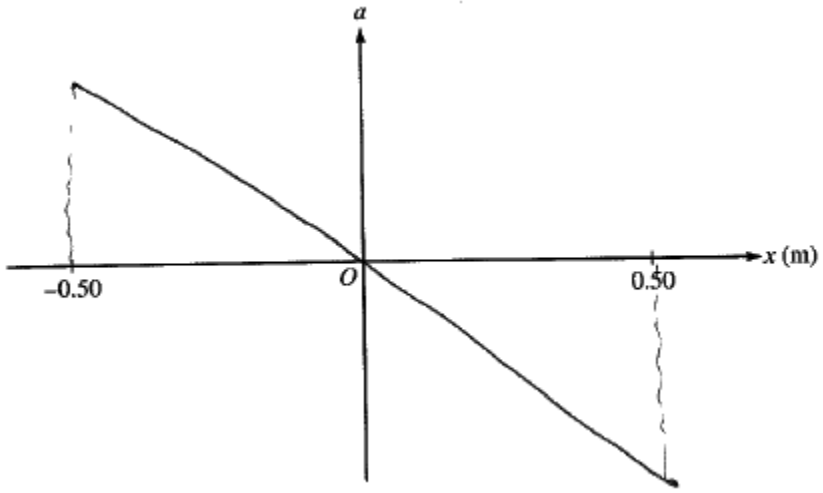
Question 2 (continued)

Distribution of points

(e) (continued)

ii. 1 point



For a straight line with negative slope that begins at −0.50 m, ends at +0.50 m, and passes through the origin — 1 point

Units 1 point

For correct units on three out of four calculated answers — 1 point

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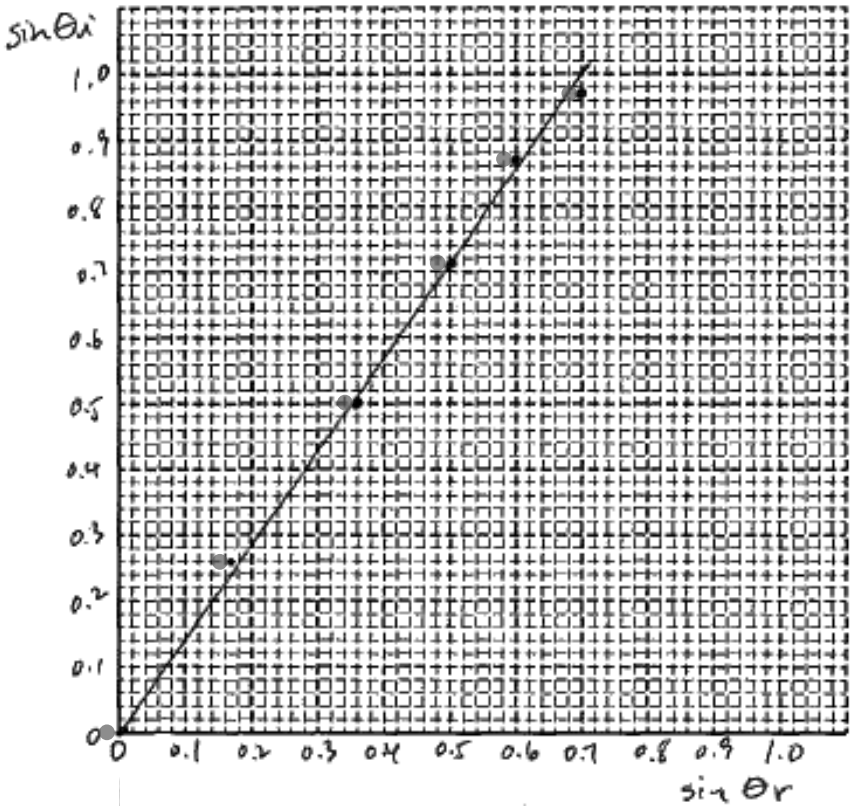
Question 3

10 points total **Distribution of points**

(a) 3 points



For labeling both axes with variables that will yield a straight-line graph 1 point
For correctly scaling both axes 1 point
For correctly plotting the points 1 point

(b) 4 points

For a straight line that best represents the data 1 point
For relating the slope to the index of refraction using Snell's law 1 point
$n =$ slope (or 1/slope if plotting $\sin\theta_r$ as a function of $\sin\theta_i$)
For substituting two points on the line 1 point
For the example graph shown, $n = \dfrac{(1.00 - 0.20)}{(0.70 - 0.14)}$
For a calculated index of refraction in the range 1.2 - 1.6 1 point
$n = 1.43$

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Question 3 (continued)

Distribution of points

(c) 3 points

For a new experimental method in which the student aims the laser at the curved side of the block — 1 point

For stating that the critical angle is the minimum angle at which no light is refracted or total internal reflection is reached — 1 point

For relating the index of refraction to the critical angle and stating that $n_2 = 1$ (the second medium is air) — 1 point

Example

Aim the laser through the curved side of the block at normal incidence, so that it emerges from the center of the flat side. Pivot the block about the center of the flat side so that the emerging beam just grazes the flat side (or the beam begins to disappear).

Measure the angle between the incident beam and the normal to the flat side. This is the critical angle θ_c .The index of refraction is given by $n = 1/\sin\theta_c$.

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Question 4

10 points total **Distribution of points**

(a) 3 points

For using a correct expression for the vertical motion to determine time t 1 point

$\Delta y = v_{yi}t + \frac{1}{2}at^2$

$v_{yi} = 0$, so $t = \sqrt{\frac{2(\Delta y)}{a}}$

For substituting the correct height and acceleration into the vertical equation 1 point

$t = \sqrt{\frac{(2)(2.4\text{ m})}{(9.8\text{ m/s}^2)}} = 0.70\text{ s}$

For substituting the correct values into the constant horizontal velocity equation 1 point

$v_x = \frac{\Delta x}{t}$

$v_x = \frac{(1.8\text{ m})}{(0.70\text{ s})} = 2.6\text{ m/s}$

(b) 2 points

For using a correct expression to determine the acceleration of the block 1 point

$v_x^2 = v_0^2 + 2ad$

$a = \frac{v_x^2}{2d}$

For correct substitutions consistent with part (a) 1 point

$a = \frac{(2.6\text{ m/s})^2}{(2)(0.95\text{ m})} = 3.5\text{ m/s}^2$

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Question 4 (continued)

Distribution of points

(c) 3 points

For using Newton's second law
$\sum F = ma$
$m_{obj}g = \left(m_{obj} + M + m_{ball}\right)a$

For a correct value for the total force on the system — 1 point
$m_{obj}g = (2.5\ \text{kg})\left(9.8\ \text{m/s}^2\right) = 25\ \text{N}$

For correct values in the expression for the total mass being accelerated — 1 point
$\left(m_{obj} + M + m_{ball}\right)a = (2.5\ \text{kg} + 0.3\ \text{kg} + M)a = (2.8\ \text{kg} + M)a$

For the correct substitution of the acceleration of the block from part (b) — 1 point
$25\ \text{N} = (2.8\ \text{kg} + M)\left(3.5\ \text{m/s}^2\right)$
$M = 4.24\ \text{kg}$

(d) 2 points

For stating that with the same force, the horizontal acceleration of the ball will be less as a result of the increased mass of the system — 1 point

For stating the launch velocity will be lower — 1 point

Example

A larger combined mass of the system will result in a smaller acceleration, so the ball has a smaller speed upon launch. However, the time to hit the floor will be the same since it's falling the same vertical distance with the same vertical acceleration in freefall. So the horizontal distance $\left(v_{launch} \times t_{fall}\right)$ will be less.

One earned point was deducted for any incorrect statement in the reasoning not included in the points shown.

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Question 5

10 points total **Distribution of points**

(a) 1 point

Use the equation for the change in internal energy (first law of thermodynamics)
$\Delta U = Q + W$
$\Delta U = (3200\ \text{J}) + (2100\ \text{J})$
For the correct answer, including units 1 point
$\Delta U = 5300\ \text{J}$

(b)

i. 2 points

For selecting "Decreases" 1 point
For a correct justification 1 point

Examples
Because work is done on the gas, W is positive. $W = -P\Delta V$, so ΔV must be negative and the volume decreases.
Because work is done on the gas, W is positive and the gas is compressed. If the gas is compressed, the volume decreases.

ii. 2 points

For selecting "Increases" 1 point
For a correct justification 1 point

Example
The internal energy increases (as shown in part (a)) and the temperature of an ideal gas increases as the internal energy increases.

iii. 2 points

For selecting "Increases" 1 point
For a correct justification 1 point

Example
From the ideal gas law, PV/T is constant. So if V decreases and T increases, P must increase.

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Question 5 (continued)

Distribution of points

(c) 1 point

For stating the internal energy does not change
$\Delta U = 0$ 1 point

(d) 2 points

For selecting "Energy is transferred out of the gas" 1 point
For a correct justification 1 point

Example

$\Delta U = Q + W$ is zero for an ideal gas at constant temperature and W is positive since work is done on the gas. Therefore Q is negative, meaning energy is transferred out of the gas by heating.

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Question 6

15 points total **Distribution of points**

(a) 2 points

For the correct substitution of the values of μ_0, I, and r into the correct expression for the magnetic field around a wire 1 point

$$B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi \times 10^{-7}\ \text{T•m/A}\right)(65\ \text{A})}{(2\pi)(0.025\ \text{m})}$$

For the correct answer 1 point

$$B = 5.2 \times 10^{-4}\ \text{T}$$

(b)

i. 4 points

For an expression of equilibrium between the magnetic and gravitational forces on the wire 1 point

$$W = F_B$$

For correct expressions for the magnetic and gravitational forces 1 point

$$mg = BIL$$

For a correct expression for the current in terms of the linear density 1 point

$$I = \left(\frac{m}{L}\right)\frac{g}{B}$$

For correctly substituting the answer from part (a) into the above equation to solve for the current 1 point

$$I = \left(5.6 \times 10^{-3}\ \text{kg/m}\right)\frac{\left(9.8\ \text{m/s}^2\right)}{\left(5.2 \times 10^{-4}\ \text{T}\right)}$$

$I = 106\ \text{A}$ (or 108 A using $g = 10\ \text{m/s}^2$)

ii. 1 point

For selecting "To the right" 1 point

(c) 2 points

For stating that the wire would move upward 1 point

For stating that the wire would <u>accelerate</u> with a correct justification 1 point

<u>Example</u>

As wire Y is moved closer to X, the magnetic field from X will increase. This will create an upward net force on Y that will accelerate Y upward toward wire X.

(d) 1 point

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Question 6 (continued)

Distribution of points

For stating that the direction of the current in one of the wires must change — 1 point

Examples
- The current must be reversed in one wire, but not in the other.
- Reverse the current in wire *X*.
- Change the direction of the current in wire *Y*.

(e)

i. 3 points

For a correct statement of either Faraday's law, or the motional emf formula — 1 point

$\mathcal{E} = Bvl$ OR $\mathcal{E} = -\frac{\Delta\phi}{\Delta t}$ (since $\mathcal{E} = -B\frac{\Delta A}{\Delta t} = -Bvl$, with the minus sign irrelevant since the question asks for a magnitude)

For a correct expression for, or determination of, the value of the magnetic field — 1 point

Method 1) Taking half the value determined in part (a), because the wires are now twice as far apart

$$B = \frac{1}{2}\left(5.2 \times 10^{-4}\ \text{T}\right) = 2.6 \times 10^{-4}\ \text{T}$$

Method 2) Using the formula for the magnetic field around a wire

$$B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi \times 10^{-7}\ \text{T•m/A}\right)(65\ \text{A})}{(2\pi)(0.050\ \text{m})} = 2.6 \times 10^{-4}\ \text{T}$$

For substituting *correct* values of l and v and *any* value of B into a correct expression — 1 point

$$\mathcal{E} = (2.6 \times 10^{-4}\ \text{T})(3.0\ \text{m/s})(1.2\ \text{m}) = 9.4 \times 10^{-4}\ \text{V}$$

ii. 2 points

For selecting "The right end" — 1 point

For a correct justification — 1 point

Example

Using the right-hand rule, positive charges moving upward in the magnetic field, which is out of the page, would experience a magnetic force to the right. Thus, the right end of wire *Y* develops a positive charge and the left end develops a negative charge.

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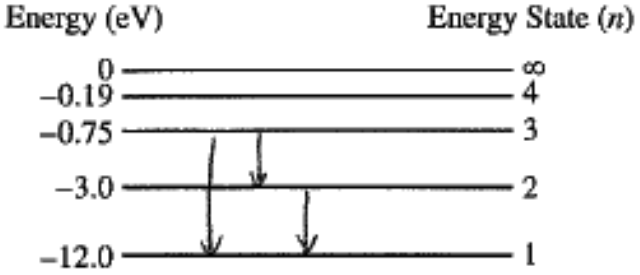
Question 7

10 points total **Distribution of points**

(a) 3 points



For an arrow from the $n = 3$ to the $n = 2$ energy state 1 point
For an arrow from the $n = 3$ to the $n = 1$ energy state 1 point
For an arrow from the $n = 2$ to the $n = 1$ energy state 1 point
One earned point was deducted if there were any incorrect or extra lines on the diagram.

(b) 2 points

Use an expression relating energy to wavelength
$E = hf = hc/\lambda$
For substitution using the correct 3 to 2 transition energy 1 point
$\lambda = hc/E = (1240 \text{ eV•nm})/((3.0 - 0.75) \text{ eV})$
For an answer consistent with whichever transition was chosen 1 point
$\lambda = 551 \text{ nm}$ or $5.51 \times 10^{-7} \text{ m}$
(138 nm for the 2 to 1 transition, and 110 nm for the 3 to 1 transition)

(c) 1 point

For the correct, positive value for the ionization energy 1 point
$E = 12 \text{ eV}$ or $1.9 \times 10^{-18} \text{ J}$

(d) 2 points

For correctly stating that an 11.0 eV photon has no effect 1 point
For a correct explanation 1 point

Example
Since there is no energy level at −1.0 eV, an 11.0 eV photon will have no effect on electrons in the −12.0 eV (n = 1) energy state.

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Question 7 (continued)

Distribution of points

(e) 2 points

For correctly stating that a 14.0 eV photon will remove the electron from (or ionize) the atom — 1 point

For a correct explanation — 1 point

Example

A 14.0 eV photon has sufficient energy to ionize the atom, since only 12.0 eV is required for ionization.

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AP® Physics B
2012 Free-Response Questions

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TABLE OF INFORMATION DEVELOPED FOR 2012

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, 1 eV $= 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{kq_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{kq_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + ...\right)$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + ...$

$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$

$R_s = R_1 + R_2 + R_3 + ...$

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA \cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

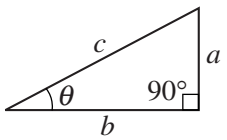
$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Rectangular Solid
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

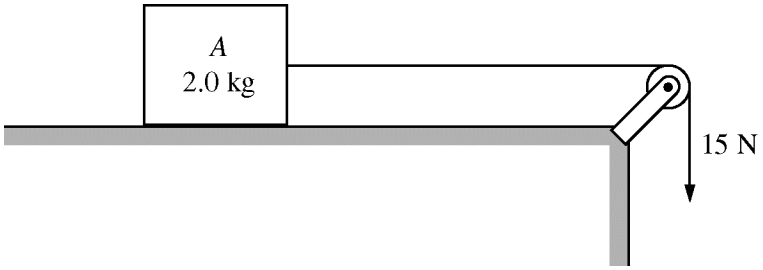
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering each of Questions 2, 3, 4, 6, and 7 and about 17 minutes for answering each of Questions 1 and 5. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. (15 points)

   Block *A* of mass 2.0 kg is pulled along a horizontal table by a force of 15 N, which is applied by a light string that passes over a light frictionless pulley, as shown above. The coefficient of kinetic friction between the block and the surface is 0.25.

   (a) On the dot below, which represents the block, draw and label the forces (not components) that act on the block as it is pulled across the table.

   ●

   (b) Calculate the magnitude of the acceleration of the block.

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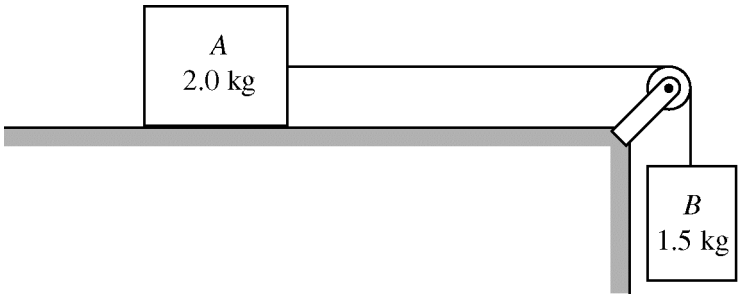

The applied force is removed. Block *B* of mass 1.5 kg is now attached to the string, as shown above. The system is released from rest so that the 1.5 kg box descends and the 2.0 kg block is again pulled across the table.

(c) Calculate the acceleration of the 1.5 kg block as it descends.

(d) Calculate the tension in the string connecting the two blocks.

(e) Calculate the distance that the 1.5 kg block descends in 0.40 s.

(f) If this system is set up in a laboratory and the acceleration of the 1.5 kg block is experimentally determined, the experimental value is found to be smaller than the value calculated above. If the given value for the coefficient of friction is correct and air resistance is negligible, explain briefly, but specifically, why the experimental value of the acceleration is smaller.

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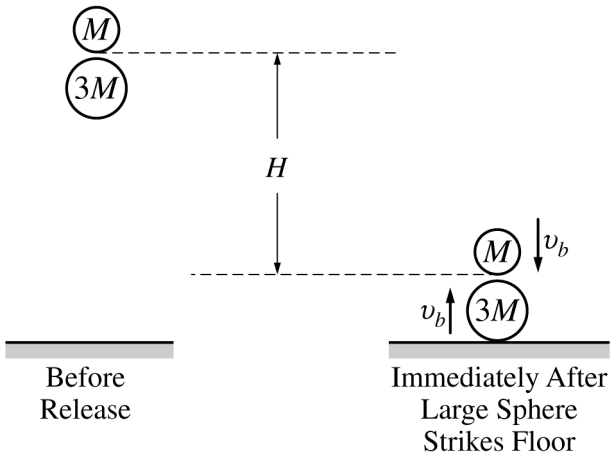

2. (10 points)

A small and a large sphere, of mass M and $3M$ respectively, are arranged as shown on the left side of the figure above. The spheres are then simultaneously dropped from rest. When the large sphere strikes the floor, the spheres have fallen a height H. Assume air resistance is negligible. Express all answers in terms of M, H, and fundamental constants, as appropriate.

(a) Derive an expression for the speed v_b with which the large sphere strikes the floor.

Immediately after striking the floor, the large sphere is moving upward with speed v_b and collides head-on with the small sphere, which is moving downward with identical speed v_b at that instant. Immediately after the collision, the small sphere moves upward with speed v_S and the large sphere has speed v_L.

(b) Derive an equation that relates v_b, v_S, and v_L.

In this particular situation $v_L = 0$.

(c) Use your relationship from part (b) to determine the speed of the small sphere in terms of v_b.

(d) Indicate whether the collision is elastic. Justify your answer using your results from parts (b) and (c).

(e) Determine the height h that the small sphere rises above its lowest position, in terms of the original height H.

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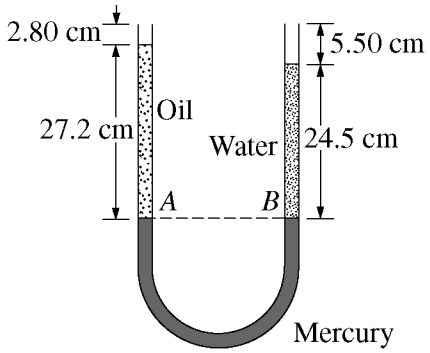
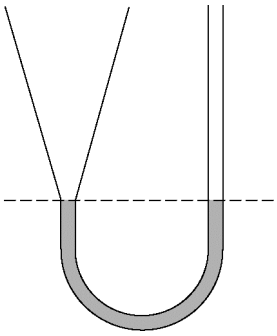


3. (10 points)

A glass U-tube with a uniform diameter of 0.850 cm is used to determine the density of an oil. As shown in the figure above, a 24.5 cm column of water balances a 27.2 cm column of the oil so that interfaces *A* and *B* of the mercury with the other liquids are at the same height. The density of water is $1.00 \times 10^3 \ \text{kg/m}^3$.

(a) Calculate the density of the oil.

(b) Calculate the absolute pressure at *B,* the interface between the water and the mercury.



A new tube, identical to the U-tube except for a cone shape on the left, as shown above, is filled with the same volume of mercury that was in the U-tube. The mercury is at the same height on both sides of the new tube as it was in the U-tube, as shown by the dashed line. The same volumes of oil and water that were in the U-tube are now poured into the new tube, on the left and right respectively.

(c) Indicate the new position of *B* relative to *A*.

____ Above *A* ____ Below *A* ____ At the same height as *A*

Justify your answer.

(d) A small piece of wood with density less than that of the oil is placed so that it floats in the left side of the tube. Indicate whether the pressure at the bottom of the tube increases, decreases, or remains the same.

____ Increases ____ Decreases ____ Remains the same

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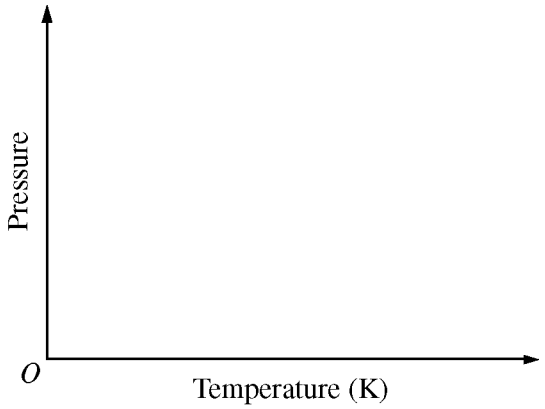
4. (10 points)

A cylindrical container is fitted with a frictionless piston that is initially locked in place. The cylinder contains a fixed amount of an ideal gas that is initially at room temperature and atmospheric pressure.

(a) The cylinder is placed in a hot-water bath. On the axes below, sketch a graph of pressure versus temperature for the process the gas undergoes as a result, and indicate the direction of the process on the graph.

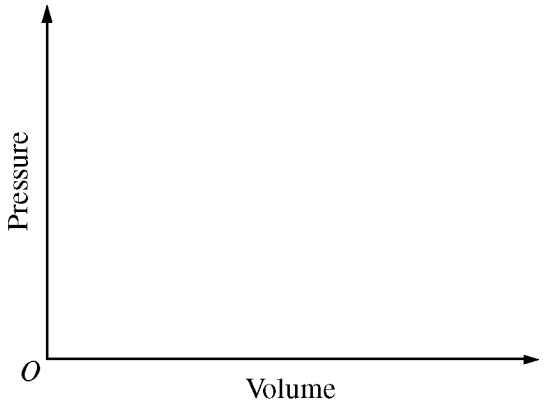


(b) The cylinder is removed from the hot-water bath. After equilibrium is reached, the lock is removed so the piston is free to move. Indicate whether the piston moves up, moves down, or remains stationary.

____ Moves up ____ Moves down ____ Remains stationary

Justify your answer.

(c) When the system is again at equilibrium, the piston is pushed down very slowly. On the axes below, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "C."



(d) Now the piston is pulled up quickly, so no heat is added to or removed from the gas during the process. On the axes above, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "D."

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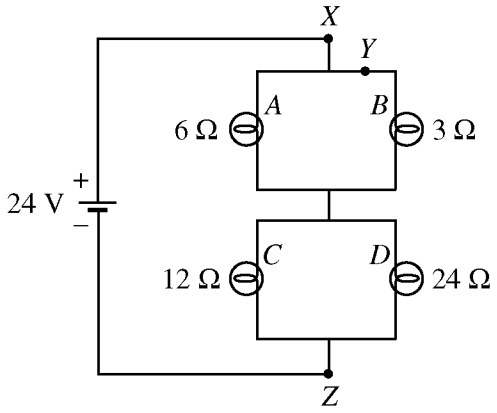

5. (15 points)

Four lightbulbs are connected in a circuit with a 24 V battery as shown above.

(a)

i. Determine the average potential energy change of an electron as it moves from point *Z* to point *X*.

ii. Indicate whether the electron gains or loses potential energy as it moves from point *Z* to point *X*.

____ Gains energy ____ Loses energy

(b) Calculate the equivalent resistance of the circuit.

(c)

i. Calculate the magnitude of the current through point *Y*.

ii. Indicate on the diagram the direction of the current through point *Y*.

(d) Calculate the energy dissipated in the 12 Ω bulb in 5 s.

(e) Rank the bulbs in order of brightness, with 1 being the brightest. If any bulbs have the same brightness, give them the same ranking.

____ Bulb *A* ____ Bulb *B* ____ Bulb *C* ____ Bulb *D*

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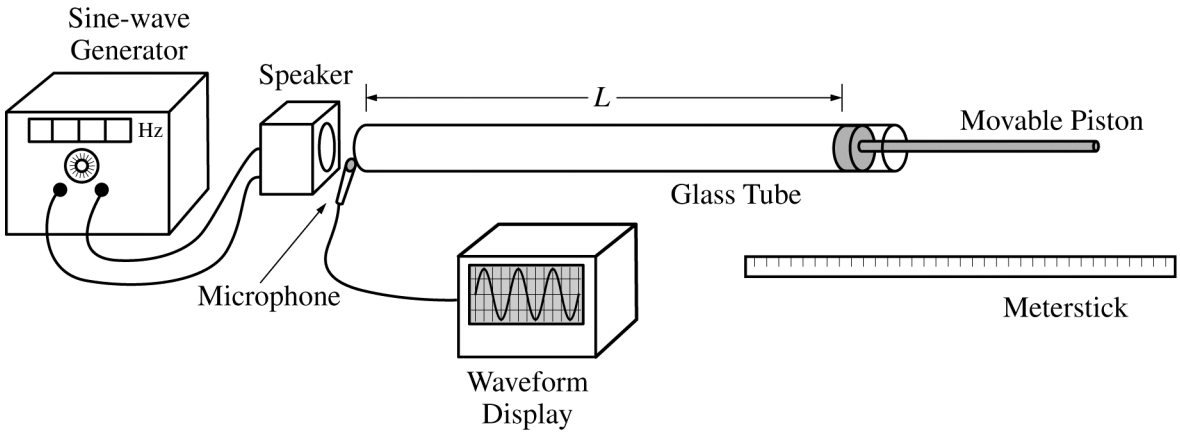

6. (10 points)

You are given the apparatus represented in the figure above. A glass tube is fitted with a movable piston that allows the indicated length L to be adjusted. A sine-wave generator with an adjustable frequency is connected to a speaker near the open end of the tube. The output of a microphone at the open end is connected to a waveform display. You are to use this apparatus to measure the speed of sound in air.

(a) Describe a procedure using the apparatus that would allow you to determine the speed of sound in air. Clearly indicate what quantities you would measure and with what instrument each measurement would be made. Represent each measured quantity with a different symbol.

(b) Using the symbols defined in part (a), indicate how your measurements can be used to determine an experimental value of the speed of sound.

(c) A more accurate experimental value can be obtained by varying one of the measured quantities to obtain multiple sets of data. Indicate one quantity that can be varied, and describe how a graph of the resulting data could be used to determine the speed of sound. Clearly identify independent and dependent variables, and indicate how the slope of the graph relates to the speed of sound.

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7. (10 points)

The momentum of a particular proton is 5.5×10^{-20} kg•m/s. Relativistic effects can be ignored throughout this question.

(a) Calculate the de Broglie wavelength of the proton.

(b) Calculate the kinetic energy of the proton.

The proton is directed toward a very distant stationary uranium nucleus, $^{235}_{92}\mathrm{U}$. The proton reaches a distance *D* from the center of the nucleus and then reverses direction. Assume that the nucleus is heavy enough to remain stationary during the interaction.

(c) Calculate the value of *D*.

(d) After the proton has moved away, the $^{235}_{92}\mathrm{U}$ nucleus spontaneously fissions into $^{148}_{57}\mathrm{La}$ and $^{84}_{35}\mathrm{Br}$, along with three neutrons. As a result, 2.5×10^{-11} J of energy is released. Indicate whether the mass of the $^{235}_{92}\mathrm{U}$ nucleus is greater or less than the mass of the fission products.

____ Greater ____ Less

Calculate the mass difference.

STOP

END OF EXAM

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AP® Physics B
2012 Scoring Guidelines

The College Board

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AP® PHYSICS
2012 SCORING GUIDELINES

General Notes About 2012 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer owing to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

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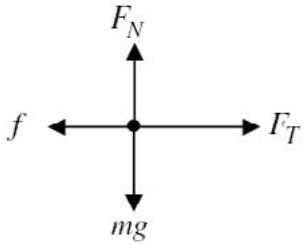
AP® PHYSICS B
2012 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 2 points



For showing a complete vector diagram in the horizontal direction with proper labels and vectors pointing in the correct directions — 1 point

For showing a complete vector diagram in the vertical direction with proper labels and vectors pointing in the correct directions — 1 point

(b) 3 points

For any use of Newton's second law to sum the forces in the horizontal direction — 1 point

$F_T - f = ma$

$a = \dfrac{F_T - f}{m}$

For a correct expression for, or value of, the frictional force — 1 point

$$a = \frac{F_T - \mu mg}{m} = \frac{(15\text{ N}) - (0.25)(2.0\text{ kg})\left(9.8\text{ m/s}^2\right)}{(2.0\text{ kg})}$$

For a correct answer, with units — 1 point

$a = 5.1\text{ m/s}^2$ (or 5.0 m/s^2 using $g = 10\text{ m/s}^2$)

(c) 4 points

For a proper summation of forces on block A in the x-direction — 1 point

$\sum F_{m_A} = m_A a = F_T - f$

For a proper summation of forces on block B in the y-direction — 1 point

$\sum F_{m_B} = m_B a = m_B g - F_T$

For a reasonable attempt to combine these two relationships — 1 point

$(m_A + m_B)a_{system} = m_B g - f$

$$a_{system} = \frac{m_B g - f}{(m_A + m_B)} = \frac{(1.5\text{ kg})\left(9.8\text{ m/s}^2\right) - (0.25)(2.0\text{ kg})\left(9.8\text{ m/s}^2\right)}{(3.5\text{ kg})}$$

For a correct answer with units — 1 point

$a = 2.8\text{ m/s}^2$ (or 2.9 m/s^2 using $g = 10\text{ m/s}^2$)

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Question 1 (continued)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

Treating the two blocks as one system with a total mass of $M_T = m_A + m_B$

For a correct statement of the net force on the system — *1 point*

For a correct expression for total mass of the system — *1 point*

$m_B g - f = (m_A + m_B)a$

For agreement between the sign of the net force and the direction of acceleration — *1 point*

$$a = \frac{m_B g - \mu m_A g}{(m_A + m_B)} = \frac{(1.5\text{ kg})\left(9.8\text{ m/s}^2\right) - (0.25)(2.0\text{ kg})\left(9.8\text{ m/s}^2\right)}{(2.0\text{ kg} + 1.5\text{ kg})}$$

For a correct answer — *1 point*

$a = 2.8\text{ m/s}^2$ (or 2.9 m/s^2 using $g = 10\text{ m/s}^2$)

(d) 2 points

For a correct expression of the summation of forces on either block A or block B — 1 point

$F_T - \mu m_A g = m_A a$ or $m_B g - F_T = m_B a$

For correct substitution of the acceleration determined in part (c) and the given masses — 1 point

$F_T = m_A(a + \mu g)$
$= (2.0\text{ kg})\left(2.8\text{ m/s}^2 + (0.25)\left(9.8\text{ m/s}^2\right)\right)$

or

$F_T = m_B(g - a)$
$= (1.5\text{ kg})\left(9.8\text{ m/s}^2 - 2.8\text{ m/s}^2\right)$

$F_T = 10.5\text{ N}$

(e) 2 points

For any proper kinematic approach to determine the displacement of block B — 1 point

$\Delta y = \frac{1}{2}at^2$

For a correct substitution of the acceleration found in part (c) into the kinematic relationship — 1 point

$\Delta y = \frac{1}{2}\left(2.8\text{ m/s}^2\right)(0.40\text{ s})^2$

$\Delta y = 0.22\text{ m}$

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Question 1 (continued)

Distribution of points

(f) 2 points

For any reasonable statement of a physical factor that would alter the measured value of the acceleration — 1 point

The following are some common acceptable responses:

- The pulley has an appreciable amount of friction in the bearings.
- The string has an appreciable mass.
- The pulley has an appreciable rotational inertia.
- A small uphill incline exists in the horizontal surface.

Note: If a response contains both correct and incorrect factors, this point can be earned only if a correct justification for a correct factor is given.

For a proper justification of how the physical factor listed causes the measured value of the acceleration to be smaller than the theoretical value of the acceleration — 1 point

The following are examples of some common correct justifications:

- The friction in the bearings of the pulley does negative work on the system, leaving less energy available for the system's kinetic energy. This will result in a slightly smaller final velocity and therefore a slightly smaller acceleration than the theoretical value.
- The slightly inclined surface creates a small downward component of gravity, which works in opposition to the acceleration. This small opposing force will create a smaller net force and a decrease in the measured acceleration of block *B*.

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Question 2

10 points total | **Distribution of points**

(a) 2 points

For a statement that shows the conservation of energy for the large sphere — 1 point

$\Delta U_{3M} = \Delta K_{3M}$

$3MgH = \frac{1}{2}(3M)v_b^2$

For a correct answer (or equivalent expression for v_b) — 1 point

$v_b = \sqrt{2gH}$

Alternate solution — *Alternate points*

For using a proper kinematic approach — *1 point*

$v_f^2 = v_0^2 + 2a\Delta y$

$v_b^2 = 2gH$

For a correct answer — *1 point*

$v_b = \sqrt{2gH}$

(b) 2 points

For stating or showing the conservation of momentum applied to the collision — 1 point

$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$

For stating or showing that the spheres are initially traveling in opposite directions — 1 point

$3Mv_b + M(-v_b) = 3Mv_L + Mv_S$

$2v_b = 3v_L + v_S$

(c) 1 point

Substituting the given zero value into the answer from part (b)

$2v_b = 3v_L + v_S$

$2v_b = 0 + v_S$

For a correct answer — 1 point

$v_S = 2v_b$

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Question 2 (continued)

Distribution of points

(d) 3 points

For any correct attempt to compare total kinetic energy before the collision to total kinetic energy after the collision — 1 point

$K_i = K_{3Mi} + K_{Mi}$ and $K_f = K_{3Mf} + K_{Mf}$

For correct substitutions of v_b, the expression for v_S from part (c), and the correct masses in the kinetic energy terms — 1 point

$$K_i = \frac{1}{2}(3M)(v_b)^2 + \frac{1}{2}(M)(-v_b)^2 = 2Mv_b^2$$

$$K_f = \frac{1}{2}(M)(2v_b)^2 = 2Mv_b^2$$

For correctly stating that the collision is elastic (or inelastic if consistent with the comparison of initial and final kinetic energies) — 1 point

(e) 2 points

For a statement of conservation of energy for ball M as it rises to the new height h — 1 point

$U_{gf} = K_0$

$$Mgh = \frac{1}{2}Mv_S^2$$

$$h = \frac{(2v_b)^2}{2g} = \frac{4v_b^2}{2g} = \frac{2\left(\sqrt{2gH}\right)^2}{g}$$

For a correct answer consistent with the expression for v_b obtained in part (a) — 1 point

$h = 4H$

Alternate solution — *Alternate points*

For using a correct kinematic approach to solve for maximum height of ball M — *1 point*

$v_f^2 = v_0^2 + 2a\Delta y$

$v_0 = v_S = 2v_b = 2\sqrt{2gH}$

$0 = \left(2\left(\sqrt{2gH}\right)\right)^2 - 2gh$

For a correct answer consistent with the expression for v_b obtained in part (a) — *1 point*

$h = 4H$

Note: Both points are awarded for any correctly determined value of h without any written justification.

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Question 3

10 points total | **Distribution of points**

(a) 3 points

For a statement or equation that the pressures at interfaces A and B are equal — 1 point
$P_{atm} + \rho_o g h_o = P_{atm} + \rho_w g h_w$

For a substitution of the correct density and the correct heights — 1 point
$\rho_o = \rho_w h_w / h_o = \left(1000 \text{ kg/m}^3\right)(24.5 \text{ cm})/(27.2 \text{ cm})$

For the correct answer — 1 point
$\rho_o = 901 \text{ kg/m}^3$

(b) 2 points

Use equation for absolute pressure
$P = P_0 + \rho g h$

For using atmospheric pressure for P_0 — 1 point

For using the correct height (in meters) with the correct density and a correct acceleration owing to gravity — 1 point
$P = P_0 + \rho g h = \left(1.0 \times 10^5 \text{ Pa}\right) + \left(1000 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(0.245 \text{ m})$

$P = 1.02 \times 10^5 \text{ Pa}$

Note: The use of 1.013×10^5 Pa and 10 m/s^2 is acceptable.

(c) 3 points

For selecting "Below A" — 1 point

For a statement that the height of the oil above the mercury is now lower — 1 point

For a statement that the pressure is lower at interface A owing to the lower height — 1 point

(d) 1 point

For selecting "Increases" — 1 point

Units 1 point

For correct units in both numerical answers of parts (a) and (b) — 1 point

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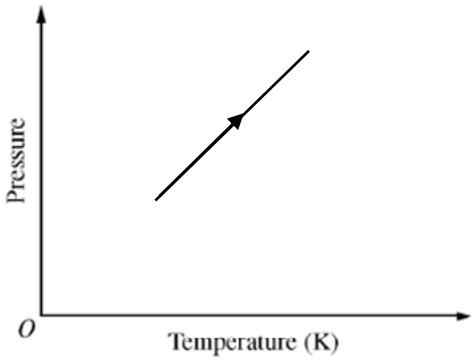
Question 4

10 points total **Distribution of points**

(a) 3 points



For a graph showing pressure proportional to temperature (i.e., a straight line segment that, if extended, would pass through the origin) 1 point

For showing that the initial pressure and initial temperature are not zero 1 point

For a final state that is at a higher pressure and temperature than the initial state (regardless of the shape of the path) 1 point

(b) 2 points

For selecting "Moves down" 1 point

For recognition of the piston's mass, which is pulled down by the force of gravity 1 point

Note: One point could be earned for selecting "Remains stationary" with a clear explanation that the internal and external pressures are equal or that the system returned to the original pressure P_0

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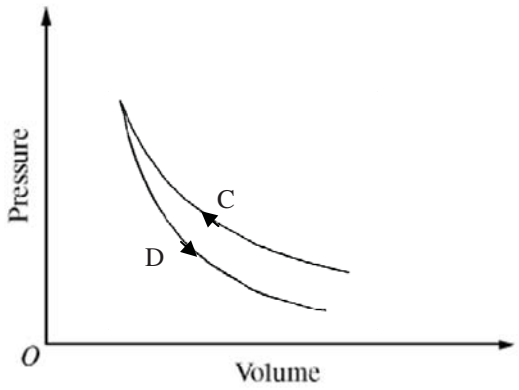
Question 4 (continued)

Distribution of points

(c) 5 points
and
(d) These two parts are closely linked; therefore they are scored as a unit.



For drawing curve C as concave up, with a negative slope	1 point
For drawing curve D as concave up, with a negative slope	1 point
For drawing the final state of curve C and the initial state of curve D as the only point where the two curves intersect	1 point
For drawing curve C above curve D	1 point
For correct labels and directions of arrows on both processes	1 point

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Question 5

15 points total **Distribution of points**

(a)

(i) 2 points

For substituting the electron charge into the equation for potential energy 1 point

$\Delta U = -W = -q\Delta V = -\left(-1.6 \times 10^{-19}\ \text{C}\right)(0 - 24\ \text{V})$

For the correct answer, with units 1 point

$\Delta U = -3.8 \times 10^{-18}\ \text{J} = -24\ \text{eV}$

Note: Full credit is given for the correct answer, with units, with no supporting calculations.

(ii) 1 point

For selecting "Loses energy" 1 point

(b) 4 points

For recognizing that the equivalent resistance is a series sum of two parallel combinations 1 point

For the correct calculation of R_{AB} 1 point

$\frac{1}{R_{AB}} = \frac{1}{R_A} + \frac{1}{R_B} = \frac{1}{6\ \Omega} + \frac{1}{3\ \Omega}$

$R_{AB} = 2\ \Omega$

For the correct calculation of R_{CD} 1 point

$\frac{1}{R_{CD}} = \frac{1}{R_C} + \frac{1}{R_D} = \frac{1}{12\ \Omega} + \frac{1}{24\ \Omega}$

$R_{CD} = 8\ \Omega$

For the correct calculation of R_T 1 point

$R_T = R_{AB} + R_{CD} = 2\ \Omega + 8\ \Omega$

$R_T = 10\ \Omega$

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Question 5 (continued)

Distribution of points

(c)

(i) 3 points

For calculation of the total current, with calculations consistent with the value of R_T found in part (b) — 1 point

$$I_T = \frac{V_T}{R_T} = \frac{(24\text{ V})}{(10\ \Omega)}$$

$$I_T = 2.4\text{ A}$$

For the use of $V_{AB} = I_T R_{AB}$ to find V_{AB} — 1 point

$$V_{AB} = I_T R_{AB} = (2.4\text{ A})(2\ \Omega)$$

$$V_{AB} = 4.8\text{ V}$$

For the use of $I_Y = V_{AB}/R_B$ to find I_Y — 1 point

$$I_Y = \frac{V_{AB}}{R_B} = \frac{(4.8\text{ V})}{(3\ \Omega)}$$

$$I_Y = 1.6\text{ A}$$

Alternate solution — *Alternate points*

For calculation of total current with calculations consistent with calculation of R_T found in part (b) — *1 point*

$$I_T = \frac{V_T}{R_T} = \frac{(24\text{ V})}{(10\ \Omega)}$$

$$I_T = 2.4\text{ A}$$

For indicating that the current splits at the juncture — *1 point*

For correct calculations of the current at Y using the correct ratio — *1 point*

$$V_B = V_{AB}$$

$$I_Y R_B = I_{AB} R_{AB}$$

$$I_Y = \frac{R_{AB}}{R_B} I_T = \frac{2}{3}(2.4\text{ A})$$

$$I_Y = 1.6\text{ A}$$

(ii) 1 point

For an arrow drawn at point *Y* pointing to the right — 1 point

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Question 5 (continued)

Distribution of points

(d) 3 points

For a correct calculation of P_C — 1 point

$$P_C = \frac{V_C^2}{R_C} = I_C^2 R_C$$

Note: Because the ratios of resistances in the two parallel segments are the same, the current in bulb C is the same as at point Y.

$P_C = (1.6\ \text{A})^2 (12\ \Omega)$

$P_C = 30.7\ \text{W}$

For using $U_C = P_C t$ or an equivalent statement with consistent values — 1 point

$U_C = P_C t = (30.7\ \text{W})(5\ \text{s})$

For a consistent answer, with units — 1 point

$U_C = 154\ \text{J}$

(e) 1 point

For a correct ranking of the bulbs in order of brightness, with 1 being the brightest — 1 point

Bulb $A = 4$ Bulb $B = 3$ Bulb $C = 1$ Bulb $D = 2$

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Question 6

10 points total **Distribution of points**

(a) 6 points
and
(b) These two parts are closely linked; therefore they are scored as a unit.

For indicating the use of the sine-wave generator to send a sound wave of a given frequency into the glass tube — 1 point

For indicating adjustment of the movable piston until the sound picked up by the microphone and shown on the waveform display indicates that resonance occurs (maximum amplitude of standing wave) or until resonance is heard by ear — 1 point

For indicating the use of the meterstick to measure the distance L from the piston to the left-hand end of the tube at resonance — 1 point

For a statement indicating that L is proportional, but not equal, to the wavelength — 1 point

For defining variables for frequency and wavelength — 1 point

For indicating that $v = \lambda f$ should be used with the measurements to determine an experimental value of the speed of sound — 1 point

Example

Send a sound wave of frequency f into the glass tube using the sine-wave generator and speaker. Move the piston all the way to the left end of the tube. Pull the piston to the right until the sound picked up by the microphone and shown on the waveform display indicates that resonance occurs. Use the meterstick to measure the distance L between the piston and the left-hand end of the tube. For a tube closed at one end, the wavelength λ is equal to $4L/n$, with the first resonance at $n = 1$. Using the above measurements, an experimental value of the speed of sound can be determined using the equation $v = \lambda f$.

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Question 6 (continued)

Distribution of points

(c) 4 points

For indicating an appropriate variable that can be varied to obtain multiple sets of data	1 point
For correctly identifying appropriate independent and dependent variables to be graphed	1 point
For indicating an appropriate plot that will produce a linear graph	1 point
For stating how the slope of this graph can be used to determine the speed of sound v	1 point

Examples

One of the measured variables that could be varied in order to obtain multiple sets of data is the frequency f. If f is varied, this means it is the independent variable, and the dependent variable is the wavelength λ. A plot of λ versus $1/f$ will produce a linear graph, the slope of which is the speed of sound.

One of the measured variables that could be varied in order to obtain multiple sets of data is the wavelength λ. If λ is varied, this means it is the independent variable, and the dependent variable is the frequency f. A plot of f versus $1/\lambda$ will produce a linear graph, the slope of which is the speed of sound.

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Question 7

10 points total **Distribution of points**

(a) 2 points

For correct substitution of the momentum value into the de Broglie wavelength relationship 1 point

$$\lambda = \frac{h}{p} = \frac{\left(6.63 \times 10^{-34}\ \text{J•s}\right)}{\left(5.5 \times 10^{-20}\ \text{kg•m/s}\right)}$$

For a correct answer, with units 1 point

$\lambda = 1.2 \times 10^{-14}$ m

(b) 2 points

For correct substitution of the momentum into an equation to compute the speed of the proton and substituting the speed into the equation for kinetic energy 1 point

$$\upsilon = \frac{p}{m_p} = \frac{5.5 \times 10^{-20}\ \text{kg•m/s}}{1.67 \times 10^{-27}\ \text{kg}} = 3.3 \times 10^{7}\ \text{m/s}$$

$$K = \frac{1}{2}m\upsilon^2 = \frac{1}{2}\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(3.3 \times 10^{7}\ \text{m/s}\right)^2$$

For a correct answer, with units 1 point

$K = 9.1 \times 10^{-13}$ J (or 9.0×10^{-13} J, depending on earlier rounding)

Alternate solution *Alternate points*

Derive formula for kinetic energy

$$K = \frac{1}{2}m\upsilon^2 = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$$

For using $K = \frac{p^2}{2m}$ *to find the kinetic energy* *1 point*

$$K = \frac{\left(5.5 \times 10^{-20}\ \text{kg•m/s}\right)^2}{(2)\left(1.67 \times 10^{-27}\ \text{kg}\right)}$$

For a correct answer, with units *1 point*

$K = 9.1 \times 10^{-13}$ J

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Question 7 (continued)

Distribution of points

(c) 3 points

For an attempt to apply conservation of energy to the system — 1 point
$U_1 + K_1 = U_2 + K_2$
U_1 is approximately zero (the proton is initially far away from the uranium nucleus)
$K_2 = 0$ (the proton is instantaneously at rest)
Therefore $K_1 = U_2$

For any correct expression that shows the electrostatic potential energy of the system at the proton's closest approach equal to the kinetic energy determined in part (b), using either symbols or values from the problem — 1 point

$$K_1 = U_2 = \frac{kq_1q_2}{r} = \frac{k(92e)(e)}{D}$$

$$K_1 = \frac{92ke^2}{D}$$

$$D = \frac{92ke^2}{K} = \frac{(92)\left(9 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left(1.6 \times 10^{-19} \text{ C}\right)^2}{\left(9.06 \times 10^{-13} \text{ J}\right)}$$

For a correct answer, with units — 1 point
$D = 2.3 \times 10^{-14}$ m

(d) 3 points

For selecting "Greater" — 1 point

For using the mass-energy relationship $E = mc^2$ in an attempt to solve for the mass defect of the uranium decaying into the daughter particles plus excess energy — 1 point

$$E = \Delta mc^2$$

$$\Delta m = \frac{E}{c^2} = \frac{\left(2.5 \times 10^{-11} \text{ J}\right)}{\left(3.0 \times 10^8 \text{ m/s}\right)^2}$$

For an answer with any proper units of mass — 1 point
$\Delta m = 2.8 \times 10^{-28}$ kg or $\Delta m = 0.17$ amu

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AP® Physics B
2011 Free-Response Questions

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TABLE OF INFORMATION FOR 2010 and 2011

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit, $1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2	
Planck's constant, $h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s	
$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm	
Vacuum permittivity, $\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2	
Coulomb's law constant, $k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2	
Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A	
Magnetic constant, $k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A	
1 atmosphere pressure, $1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa	

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

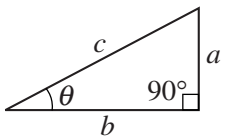
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

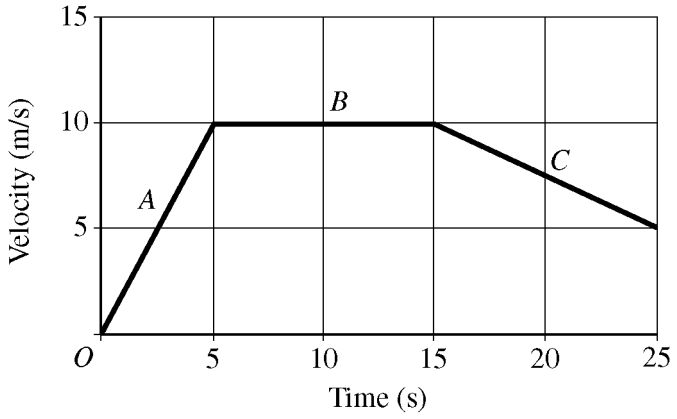
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
6 Questions

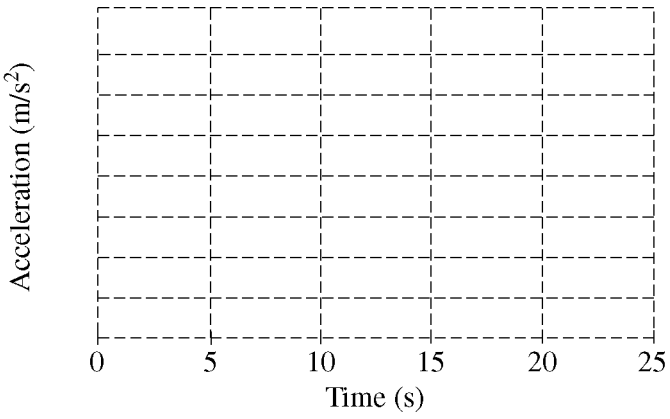
Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-3 and 5 and about 11 minutes for answering each of Questions 4 and 6. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (15 points)

A 0.40 kg object moves in a straight line under the action of a net force. The graph above shows the velocity as a function of time for the object during a 25 s interval. At time $t = 0$, the object is at the position $x = 0$.

(a) On the grid below, sketch a graph of the acceleration as a function of time for the object. Label the scale for the acceleration.



(b) Calculate the position of the object at $t = 5.0$ s.

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(c) On which segment of the graph is the net force acting on the object zero?

____ *A* ____ *B* ____ *C*

Justify your answer.

(d) Calculate the net force on the object during the first 3.0 s of the motion.

(e) Calculate the amount of work done on the object by the net force during the first 15 s of the motion.

(f) For the interval t = 15 s to t = 25 s, is the work done on the object by the net force positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

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2. (15 points)

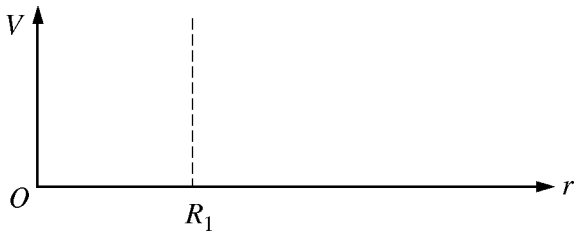
An isolated, solid copper sphere of radius $R_1 = 0.12$ m has a positive charge of 6.4×10^{-9} C.

(a)

i. Calculate the electric potential at a point 0.10 m from the center of the sphere.

ii. Calculate the electric potential at a point 0.24 m from the center of the sphere.

(b) On the axes below, sketch a graph of electric potential V versus radius r from the center of the sphere. Label the value at $r = 0$ on the vertical axis.

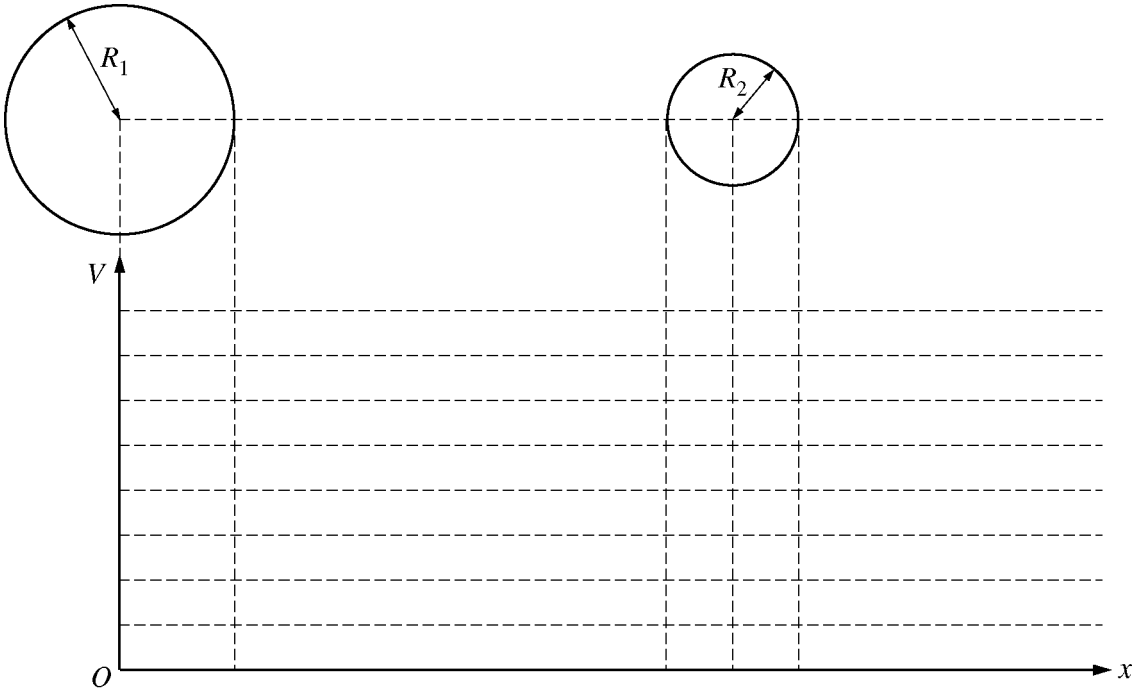


(c)

i. Determine the magnitude of the electric field at a point 0.10 m from the center of the sphere.

ii. Determine the magnitude of the electric field at a point 0.24 m from the center of the sphere.

(d) A second copper sphere of radius R_2 that is uncharged is placed near the first sphere, as represented in the figure below. On the axes below, sketch a graph of electric potential V versus distance along the x-axis shown, where the center of the first sphere is at $x = 0$.



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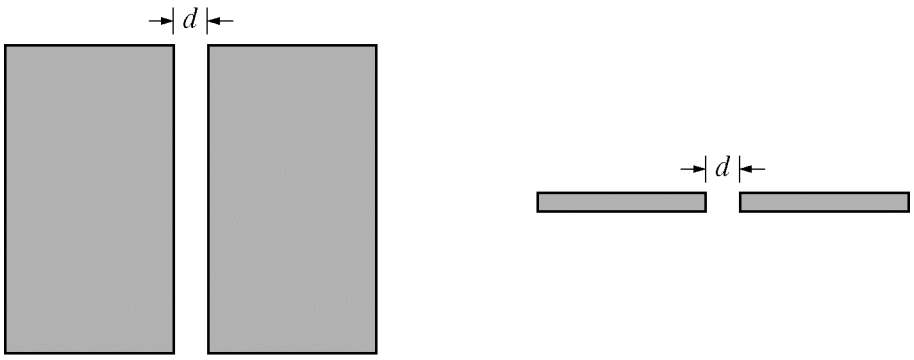

Front View Top View

3. (15 points)

Two metal strips are brought together until their edges are separated by a small distance d, forming a narrow slit, as represented above. You are to design a laboratory experiment to determine the width of the slit.

(a) From the following list of available equipment, check those additional items you would use for the purpose of determining the slit width d.

_____ Laser pointer (λ = 635 nm)	_____ Meterstick
_____ Mirror	_____ Metric ruler
_____ Screen	_____ Prism
_____ Filament lamp	_____ Stopwatch

(b) Sketch a diagram of your experimental setup and label the pieces of equipment that would be used.

(c) Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.

(d) Explain how you would calculate the slit width d by using the measured quantities identified in (c).

(e) Suppose the separation d between the strips was increased, but everything else was kept the same. What changes would you expect to observe? Explain your reasoning.

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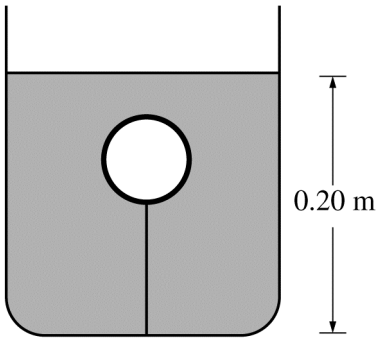

Note: Figure not drawn to scale.

4. (10 points)

A beaker weighing 2.0 N is filled with 5.0×10^{-3} m^3 of water. A rubber ball weighing 3.0 N is held entirely underwater by a massless string attached to the bottom of the beaker, as represented in the figure above. The tension in the string is 4.0 N. The water fills the beaker to a depth of 0.20 m. Water has a density of 1000 kg/m^3. The effects of atmospheric pressure may be neglected.

(a) Calculate the weight of the entire apparatus.

(b) On the dot below that represents the ball, draw and label the forces (not components) that act on the ball.

●

(c) Calculate the buoyant force exerted on the ball by the water. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

(d) Calculate the pressure due to the liquid (the gauge pressure) at the bottom of the beaker.

(e) The string is cut, and the ball rises to the surface and floats. Indicate whether the water level is higher, lower, or the same after equilibrium is reached.

____ Higher ____ Lower ____ The same

Justify your answer.

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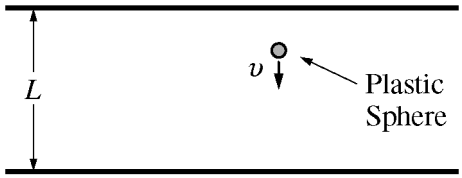


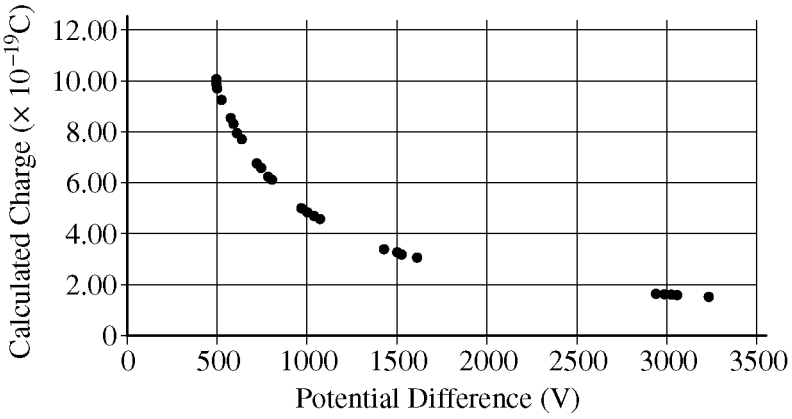
Note: Figure not drawn to scale.

5. (15 points)

In the experimental setup represented above, a very small plastic sphere of mass m with charge q is allowed to fall under the influence of gravity between two parallel metal plates separated by a fixed distance L. A variable potential difference may be applied between the two plates. The experiment is conducted inside a vacuum chamber.

(a) A potential difference of magnitude V is applied between the top and bottom plates such that the sphere falls at constant speed v. Derive an expression for the magnitude of the charge q on the sphere. Express your answer in terms of m, L, V, and fundamental constants, as appropriate.

The experiment is performed many times with spheres of identical known mass but different unknown charges, each time adjusting the potential difference V to the value needed so that the sphere falls at constant speed v. The magnitudes of the charges are calculated from the measured values of the potential difference. The data is plotted below as a function of the magnitude of V.



(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

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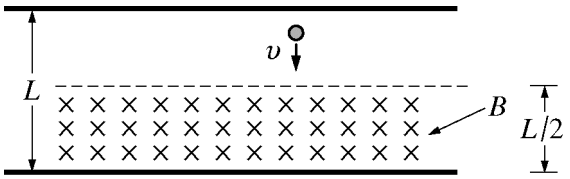
(c) If the value of L is 0.050 m, calculate the mass m of the spheres.

A uniform magnetic field of magnitude B, directed into the page, is now applied in the bottom half of the region between the plates, as shown in the figure below. The experiment is repeated, with the potential difference adjusted again so that the charged sphere falls with constant speed prior to entering the magnetic field.



Note: Figure not drawn to scale.

(d)

i. Describe the motion of the sphere as it travels through the magnetic field.

ii. Describe how the motion could be used to determine the sign of the charge.

(e) Derive an expression for the minimum value of B needed to prevent the sphere from reaching the bottom plate. Express your answer in terms of m, q, v, L, and fundamental constants, as appropriate.

---

6. (10 points)

The allowed energies of a simple hypothetical atom are -6.0 eV, -3.0 eV, and -1.0 eV.

(a) Draw the atom's energy-level diagram. Label each level with the energy and the principal quantum number.

(b) Calculate the wavelengths associated with each possible transition between energy levels for the atom.

(c) The atom is in the ground state when an electron traveling with a speed of 1.3×10^6 m/s collides with it. Can the electron excite the atom to the $n = 2$ state?

___ Yes _____ No _____ It cannot be determined with the information given.

Justify your answer.

(d) Another electron excites the atom from the ground state to the $n = 2$ state. The atom then decays back to the ground state by emitting a photon.

i. Calculate the energy of the emitted photon in joules.

ii. In what region of the electromagnetic spectrum is the radiation?

_____ Radio _____ X-rays _____ Visible light

_____ It cannot be determined with the information given.

END OF EXAM

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AP® Physics B
2011 Scoring Guidelines

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AP® PHYSICS
2011 SCORING GUIDELINES

General Notes About 2011 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be earned. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally earn credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still earned. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \mathrm{m/s^2}$, but use of $10\ \mathrm{m/s^2}$ is also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically earn full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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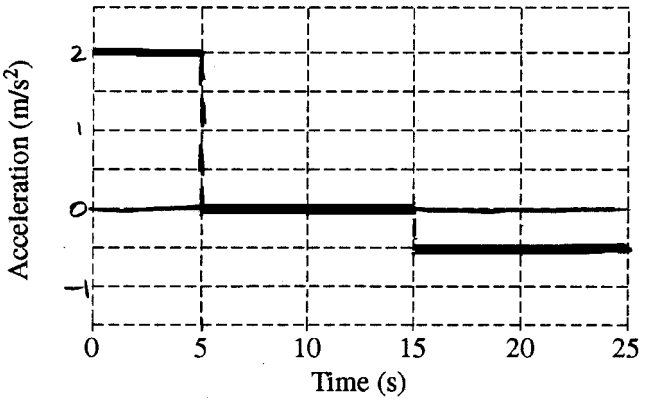
AP® PHYSICS B
2011 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 3 points



For using a linear scale on the vertical axis 1 point
For showing horizontal lines in the three appropriate time frames 1 point
For having the correct acceleration values for segments *B* and *C* 1 point
(The correct value for segment *A* is accounted for in the answer point in part (d).)

$a = \Delta v/\Delta t$ (or the slope of the velocity versus time curve)

For segment *A*: $a = (10\,\text{m/s} - 0\,\text{m/s})/(5\text{ s} - 0\text{ s}) = 2\,\text{m/s}^2$

For segment *B*: slope is zero, so acceleration is zero

For segment *C*: $a = (5\,\text{m/s} - 10\,\text{m/s})/(25\text{ s} - 15\text{ s}) = -0.5\,\text{m/s}^2$

(b) 2 points

$x = x_0 + v_0 t + (1/2)at^2$, where $x_0 = 0$

For substituting $v_0 = 0$ and $t = 5$ s into the equation above 1 point

For substituting the value on the graph of the constant acceleration between 0 and 5 s or an explicit calculation of $2\,\text{m/s}^2$ 1 point

$x = (1/2)\left(2\ \text{m/s}^2\right)(5\text{ s})^2$

$x = 25$ m

Alternate solution *Alternate points*

Position is the area under the velocity versus time curve.

For correctly substituting into the expression for the area under the curve *1 point*

$x = (1/2)(10\,\text{m/s})(5\text{ s})$

For the correct answer *1 point*

$x = 25$ m

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Question 1 (continued)

Distribution of points

(c) 2 points

For selecting segment B 1 point
For an appropriate justification 1 point
Example: $F_{net} = ma = m(\Delta v/\Delta t)$, the velocity is constant for this segment, so $\Delta v = 0$; therefore, $F_{net} = 0$.

(d) 2 points

For using Newton's second law 1 point
$F_{net} = ma$
$F_{net} = (0.40 \text{ kg})\left(2 \text{ m/s}^2\right)$
For the correct answer 1 point
$F_{net} = 0.80 \text{ N}$

(e) 2 points

For using the work-energy theorem 1 point
$W = F\Delta r\cos\theta$
To move in a straight line, the net force must be in the direction of motion, so $\theta = 0°$.
$W = F_{net}d$

For substituting the value of the position determined in from part (b), which is equal to the displacement, to determine the work done for segment A 1 point
For segment A, $W_A = (0.8 \text{ N})(25 \text{ m}) = 20 \text{ J}$
For segment B, $W_B = (0 \text{ N})(10 \text{ m/s})(10 \text{ s}) = 0 \text{ J}$
$W_{tot} = W_A + W_B = 20 \text{ J} + 0 \text{ J} = 20 \text{ J}$

Alternate solution *Alternate points*
$W = \Delta K$
$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$
For correct substitutions into the equation above *1 point*
$W = \frac{1}{2}(0.40 \text{ kg})(10 \text{ m/s})^2 - \frac{1}{2}(0.40 \text{ kg})(0 \text{ m/s})^2$
For the correct answer *1 point*
$W = 20 \text{ J}$

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Question 1 (continued)

		Distribution of points
(f)	3 points	
	For selecting "Negative"	1 point
	For an appropriate explanation using kinematic or dynamic principles	1 point
	Examples: The velocity is decreasing, so the kinetic energy is also decreasing. The acceleration is negative; therefore, the direction of the net force is opposite to the direction of the displacement.	
	For connecting the explanation to the work done	1 point
	Units	1 point
	For correct units on at least two parts with a calculated numerical answer and no incorrect units	1 point

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AP® PHYSICS B
2011 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**

(a)

i. 3 points

For writing the appropriate expression for the electric potential, given the spherical symmetry of the situation — 1 point

$V = \frac{kq}{r}$

The electric field inside a conducting sphere in equilibrium is zero, so the potential inside the sphere is constant, uniform, and equal to the potential at the surface.

$V = \frac{kq}{R_1}$

For correct substitutions — 1 point

$V = \frac{\left(9.0 \times 10^9 \ \text{N•m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9} \ \text{C}\right)}{0.12 \ \text{m}}$

For the correct answer — 1 point

$V = 480 \ \text{V}$

ii. 2 points

For writing the appropriate expression for the electric potential — 1 point

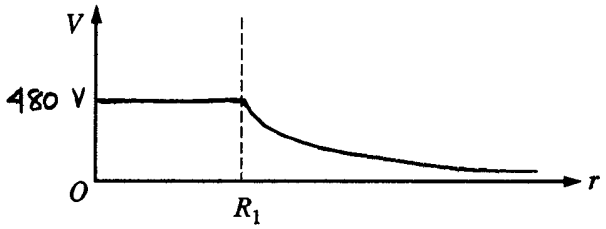
$V = \frac{kq}{r}$

$V = \frac{\left(9.0 \times 10^9 \ \text{N•m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9} \ \text{C}\right)}{0.24 \ \text{m}}$

For the correct answer calculated from a correct expression showing substitutions — 1 point

$V = 240 \ \text{V}$

(b) 3 points



For labeling the potential at $r = 0$ with the value from part (a) i — 1 point

For drawing a horizontal line from $r = 0$ to $r = R_1$ that is continuous with the other part of the graph — 1 point

For drawing a reasonable curve for the $1/r$ dependence in the region beyond R_1 — 1 point

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Question 2 (continued)

Distribution of points

(c)

i. 2 points

$r = 0.10 \text{ m} < 0.12 \text{ m} = R_1$

There is no electric field inside a conducting sphere in equilibrium.

For the correct answer 2 points

$E = 0 \text{ N/C}$

ii. 2 points

$r = 0.24 \text{ m} > 0.12 \text{ m} = R_1$, so the charge can be treated as a point charge at the center of the sphere.

For writing the appropriate expression for the electric field 1 point

$$E = \frac{kq}{r^2}$$

$$E = \frac{\left(9.0 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9} \text{ C}\right)}{(0.24 \text{ m})^2}$$

For the correct answer 1 point

$E = 1000 \text{ N/C}$

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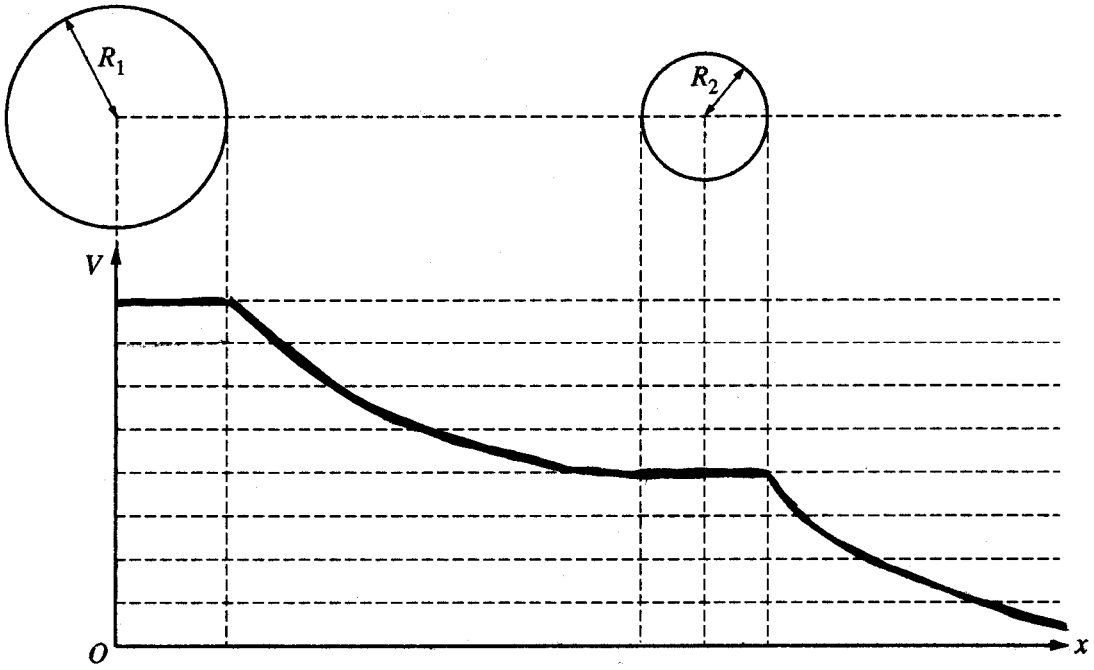
Question 2 (continued)

Distribution of points

(d) 2 points

Sample Sketch



For a horizontal line inside the second sphere, with a nonzero value and continuous with the parts of the graph on either side — 1 point

For $1/r$ curves in the regions on either side of the second sphere, with the curve in the region to the right at lower values than the curve to the left — 1 point

Note: Except for the stipulation above for the $1/r$ curves, the relative values of the potentials of the two spheres are not scored. The sample graph shows an acceptable answer that does not include exact relative values.

Units point

For correct units in parts (a) ii and (c) ii — 1 point

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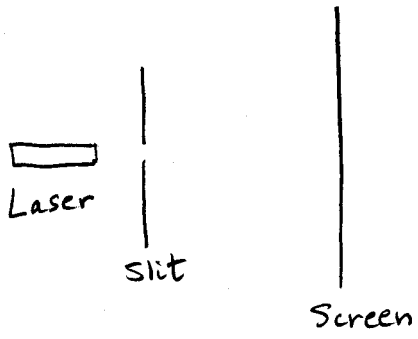
Question 3

15 points total | **Distribution of points**

(a) 2 points

For selection of a length-measuring device (meter stick or metric ruler) — 1 point
For selection of a light source (laser pointer or filament lamp AND prism) — 1 point

(b) 2 points



For a sketch of the equipment selected in part (a), including slit (meter stick or ruler not required) — 1 point
For labeling all the selected equipment, including the slit — 1 point

(c) 4 points

In the scoring of this part, the following aspects of the response earn points:
For shining the laser light through the slit — 1 point
For using the meter stick or ruler to measure at least one distance to be used in the calculation — 1 point
For measuring the distance from the slit to the screen or wall — 1 point
For making reference to some interference pattern formed on the screen or wall — 1 point
Example:

Set up the equipment as shown in the diagram. Shine the laser light through the slit to form a diffraction pattern on the screen. Using the meter stick, measure the distance L between the slit and the screen. Using the metric ruler, measure the width Δx of the central bright maximum on the screen.

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Question 3 (continued)

Distribution of points

(d) 5 points

In the scoring for this part, the following aspects of the explanation earn points:

For including correct expressions for single-slit diffraction, such as the following: 1 point

$x_m = \frac{m\lambda L}{d}$ AND some indication that this is valid only for the small angle approximation, such as saying that $L >> x_m$

OR

$m\lambda = d\sin\theta$ AND $\tan\theta = x_m/L$

For solving for a correct expression for d 1 point

For using the measurements described in part (c) 1 point

For correctly identifying m, consistent with a single-slit diffraction pattern 2 points

Example:

Because $L >> x_m$, the relationship that applies is $x_m = \frac{m\lambda L}{d}$, where x_1 is the distance from the center of the diffraction pattern to the first minimum. This is half the width Δx measured in part (c). L is the distance between the slit and the screen. The final expression for d is $d = \frac{2\lambda L}{\Delta x}$.

(e) 2 points

For indicating that the central bright maximum gets narrower or that the fringes get closer together 1 point

For indicating in the explanation that since x is proportional to $1/d$, if d increases, then x decreases 1 point

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Question 4

10 points total **Distribution of points**

(a) 2 points

For any statement indicating that the total weight is the sum of three terms, that of the beaker, ball, and water — 1 point

$W_{\text{tot}} = W_{\text{beaker}} + W_{\text{ball}} + W_{\text{water}}$

For calculating W_{water} — 1 point

$\rho = m/V$, so $m = \rho V$

$W_{\text{water}} = m_{\text{water}} g = \rho_{\text{water}} V_{\text{water}} g$

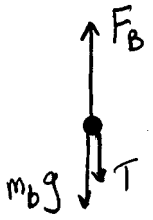
$W_{\text{water}} = \left(1000 \text{ kg/m}^3\right)\left(5.0 \times 10^{-3} \text{ m}^3\right)\left(9.8 \text{ m/s}^2\right) = 49 \text{ N}$

$W_{\text{water}} = 49 \text{ N}$

$W_{\text{tot}} = 2.0 \text{ N} + 3.0 \text{ N} + 49 \text{ N}$

$W_{\text{tot}} = 54 \text{ N}$ (or 55 N using $g = 10 \text{ m/s}^2$)

(b) 3 points



One point for each of the three correctly drawn and appropriately labeled forces — 3 points
One point deducted for any extraneous forces or forces not drawn near the object

(c) 1 point

$\Sigma F_y = ma_y$

The ball is in equilibrium, so $a_y = 0$.

$\Sigma F_y = F_B - T - m_b g = 0$

$F_B = T + m_b g$

$F_B = 4.0 \text{ N} + 3.0 \text{ N}$

For the correct answer — 1 point

$F_B = 7.0 \text{ N}$

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Question 4 (continued)

Distribution of points

(d) 2 points

$P = \rho g h$

For correct substitutions 1 point

$P = \left(1000 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(0.20 \text{ m})$

For the correct answer with units 1 point

$P = 1960$ Pa (or 2000 Pa using $g = 10 \text{ m/s}^2$)

(e) 2 points

For selecting "Lower" 1 point

For an appropriate justification 1 point

Example: Less fluid is displaced by the rubber ball because less of the ball's volume is submerged in the water.

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Question 5

15 points total **Distribution of points**

(a) 4 points

$\Sigma F_y = F_E - F_g = ma_y$

The sphere is in equilibrium, so $a_y = 0$.

For setting the electrical force equal to the gravitational force 1 point

$F_E = F_g$

For correct substitutions for F_E and F_g 1 point

$qE = mg$

Note: If the solution starts with the equation above, the first 2 points are earned.

For substituting into the equation above the relationship $E = V/L$ 1 point

$q\frac{V}{L} = mg$

For the correct final expression for q 1 point

$q = mgL/V$

Note: The points for substitution of expressions for F_E, F_g, and E are earned only if the solution starts with an indication that the electric and gravitational forces are equal in magnitude.

Alternate solution: *Alternate points*

For setting the amount of gravitational potential energy lost equal to the amount of electrical potential energy gained *1 point*

$|\Delta U_g| = |\Delta U_E|$

For substituting mgL for $|\Delta U_g|$ *1 point*

Substituting qV for $|\Delta U_E|$ *1 point*

$mgL = qV$

For the correct final expression for q *1 point*

$q = mgL/V$

Note: The points for the substitution of expressions for $|\Delta U_g|$ *and* $|\Delta U_E|$ *are earned only if the solution starts with an indication of conservation of energy between gravitational and electric potential energy.*

(b) 1 point

For an appropriate physical explanation 1 point

Example: The gap can be explained by the quantization of electric charge. There are no spheres with charges between the values of 3.2×10^{-19} C and 1.6×10^{-19} C, the difference being the electron charge, the smallest charge that can exist.

Note: Answers that refer to the fact that charge is quantized earn this point.

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Question 5 (continued)

Distribution of points

(c) 3 points

From part (a), $q = mgL/V$

$$m = \frac{qV}{gL}$$

For selecting a correct data point (V, q) from the graph, such as $\left(500\text{ V}, 9.6 \times 10^{-19}\text{ C}\right)$ — 1 point

Note: This point is earned for the use of any correct data point from the graph. Many students used the point $\left(500\text{ V}, 1.0 \times 10^{-18}\text{ C}\right)$, which is acceptable.

For substituting the data point value into a correct expression for m — 1 point

$$m = \frac{\left(9.6 \times 10^{-19}\text{ C}\right)(500\text{ V})}{\left(9.8\text{ m/s}^2\right)(0.050\text{ m})}$$

For the correct value of m with correct units — 1 point

$m = 9.8 \times 10^{-16}$ kg (or an equivalent correct value using a different data point or using $g = 10\text{ m/s}^2$)

(d)

When the sphere enters the magnetic field, the upward electric force and the downward gravitational force do not change in magnitude or direction, so they still cancel each other. The resultant force on the sphere is then due to the magnetic force only.

i. 1 point

For an indication that the sphere moves in a circular arc or a curved path — 1 point

ii. 2 points

For stating that if q is positive, then when the sphere enters the magnetic field it will move toward the right (or counterclockwise); however, if q is negative, it will move toward the left (or clockwise). — 2 points

Notes:

One point only is earned if the description mentions that the sphere would move either left or right depending on its charge but does not link a positive charge to moving right and a negative charge to moving left.

One point only is also earned if the description mentions either that if q is positive the sphere would move to the right or that if q is negative the sphere would move to the left but does not mention both.

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Question 5 (continued)

Distribution of points

(e) 4 points

$\Sigma F = F_B = ma_c$

For an indication that it is the magnetic force F_B that provides the centripetal force — 1 point

For a correct substitution for the magnetic force $F_B = q\upsilon B$ — 1 point

For a correct substitution for the centripetal force $ma_c = m\upsilon^2/r$ — 1 point

Note: The two substitution points are earned only if the solution starts with an indication that the centripetal force is due to the magnetic force.

$q\upsilon B = m\dfrac{\upsilon^2}{r}$

Note: If a response starts with the equation above, 3 points are earned.

$B = \dfrac{m\upsilon}{qr}$

For an indication that the radius r must be smaller than $L/2$ to prevent the sphere from reaching the bottom of the plate, so $r_{\max} = L/2$ — 1 point

Because B is inversely proportional to r, the value $r_{\max}$ corresponds to the minimum value of B needed.

$B_{\min} = \dfrac{2m\upsilon}{qL}$

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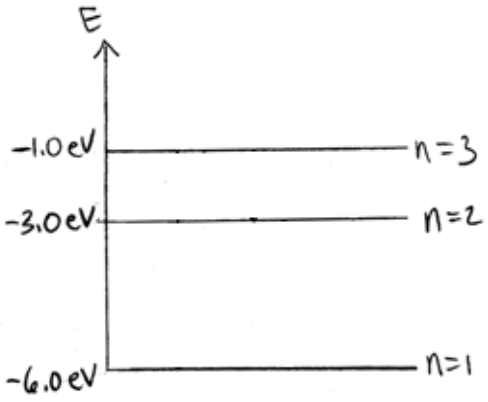
AP® PHYSICS B
2011 SCORING GUIDELINES

Question 6

10 points total **Distribution of points**

(a) 2 points



Note: Figure not to scale

For a correct energy-level diagram with horizontal lines and -6 eV at the bottom — 1 point

Note: The energy-level diagram does not need to be drawn to scale in order to earn this point.

For correct labeling of energy levels and quantum numbers (e.g., $n = 1$ correlated with -6 eV) and no other incorrect energy levels shown — 1 point

(b) 3 points

For correctly relating photon energy to wavelength — 1 point

$E = hc/\lambda$ OR $E = hf$ and $c = \lambda f$ OR $E = pc$ and $p = h/f$

The energy in these equations is equal to the change in energy for each transition, so the wavelength of a photon for each transition becomes $\lambda = hc/\Delta E$, where the value of hc is given on the equation sheet.

For the indication that there are three possible transitions — 1 point

For the substitution of correct values of ΔE in all attempted transitions — 1 point

$n = 3 \rightarrow n = 1$

$\Delta E = -1 \text{ eV} - (-6 \text{ eV}) = 5 \text{ eV}$

$$\lambda_{n=3\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{5.0 \text{ eV}} = 248 \text{ nm}$$

$n = 3 \rightarrow n = 2$

$\Delta E = -1 \text{ eV} - (-3 \text{ eV}) = 2 \text{ eV}$

$$\lambda_{n=3\rightarrow n=2} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{2.0 \text{ eV}} = 620 \text{ nm}$$

$n = 2 \rightarrow n = 1$

$\Delta E = -3 \text{ eV} - (-6 \text{ eV}) = 3 \text{ eV}$

$$\lambda_{n=2\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{3.0 \text{ eV}} = 413 \text{ nm}$$

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Question 6 (continued)

Distribution of points

(c) 3 points

For selecting "Yes," along with a statement that the kinetic energy of the electron is greater than the transition energy. (Note: The selection of "yes" with no justification does not earn this point.) — 1 point

Points are earned for an appropriate justification as follows:

For a correct calculation of the electron's kinetic energy — 1 point

For an identification of the energy needed for the transition from ground state to the first excited state (Note: This point is earned for explicit mention of the needed excitation energy, either 3 eV or a value consistent with the energy-level diagram shown in part (a).) — 1 point

Example:

To excite the atom in the ground state ($n = 1$) to the first excited state ($n = 2$), the incident electron must have a kinetic energy at least equal to the $n = 1 \rightarrow n = 2$ transition energy, which is $\Delta E = -3 \text{ eV} - (-6 \text{ eV}) = 3 \text{ eV}$.

The kinetic energy of the incident electron is

$$K = \frac{1}{2} m_e v^2$$

$$K = \frac{1}{2}\left(9.11 \times 10^{-31} \text{ kg}\right)\left(1.3 \times 10^{6} \text{ m/s}\right)^2 = 7.7 \times 10^{-19} \text{ J} = 4.8 \text{ eV}$$

Since the kinetic energy of the electron is greater than the transition energy, the electron can excite the atom to the $n = 2$ state.

Note: Credit is earned for a "No" response with complete justification only if the justification is consistent with any errors in the energy-level diagram or in the calculation of kinetic energy.

Note: Full credit can also be earned for an answer that (1) calculates the speed of an electron having a kinetic energy equal to that of the energy required to raise the atom from the ground state to the first excited state and (2) then shows that that speed is less than the speed of the electron given in the question, thus concluding that the electron can excite the atom from the ground state to the first excited state.

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Question 6 (continued)

Distribution of points

(d)

i. 1 point

The energy of the emitted photon for the $n = 2 \rightarrow n = 1$ transition is calculated in part (b).

$\Delta E = -3 \text{ eV} - (-6 \text{ eV}) = 3 \text{ eV}$

Converting this value to joules:

$$\Delta E = 3 \text{ eV}\left(\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right)$$

For the correct answer 1 point

$\Delta E = 4.8 \times 10^{-19} \text{ J}$

Note: This point is also awarded for an answer consistent with the energy-level diagram shown in part (a).

ii. 1 point

For selecting "Visible Light" only 1 point

The wavelength for the $n = 2 \rightarrow n = 1$ transition is found in part (b).

$\lambda_{n=2 \rightarrow n=1} = 413 \text{ nm}$

A wavelength of 413 nm is the wavelength for violet in the visible light region of the electromagnetic spectrum.

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AP® Physics B
2010 Free-Response Questions

The College Board

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TABLE OF INFORMATION FOR 2010 and 2011

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

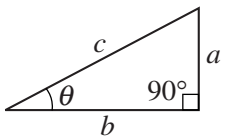
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

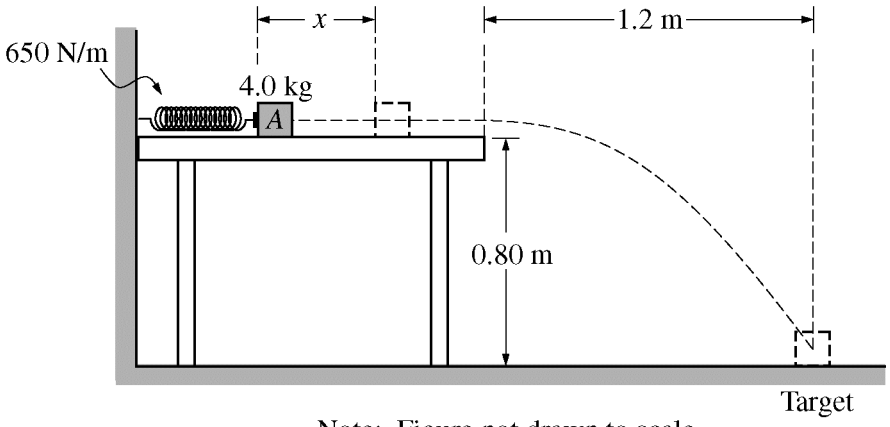
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-2 and about 11 minutes for answering each of Questions 3-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



Note: Figure not drawn to scale.

1. (15 points)

Block *A* of mass 4.0 kg is on a horizontal, frictionless tabletop and is placed against a spring of negligible mass and spring constant $650\ \text{N/m}$. The other end of the spring is attached to a wall. The block is pushed toward the wall until the spring has been compressed a distance *x*, as shown above. The block is released and follows the trajectory shown, falling 0.80 m vertically and striking a target on the floor that is a horizontal distance of 1.2 m from the edge of the table. Air resistance is negligible.

(a) Calculate the time elapsed from the instant block *A* leaves the table to the instant it strikes the floor.

(b) Calculate the speed of the block as it leaves the table.

(c) Calculate the distance *x* the spring was compressed.

Block *B*, also of mass 4.0 kg, is now placed at the edge of the table. The spring is again compressed a distance *x*, and block *A* is released. As it nears the end of the table, it instantaneously collides with and sticks to block *B*. The blocks follow the trajectory shown in the figure below and strike the floor at a horizontal distance *d* from the edge of the table.

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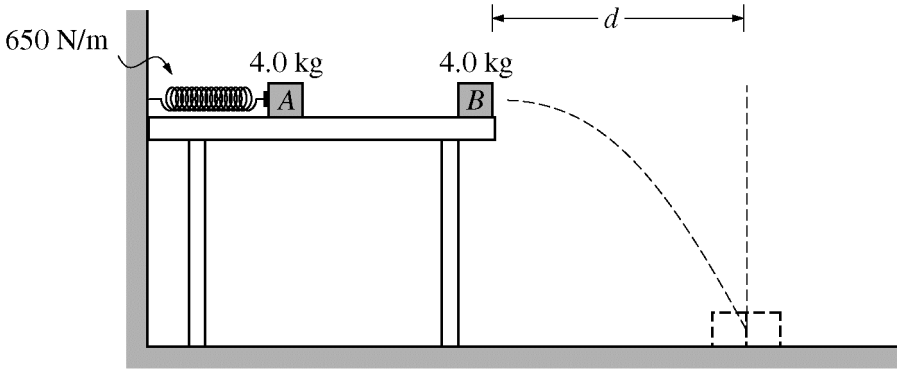

Note: Figure not drawn to scale.

(d) Calculate d if x is equal to the value determined in part (c).

(e) Consider the system consisting of the spring, the blocks, and the table. How does the total mechanical energy E_2 of the system just before the blocks leave the table compare to the total mechanical energy E_1 of the system just before block A is released?

____ $E_2 < E_1$ ____ $E_2 = E_1$ ____ $E_2 > E_1$

Justify your answer.

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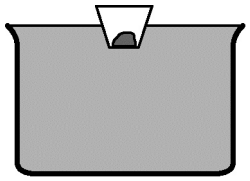

2. (15 points)

A large pan is filled to the top with oil of density ρ_O. A plastic cup of mass m_C, containing a sample of known mass m_S, is placed in the oil so that the cup and sample float, as shown above. The oil that overflows from the pan is collected, and its volume is measured. The procedure is repeated with a variety of samples of different mass, and the pan is refilled each time.

(a) On the dot below that represents the cup-sample system, draw and label the forces (not components) that act on the system when it is floating on the surface of the oil.

●

(b) Derive an expression for the overflow volume V_O (the volume of oil that overflows due to the floating system) in terms of ρ_O, m_S, m_C, and fundamental constants. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

Assume that the following data are obtained for the overflow volume V_O for several sample masses m_S.

Sample mass m_S (kg)	0.020	0.030	0.040	0.050	0.060	0.070
Overflow volume V_O (m^3)	29×10^{-6}	38×10^{-6}	54×10^{-6}	62×10^{-6}	76×10^{-6}	84×10^{-6}

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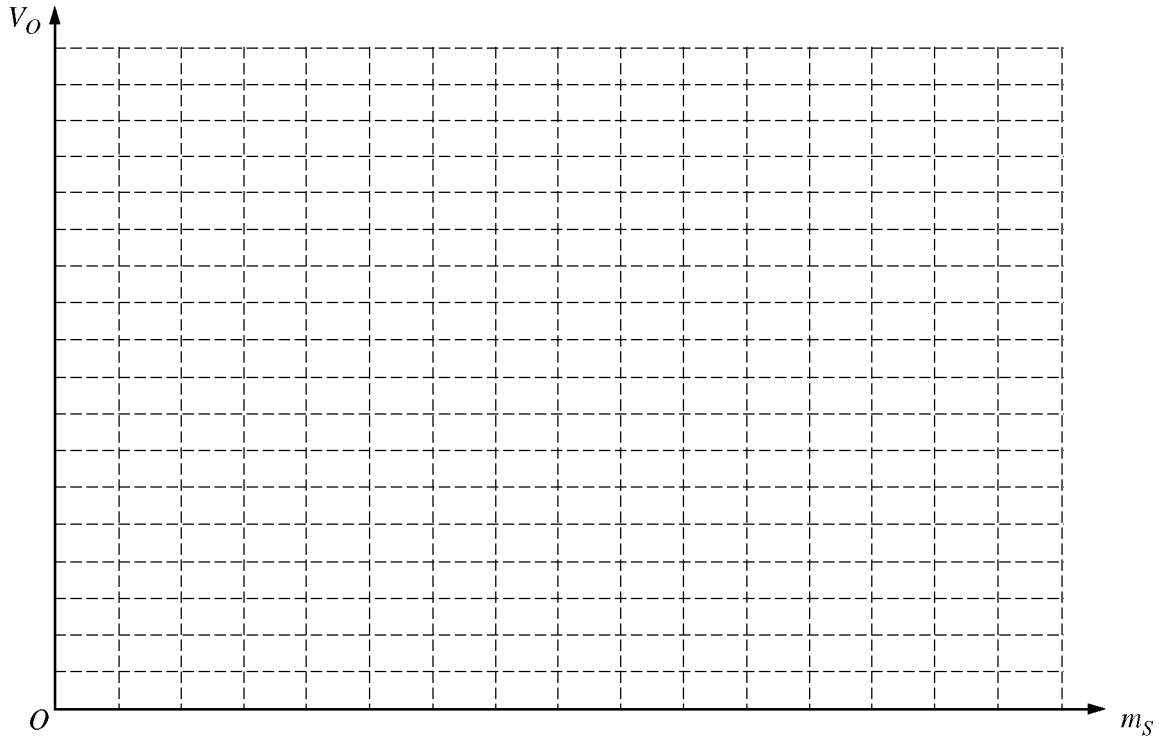
(c) Graph the data on the axes below, plotting the overflow volume as a function of sample mass. Place numbers and units on both axes. Draw a straight line that best represents the data.



(d) Use the slope of the best-fit line to calculate the density of the oil.

(e) What is the physical significance of the intercept of your line with the vertical axis?

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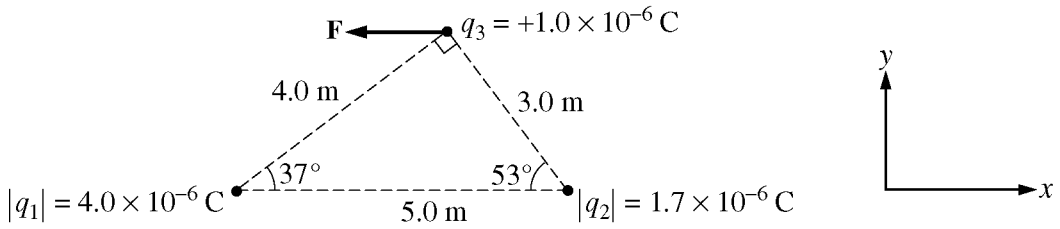


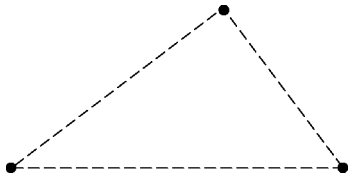
3. (10 points)

Three particles are fixed in place in a horizontal plane, as shown in the figure above. Particle 3 at the top of the triangle has charge q_3 of $+1.0 \times 10^{-6}$ C, and the electrostatic force **F** on it due to the charge on the two other particles is measured to be entirely in the negative *x*-direction. The magnitude of the charge q_1 on particle 1 is known to be 4.0×10^{-6} C, and the magnitude of the charge q_2 on particle 2 is known to be 1.7×10^{-6} C, but their signs are not known.

(a) Determine the signs of the charges q_1 and q_2 and indicate the correct signs below.

q_1	____ Negative	q_2	____ Negative
	____ Positive		____ Positive

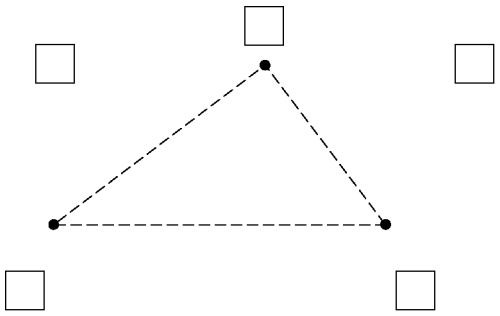
(b) On the diagram below, draw and label arrows to indicate the direction of the force F_1 exerted by particle 1 on particle 3 and the force F_2 exerted by particle 2 on particle 3.



(c) Calculate the magnitude of **F**, the electrostatic force on particle 3.

(d) Calculate the magnitude of the electric field at the position of particle 3 due to the other two particles.

(e) On the figure below, draw a small × in the box that is at a position where another positively charged particle could be fixed in place so that the electrostatic force on particle 3 is zero.



Justify your answer.

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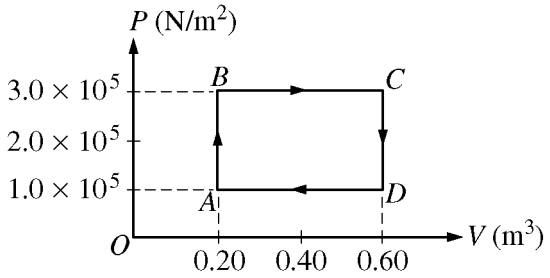
4. (10 points)

A locomotive runs on a steam engine with a power output of 4.5×10^6 W and an efficiency of 12 percent.

(a) Calculate the rate at which heat is being delivered to the steam engine.

(b) Calculate the magnitude of the resistive forces acting on the locomotive when it is moving with a constant speed of $7.0\ \text{m/s}$.

Suppose the gas in another heat engine follows the simplified path *ABCDA* in the *PV* diagram below at a rate of 4 cycles per second.



(c)

i. What does the area bounded by path *ABCDA* represent?

ii. Calculate the power output of the engine.

(d) Indicate below all of the processes during which heat is added to the gas in the heat engine.

____ *AB* ____*BC* ____*CD* ____*DA*

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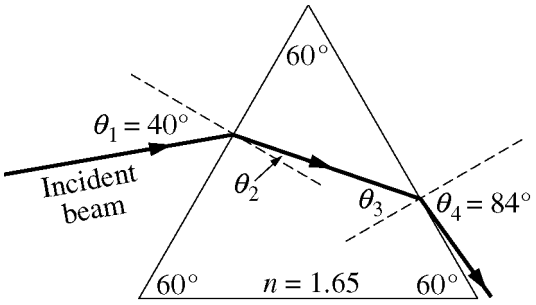

Note: Figure not drawn to scale.

5. (10 points)

As shown above, a beam of red light of wavelength 6.65×10^{-7} m in air is incident on a glass prism at an angle θ_1 with the normal. The glass has index of refraction $n = 1.65$ for the red light. When $\theta_1 = 40°$, the beam emerges on the other side of the prism at an angle $\theta_4 = 84°$.

(a) Calculate the angle of refraction θ_2 at the left side of the prism.

(b) Using the same prism, describe a change to the setup that would result in total internal reflection of the beam at the right side of the prism. Justify your answer.

(c) The incident beam is now perpendicular to the surface. The glass is coated with a thin film that has an index of refraction $n_f = 1.38$ to reduce the partial reflection of the beam at this angle.

i. Calculate the wavelength of the red light in the film.

ii. Calculate the minimum thickness of the film for which the intensity of the reflected red ray is near zero.

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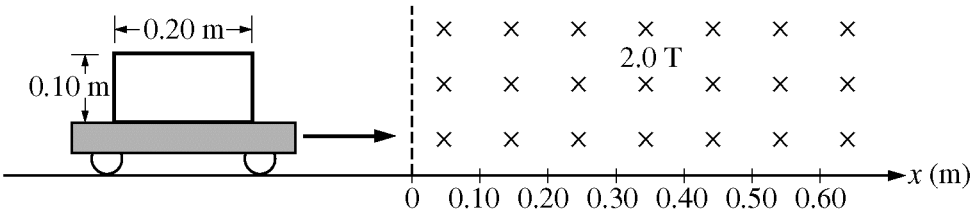
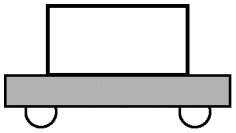


6. (10 points)

The plastic cart shown in the figure above has mass 2.5 kg and moves with negligible friction on a horizontal surface. Attached to the cart is a rigid rectangular loop of wire that is 0.10 m by 0.20 m, has resistance 4.0 Ω, and has a mass that is negligible compared to the mass of the cart. The plane of the rectangular loop is parallel to the plane of the page. A uniform magnetic field of 2.0 T, perpendicular to and directed into the plane of the page, starts at $x = 0$, as shown above.

(a) On the figure below, indicate the direction of the induced current in the loop when its front edge is at $x = 0.12$ m.



Justify your answer.

(b) When the front edge of the rectangular loop is at $x = 0.12$ m, its speed is 3.0 m/s. Calculate the following for that instant.

i. The magnitude of the induced current in the rectangular loop of wire

ii. The magnitude of the net force on the loop

(c) At a later time, the cart and loop are completely inside the magnetic field. Determine the magnitude of the net force on the loop at that time. Justify your answer.

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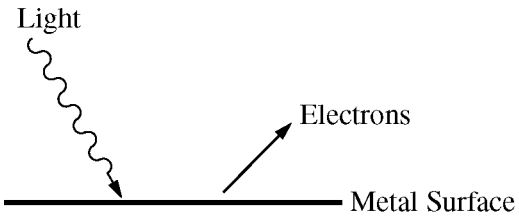

7. (10 points)

Light of wavelength 400 nm is incident on a metal surface, as shown above. Electrons are ejected from the metal surface with a maximum kinetic energy of 1.1×10^{-19} J.

(a) Calculate the frequency of the incoming light.

(b) Calculate the work function of the metal surface.

(c) Calculate the stopping potential for the emitted electrons.

(d) Calculate the momentum of an electron with the maximum kinetic energy.

END OF EXAM

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AP® Physics B
2010 Scoring Guidelines

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AP® PHYSICS
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong — for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
2010 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 3 points

For a correct relationship between the vertical distance and time 1 point

$h = \frac{1}{2}gt^2$

For substitution of the vertical height and the acceleration due to gravity 1 point

$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2(0.80\text{ m})}{9.8\text{ m/s}^2}}$

For the correct answer 1 point

$t = 0.40$ s

Note: Credit was awarded for an alternate solution using $v_y^2 = 2gh$ with appropriate substitutions to find the vertical velocity when the block lands, followed by substitution of this velocity into $v_y = gt$ (or equivalent) to find the time.

(b) 2 points

For a correct relationship between the horizontal distance and time 1 point

$x = vt$

For a consistent substitution of time from part (a) into the correct equation 1 point

$v = \frac{x}{t} = \frac{1.2\text{ m}}{0.40\text{ s}}$

$v = 3.0\text{ m/s}$

(c) 3 points

For any statement of conservation of energy 1 point

For correct use of appropriate energy equations 1 point

$\frac{1}{2}kx^2 = \frac{1}{2}mv^2$

For a consistent substitution of velocity from part (b) into the correct equation 1 point

$x = \sqrt{\frac{m}{k}}v = \sqrt{\frac{4\text{ kg}}{650\text{ N/m}}}(3.0\text{ m/s})$

$x = 0.24$ m

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Question 1 (continued)

Distribution of points

(d) 4 points

For any statement of conservation of momentum 1 point
$m_A v_i = (m_A + m_B) v_f$

For substitution of both masses into the equation 1 point

For substitution of the velocity from part (b) into the equation 1 point
$v_f = \left(\frac{m_A}{m_A + m_B}\right) v_i = \left(\frac{4 \text{ kg}}{4 \text{ kg} + 4 \text{ kg}}\right) 3.0 \text{ m/s} = 1.5 \text{ m/s}$

For substitution of time from part (a) into a correct relationship between the horizontal distance and time 1 point
$d = v_f t = (1.5 \text{ m/s})(0.40 \text{ s})$
$d = 0.60 \text{ m}$

(e) 2 points

For indicating that $E_2 < E_1$ 1 point

For a correct justification stating one of the following: 1 point
- the kinetic energy (or energy) is transformed into other forms of energy during the collision (e.g., by reference to heat, internal energy, sound)
- the kinetic energy is not conserved in an inelastic collision
- a numerical calculation of the relevant energies

Units 1 point

For correct units on all completed answers 1 point

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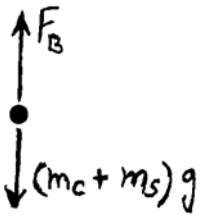
Question 2

15 points total **Distribution of points**

(a) 2 points



For a single upward force, appropriately labeled, representing the buoyant force 1 point

For downward gravitational force (or forces), appropriately labeled, representing the cup and the sample 1 point

One earned point was deducted if any extraneous forces were present.

(b) 3 points

For any statement of equilibrium 1 point

$F_B = F_g$

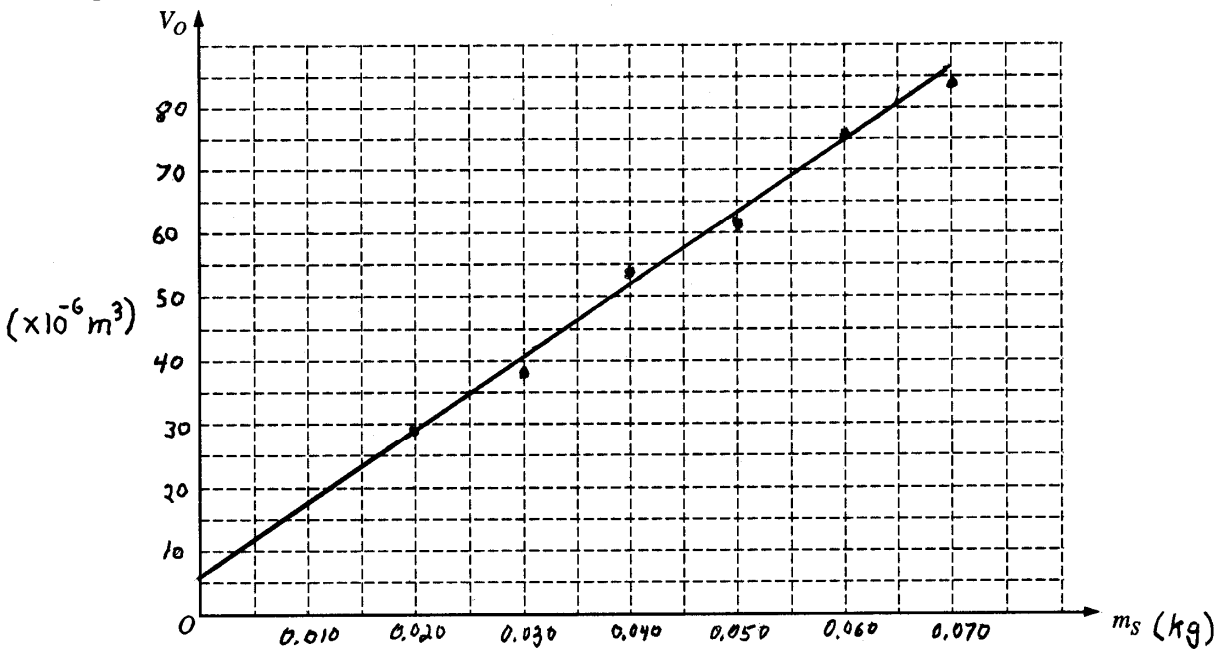
For a correct substitution including both masses m_C and m_S 1 point

$\rho_O V_O g = (m_C + m_S)g$

For correct statement of the overflow volume, V_O 1 point

$$V_O = \frac{m_C + m_S}{\rho_O}$$

(c) 4 points



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Question 2 (continued)

Distribution of points

(c) (continued)

For data plotted correctly — 1 point
For correct units on both axes — 1 point
For numerical scales that are linear and allow the plotted data to extend over about half the grid area — 1 point
For a reasonable single straight best-fit line that does not go through (0,0) — 1 point

(d) 4 points

From part (b), $V_O = \frac{m_C}{\rho_O} + \frac{1}{\rho_O} m_S$

For properly calculating a slope using points on the straight line drawn, including data points only if they are on that line — 1 point

Example: Using the two points (0.060 kg, 75×10^{-6} m^3) and (0.025 kg, 35×10^{-6} m^3) that are on the line in the graph above

For calculating a reasonable value of slope — 1 point

$$\text{slope} = \frac{1}{\rho_0} = \frac{(75 - 35) \times 10^{-6} \text{ m}^3}{(.060 - 0.025) \text{ kg}} = 1.14 \times 10^{-3} \text{ m}^3/\text{kg}$$

For an explicit or implicit indication of inverting the slope — 1 point
For calculating a reasonable value for the oil's density (including units and four significant figures or less) — 1 point

$\rho_O = 8.8 \times 10^2 \text{ kg}/\text{m}^3$

(e) 2 points

For a complete statement that the *y* intercept is the volume of the oil displaced by the empty cup — 2 points

Note: 1 point is given for a partially correct answer

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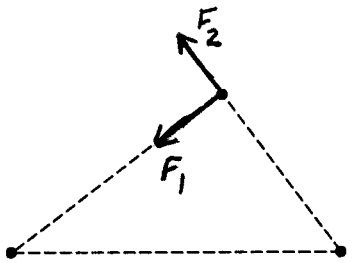
Question 3

10 points total **Distribution of points**

(a) 1 point

For an indication that q_1 is negative and q_2 is positive 1 point

(b) 2 points



For force $\mathbf{F}_1$ drawn and labeled correctly 1 point

For force $\mathbf{F}_2$ drawn and labeled correctly 1 point

Notes: The force vectors must either originate or terminate on q_3.
Forces on other particles are ignored.

(c) 3 points

For a correct statement or use of Coulomb's law 1 point

Applying Coulomb's law to determine the magnitude of the forces $\mathbf{F}_1$ and $\mathbf{F}_2$:

$$F_1 = \frac{kq_1q_3}{r_{13}^2} = \frac{\left(9\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(4.0\times10^{-6}\ \text{C}\right)\left(1.0\times10^{-6}\ \text{C}\right)}{(4.0\ \text{m})^2} = 2.25\times10^{-3}\ \text{N}$$

$$F_2 = \frac{kq_2q_3}{r_{23}^2} = \frac{\left(9\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(1.7\times10^{-6}\ \text{C}\right)\left(1.0\times10^{-6}\ \text{C}\right)}{(3.0\ \text{m})^2} = 1.70\times10^{-3}\ \text{N}$$

For any indication that $\mathbf{F}$ is the vector sum of the two forces: $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$ 1 point

Since $\mathbf{F}_1$ and $\mathbf{F}_2$ are at right angles to each other, the magnitude can be found using the Pythagorean theorem.

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{\left(2.25\times10^{-3}\ \text{N}\right)^2 + \left(1.70\times10^{-3}\ \text{N}\right)^2}$$

Alternate solution: The y components cancel, so the magnitude of $\mathbf{F}$ *is the sum of the x components.*

$$F = F_{1x} + F_{2x} = F_1\cos37^\circ + F_2\cos53^\circ$$

$$F = \left(2.25\times10^{-3}\ \text{N}\right)\cos37^\circ + \left(1.70\times10^{-3}\ \text{N}\right)\cos53^\circ$$

$$F = 1.8\times10^{-3}\ \text{N} + 1.0\times10^{-3}\ \text{N}$$

For the correct answer with units 1 point

$$F = 2.8\times10^{-3}\ \text{N}$$

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Question 3 (continued)

Distribution of points

(d) 2 points

For substituting the value of F from part (c) and using the correct value for q_3 1 point

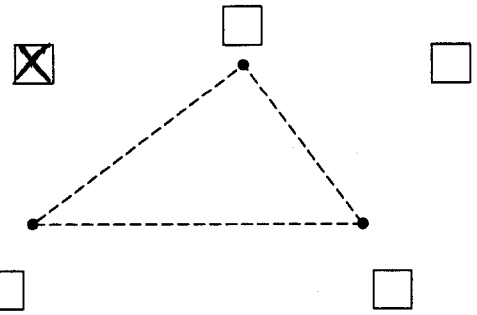
$$E = \frac{F}{q_3} = \frac{2.8 \times 10^{-3}\ \text{N}}{1.0 \times 10^{-6}\ \text{C}}$$

This point could also be earned for substituting F_1 and F_2 from part (c) into $E = F/q_3$ and then calculating the magnitude of the vector sum, or calculating E_1 and E_2 from $E = kq/r^2$ with correct q's and r's and then calculating the magnitude of the vector sum.

For a calculated answer with correct units 1 point

$$E = 2.8 \times 10^3\ \text{N/C}$$

(e) 2 points



For an $\times$ in the correct position as shown above 1 point

For a correct justification that refers to forces 1 point

For example: Positive charges repel and a force to the right would cancel force **F**.

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Question 4

10 points total **Distribution of points**

(a) 3 points

$e = W_{\text{out}}/Q_{\text{in}}$ or $e = P_{\text{out}}/P_{\text{in}}$ $\left(\text{i.e. } \dfrac{W_{\text{out}}/t}{Q_{\text{in}}/t}\right)$

For a correct substitution of the efficiency into a correct equation 1 point

$0.12 = W_{\text{out}}/Q_{\text{in}}$ or $0.12 = P_{\text{out}}/P_{\text{in}}$

For a correct recognition of the relationship between power, energy and time 1 point

Examples of exhibiting that relationship include: starting with $e = P_{\text{out}}/P_{\text{in}}$, using $P = W/t$ or Q/t in the efficiency equation or referring to the power as a rate.

$P_{\text{in}} = P_{\text{out}}/e = 4.5 \times 10^6 \text{ W}/0.12$

For a correct answer with correct units 1 point

$P_{\text{in}} = 3.8 \times 10^7 \text{ W}$

(b) 2 points

$P_{\text{out}} = Fv\cos\theta$

$F = P_{\text{out}}/(v\cos\theta)$

For a correct substitution of P_{out} into a correct expression 1 point

The resistive force acts opposite to the velocity, so $\theta = 180°$.

$F = 4.5 \times 10^6 \text{ W}/[(7.0 \text{ m/s})(\cos 180°)]$

For an answer consistent with the value of P_{out} substituted, with correct units 1 point

$|F| = 6.4 \times 10^5 \text{ N}$

(c)

(i) 1 point

For an answer that uses the word "work" to represent the area 1 point

(ii) 2 points

For a correct calculation of the work (either on the gas or by the gas) represented by the rectangular path 1 point

$W = \text{base} \times \text{height} = (V_D - V_A)(P_B - P_A)$

$W = \left(0.60 \text{ m}^3 - 0.20 \text{ m}^3\right)\left(3.0 \times 10^5 \text{ N/m}^2 - 1.0 \times 10^5 \text{ N/m}^2\right) = 8.0 \times 10^4 \text{ J}$

There are four cycles per second, so the time for one cycle is 0.25 s.

$P_{\text{out}} = W_{\text{out}}/\Delta t = 8.0 \times 10^4 \text{ J}/0.25 \text{ s}$

For a consistent calculation of the power output from the work calculated, with units 1 point

$P_{\text{out}} = 3.2 \times 10^5 \text{ W}$

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Question 4 (continued)

Distribution of points

(d) 2 points

For indicating *AB* as a correct process 1 point
For indicating *BC* as a correct process 1 point
One point is deducted for each incorrect process indicated, up to the number of points earned for correct processes.

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Question 5

10 points total **Distribution of points**

(a) 2 points

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_2 = \dfrac{n_1 \sin\theta_1}{n_2}$

For correct substitutions into Snell's Law 1 point

$\sin\theta_2 = \dfrac{(1.0)\sin 40°}{1.65} = 0.390$

For the correct answer 1 point

$\theta_2 = 22.9°$ or $23°$

(b) 3 points

In order for total internal reflection to occur, θ_3 must increase until it is greater than θ_{critical}. For this to occur, θ_2 must decrease. Finally, to decrease θ_2 there must be a decrease in θ_1.

For stating that θ_3 must increase to become greater than θ_{critical} 1 point

For stating that θ_2 must decrease 1 point

For stating that θ_1 must decrease 1 point

Alternate solution *Alternate points*

For calculating the minimum value of θ_3 that will result in total internal reflection *1 point*

$\theta_{\text{critical}} = \sin^{-1}\left(\dfrac{1}{1.65}\right) = 37.3°$

For calculating the corresponding value of θ_2 *1 point*

$\theta_2 = 60° - \theta_3 = 22.7°$

For calculating the corresponding value of θ_1 *1 point*

$\theta_1 = \sin^{-1}[1.65(\sin 22.7°)] = 39.5°$, *therefore θ_1 must be decreased.*

Other correct methods also received appropriate credit.

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Question 5 (continued)

Distribution of points

(c)

(i) 2 points

For a correct relationship between the wavelength in air and the wavelength in the film, which can be derived from $\lambda = vf$ and $n = c/v$ — 1 point

$$\lambda_{\text{film}} = \frac{\lambda_{\text{air}}}{n_{\text{film}}}$$

$$\lambda_{\text{film}} = \frac{6.65 \times 10^{-7}\ \text{m}}{1.38}$$

For the correct answer with units — 1 point

$$\lambda_{\text{film}} = 4.82 \times 10^{-7}\ \text{m}$$

Alternate solution — *Alternate points*

For the correct calculation of either the velocity of light in the medium or the frequency of the light — *1 point*

$$v_{\text{film}} = \frac{c}{n_{\text{film}}} = \frac{3.00 \times 10^{8}\ \text{m/s}}{1.38} = 2.17 \times 10^{8}\ \text{m/s}$$

$$\text{OR} \quad f = \frac{c}{\lambda_{\text{air}}} = \frac{3.00 \times 10^{8}\ \text{m/s}}{6.65 \times 10^{-7}\ \text{m}} = 4.51 \times 10^{14}\ \text{Hz}$$

$$\lambda_{\text{film}} = \frac{v_{\text{film}}}{f} = \frac{2.17 \times 10^{8}\ \text{m/s}}{4.51 \times 10^{14}\ \text{Hz}}$$

For the correct answer with units — *1 point*

$$\lambda_{\text{film}} = 4.81 \times 10^{-7}\ \text{m}$$

(ii) 3 points

The light that enters the film and reflects off the prism travels a total distance $2t$ through the film. At both interfaces, there is a 180° phase change when the light is reflected, so the relative phase change of the interfering rays is zero. For destructive interference, the minimum path length in the film must equal $\lambda_{\text{film}}/2$. Therefore, we have the relationship $2t = \lambda_{\text{film}}/2$.

For the relationship between the thickness of the film and the wavelength of light in the film — 1 point

$$t = \frac{\lambda_{\text{film}}}{4} \text{ or } t = \frac{\lambda_{\text{air}}}{4n_{\text{film}}}$$

For the correct substitution of the wavelength of light in the film — 1 point

$$t = \frac{\lambda_{\text{film}}}{4} = \frac{4.82 \times 10^{-7}\ \text{m}}{4} \quad \text{OR} \quad t = \frac{\lambda_{\text{air}}}{4n_{\text{film}}} = \frac{6.65 \times 10^{-7}\ \text{m}}{4(1.38)}$$

For the correct answer with units — 1 point

$$t = 1.20 \times 10^{-7}\ \text{m}$$

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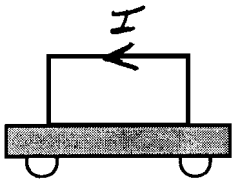
Question 6

10 points total **Distribution of points**

(a) 3 points



For an unambiguous indication that the induced current in the loop is in the counterclockwise direction — 1 point

For a justification that includes <u>two</u> correct and relevant principles, such as the following: — 2 points

- The flux is changing (or increasing into the page).
- The induced current will oppose the change in flux.
- A counterclockwise current will produce flux out of the page.
- The magnetic forces on charges in the right-hand wire will drive a counter-clockwise current.
- Velocity is to the right, and $\mathbf{B}$ into the page, so $q\mathbf{v} \times \mathbf{B}$ points toward the top of the page.
- The induced current must produce a magnetic drag force (opposite the motion).

A single relevant principle earns 1 point.

(b)

(i) 2 points

For writing relevant algebraic expressions for both the current and the emf somewhere in the part (b) answer space — 1 point

$I = \dfrac{\mathcal{E}}{R}$ and $\mathcal{E} = -\dfrac{\Delta\phi_m}{\Delta t}$ or $\mathcal{E} = B\ell v$

$I = B\ell v/R = (2.0\text{ T})(0.10\text{ m})(3.0\text{ m/s})/4.0\,\Omega$

For the correct magnitude of the current — 1 point

$I = 0.15$ A

(ii) 1 point

$F_B = BI\ell\sin\theta$, where $\theta = 90°$ because the field is perpendicular to the direction of the current.

For an unambiguous substitution of current and wire length consistent with part (i) and the correct magnetic field into a correct expression for force — 1 point

$F_B = (2.0\text{ T})(0.15\text{ A})(0.10\text{ m})\sin 90°$

$F_B = 0.030$ N

Units 1 point

For correct units in the answers to both parts (i) and (ii) — 1 point

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Question 6 (continued)

	Distribution of points
(c) 3 points	
For an unambiguous indication that the net force is zero	1 point
For stating that the current is zero	1 point
For either correctly explaining why the current is zero (such as "there is no change in magnetic flux" or "magnetic forces on charges in the two sides of the loop push the charges in opposite directions") or explaining how zero current results in zero magnetic force on the wire loop	1 point

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Question 7

10 points total **Distribution of points**

(a) 2 points

$v = f\lambda$

For substitution of the appropriate values of the speed of light and the wavelength into the correct expression — 1 point

$f = \frac{v}{\lambda} = \frac{c}{\lambda} = \frac{3.0 \times 10^{8} \text{ m/s}}{400 \times 10^{-9} \text{ m}}$

For the correct answer — 1 point

$f = 7.5 \times 10^{14} \text{ Hz}$

(b) 2 points

$K_{\max} = hf - \phi$

$\phi = hf - K_{\max}$

For consistent substitution of the maximum kinetic energy into the correct expression — 1 point

For consistent substitution of the frequency into the correct expression — 1 point

$\phi = \left(6.63 \times 10^{-34} \text{ J•s}\right)\left(7.5 \times 10^{14} \text{ Hz}\right) - 1.1 \times 10^{-19} \text{ J}$

$\phi = 3.9 \times 10^{-19} \text{ J}$

(c) 2 points

$eV = K_{\max}$

For substitution of the appropriate values of the maximum kinetic energy and the charge of the electron into the correct expression — 1 point

$V = \frac{K_{\max}}{e} = \frac{1.1 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ C}}$

For the correct magnitude of the stopping potential — 1 point

$V = 0.69 \text{ V}$

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Question 7 (continued)

Distribution of points

(d) 3 points

$K = \frac{1}{2}mv^2$ 1 point

For substitution of the appropriate values of the maximum kinetic energy and the mass of the electron into the correct expression

$$v = \sqrt{\frac{2K_{\max}}{m}} = \sqrt{\frac{2\left(1.1 \times 10^{-19}\ \text{J}\right)}{9.11 \times 10^{-31}\ \text{kg}}} = 4.91 \times 10^{5}\ \text{m/s}$$

For consistent substitution of velocity and mass of the electron into the correct expression 1 point

$$p = mv = \left(9.11 \times 10^{-31}\ \text{kg}\right)\left(4.91 \times 10^{5}\ \text{m/s}\right)$$

For the correct answer 1 point

$p = 4.5 \times 10^{-25}\ \text{kg•m/s}$

Units 1 point

For using correct units in completed answers 1 point

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AP® Physics B
2009 Free-Response Questions

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TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, 1 eV $= 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

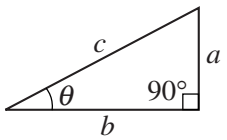
$d\sin\theta = m\lambda$

$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

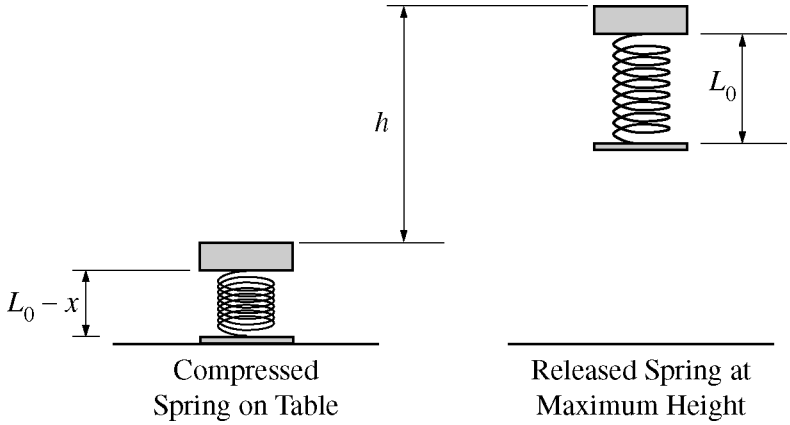
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1 and 3 and about 11 minutes for answering each of Questions 2 and 4-7. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



1. (15 points)

In an experiment, students are to calculate the spring constant k of a vertical spring in a small jumping toy that initially rests on a table. When the spring in the toy is compressed a distance x from its uncompressed length L_0 and the toy is released, the top of the toy rises to a maximum height h above the point of maximum compression. The students repeat the experiment several times, measuring h with objects of various masses taped to the top of the toy so that the combined mass of the toy and added objects is m. The bottom of the toy and the spring each have negligible mass compared to the top of the toy and the objects taped to it.

(a) Derive an expression for the height h in terms of m, x, k, and fundamental constants.

With the spring compressed a distance $x = 0.020$ m in each trial, the students obtained the following data for different values of m.

	m (kg)	h (m)	
	0.020	0.49	
	0.030	0.34	
	0.040	0.28	
	0.050	0.19	
	0.060	0.18	

(b)

i. What quantities should be graphed so that the slope of a best-fit straight line through the data points can be used to calculate the spring constant k ?

ii. Fill in one or both of the blank columns in the table with calculated values of your quantities, including units.

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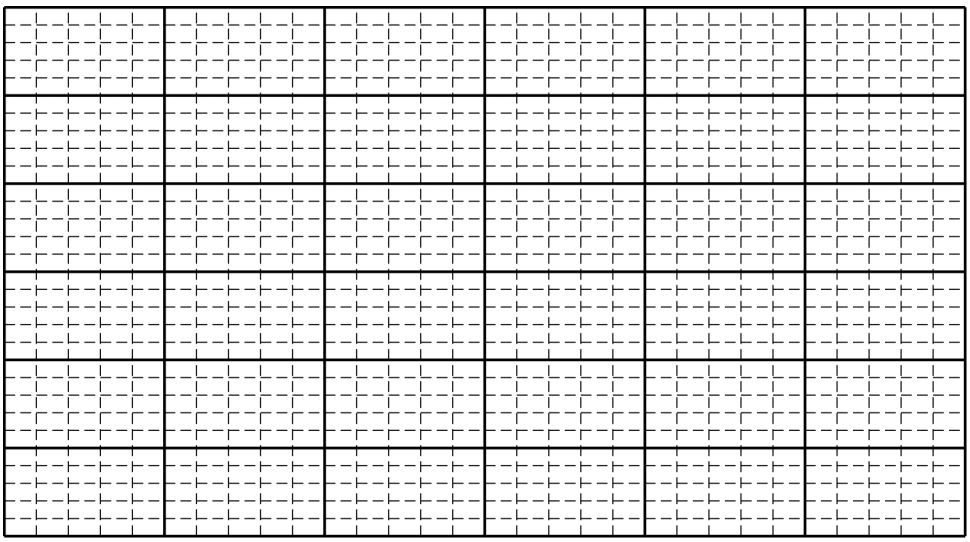
(c) On the axes below, plot your data and draw a best-fit straight line. Label the axes and indicate the scale.



(d) Using your best-fit line, calculate the numerical value of the spring constant.

(e) Describe a procedure for measuring the height h in the experiment, given that the toy is only momentarily at that maximum height.

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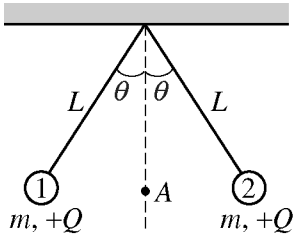
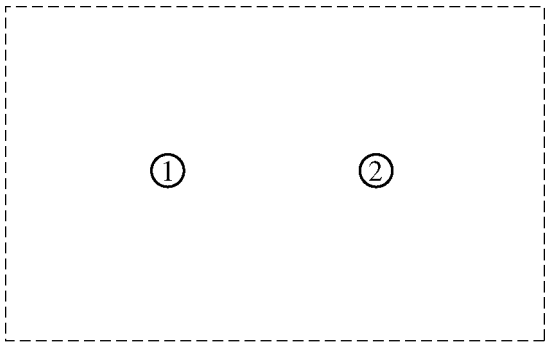


2. (10 points)

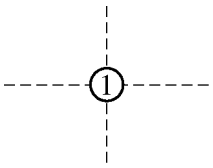
Two small objects, labeled 1 and 2 in the diagram above, are suspended in equilibrium from strings of length L. Each object has mass m and charge $+Q$. Assume that the strings have negligible mass and are insulating and electrically neutral. Express all algebraic answers in terms of m, L, Q, θ, and fundamental constants.

(a) On the following diagram, sketch lines to illustrate a 2-dimensional view of the net electric field due to the two objects in the region enclosed by the dashed lines.



(b) Derive an expression for the electric potential at point A, shown in the diagram at the top of the page, which is midway between the charged objects.

(c) On the following diagram of object 1, draw and label vectors to represent the forces on the object.



(d) Using the conditions of equilibrium, write—but do not solve—two equations that could, together, be solved for θ and the tension T in the left-hand string.

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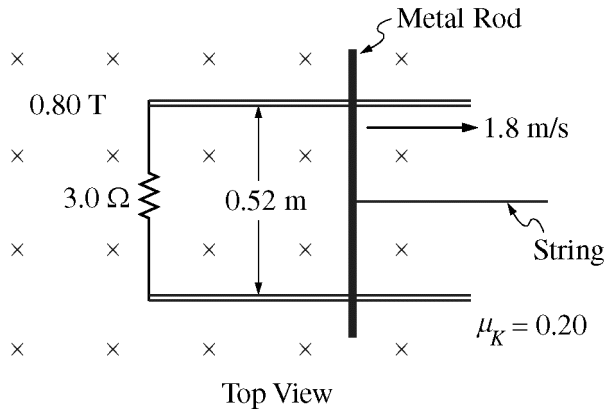

3. (15 points)

A metal rod of mass 0.22 kg lies across two parallel conducting rails that are a distance of 0.52 m apart on a tabletop, as shown in the top view above. A 3.0 Ω resistor is connected across the left ends of the rails. The rod and rails have negligible resistance but significant friction with a coefficient of kinetic friction of 0.20. There is a magnetic field of 0.80 T perpendicular to the plane of the tabletop. A string pulls the metal rod to the right with a constant speed of 1.8 m/s.

(a) Calculate the magnitude of the current induced in the loop formed by the rod, the rails, and the resistor.

(b) Calculate the magnitude of the force required to pull the rod to the right with constant speed.

(c) Calculate the energy dissipated in the resistor in 2.0 s.

(d) Calculate the work done by the string pulling the rod in 2.0 s.

(e) Compare your answers to parts (c) and (d). Provide a physical explanation for why they are equal or unequal.

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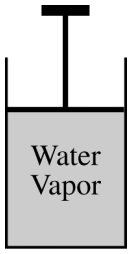
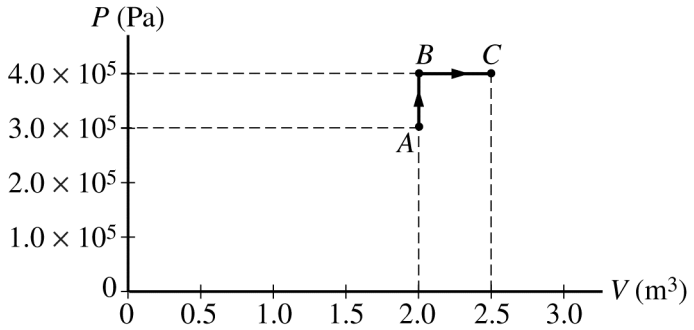


4. (10 points)

The cylinder represented above contains 2.2 kg of water vapor initially at a volume of $2.0\ \text{m}^3$ and an absolute pressure of 3.0×10^5 Pa. This state is represented by point A in the PV diagram below. The molar mass of water is 18 g, and the water vapor can be treated as an ideal gas.



(a) Calculate the temperature of the water vapor at point A.

The absolute pressure of the water vapor is increased at constant volume to 4.0×10^5 Pa at point B, and then the volume of the water vapor is increased at constant pressure to $2.5\ \text{m}^3$ at point C, as shown in the PV diagram.

(b) Calculate the temperature of the water vapor at point C.

(c) Does the internal energy of the water vapor for the process $A \rightarrow B \rightarrow C$ increase, decrease, or remain the same?

____Increase ____Decrease ____Remain the same

Justify your answer.

(d) Calculate the work done on the water vapor for the process $A \rightarrow B \rightarrow C$.

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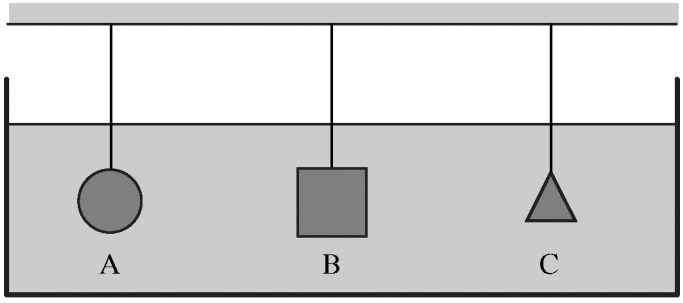

5. (10 points)

Three objects of identical mass attached to strings are suspended in a large tank of liquid, as shown above.

(a) Must all three strings have the same tension?

____ Yes ____ No

Justify your answer.

Object A has a volume of 1.0×10^{-5} m^3 and a density of 1300 kg/m^3. The tension in the string to which object A is attached is 0.0098 N.

(b) Calculate the buoyant force on object A.

(c) Calculate the density of the liquid.

(d) Some of the liquid is now drained from the tank until only half of the volume of object A is submerged. Would the tension in the string to which object A is attached increase, decrease, or remain the same?

____ Increase ____ Decrease ____ Remain the same

Justify your answer.

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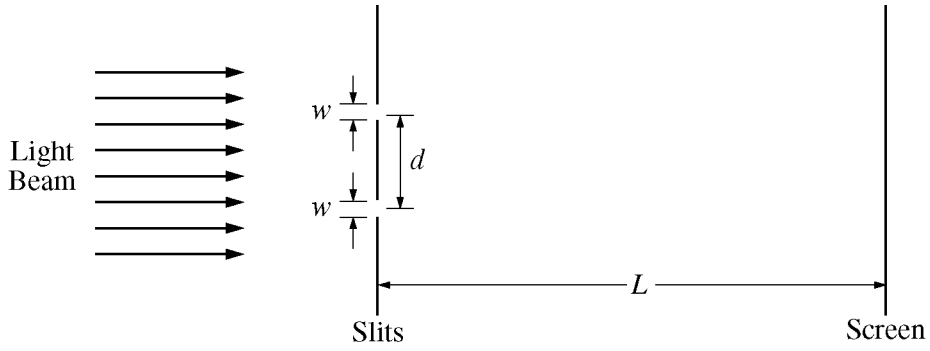
6. (10 points)

In a classroom demonstration, a beam of coherent light of wavelength 550 nm is incident perpendicularly onto a pair of slits. Each slit has a width w of 1.2×10^{-6} m, and the distance d between the centers of the slits is 1.8×10^{-5} m. The class observes light and dark fringes on a screen that is a distance L of 2.2 m from the slits. Your notebook shows the following setup for the demonstration.



Note: Figure not drawn to scale.

(a) Calculate the frequency of the light.

(b) Calculate the distance between two adjacent dark fringes on the screen.

The entire apparatus is now immersed in a transparent fluid having index of refraction 1.4.

(c) What is the frequency of the light in the transparent fluid?

(d) Does the distance between the dark fringes increase, decrease, or remain the same?

_____ Increase _____ Decrease _____ Remain the same

Explain your reasoning.

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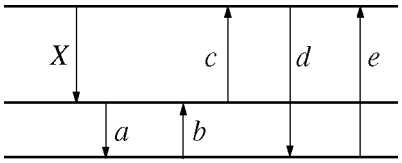
7. (10 points)

A photon of wavelength 250 nm ejects an electron from a metal. The ejected electron has a de Broglie wavelength of 0.85 nm.

(a) Calculate the kinetic energy of the electron.

(b) Assuming that the kinetic energy found in (a) is the maximum kinetic energy that it could have, calculate the work function of the metal.

(c) The incident photon was created when an atom underwent an electronic transition. On the energy level diagram of the atom below, the transition labeled X corresponds to a photon wavelength of 400 nm. Indicate which transition could be the source of the original 250 nm photon by circling the correct letter.



Justify your answer.

END OF EXAM

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AP® Physics B
2009 Scoring Guidelines

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AP® PHYSICS
2009 SCORING GUIDELINES

General Notes About 2009 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point and a student's solution contains the application of that equation to the problem, but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
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Question 1

15 points total **Distribution of points**

(a) 3 points

For a correct statement of conservation of mechanical energy (which might be implied in the next statement) 1 point

For correct energy expressions set equal 1 point

$$mgh = \frac{1}{2}kx^2$$

For solving for h, consistent with the energy equation 1 point

$$h = \frac{kx^2}{2mg}$$

(b)

(i) 2 points

For a correct combination of ($1/m$ and h) or ($1/h$ and m), with or without constants 2 points

Notes:

- If both $1/m$ and $1/h$ were chosen, only 1 point was earned.
- If part (b)(i) contained quantities that would not yield a correct graph for part (c), no credit was given for parts (b)(ii) through (d). But if part (b)(i) was left blank, parts (b)(ii) through (d) were examined for correct results.

The example of h versus $1/m$ is used in the remainder of the scoring guideline.

(ii) 2 points

$1/m$ $\left(\text{kg}^{-1}\right)$	m (kg)	h (m)	
50	0.020	0.49	
33	0.030	0.34	
25	0.040	0.28	
20	0.050	0.19	
17	0.060	0.18	

For correctly filling in the table with the appropriate data 1 point

For including the correct units in the table 1 point

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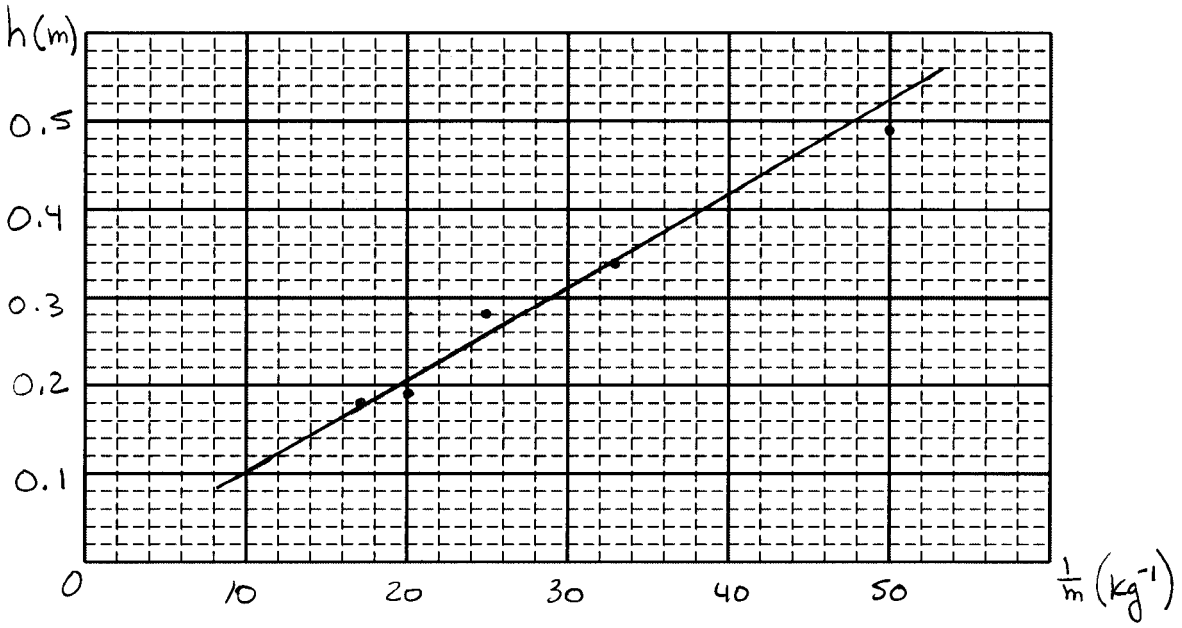
Question 1 (continued)

Distribution of points

(c) 4 points



For correctly plotting appropriate data (all five data points plotted correctly, assuming the data represented an inverse relationship between m and h) 1 point

For correctly drawing a best-fit straight line (a single straight line with data points reasonably scattered above and below the line) 1 point

For correctly labeling both axes 1 point

For correctly indicating the scale on both axes 1 point

(d) 2 points

For correctly calculating the slope from points on the line 1 point

For example: $\text{slope} = \dfrac{(0.42 - 0.10)\ \text{m}}{(40 - 10)\ \text{kg}^{-1}} = \dfrac{0.32\ \text{m}}{30\ \text{kg}^{-1}} = 1.07 \times 10^{-2}\ \text{m•kg}$

For a correct numerical value of the spring constant 1 point

From (a), $h = \dfrac{kx^2}{2mg}$, so the slope of the line = $\dfrac{kx^2}{2g}$

$$k = \frac{2g(\text{slope})}{x^2}$$

$$k = \frac{2\left(9.8\ \text{m/s}^2\right)\left(1.07 \times 10^{-2}\ \text{m•kg}\right)}{(0.02\ \text{m})^2}$$

$k = 524\ \text{N/m}$ $(535\ \text{N/m}$ using $g = 10\ \text{m/s}^2)$

Note: Values between $450\ \text{N/m}$ and $550\ \text{N/m}$ were accepted.

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Question 1 (continued)

Distribution of points

(e) 2 points

For a correct, complete procedure 2 points

Examples: Use a meter stick and a visual recorder, such as the eye, a video camera, or a camera.
Use a sonic range finder and appropriate computer software.
Measure the time (either to rise or for a round trip) and give the correct appropriate kinematics equations (the equations must be included in the answer).

One point was awarded for a partially correct or incomplete procedure.

Examples: Use a meter stick.
Use a photogate.

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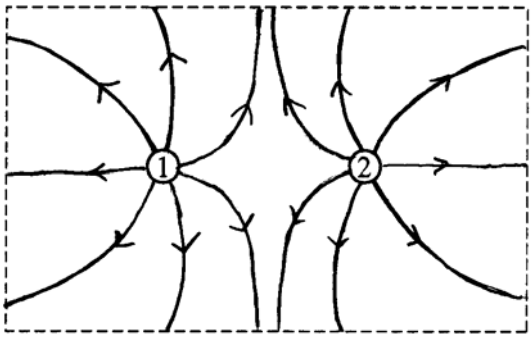
Question 2

10 points total **Distribution of points**

(a) 3 points



For the direction of all field lines away from the source charges 1 point
For the correct shape, symmetry, and curvature of the field lines 1 point
For a clear indication that the net field about point *A*, the point midway between the two charges, is zero; example: an absence of field lines in the area around point *A* 1 point

(b) 2 points

For clearly showing the addition of both contributions to the potential at point *A* 1 point

$V = \frac{kq_1}{r_1} + \frac{kq_2}{r_2}$ OR $V = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{d} + \frac{Q}{d}\right)$ OR equivalent

For a correct expression in terms of the given quantities 1 point

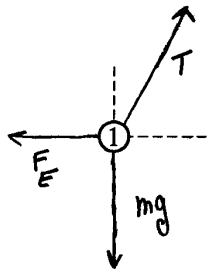
$V = \frac{2kQ}{L\sin\theta}$ OR $\frac{2Q}{4\pi\epsilon_0 L\sin\theta}$ OR $\frac{Q}{2\pi\epsilon_0 L\sin\theta}$ OR equivalent

Notes:

- The answer with no work shown earned 1 point.
- The following expression or its equivalents, with no other work shown, earned both points:

$$V = \frac{kQ}{L\sin\theta} + \frac{kQ}{L\sin\theta}$$

(c) 2 points



For all three vectors correctly drawn, with arrowheads, and no extraneous vectors 1 point
For appropriate labeling of vectors (only if first point was awarded) 1 point

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Question 2 (continued)

Distribution of points

(d) 3 points

For an expression indicating that the *x*-component of tension is equal to F_E 1 point

$T_x - F_E = 0$ OR $T\sin\theta = F_E$ OR equivalent

For an expression indicating that the *y*-component of tension is equal to *mg* 1 point

$T_y - mg = 0$ OR $T\cos\theta = mg$ OR equivalent

For stating the two equations in terms of the given quantities 1 point

$T\sin\theta = \dfrac{kQ^2}{4L^2\sin^2\theta}$ OR $\dfrac{Q^2}{16\pi\epsilon_0 L^2\sin^2\theta}$ OR $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q^2}{4L^2\sin^2\theta}$ OR equivalent

$T\cos\theta = mg$

Notes:

- Correct statement of both of the final two equations, in the absence of any other expressions, earned full credit.
- One point was deducted if sine and cosine were interchanged at any point.

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Question 3

15 points total **Distribution of points**

(a) 3 points

For a correct statement of Ohm's law (symbolic or numeric) 1 point
For a correct statement of Faraday's law (symbolic or numeric) 1 point

$I = \dfrac{\mathcal{E}}{R} = \dfrac{B\ell v}{R}$

$I = \dfrac{(0.80\ \text{T})(0.52\ \text{m})(1.8\ \text{m/s})}{3.0\ \Omega}$

For the correct answer 1 point

$I = 0.25\ \text{A}$

(b) 4 points

For a correct expression for the friction force (symbolic or numeric) 1 point

$F_f = \mu_k mg$

$F_f = (0.20)(0.22\ \text{kg})\left(9.8\ \text{m/s}^2\right)$

$F_f = 0.43\text{N}$ $(0.44\ \text{N using } g = 10\ \text{m/s}^2)$

For a correct expression for the magnetic force (symbolic or numeric) 1 point

$F_B = BI\ell$

$F_B = (0.80\ \text{T})(0.25\ \text{A})(0.52\ \text{m})$

$F_B = 0.10\text{N}$

For any indication of multiple forces (explicit, implied, free-body diagram, etc.) 1 point

$F = F_f + F_B$

For a correct answer consistent with the current from part (a) 1 point

$F = 0.43\ \text{N} + 0.10\ \text{N} = 0.53\ \text{N}$ $(0.54\ \text{N using } g = 10\ \text{m/s}^2)$

(c) 3 points

For a correct expression for energy (including time) 1 point

$E_{diss} = Pt$

For a correct expression for power (individually or in another expression) 1 point

$P = I^2R$ OR $P = IV$ OR $P = V^2/R$

For consistent substitution of current or voltage from part (a) into a correct equation 1 point

$E_{diss} = I^2Rt$ OR $E_{diss} = IVt$ OR $E_{diss} = V^2t/R$

For example:

$E_{diss} = (0.25\ \text{A})^2(3.0\ \Omega)(2.0\ \text{s})$

$E_{diss} = 0.38\ \text{J}$

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Question 3 (continued)

Distribution of points

(d) 2 points

For a correct expression for distance 1 point
$d = vt$
$d = (1.8\ \text{m/s})(2.0\ \text{s})$
$d = 3.6\ \text{m}$
For a consistent substitution of force from part (b) 1 point
$W = Fd$
$W = (0.54\ \text{N})(3.6\ \text{m})$
$W = 1.9\ \text{J}$
Full credit could also be given for equivalent solutions (e.g., combining the expression $P = Fv$ for power with the expression $W = Pt$ for work to get $W = Fvt$, followed by consistent substitutions).

(e) 2 points

For mentioning the force of friction but not including the concept of work 1 point
For including a statement that friction does work or dissipates energy 1 point
Note: If the answer for part (d) is less than or equal to the answer for part (c), no credit was given.

Units point

For correct units on all numerical answers 1 point

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Question 4

10 points total **Distribution of points**

(a) 3 points

For any attempt to use the ideal gas equation of state, i.e., by attempting to substitute values into the equation (simply writing the equation did not earn this point) 1 point

$PV = nRT$

$T = PV/nR$

For correctly calculating the number of moles 1 point

$n = 2.2 \text{ kg}/18 \times 10^{-3} \text{ kg/mol} = 122 \text{ mol}$

For substituting the correct values for pressure, volume, and the universal gas constant into the ideal gas equation 1 point

$T_A = \left(3.0 \times 10^5 \text{ Pa}\right)\left(2.0 \text{ m}^3\right)/(122 \text{ mol})(8.31 \text{ J/mol•K})$

$T_A = 590 \text{ K}$

(b) 1 point

$T = PV/nR$

$T_C = \left(4.0 \times 10^5 \text{ Pa}\right)\left(2.5 \text{ m}^3\right)/(122 \text{ mol})(8.31 \text{ J/mol•K})$

For the correct answer, with the correct unit 1 point

$T_C = 980 \text{ K}$

Note: An alternate solution uses the ratios $P_A V_A/T_A = P_C V_C/T_C$ to obtain $T_C = 5T_A/3$. The point could be earned if the answers in parts (b) and (a) were in the ratio $5/3$ and the temperatures were in Kelvin.

(c) 3 points

For indicating that the internal energy increases 1 point

For a correct justification, with no incorrect statements 2 points

For example: internal energy is proportional to the temperature, which increases as the gas is taken from *A* to *C*.

One point could be earned for an incomplete justification or one that would be complete and correct but for an incorrect physical statement.

(d) 3 points

W = area under the curve = $-P\Delta V$ (the minus sign is not needed for this point) 1 point

$W = -\left(4.0 \times 10^5 \text{ Pa}\right)\left(0.5 \text{ m}^3\right)$

For an answer having the correct magnitude, including the correct unit 1 point

For the negative sign on the answer 1 point

$W = -2.0 \times 10^5 \text{ J}$

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Question 5

10 points total **Distribution of points**

(a) 3 points

For checking "No" 1 point
For a complete and correct justification, with no incorrect statements 2 points
For example: the tension in each string depends on the weight and the buoyant force. The buoyant force depends on the volume of the object. Objects of identical mass have the same weight but need not have identical volumes.
One point could be earned for a partial justification, or one that contained an incorrect statement.

(b) 3 points

For any correct expression of the equilibrium of the three forces on object A 1 point
$T = mg - B$, where B is the buoyant force
For correctly using the density and volume of object A to calculate its weight and labeling as such 1 point

$$mg = \rho Vg = \left(1300 \text{ kg/m}^3\right)\left(1.0 \times 10^{-5} \text{ m}^3\right)\left(9.8 \text{ m/s}^2\right) = 0.13 \text{ N}$$

$$B = mg - T = 0.13 \text{ N} - 0.0098 \text{ N}$$

For an answer consistent with preceding work 1 point
$B = 0.12$ N

(c) 2 points

The buoyant force equals the weight of the displaced liquid, which depends on its density.

$$B = \rho_\ell Vg$$

$$\rho_\ell = B/Vg$$

For substituting the buoyant force from part (b) and the correct values for volume and g into a correct expression 1 point

$$\rho_\ell = (0.12 \text{ N})/\left(1.0 \times 10^{-5} \text{ m}^3\right)\left(9.8 \text{ m/s}^2\right)$$

For an answer consistent with the above substitutions, including correct units 1 point

$$\rho_\ell = 1200 \text{ kg/m}^3$$

An alternate solution using the ratio of forces $F_B/F_g = \rho_\ell Vg/\rho_A Vg = \rho_\ell/\rho_A$ earned similar substitution and answer points.

(d) 2 points

For indicating that the tension increases 1 point
For a correct justification 1 point
For example: less of the object submerged means less liquid displaced, which means less buoyant force. By the equation in part (b), the tension is greater.

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Question 6

10 points total **Distribution of points**

(a) 2 points

For a meaningful attempt to use the equation $f = c/\lambda$ 1 point

$f = \left(3.00 \times 10^{8}\ \text{m/s}\right)/\left(550 \times 10^{-9}\ \text{m}\right)$

For the correct answer, with correct units 1 point

$f = 5.5 \times 10^{14}\ \text{Hz}$

(b) 3 points

For writing one or more equations that can be used to solve the problem 1 point

$x \approx m\lambda L/d$ OR $d\sin\theta = m\lambda$ and $\sin\theta \approx x/L$ (or $\tan\theta \approx x/L$)

For indicating that the calculation is for the spacing between fringes, rather than the position of a single fringe 1 point

$\Delta x = \Delta m\lambda L/d$

Adjacent fringes means $\Delta m = 1$

$\Delta x = \lambda L/d$

For correct substitutions into the correct expression 1 point

$\Delta x = \left(550 \times 10^{-9}\ \text{m}\right)(2.2\ \text{m})/\left(1.8 \times 10^{-5}\ \text{m}\right)$

$\Delta x = 0.067\ \text{m}$

(c) 2 points

For indicating that the frequency is the same as in part (a) 2 points

$f = 5.5 \times 10^{14}\ \text{Hz}$

Note: If there was no answer in part (a) and a calculation was done in this part, the scoring guideline for part (a) was applied.

(d) 3 points

For correctly indicating that the fringe spacing decreases 1 point

For indicating in the explanation that the wavelength decreases 1 point

For indicating in the explanation that Δx is proportional to the wavelength 1 point

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Question 7

10 points total **Distribution of points**

(a) 3 points

$\lambda = h/p = h/m\upsilon$

$\upsilon = h/m\lambda$

For substituting the correct value of the electron wavelength into a correct expression 1 point

For substituting a correct value of Planck's constant into a correct expression 1 point

$\upsilon = \left(6.63 \times 10^{-34}\ \text{J•s}\right)/\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(0.85 \times 10^{-9}\ \text{m}\right)$

$\upsilon = 8.56 \times 10^{5}\ \text{m/s}$

For substituting the correct value of the electron mass into a correct expression for the kinetic energy 1 point

$K = m\upsilon^2/2$

$K = \left(9.11 \times 10^{-31}\ \text{kg}\right)\left(8.56 \times 10^{5}\ \text{m/s}\right)^2/2$

$K = 3.3 \times 10^{-19}\ \text{J}$ (or 2.1 eV)

(b) 3 points

For any indication that the student used the equation for the photoelectric effect 1 point

$K_{\max} = hf - \phi$

$\phi = hf - K_{\max} = (hc/\lambda) - K_{\max}$

For substituting the correct value of the photon wavelength into the correct expression 1 point

For substituting for hc in appropriate energy units into the correct expression 1 point

$\phi = \left[\left(6.63 \times 10^{-34}\ \text{J•s}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)/\left(250 \times 10^{-9}\ \text{m}\right)\right] - 3.3 \times 10^{-19}\ \text{J}$

$\phi = 4.7 \times 10^{-19}\ \text{J}$ (or 2.9 eV)

Units point

For correct units in both parts (a) and (b) 1 point

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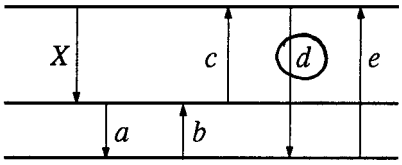
Question 7 (continued)

Distribution of points

(c) 3 points



For choosing the correct transition 1 point

For indicating that the emission of a photon requires the atom to go to a lower energy level 1 point

For indicating that $E = hc/\lambda$ for a photon, so a smaller wavelength means a larger energy difference 1 point

Notes:

- Two points could be earned by choosing transition *a* and stating that the emission of a photon requires a drop to a lower energy level.
- Two points could be earned by choosing transition *e* and stating that the shorter photon wavelength implies a larger difference between energy levels.

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AP® Physics B
2009 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, 1 eV $= 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

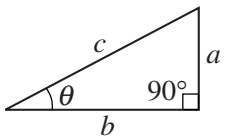
$d\sin\theta = m\lambda$

$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

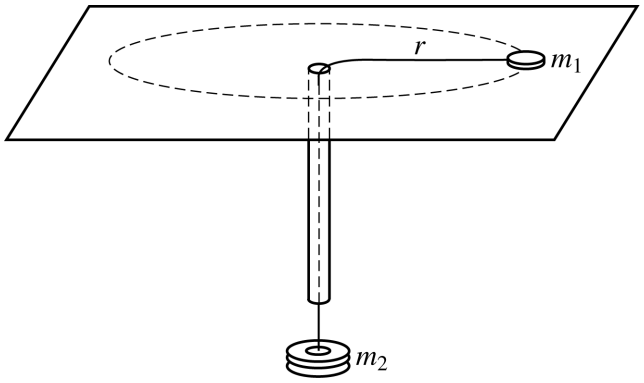
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
6 Questions

Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-4 and about 11 minutes for answering each of Questions 5-6. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the lavender insert.



1. (15 points)

An experiment is performed using the apparatus above. A small disk of mass m_1 on a frictionless table is attached to one end of a string. The string passes through a hole in the table and an attached narrow, vertical plastic tube. An object of mass m_2 is hung at the other end of the string. A student holding the tube makes the disk rotate in a circle of constant radius r, while another student measures the period P.

(a) Derive the equation $P = 2\pi\sqrt{\frac{m_1 r}{m_2 g}}$ that relates P and m_2.

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The procedure is repeated, and the period P is determined for four different values of m_2, where $m_1 = 0.012$ kg and $r = 0.80$ m. The data, which are presented below, can be used to compute an experimental value for g.

m_2 (kg)	0.020	0.040	0.060	0.080
P (s)	1.40	1.05	0.80	0.75

(b) What quantities should be graphed to yield a straight line with a slope that could be used to determine g ?

(c) On the grid below, plot the quantities determined in part (b), label the axes, and draw the best-fit line to the data. You may use the blank rows above to record any values you may need to calculate.



(d) Use your graph to calculate the experimental value of g.

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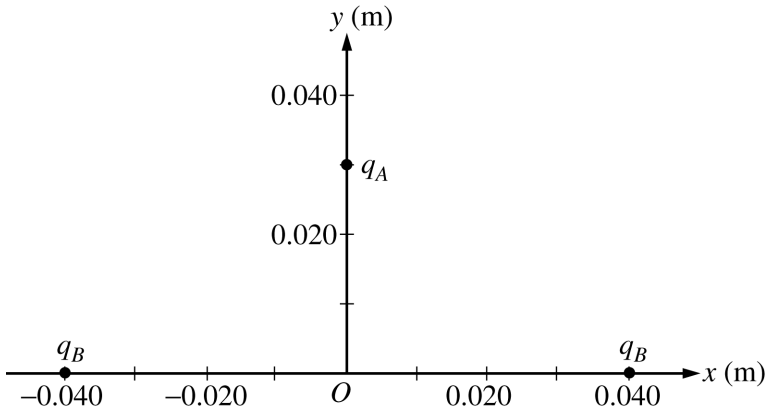


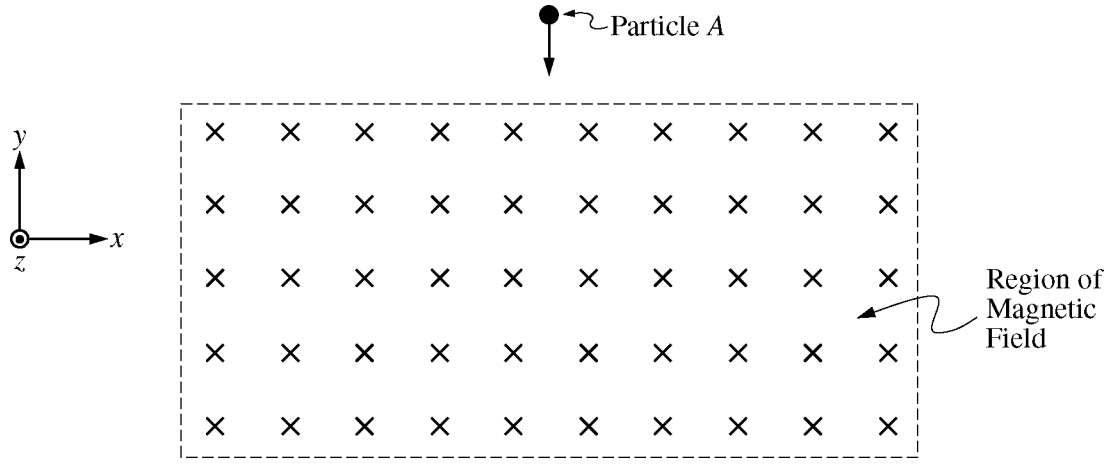
2. (15 points)

Three particles are arranged on coordinate axes as shown above. Particle *A* has charge $q_A = -0.20$ nC, and is initially on the *y*-axis at $y = 0.030$ m. The other two particles each have charge $q_B = +0.30$ nC and are held fixed on the *x*-axis at $x = -0.040$ m and $x = +0.040$ m, respectively.

(a) Calculate the magnitude of the net electric force on particle *A* when it is at $y = 0.030$ m, and state its direction.

(b) Particle *A* is then released from rest. Qualitatively describe its motion over a long time.

In another experiment, particle *A* of charge $q_A = -0.20$ nC is injected into a uniform magnetic field of strength 0.50 T directed into the page, as shown below, entering the field with speed 6000 m/s.



(c) On the diagram above, sketch a complete path of particle *A* as it moves in the magnetic field.

(d) Calculate the magnitude of the force the magnetic field exerts on particle *A* as it enters the magnetic field.

(e) An electric field can be applied to keep particle *A* moving in a straight line through the magnetic field. Calculate the magnitude of this electric field and state its direction.

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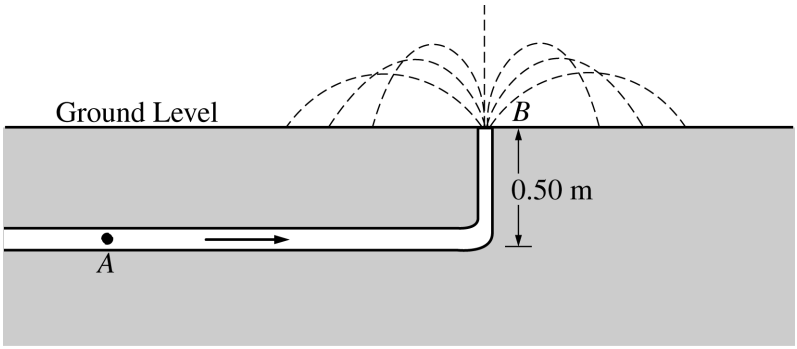

3. (15 points)

An underground pipe carries water of density $1000\ \text{kg/m}^3$ to a fountain at ground level, as shown above. At point *A*, 0.50 m below ground level, the pipe has a cross-sectional area of $1.0 \times 10^{-4}\ \text{m}^2$. At ground level, the pipe has a cross-sectional area of $0.50 \times 10^{-4}\ \text{m}^2$. The water leaves the pipe at point *B* at a speed of 8.2 m/s.

(a) Calculate the speed of the water in the pipe at point *A*.

(b) Calculate the absolute water pressure in the pipe at point *A*.

(c) Calculate the maximum height above the ground that the water reaches upon leaving the pipe vertically at ground level, assuming air resistance is negligible.

(d) Calculate the horizontal distance from the pipe that is reached by water exiting the pipe at $60°$ from the level ground, assuming air resistance is negligible.

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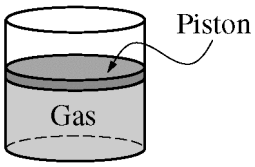

4. (15 points)

The cylinder shown above has an open top, and gas is held inside it by a piston of mass m and area A. The gas is insulated from its surroundings and is initially in equilibrium at volume V_i. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the absolute pressure P_i of the gas at equilibrium.

The gas is heated by a circuit that contains three resistors, each of known resistance R_0, connected in parallel to a power source of emf $\mathcal{E}$. The piston is held fixed so that the gas remains at constant volume while being heated for a period of time t.

(b) Determine the resistance of the circuit.

(c) Calculate the change in internal energy of the gas.

After the time t, the circuit is disconnected. The piston is then released and the gas is allowed to expand adiabatically until it reaches volume V_f.

(d) Indicate below whether the temperature increases, decreases, or remains the same during this process.

_____ Increases _____ Decreases _____ Remains the same

Justify your answer.

(e) The gas is then compressed isothermally to its original pressure and volume. On the axes below, draw a PV diagram for the complete cycle described in this question, labeling V_i and V_f on the volume axis.



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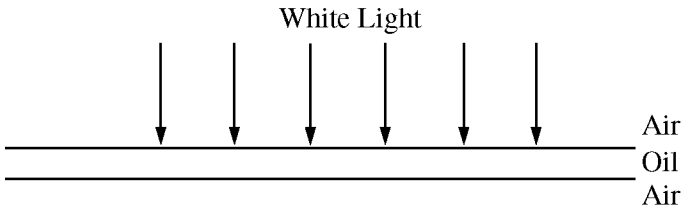


5. (10 points)

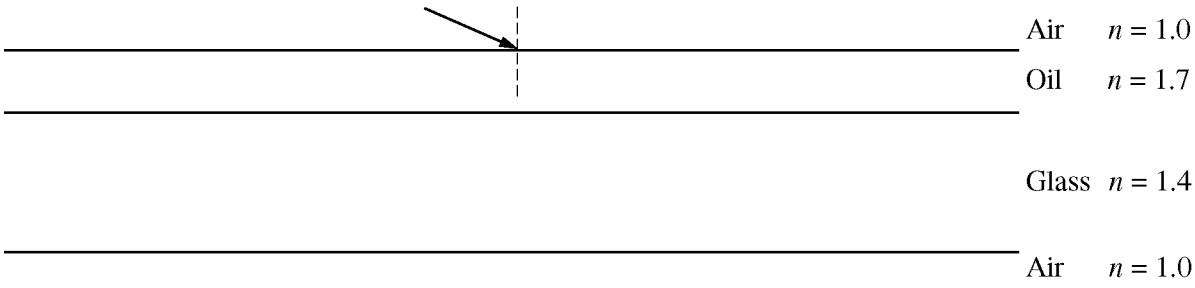
A wide beam of white light is incident normal to the surface of a uniform oil film. An observer looking down at the film sees green light that has maximum intensity at a wavelength of 5.2×10^{-7} m. The index of refraction of the oil is 1.7.

(a) Calculate the speed at which the light travels within the film.

(b) Calculate the wavelength of the green light within the film.

(c) Calculate the minimum possible thickness of the film.

(d) The oil film now rests on a thick slab of glass with index of refraction 1.4, as shown in the figure below. A light ray is incident on the film at the angle shown. On the figure, sketch the path of the refracted light ray that passes through the film and the glass slab and exits into the air. Clearly show any bending of the ray at each interface. You are NOT expected to calculate the sizes of any angles.



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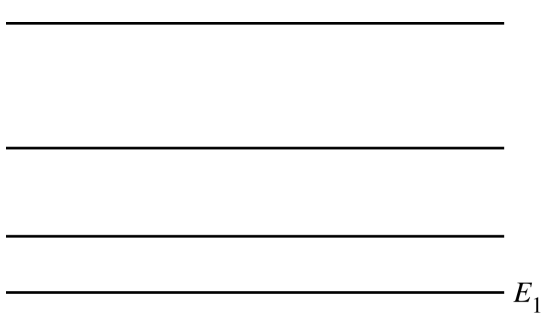

Note: Energy levels not drawn to scale.

6. (10 points)

The electron energy levels above are for an electron confined to a certain very small one-dimensional region of space. The energy E_n of the levels, where $n = 1, 2, 3, \ldots$, is given by $E_n = n^2 E_1$. Express all algebraic answers in terms of E_1 and fundamental constants.

(a) On the diagram above, label the three excited energy levels with the values for their energies in terms of E_1, the energy of the ground state.

(b) Calculate the smallest frequency of light that can be absorbed by an electron in this system when it is in the ground state, $n = 1$.

(c) If an electron is raised into the second excited state, draw on the diagram all the possible transitions that the electron can make in returning to the ground state.

(d) Calculate the wavelength of the highest energy photon that can be emitted in the transitions in part (c).

END OF EXAM

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AP® Physics B
2009 Scoring Guidelines
Form B

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AP® PHYSICS
2009 SCORING GUIDELINES

General Notes About 2009 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point and a student's solution contains the application of that equation to the problem, but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
2009 SCORING GUIDELINES (Form B)

Question 1

15 points total **Distribution of points**

(a) 4 points

For any indication that the centripetal force on the small disk equals the weight of the hanging objects — 1 point

For using the correct expression for the centripetal acceleration — 1 point

$$\frac{m_1 v^2}{r} = m_2 g$$

For the correct expression for the speed of the disk in terms of the period — 1 point

$v = 2\pi r / P$

$$\frac{m_1}{r}\left(\frac{2\pi r}{P}\right)^2 = m_2 g$$

For a correct expression relating m_2 and P in terms of the specified quantities — 1 point

$$\frac{4\pi^2 m_1 r}{P^2} = m_2 g$$

$$P = 2\pi\sqrt{\frac{m_1 r}{m_2 g}}$$

(b) 2 points

For listing two quantities, one of which is correct, consistent with equation obtained in part (a) — 1 point

For having both quantities correct, consistent with equation obtained in part (a) — 1 point

For example: $1/P^2$ and m_2, P^2 and $1/m_2$, P and $1/\sqrt{m_2}$

(c) 4 points

Using the example of $1/P^2$ and m_2

m_2 (kg)	0.020	0.040	0.060	0.080
P (s)	1.40	1.05	0.80	0.75
$1/P^2$	0.51	0.91	1.6	1.8

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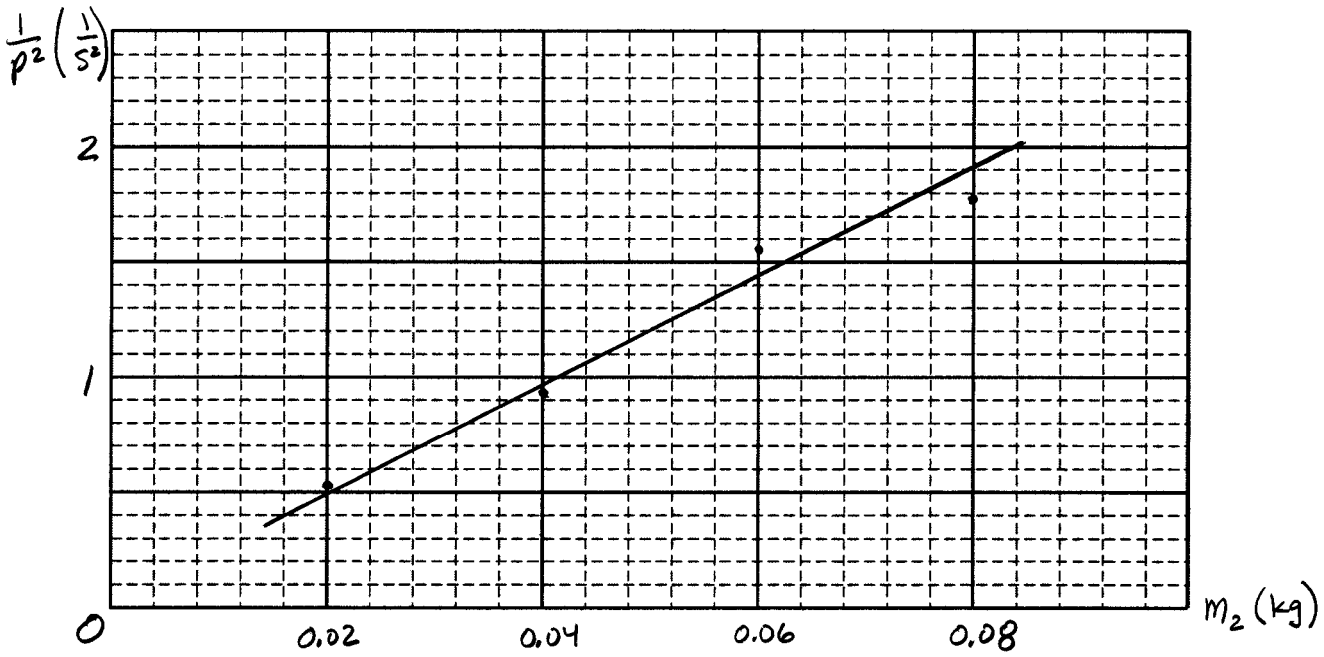
Question 1 (continued)

Distribution of points

(c) (continued)



For correctly labeling both axes 1 point
For correctly scaling both axes 1 point
For a reasonably correct plotting of the data 1 point
For a reasonably correct best-fit line 1 point

(d) 5 points

For associating the slope of the line with the correct coefficient for the quantities graphed 1 point

For the example graph given, $\frac{1}{P^2} = \frac{m_2 g}{4\pi^2 m_1 r}$, so slope $= \frac{g}{4\pi^2 m_1 r}$

For a correct method of calculating the slope, including substitution of points on the line 1 point
For a correct substitution of given values (i.e., all values except the points from the line) 1 point
For example:

$$g = (\text{slope})\left(4\pi^2 m_1 r\right) = \frac{\left(2\ \text{s}^{-2} - 0.4\ \text{s}^{-2}\right)}{(0.084\ \text{kg} - 0.016\ \text{kg})}\left(4\pi^2\right)(0.012\ \text{kg})(0.80\ \text{m})$$

For a reasonable numerical value 1 point
For correct units 1 point
$g = 8.9\ \text{m/s}^2$

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2009 SCORING GUIDELINES (Form B)

Question 2

15 points total **Distribution of points**

(a) 6 points

The solution starts with the expression for the force between point charges.

$F = \frac{kq_1q_2}{r^2}$

For having equal contributions to the force from each charge on the *x* axis (e.g., by including a factor of 2 in the calculation) 1 point

For using the correct distance between charges 1 point

$r^2 = y_A^2 + x_B^2$

For including only the *y* component of the forces, since the *x* components cancel (e.g., by including $\sin\theta$ in the equation, where θ is the angle between the *x* axis and the line connecting particle *A* and either of the other two particles) 1 point

For correctly determining the angle θ from the geometry 1 point

For example: $\theta = \tan^{-1}(y_A/x_B)$

These elements combine to yield the following expression.

$F = 2\frac{kq_Aq_B}{y_A^2 + x_B^2}\sin\left[\tan^{-1}(y_A/x_B)\right]$

$F = 2\frac{\left(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(0.20\times10^{-9}\ \text{C}\right)\left(0.30\times10^{-9}\ \text{C}\right)}{(0.030\ \text{m})^2 + (0.040\ \text{m})^2}\sin\left[\tan^{-1}\left(\frac{0.030\ \text{m}}{0.040\ \text{m}}\right)\right]$

For the correct numerical answer 1 point

$F = 2.59\times10^{-7}\ \text{N}$

For correctly indicating that the force is in the negative *y* direction 1 point

(b) 2 points

For any indication that particle *A* will move toward the origin after release 1 point

For any indication that the particle goes past the origin, then reverses direction 1 point

For example: The particle oscillates between $y = \pm 0.030$ m

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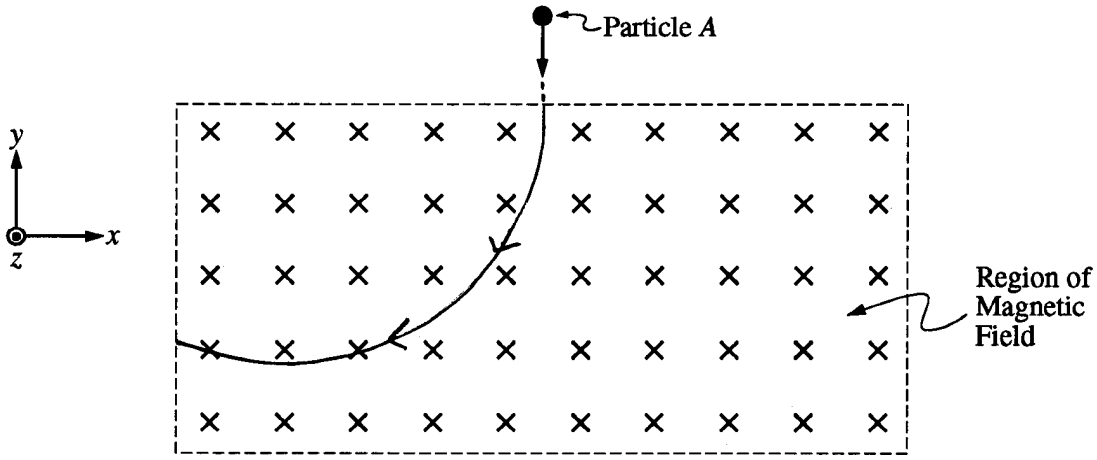
Question 2 (continued)

Distribution of points

(c) 2 points



For any path that (1) is an arc of a circle whose center lies on the line defining the side of the field where the particle enters and (2) goes completely through the field region — 1 point

For the path curving to the left — 1 point

(d) 2 points

For the correct expression for the force on a particle moving perpendicular to a magnetic field — 1 point

$F = qvB\sin\theta = qvB$

$F = \left(0.20 \times 10^{-9}\ \text{C}\right)(6000\ \text{m/s})(0.50\ \text{T})$

For the correct answer — 1 point

$F = \left(6.0 \times 10^{-7}\ \text{N}\right)$

(e) 3 points

For equating the expression for the electric and magnetic forces on the particle — 1 point

$qE = qvB$

$E = vB$

$E = (6000\ \text{m/s})(0.50\ \text{T})$

For the correct numerical answer — 1 point

$E = 3000\ \text{N/C}$

For correctly indicating that the field is in the negative x direction — 1 point

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Question 3

15 points total **Distribution of points**

(a) 3 points

For a meaningful use of the correct expression for flow rate, Av (e.g., an attempt to substitute for volume and speed) 1 point

For relating the flow rates at points A and B 1 point

$A_A v_A = A_B v_B$

$v_A = A_B v_B / A_A = \left(0.50 \times 10^{-4}\ \text{m}^2\right)(8.2\ \text{m/s}) \Big/ \left(1.0 \times 10^{-4}\ \text{m}^2\right)$

For the correct answer 1 point

$v_A = 4.1\ \text{m/s}$

(b) 5 points

For applying Bernoulli's equation to this situation 1 point

$P_A + \rho g y_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g y_B + \frac{1}{2}\rho v_B^2$

$P_A = P_B + \rho g (y_B - y_A) + \frac{1}{2}\rho\left(v_B^2 - v_A^2\right)$

For using atmospheric pressure $\left(1.0 \times 10^5\ \text{Pa}\right)$ for the pressure at point B 1 point

For correctly substituting values for y_A and y_B 1 point

For correctly substituting values for v_A and v_B consistent with the work in part (a) 1 point

$P_A = \left(1.0 \times 10^5\ \text{Pa}\right) + \left(1000\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)(0.50\ \text{m} - 0)$

$\quad + \frac{1}{2}\left(1000\ \text{kg/m}^3\right)\left([8.2\ \text{m/s}]^2 - [4.1\ \text{m/s}]^2\right)$

For correct units for the answer 1 point

$P_A = 1.3 \times 10^5\ \text{N/m}^2$ (or Pa)

(c) 2 points

For correctly relating the initial speed and the maximum height 1 point

$v^2 = {v_0}^2 + 2a(x - x_0)$ OR $\frac{1}{2}mv^2 = mgh$

$v_B^2 = 2gh$

$h = v_B^2 / 2g = (8.2\ \text{m/s})^2 \big/ 2\left(9.8\ \text{m/s}^2\right)$

For the correct answer with correct units 1 point

$h = 3.4\ \text{m}$

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Question 3 (continued)

Distribution of points

(d) 5 points

For correctly analyzing the vertical motion with constant acceleration, to find the time for the water to reach maximum height — 1 point

$v = v_0 + at$

$0 = v_{By} + gt$

$v_{By} = gt$

For the correct vertical component of speed — 1 point

$v_{By} = v_B \sin\theta$

$t = v_{By}/g = v_B \sin\theta/g$

For correctly analyzing the horizontal motion with constant speed — 1 point

$x = v_{Bx}(2t)$

For the correct horizontal component of speed — 1 point

$v_{Bx} = v_B \cos\theta$

$x = v_B \cos\theta(2v_B \sin\theta/g) = 2v_B^2 \cos\theta \sin\theta/g$

$x = 2(8.2 \text{ m/s})^2 \cos 60° \sin 60°/(9.8 \text{ m/s}^2)$

For the correct answer with units — 1 point

$x = 5.9$ m (or 5.8 m using $g = 10 \text{ m/s}^2$)

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Question 4

15 points total **Distribution of points**

(a) 2 points

For a correct expression for the pressure due to the weight of the piston 1 point
For including atmospheric pressure 1 point
$P = P_{atm} + (mg/A)$

Notes:
The second point was also awarded for stating the assumption that the cylinder is in a vacuum.
A numeric value for atmospheric pressure instead of a variable in the equation was acceptable.

(b) 2 points

For combining resistors in parallel 1 point
$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$\frac{1}{R_{eq}} = \frac{1}{R_0} + \frac{1}{R_0} + \frac{1}{R_0} = \frac{3}{R_0}$

For the correct answer 1 point
$R_{eq} = R_0/3$

(c) 3 points

For correctly relating the change in internal energy of the gas to the energy provided by the circuit 1 point
$\Delta U = P_{cir}t$

For a correct relationship for the power delivered by the circuit in terms of voltage difference and resistance 1 point
$P_{cir} = \mathcal{E}^2/R_{eq}$

$\Delta U = \left(\mathcal{E}^2 \Big/ \frac{R_0}{3}\right)t$

For the correct answer 1 point
$\Delta U = 3\mathcal{E}^2 t/R_0$

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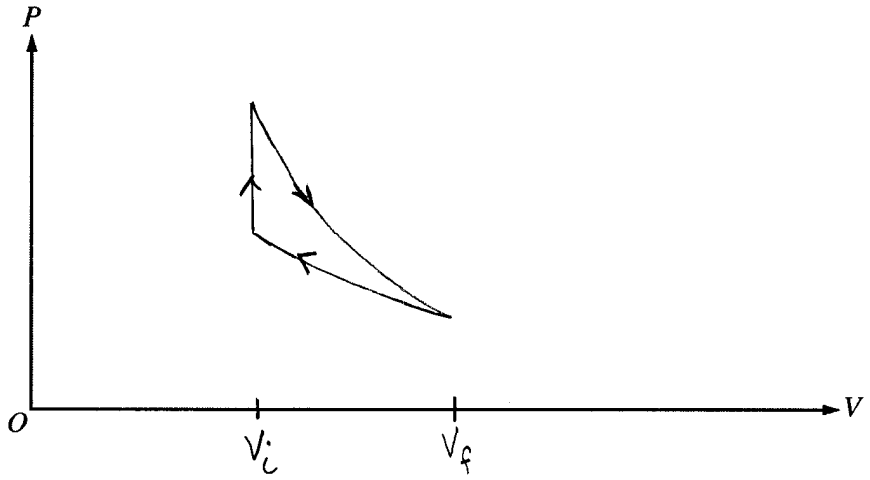
Question 4 (continued)

Distribution of points

(d) 3 points

For indicating that the temperature decreases	1 point
Justifying using the first law of thermodynamics: $\Delta U = Q + W$	
For indicating that $Q = 0$ (the definition of an adiabatic process)	1 point
For indicating that negative work is done on the piston, so applying the first law gives a net loss of energy in the gas and thus the internal energy decreases	1 point
Since the internal energy is proportional to temperature, the temperature must also decrease.	

(e) 5 points



For a vertical straight segment	1 point
One point for each curved segment from one end of the straight line to a point at a lower pressure and higher volume	2 points
(Only the segments were scored. Presence or correctness of arrowheads was not considered.)	
For correctly labeling V_i	1 point
For correctly labeling V_f	1 point

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Question 5

10 points total **Distribution of points**

(a) 2 points

Using the relationship for the speed of light inside a material: $n = c/v$

For correct substitutions 1 point

$v_{oil} = c/n = \left(3.00 \times 10^{8} \text{ m/s}\right)/1.7$

For the correct answer 1 point

$v_{oil} = 1.8 \times 10^{8} \text{ m/s}$

(b) 2 points

For using the relationship for the wavelength of light inside a material, which can be derived as follows: 1 point

$f_{oil} = f_{air}$, and $f = v/\lambda$

$v_{oil}/\lambda_{oil} = v_{air}/\lambda_{air}$

$(c/n)/\lambda_{oil} = c/\lambda_{air}$

$\lambda_{oil} = \lambda_{air}/n$

For correct substitutions 1 point

$\lambda_{oil} = \left(5.2 \times 10^{-7} \text{ m}\right)/1.7$

$\lambda_{oil} = 3.1 \times 10^{-7} \text{ m}$

(c) 3 points

There is a 180° phase shift when light is reflected at the lower interface, so for constructive interference the path length in the film must be an odd multiple of a half wavelength.

For any indication of the phase shift (e.g., a description as above or a $\lambda_{oil}/2$ correction in an equation such as $2t + \lambda_{oil}/2 = \lambda_{oil}$, where t is the thickness of the film) 1 point

For work that correctly accounts for constructive interference (e.g., a description as in the first statement above for the net path length, or correct factors of λ in an equation as in the second statement above) 1 point

$2t = \lambda_{oil}/2$

For substituting the correct value for the wavelength 1 point

$t = \lambda_{oil}/4 = \left(3.1 \times 10^{-7} \text{ m}\right)/4$

$t = 7.8 \times 10^{-8} \text{ m}$

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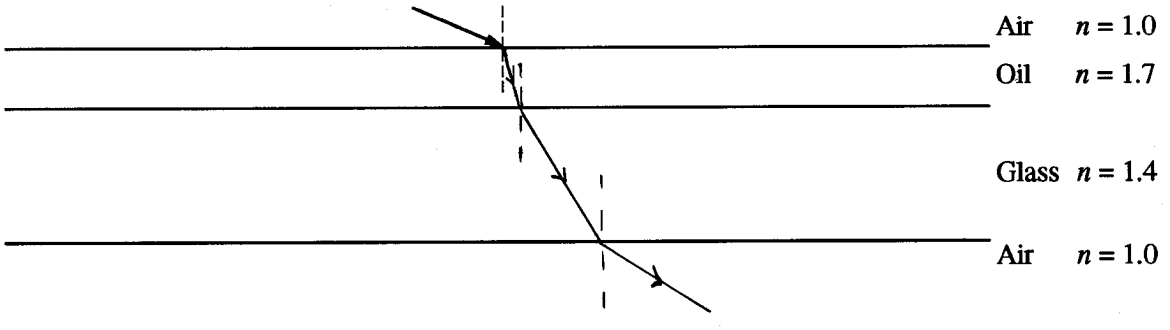
Question 5 (continued)

Distribution of points

(d) 3 points



For a ray at the first interface that bends toward the normal	1 point
For a ray at the second interface that bends away from the normal	1 point
For a ray at the third interface that bends away from the normal (This ray does not have to be parallel to the initial ray.)	1 point

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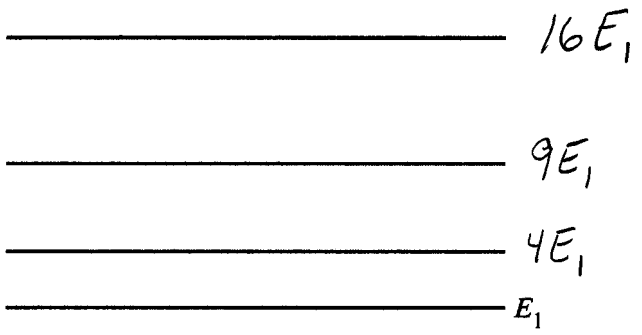
Question 6

10 points total **Distribution of points**

(a) 3 points



Note: Energy levels not drawn to scale.

The given equation, $E_n = n^2 E_1$, is used to calculate the other energies

One point for each correctly labeled energy level 3 points

(b) 2 points

From the relationship between frequency and energy, $\Delta E = hf$, it is seen that the smallest frequency corresponds to the smallest energy difference.

For a correct determination of the energy difference 1 point

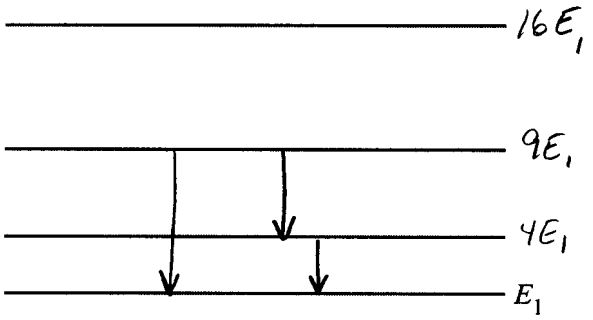
$\Delta E = 4E_1 - E_1 = 3E_1$

For a correct relationship between the minimum energy difference and the frequency 1 point

$hf = 3E_1$

$f = 3E_1/h$

(c) 2 points



Note: Energy levels not drawn to scale.

For the transition from $9E_1$ to E_1 1 point

For the pair of transitions from $9E_1$ to $4E_1$ and $4E_1$ to E_1 1 point

One point earned for this part was deducted for one extraneous line, and two or more extraneous lines resulted in no credit for this part.

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Question 6 (continued)

Distribution of points

(d) 3 points

For a correct relationship between the maximum energy difference and the frequency 1 point

$hf = 9E_1 - E_1 = 8E_1$

$f = 8E_1/h$

For a correct relationship between the wavelength and frequency of the light 1 point

$f = c/\lambda$

A single equation that directly relates energy and wavelength could earn both points.

$c/\lambda = 8E_1/h$

For the correct answer 1 point

$\lambda = hc/8E_1$

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AP® Physics B
2008 Free-Response Questions

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TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

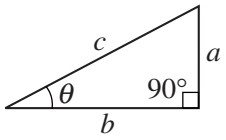
$d\sin\theta = m\lambda$

$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

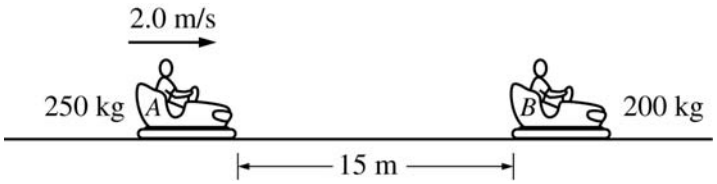
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell w h$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering Questions 1 and 4-7 and about 17 minutes for answering each of Questions 2 and 3. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (10 points)

   Several students are riding in bumper cars at an amusement park. The combined mass of car *A* and its occupants is 250 kg. The combined mass of car *B* and its occupants is 200 kg. Car *A* is 15 m away from car *B* and moving to the right at 2.0 m/s, as shown, when the driver decides to bump into car *B*, which is at rest.

   (a) Car *A* accelerates at $1.5\ \text{m/s}^2$ to a speed of $5.0\ \text{m/s}$ and then continues at constant velocity until it strikes car *B*. Calculate the total time for car *A* to travel the 15 m.

   (b) After the collision, car *B* moves to the right at a speed of $4.8\ \text{m/s}$.

   i. Calculate the speed of car *A* after the collision.

   ii. Indicate the direction of motion of car *A* after the collision.

   ____ To the left ____ To the right ____ None; car *A* is at rest.

   (c) Is this an elastic collision?

   ____ Yes ____ No

   Justify your answer.

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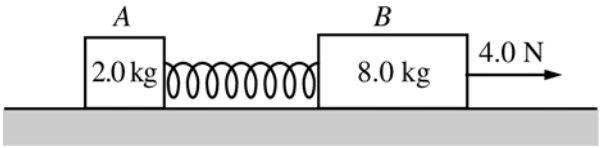


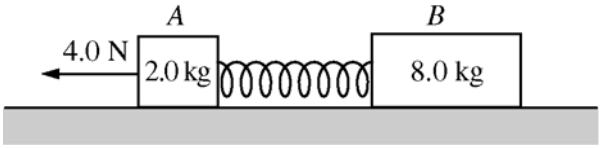
2. (15 points)

Block *A* of mass 2.0 kg and block *B* of mass 8.0 kg are connected as shown above by a spring of spring constant 80 N/m and negligible mass. The system is being pulled to the right across a horizontal frictionless surface by a horizontal force of 4.0 N, as shown, with both blocks experiencing equal constant acceleration.

(a) Calculate the force that the spring exerts on the 2.0 kg block.

(b) Calculate the extension of the spring.

The system is now pulled to the left, as shown below, with both blocks again experiencing equal constant acceleration.



(c) Is the magnitude of the acceleration greater than, less than, or the same as before?

____ Greater ____ Less ____ The same

Justify your answer.

(d) Is the amount the spring has stretched greater than, less than, or the same as before?

____ Greater ____ Less ____ The same

Justify your answer.

(e) In a new situation, the blocks and spring are moving together at a constant speed of $0.50\ \text{m/s}$ to the left. Block *A* then hits and sticks to a wall. Calculate the maximum compression of the spring.

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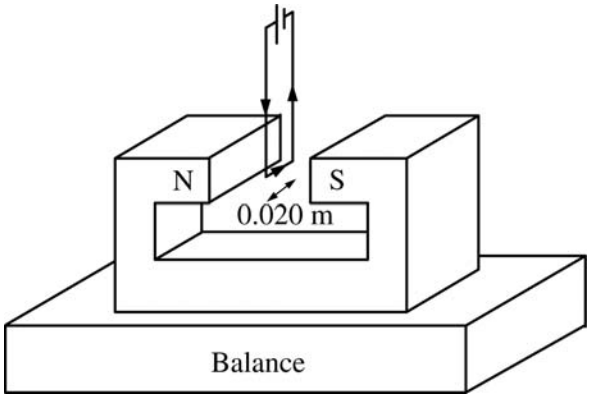
3. (15 points)

A rectangular wire loop is connected across a power supply with an internal resistance of $0.50\ \Omega$ and an emf of 16 V. The wire has resistivity $1.7 \times 10^{-8}\ \Omega\text{•m}$ and cross-sectional area $3.5 \times 10^{-9}\ \text{m}^2$. When the power supply is turned on, the current in the wire is 4.0 A.

(a) Calculate the length of wire used to make the loop.

The wire loop is then used in an experiment to measure the strength of the magnetic field between the poles of a magnet. The magnet is placed on a digital balance, and the wire loop is held fixed between the poles of the magnet, as shown below. The 0.020 m long horizontal segment of the loop is midway between the poles and perpendicular to the direction of the magnetic field. The power supply in the loop is turned on, so that the 4.0 A current is in the direction shown.



Note: Figure not drawn to scale.

(b) In which direction is the force on the magnet due to the current in the wire segment?

____Upward ____Downward

Justify your answer.

(c) The reading on the balance changed by 0.060 N when the power supply was turned on. Calculate the strength of the magnetic field.

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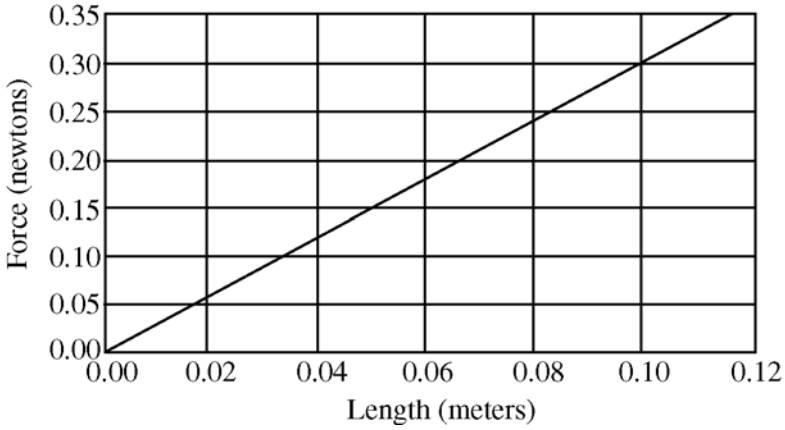
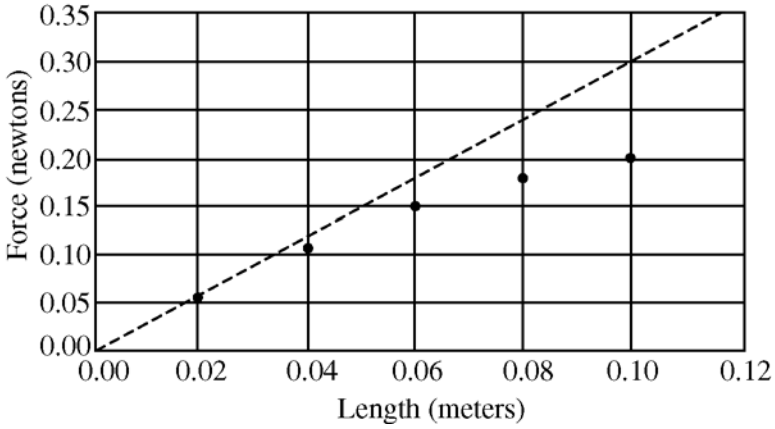
Suppose that various rectangular loops with the same total length of wire as found in part (a) were constructed such that the lengths of the horizontal segments of the wire loops varied between 0.02 m and 0.10 m. The horizontal segment of each loop was always centered between the poles, and the current in each loop was always 4.0 A. The following graph represents the theoretical relationship between the magnitude of the force on the magnet and the length of the wire.



(d) On the graph above, sketch a possible relationship between the magnitude of the force on the magnet and the length of the wire segment if the wire segments were misaligned and placed at a constant nonperpendicular angle to the magnetic field, as shown below.



(e) Suppose the loops are correctly placed perpendicular to the field and the following data are obtained. Describe a likely cause of the discrepancy between the data and the theoretical relationship.



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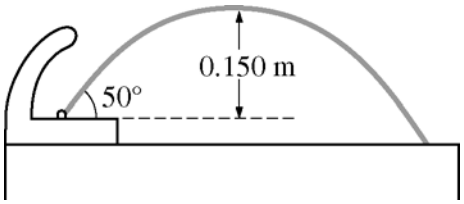


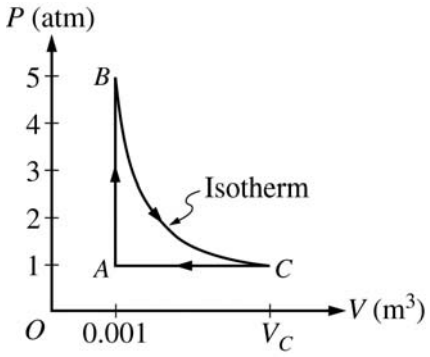
4. (10 points)

A drinking fountain projects water at an initial angle of 50° above the horizontal, and the water reaches a maximum height of 0.150 m above the point of exit. Assume air resistance is negligible.

(a) Calculate the speed at which the water leaves the fountain.

(b) The radius of the fountain's exit hole is 4.00×10^{-3} m . Calculate the volume rate of flow of the water.

(c) The fountain is fed by a pipe that at one point has a radius of 7.00×10^{-3} m and is 3.00 m below the fountain's opening. The density of water is 1.0×10^{3} kg/m^3 . Calculate the gauge pressure in the feeder pipe at this point.



5. (10 points)

A 0.03 mol sample of helium is taken through the cycle shown in the diagram above. The temperature of state *A* is 400 K.

(a) For each process in this cycle, indicate in the table below whether the quantities *W*, *Q*, and ΔU are positive (+), negative (–), or zero (0). *W* is the work done on the helium sample.

Process	*W*	*Q*	ΔU
$A \rightarrow B$			
$B \rightarrow C$			
$C \rightarrow A$			

(b) Explain your response for the signs of the quantities for process $A \rightarrow B$.

(c) Calculate V_C .

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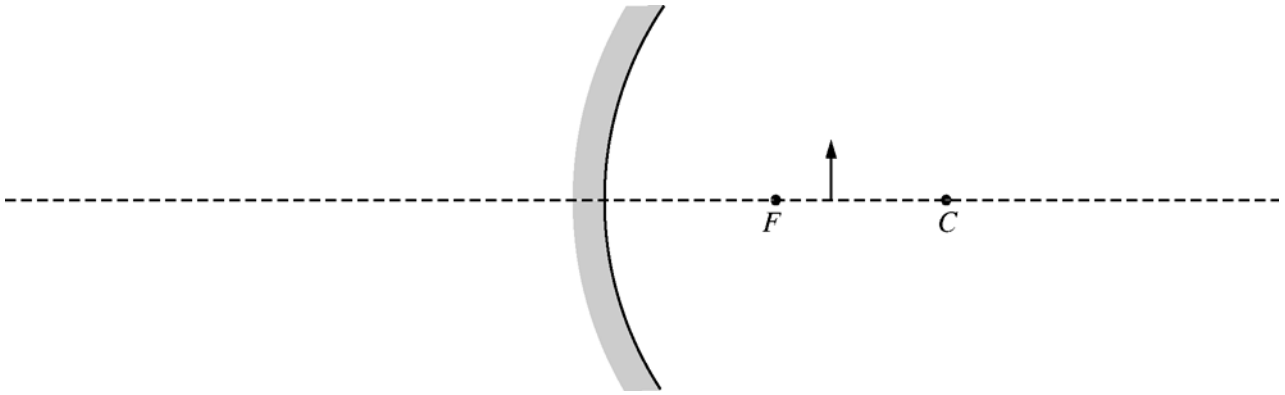


6. (10 points)

The figure above shows a converging mirror, its focal point *F*, its center of curvature *C*, and an object represented by the solid arrow.

(a) On the figure above, draw a ray diagram showing at least two incident rays and the image formed by them.

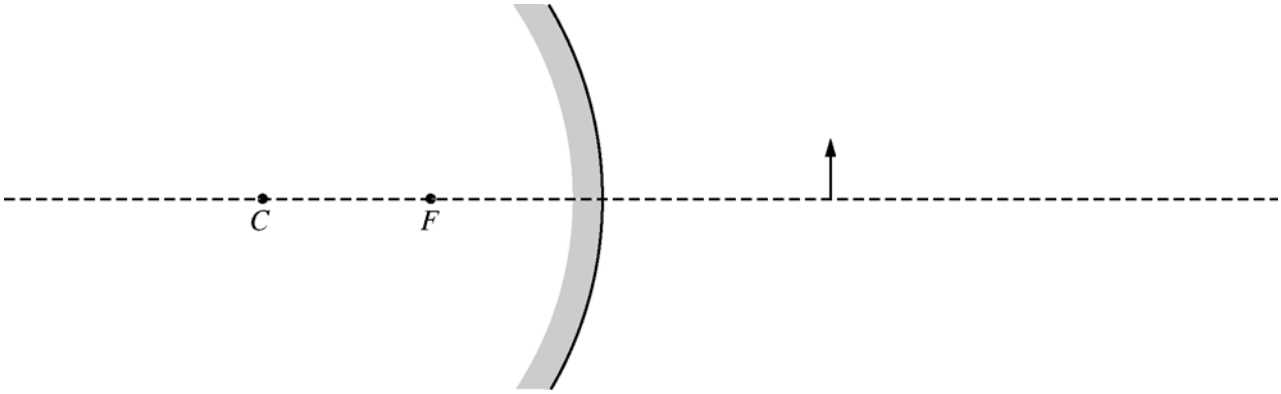
(b) Is the image real or virtual?

____ Real ____ Virtual

Justify your answer.

(c) The focal length of this mirror is 6.0 cm, and the object is located 8.0 cm away from the mirror. Calculate the position of the image formed by the mirror. (Do NOT simply measure your ray diagram.)

(d) Suppose that the converging mirror is replaced by a diverging mirror with the same radius of curvature that is the same distance from the object, as shown below.



For this mirror, how does the size of the image compare with that of the object?

____ Larger than the object ____ Smaller than the object ____ The same size as the object

Justify your answer.

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7. (10 points)

In an electron microscope, a tungsten cathode with work function 4.5 eV is heated to release electrons that are then initially at rest just outside the cathode. The electrons are accelerated by a potential difference to create a beam of electrons with a de Broglie wavelength of 0.038 nm. Assume nonrelativistic equations apply to the motion of the electrons.

(a) Calculate the momentum of an electron in the beam, in $\text{kg}\cdot\text{m/s}$.

(b) Calculate the kinetic energy of an electron in the beam, in joules.

(c) Calculate the accelerating voltage.

(d) Suppose that light, instead of heat, is used to release the electrons from the cathode. What minimum frequency of light is needed to accomplish this?

END OF EXAM

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AP® Physics B
2008 Scoring Guidelines

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AP® PHYSICS
2008 SCORING GUIDELINES

General Notes About 2008 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
2008 SCORING GUIDELINES

Question 1

10 points total **Distribution of points**

(a) 4 points

For the correct value of t_1, the time car *A* is accelerating — 1 point

$v_f = v_i + at_1$

$t_1 = \left(v_f - v_i\right)/a = (5.0\ \text{m/s} - 2.0\ \text{m/s})/(1.5\ \text{m/s})$

$t_1 = 2.0\ \text{s}$

For a correct value of x_1, the distance car *A* travels while accelerating — 1 point

$x_1 = v_i t_1 + \frac{1}{2}at_1^2$

$x_1 = (2.0\ \text{m/s})(2.0\ \text{s}) + \frac{1}{2}\left(1.5\ \text{m/s}^2\right)(2.0\ \text{s})^2$

$x_1 = 7.0\ \text{m}$

Note: The equation $v_f^2 = v_i^2 + 2ax_1$ could also be used.

For a correct value of $(x - x_1)$, the distance car *A* travels at constant velocity — 1 point

$(x - x_1) = (15.0\ \text{m} - 7.0\ \text{m}) = 8.0\ \text{m}$

For correctly calculating t_2, the time car *A* travels at constant velocity — 1 point

$x = x_1 + v_f t_2$

$t_2 = (x - x_1)/v_f = (15.0\ \text{m} - 7.0\ \text{m})/5.0\ \text{m/s}$

$t_2 = 1.6\ \text{s}$

$t_{tot} = t_1 + t_2 = 2.0\ \text{s} + 1.6\ \text{s}$

$t_{tot} = 3.6\ \text{s}$

(b)

(i) 2 points

For any clear statement that momentum is conserved — 1 point

$m_A v_{Ai} = m_A v_{Af} + m_B v_B$

$v_{Af} = \frac{m_A v_{Ai} - m_B v_B}{m_A} = \frac{(250\ \text{kg})(5.0\ \text{m/s}) - (200\ \text{kg})(4.8\ \text{m/s})}{250\ \text{kg}}$

For a correct answer — 1 point

$v_{Af} = 1.2\ \text{m/s}$

(ii) 1 point

For indicating a direction of car *A* after the collision that is consistent with the calculation of v_{Af} — 1 point

Note: A correct calculation yields a direction to the right.

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Question 1 (continued)

Distribution of points

(c) 3 points

For correctly indicating that the collision is <u>not</u> elastic — 1 point
For a statement that kinetic energy is not conserved — 1 point
For clearly showing that $K_f < K_i$, implying the collision is non-elastic — 1 point

$$K_i = \frac{1}{2} m_A v_{Ai}^2 = \frac{1}{2}(250 \text{ kg})(5.0 \text{ m/s})^2$$

$$K_i = 3125 \text{ J}$$

$$K_f = \frac{1}{2} m_A v_{Af}^2 + \frac{1}{2} m_B v_B = \frac{1}{2}(250 \text{ kg})(1.2 \text{ m/s})^2 + \frac{1}{2}(200 \text{ kg})(4.8 \text{ m/s})^2$$

$$K_f = 2484 \text{ J}$$

<u>Note</u>: Two points were awarded for checking "yes" with a clear, correct explanation that it is a partially elastic collision.

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AP® PHYSICS B
2008 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**

(a) 4 points

For a correct application of Newton's 2nd law for the two-block system 1 point

$F = (m_A + m_B)a$

Note: Newton's 2nd law may be applied to each block separately to produce an equivalent solution.

For a correct determination of the acceleration 1 point

$$a = \frac{F}{(m_A + m_B)} = \frac{4.0 \text{ N}}{(2.0 \text{ kg} + 8.0 \text{ kg})}$$

$a = 0.40 \text{ m/s}^2$

For correct substitution of the acceleration into Newton's 2nd law for one of the blocks 1 point

$F_{spring} = m_A a$ (or $F - F_{spring} = m_B a$)

For the correct solution (consistent with the value of the acceleration found above) 1 point

$F_{spring} = (2.0 \text{ kg})(0.40 \text{ m/s}^2)$ (or $F_{spring} = 4.0 \text{ N} - (8.0 \text{ kg})(0.40 \text{ m/s}^2)$)

$F_{spring} = 0.80 \text{ N}$

Note: A correct free-body diagram for each block could earn 1 point each.

(b) 2 points

For a correct expression relating spring force to extension 1 point

$F_{spring} = kx$

For the correct solution using the spring force from part (a) 1 point

$$x = \frac{F_{spring}}{k} = \frac{0.80 \text{ N}}{80 \text{ N/m}}$$

$x = 0.010 \text{ m}$

(c) 3 points

For correctly indicating that the acceleration will be the same as before 1 point

For a correct justification (only if the previous point was awarded) 2 points

Examples:

- Explaining that in both cases there is a 4.0 N force pulling a combined mass of 10 kg, and hence the acceleration will be the same in the two cases.
  (Note: One point was awarded when the student noted that either the net force acting on the system of two blocks or the mass of the system is unchanged. For full credit, the student must have noted that both the force and mass are the same in the two cases.)
- Applying Newton's 2nd law to each block and calculating an acceleration with the same value as in part (a).

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Question 2 (continued)

Distribution of points

(d) 3 points

For correctly indicating that the spring extension is greater than in part (b) 1 point
For a correct justification (only if the previous point was awarded) 2 points
Examples:

- The spring force on the 8.0 kg block produces the same acceleration as the spring force on the 2.0 kg block in part (a); hence the spring force is greater than in part (a) so the extension is greater.
- Applying Newton's 2nd law to show that the new spring extension is 0.040 m.

Notes:

- A partial justification worth a single point may note that the spring is pulling on a larger mass than before, or may note that the force exerted by the spring is larger than before (without explaining why this force is larger).
- Students who answered part (c) by saying that the acceleration is greater could earn 2 points here by noting that the force exerted by the spring on block B must be larger in order to give the larger mass a greater acceleration.

(e) 3 points

For indicating that, after block A impacts the wall, mechanical energy is conserved 1 point
For correctly applying conservation of energy, equating the energy immediately after block A hits the wall to the energy when the spring is at maximum compression 1 point

$$K_{before} + U_{before} = K_{after} + U_{after}$$

$$\frac{1}{2}m_B v^2 + 0 = 0 + \frac{1}{2}kx^2$$

For the correct solution 1 point

$$x = \sqrt{\frac{m_B v^2}{k}} = \sqrt{\frac{(8.0\text{ kg})(0.50\text{ m/s})^2}{80\text{ N/m}}}$$

$$x = 0.16\text{ m}$$

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AP® PHYSICS B
2008 SCORING GUIDELINES

Question 3

15 points total **Distribution of points**

(a) 4 points

For using Ohm's law to find the total resistance of the circuit 1 point

$\mathcal{E}/I = R_{\text{total}}$

$16\ \text{V}/4.0\ \text{A} = 4.0\ \Omega$

For a correct expression for the total resistance that has the internal resistance of the power supply in series with the wire's resistance 1 point

$R_{\text{internal}} + R_{\text{wire}} = R_{\text{total}}$

$0.50\ \Omega + R_{\text{wire}} = 4.0\ \Omega$

$R_{\text{wire}} = 3.5\ \Omega$

An alternate solution is to use a circuit equation to determine the voltage across the wire for the first point, and then Ohm's law to determine its resistance for the second point.

$V_{\text{wire}} = V_{\text{term}} = \mathcal{E} - V_{\text{int}} = 16\ \text{V} - (4.0\ \text{A})(0.50\ \Omega) = 14\ \text{V}$

$R_{\text{wire}} = V/I = 14\ \text{V}/4.0\ \text{A} = 3.5\ \Omega$

Using the expression for the resistance of a wire in terms of its dimensions

$R_{\text{wire}} = \rho L/A$

$L = R_{\text{wire}}A/\rho$

For correct substitutions 1 point

$L = (3.5\ \Omega)\left(3.5 \times 10^{-9}\ \text{m}^2\right)/\left(1.7 \times 10^{-8}\ \Omega\text{•m}\right)$

For a correct answer with correct units 1 point

$L = 0.72\ \text{m}$

Note: The last 2 points could be earned for showing understanding of $R = \rho L/A$ by using it with the appropriate values of ρ and A and some value of resistance.

(b) 4 points

The force on the magnet is upwards.

Points are awarded for the justification as follows.

For indicating that the right-hand rule should be used 1 point

For correctly identifying the direction of the magnetic field between the poles of the magnet as being to the right 1 point

For obtaining a downward force on the wire using the right-hand rule 1 point

Example for the above 3 points: The direction of the force on the wire is given by the right-hand rule. The current is into the page and the magnetic field is to the right. By the right-hand rule, the force on the wire is then downwards.

For using Newton's 3rd Law 1 point

For example: The force on the wire is downwards, so the force on the magnet must be upwards.

Note: A student who checks "downward" can receive 3 of 4 points if they correctly use the right-hand rule to show that the force on the wire is downward. Just checking the box "upward" without justification received no points.

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Question 3 (continued)

Distribution of points

(c) 3 points

For simplifying the formula given in the equation table for the force on a current-carrying wire (or stating that $\theta = 90°$) — 1 point

$F = ILB$

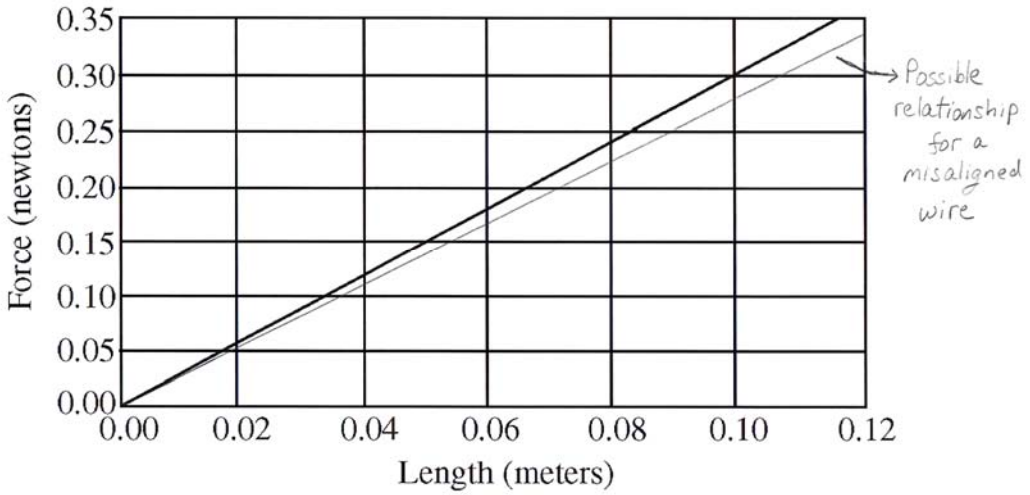
For correct substitutions — 1 point

$$B = \frac{F}{IL} = \frac{(0.060\ \text{N})}{(4.0\ \text{A})(0.020\ \text{m})}$$

For a correct answer with correct units — 1 point

$B = 0.75\ \text{T}$

(d) 3 points



For a straight-line relationship — 1 point
For a relationship that passes through the origin — 1 point
For a slope less than the original line but NOT zero — 1 point

(e) 1 point

For a plausible source of error that would produce the plotted results — 1 point
For example: The horizontal width of the wire approaches the width of the magnet. Near the edges of the magnet the strength of the magnetic field decreases. As the length of the wire increases, the magnetic field experienced by the ends of the wire decreases in strength, leading to a smaller magnetic force than expected.

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Question 4

10 points total **Distribution of points**

(a) 3 points

For a correct application of kinematics to the vertical motion 1 point

$v_{yf}^2 = v_{y0}^2 - 2gh = 0$

$v_{y0}^2 = 2gh$

For correctly expressing the vertical component of the initial velocity 1 point

$v_{y0} = v_0 \sin 50°$

For a correct solution 1 point

$v_0 \sin 50° = \sqrt{2gh}$

$$v_0 = \frac{\sqrt{2gh}}{\sin 50°} = \frac{\sqrt{2\left(9.8 \text{ m/s}^2\right)(0.150 \text{ m})}}{\sin 50°}$$

$v_0 = 2.24 \text{ m/s}$ (or 2.26 m/s using $g = 10 \text{ m/s}^2$)

(b) 2 points

For a correct expression for the volume flow rate, using an area of πr_0^2 1 point

Volume flow rate $= A_0 v_0 = \pi r_0^2 v_0$

For a correct solution with correct units, consistent with v_0 found in part (a) 1 point

Volume flow rate $= \pi\left(4.00 \times 10^{-3} \text{ m}\right)^2 (2.24 \text{ m/s})$

Volume flow rate $= 1.13 \times 10^{-4} \text{ m}^3/\text{s}$ (or $1.14 \times 10^{-4} \text{ m}^3/\text{s}$ using $g = 10 \text{ m/s}^2$)

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Question 4 (continued)

Distribution of points

(c) 5 points

For a correct expression for the water velocity in the feeder pipe with substitutions consistent with previous work — 1 point

$A_0 v_0 = A_p v_p$

$$v_p = \frac{A_0}{A_p} v_0 = \left(\frac{r_0}{r_p}\right)^2 v_0 = \left(\frac{4.00 \times 10^{-3}\ \text{m}}{7.00 \times 10^{-3}\ \text{m}}\right)^2 2.24\ \text{m/s}$$

For a correctly calculated answer consistent with previous work — 1 point

$v_p = 0.731\ \text{m/s}$ (or $v_p = 0.738\ \text{m/s}$ using $g = 10\ \text{m/s}^2$)

For a correct expression of Bernoulli's equation — 1 point

$$P_0 + \rho g h_0 + \frac{1}{2}\rho v_0^2 = P_p + \rho g h_p + \frac{1}{2}\rho v_p^2$$

$$P_p - P_0 = \rho g\left(h_0 - h_p\right) + \frac{1}{2}\rho\left(v_0^2 - v_p^2\right)$$

For consistent/correct substitutions of heights and velocities — 1 point

$$P_p - P_0 = \left(1.0 \times 10^3\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)(3.00\ \text{m}) + \frac{1}{2}\left(1.0 \times 10^3\ \text{kg/m}^3\right)\left[(2.24\ \text{m/s})^2 - (0.731\ \text{m/s})^2\right]$$

For correctly accounting for atmospheric pressure (with no obvious algebraic errors) leading to an answer — 1 point

P_0 is atmospheric pressure, and $P_p = P_0 + P_{gauge}$

$P_{gauge} = P_p - P_0 = 3.16 \times 10^4$ Pa (or 3.23×10^4 Pa using $g = 10\ \text{m/s}^2$)

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Question 5

10 points total **Distribution of points**

(a) 3 points

Process	W	Q	ΔU
$A \rightarrow B$	0	+	+
$B \rightarrow C$	–	+	0
$C \rightarrow A$	+	–	–

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $A \rightarrow B$ 1 point

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $B \rightarrow C$ 1 point

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $C \rightarrow A$ 1 point

(b) 4 points

For a correct explanation of why zero work is done on the gas 1 point

Examples of correct responses include:

- There is no area under the graph/curve.
- There is no volume change.
- The piston does not move.
- $W = -P\Delta V$, where $\Delta V = 0$.
- $W = 0$ by definition in an isochoric/isovolumetric process.

For a correct explanation of why ΔU is positive 1 point

Examples of correct responses include:

- For a fixed number of moles of a sample, an increase in pressure at constant volume implies an increase in temperature, and an increased temperature implies an increase in internal energy (ΔU is positive).
- State *B* is on a higher isotherm than state *A*.
- $U = \frac{3}{2}nRT$; since T increases, ΔU is positive.
- $U = \frac{3}{2}PV$; since P increases at a constant V, ΔU is positive.
- A correct use of the first law of thermodynamics leading to ΔU being positive ($\Delta U = Q + W$, but $W = 0$ so $\Delta U = Q$; since Q is positive, ΔU must be also).

For a correct explanation of why Q is positive 1 point

Examples of correct responses include:

- If pressure increases *and* volume is constant, heat must be added to system.
- If temperature increases *and* volume is constant, heat must be added to system.
- A correct use of the first law of thermodynamics leading to Q being positive ($\Delta U = Q + W$, but $W = 0$ so $\Delta U = Q$; since ΔU is positive, Q must be also).

For stating the first law of thermodynamics, whether used correctly or not, OR for correctly explaining all three variables without reference to the first law of thermodynamics 1 point

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Question 5 (continued)

Distribution of points

(c) 3 points

For correctly relating states *B* and *C* at a constant temperature, using either the ideal gas law or Boyle's Law — 1 point

$\frac{P_B V_B}{T_B} = \frac{P_C V_C}{T_C}$ or $P_B V_B = P_C V_C$

For the correct substitution of the appropriate values — 1 point

$V_C = \frac{P_B}{P_C} V_B = \left(\frac{5 \text{ atm}}{1 \text{ atm}}\right)\left(0.001 \text{ m}^3\right)$

For the correct answer including units — 1 point

$V_C = 0.005 \text{ m}^3$

Alternate solution — *Alternate points*

For correctly relating states A and B at a constant volume, using the ideal gas law, to determine the temperature T_B — *1 point*

$\frac{P_A V_A}{T_A} = \frac{P_B V_B}{T_B}$

$T_B = \frac{P_B}{P_A} T_A = \left(\frac{5 \text{ atm}}{1 \text{ atm}}\right)(400 \text{ K}) = 2000 \text{ K}$

For realizing that $T_C = T_B$ and correctly relating states A and C at constant pressure, using the value of T_B and the ideal gas law or Charles' Law to calculate V_C. — *1 point*

$\frac{P_A V_A}{T_A} = \frac{P_C V_C}{T_C}$ or $\frac{V_A}{T_A} = \frac{V_C}{T_C}$

$V_C = \frac{T_C}{T_A} V_A = \frac{T_B}{T_A} V_A = \left(\frac{2000 \text{ K}}{400 \text{ K}}\right)\left(0.001 \text{ m}^3\right)$

For the correct answer, including units — *1 point*

$V_C = 0.005 \text{ m}^3$

Another method is to use the ideal gas law to calculate T_B, set $T_C = T_B$, and once again use the ideal gas law to calculate V_C.

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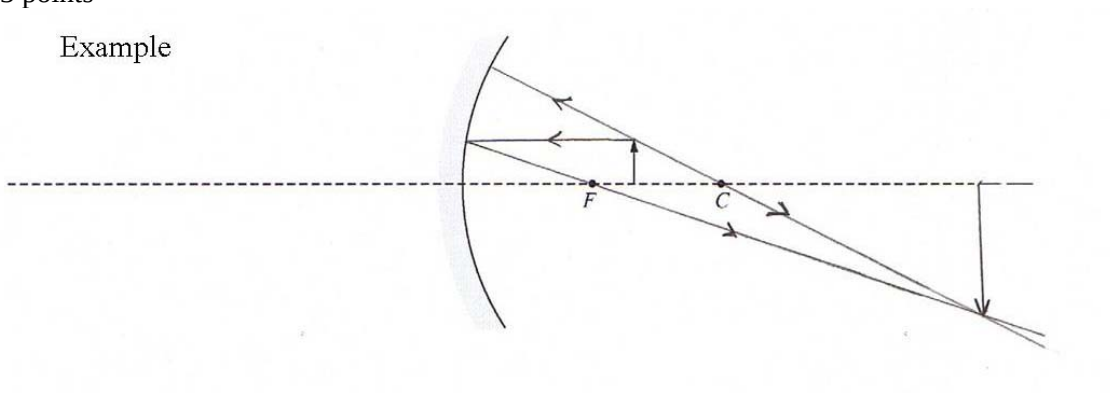
Question 6

10 points total **Distribution of points**

(a) 3 points

Example



For a correct ray, correctly drawn (must reflect off mirror and must extend below principal axis) 1 point

For a second correct ray, correctly drawn (must reflect off mirror and must extend below principal axis) 1 point

For an inverted image located to the right of C and at the location where the rays converge 1 point

(b) 2 points

For correctly indicating that the image is real 1 point

For a correct justification with no incorrect statements 1 point

Examples of correct responses include:

- Image is inverted.
- Image is on the same side of the mirror as the object $(s_i > 0)$.
- Light from the object passes through the image point.
- Rays converge at the image.
- Image could be projected on a screen.
- Object is placed beyond the focal point of a converging mirror.

(c) 2 points

For a correct mirror equation and at least one step toward a correct solution 1 point

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$, leading to $\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$, for example

Substituting into the second equation above

$$\frac{1}{s_i} = \frac{1}{6.0\text{ cm}} - \frac{1}{8.0\text{ cm}} = \frac{8-6}{48}\frac{1}{\text{cm}} = \frac{2}{48}\frac{1}{\text{cm}}$$

For a correct calculation with correct units, consistent with substitutions made 1 point

$s_i = 24$ cm

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Question 6 (continued)

Distribution of points

(d) 3 points

For correctly indicating that the image is smaller than the object 1 point
For a correct justification 2 points

Numerical justification:

$$\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$$

$$\frac{1}{s_i} = \frac{1}{-6.0\text{ cm}} - \frac{1}{8.0\text{ cm}} = -\frac{8+6}{48}\frac{1}{\text{cm}} = \frac{14}{48}\frac{1}{\text{cm}}$$

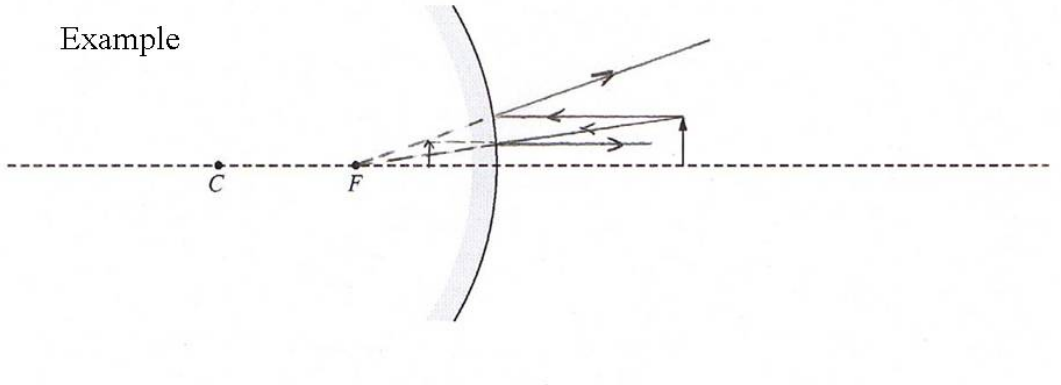
$$s_i = -3.4\text{ cm}$$

$$M = -\frac{s_i}{s_o} = -\frac{-3.4\text{ cm}}{8.0\text{ cm}} = 0.43$$

Qualitative justifications:

- Diverging mirrors always form an image that is smaller than the object.
- $s_i < s_o$ and so $h_i < h_o$. The student must prove the inequality with calculations or a diagram.

Ray diagram justification:



The ray diagram must contain at least two correct rays that show reflection and correctly show the image upright and smaller than the object, between the focal point and the mirror. The student must specifically indicate that his/her ray diagram is the justification to earn any points for it.

An incomplete but not incorrect justification earns 1 point.

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Question 7

10 points total **Distribution of points**

(a) 2 points

For correct substitutions into the relationship between the de Broglie wavelength and the momentum 1 point

$$p = \frac{h}{\lambda}$$

$$p = \frac{6.63 \times 10^{-34}\ \text{J•s}}{0.038 \times 10^{-9}\ \text{m}}$$

For a correct answer 1 point

$$p = 1.74 \times 10^{-23}\ \frac{\text{kg•m}}{\text{s}}$$

(b) 2 points

Calculating the speed of an electron

$$v = \frac{p}{m} = \frac{1.74 \times 10^{-23}\ \text{kg•m/s}}{9.11 \times 10^{-31}\ \text{kg}} = 1.91 \times 10^{7}\ \text{m/s}$$

For correct substitutions into a correct expression for kinetic energy 1 point

$$K = \frac{1}{2}mv^2$$

$$K = \frac{1}{2}\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(1.91 \times 10^{7}\ \text{m/s}\right)^2$$

For a correct answer 1 point

$$K = 1.66 \times 10^{-16}\ \text{J}$$

(c) 3 points

For any indication of conservation of energy 1 point

$$K = qV$$

For correct substitutions into a correct expression 1 point

$$V = \frac{K}{q} = \frac{\left(1.66 \times 10^{-16}\ \text{J}\right)}{\left(1.60 \times 10^{-19}\ \text{C}\right)}$$

For a correct answer 1 point

$$V = 1.04 \times 10^{3}\ \text{V}$$

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Question 7 (continued)

Distribution of points

(d) 3 points

For any indication that this process is the photoelectric effect — 1 point

$K_{\max} = hf - \phi$

For recognizing that $K_{\max} = 0$ — 1 point

$f = \dfrac{\phi}{h} = \dfrac{4.5 \text{ eV}}{4.14 \times 10^{-15} \text{ eV•s}}$

For a correct answer with units — 1 point

$f = 1.09 \times 10^{15} \text{ Hz}$

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AP® Physics B
2008 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T·m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS								
	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2008 and 2009

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\,\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

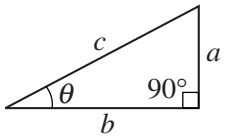
$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell w h$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 11 minutes for answering Questions 1 and 4-7 and about 17 minutes for answering each of Questions 2 and 3. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (10 points)

   A 70 kg woman and her 35 kg son are standing at rest on an ice rink, as shown above. They push against each other for a time of 0.60 s, causing them to glide apart. The speed of the woman immediately after they separate is $0.55\ \text{m/s}$. Assume that during the push, friction is negligible compared with the forces the people exert on each other.

   (a) Calculate the initial speed of the son after the push.

   (b) Calculate the magnitude of the average force exerted on the son by the mother during the push.

   (c) How do the magnitude and direction of the average force exerted on the mother by the son during the push compare with those of the average force exerted on the son by the mother? Justify your answer.

   (d) After the initial push, the friction that the ice exerts cannot be considered negligible, and the mother comes to rest after moving a distance of 7.0 m across the ice. If their coefficients of friction are the same, how far does the son move after the push?

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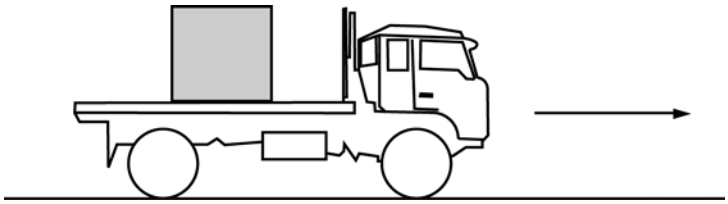


2. (15 points)

A 4700 kg truck carrying a 900 kg crate is traveling at 25 m/s to the right along a straight, level highway, as shown above. The truck driver then applies the brakes, and as it slows down, the truck travels 55 m in the next 3.0 s. The crate does not slide on the back of the truck.

(a) Calculate the magnitude of the acceleration of the truck, assuming it is constant.

(b) On the diagram below, draw and label all the forces acting on the crate during braking.



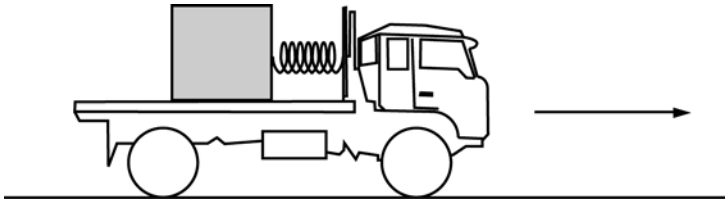
(c)

i. Calculate the minimum coefficient of friction between the crate and truck that prevents the crate from sliding.

ii. Indicate whether this friction is static or kinetic.

____ Static ____Kinetic

Now assume the bed of the truck is frictionless, but there is a spring of spring constant 9200 N/m attaching the crate to the truck, as shown below. The truck is initially at rest.



(d) If the truck and crate have the same acceleration, calculate the extension of the spring as the truck accelerates from rest to 25 m/s in 10 s.

(e) At some later time, the truck is moving at a constant speed of 25 m/s and the crate is in equilibrium. Indicate whether the extension of the spring is greater than, less than, or the same as in part (d) when the truck was accelerating.

___ Greater ___ Less ___ The same

Explain your reasoning.

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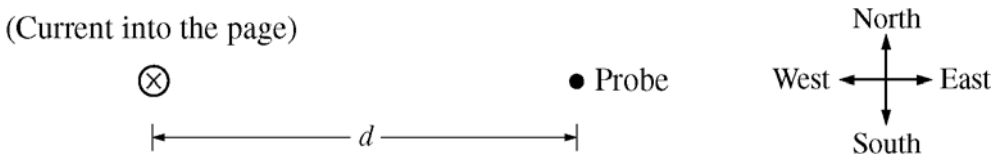
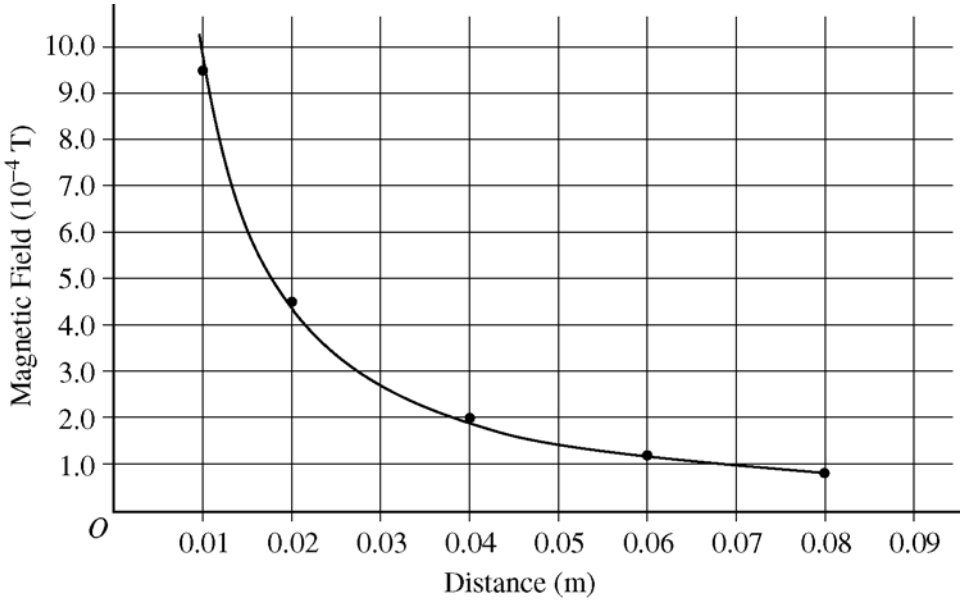


3. (15 points)

A student is measuring the magnetic field generated by a long, straight wire carrying a constant current. A magnetic field probe is held at various distances d from the wire, as shown above, and the magnetic field is measured. The graph below shows the five data points the student measured and a best-fit curve for the data.

Unfortunately, the student forgot about Earth's magnetic field, which has a value of 5.0×10^{-5} T at this location and is directed north.



(a) On the graph, plot new points for the field due only to the wire.

(b) Calculate the value of the current in the wire.

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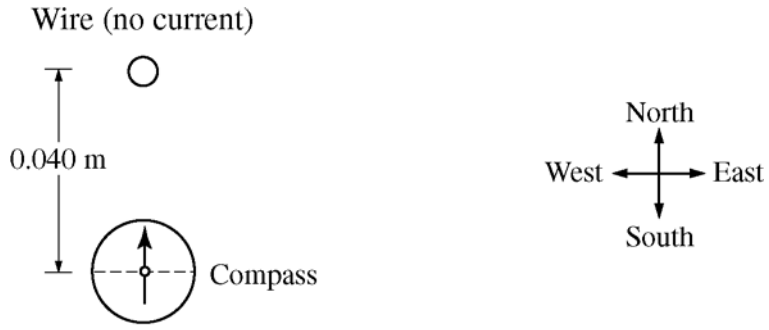
Another student, who does not have a magnetic field probe, uses a compass and the known value of Earth's magnetic field to determine the magnetic field generated by the wire. With the current turned off, the student places the compass 0.040 m from the wire, and the compass points directly toward the wire as shown below. The student then turns on a 35 A current directed into the page.



Note: Figure not drawn to scale.

(c) On the compass, sketch the general direction the needle points after the current is established.

(d) Calculate how many degrees the compass needle rotates from its initial position pointing directly north.

The wire is part of a circuit containing a power source with an emf of 120 V and negligible internal resistance.

(e) Calculate the total resistance of the circuit.

(f) Calculate the rate at which energy is dissipated in the circuit.

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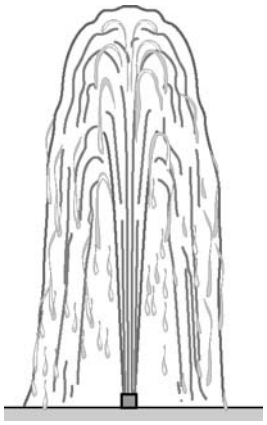

4. (10 points)

A fountain with an opening of radius 0.015 m shoots a stream of water vertically from ground level at 6.0 m/s . The density of water is $1000\ \text{kg}/\text{m}^3$.

(a) Calculate the volume rate of flow of water.

(b) The fountain is fed by a pipe that at one point has a radius of 0.025 m and is 2.5 m below the fountain's opening. Calculate the absolute pressure in the pipe at this point.

(c) The fountain owner wants to launch the water 4.0 m into the air with the same volume flow rate. A nozzle can be attached to change the size of the opening. Calculate the radius needed on this new nozzle.

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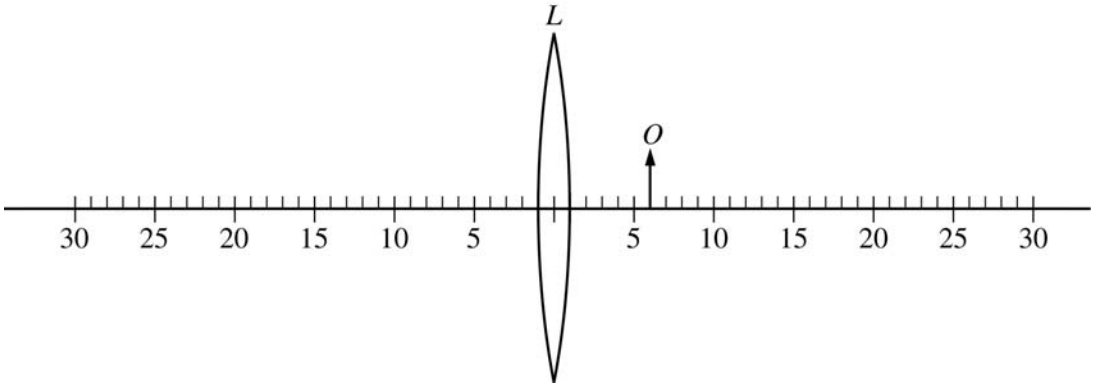
5. (10 points)

A thin converging lens *L* of focal length 10.0 cm is used as a simple magnifier to examine an object *O* that is placed 6.0 cm from the lens.

(a) On the figure below, draw a ray diagram showing at least two incident rays and the position and size of the image formed.



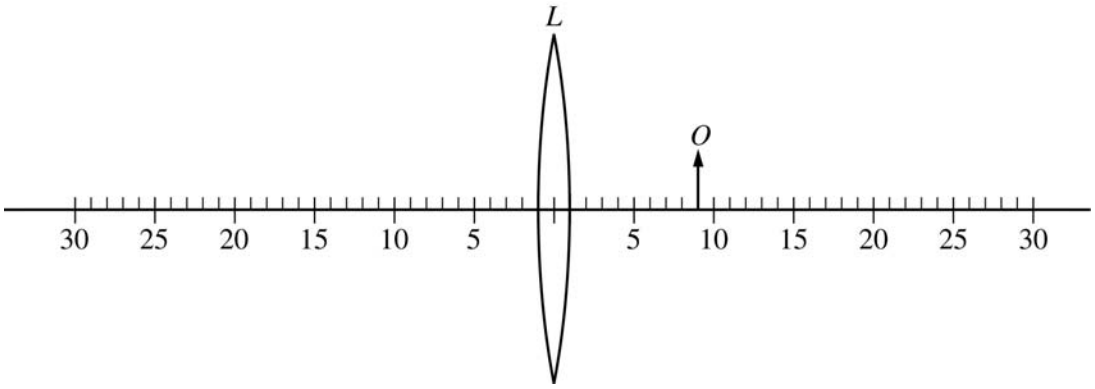
(b)

i. Indicate whether the image is real or virtual.

____ Real ____ Virtual

ii. Justify your answer.

(c) Calculate the distance of the image from the center of the lens. (Do NOT simply measure your ray diagram.)



(d) The object is now moved 3.0 cm to the right, as shown above. How does the height of the new image compare with that of the previous image?

____ It is larger. ____ It is smaller. ____ It is the same size.

Justify your answer.

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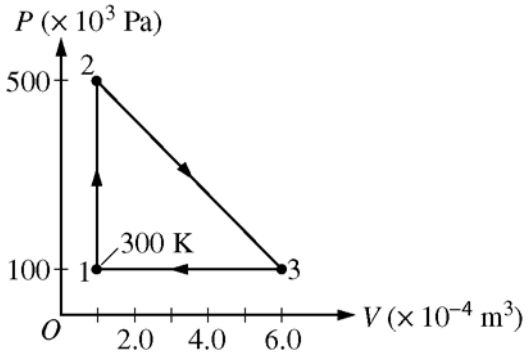

6. (10 points)

A 0.0040 mol sample of a monatomic gas is taken through the cycle shown above. The temperature T_1 of state 1 is 300 K.

(a) Calculate T_2 and T_3.

(b) Calculate the amount of work done on the gas in one cycle.

(c) Is the net work done on the gas in one complete cycle positive, negative, or zero?

____ Positive ____ Negative ____ Zero

(d) Calculate the heat added to the gas during process 1→2.

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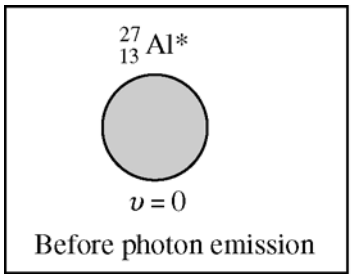

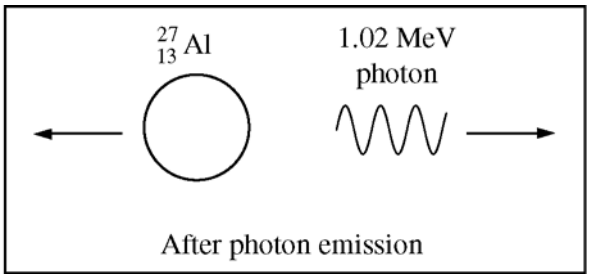

7. (10 points)

Following a nuclear reaction, a nucleus of aluminum is at rest in an excited state represented by $^{27}_{13}\text{Al}^*$, as shown above left. The excited nucleus returns to the ground state $^{27}_{13}\text{Al}$ by emitting a gamma ray photon of energy 1.02 MeV, as shown above right. The aluminum nucleus in the ground state has a mass of 4.48×10^{-26} kg. Assume nonrelativistic equations apply to the motion of the nucleus.

(a) Calculate the wavelength of the emitted photon in meters.

(b) Calculate the momentum of the emitted photon in kg•m/s.

(c) Calculate the speed of the recoiling nucleus in m/s.

(d) Calculate the kinetic energy of the recoiling nucleus in joules.

END OF EXAM

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AP® Physics B
2008 Scoring Guidelines
Form B

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AP® PHYSICS
2008 SCORING GUIDELINES

General Notes About 2008 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
2008 SCORING GUIDELINES (Form B)

Question 1

10 points total **Distribution of points**

(a) 2 points

For a correct expression of conservation of momentum 1 point

$m_w v_w = m_s v_s$

$v_s = \frac{m_w v_w}{m_s} = \frac{(70 \text{ kg})(0.55 \text{ m/s})}{35 \text{ kg}}$

For the correct final answer 1 point

$v_s = 1.1 \text{ m/s}$

(b) 2 points

For correct use of the impulse–momentum relationship 1 point

$F_{avg}\Delta t = m_s \Delta v_s$

$F_{avg} = \frac{m_s \Delta v_s}{\Delta t} = \frac{(35 \text{ kg})(1.1 \text{ m/s} - 0 \text{ m/s})}{0.60 \text{ s}}$

For the correct final answer 1 point

$F_{avg} = 64 \text{ N}$

Alternate solution *Alternate points*

For correct calculation of the average acceleration of the son during the push *1 point*

$a_s = \frac{\Delta v_s}{\Delta t}$

$a_s = \frac{1.1 \text{ m/s}}{0.6 \text{ s}} = 1.83 \text{ m/s}^2$

For the correct final answer using Newton's second law *1 point*

$F_{avg} = m_s a_s = (35 \text{ kg})(1.83 \text{ m/s}^2)$

$F_{avg} = 64 \text{ N}$

(c) 3 points

For indicating that the average force exerted on the mother by the son is equal in magnitude to that exerted on the son by the mother 1 point

For indicating that the average force exerted on the mother by the son is opposite in direction to that exerted on the son by the mother 1 point

For a correct justification invoking Newton's third law 1 point

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Question 1 (continued)

Distribution of points

(d) 3 points

For correctly finding the acceleration of the mother — 1 point

In the following solution, the positive direction for all quantities is to the right relative to the figure shown in the question.

$v_{wf}^2 = v_{wi}^2 + 2a_w\Delta x_w$

$0 = (0.55 \text{ m/s})^2 + 2a_w(-7 \text{ m})$

$a_w = 0.022 \text{ m/s}^2$

For recognizing that the accelerations of both the mother and the son are the same magnitude, since the acceleration is caused by friction — 1 point

$F_{fric} = \mu N = \mu mg = ma$

$a = \mu g$

$|a_w| = |a_s|$

$a_s = -0.022 \text{ m/s}^2$

For correctly finding the displacement of the son, with units — 1 point

$v_{sf}^2 = v_{si}^2 + 2a_s\Delta x_s$

$0 = (1.1 \text{ m/s})^2 + 2\left(-0.022 \text{ m/s}^2\right)\Delta x_s$

$\Delta x_s = 28 \text{ m}$

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2008 SCORING GUIDELINES (Form B)

Question 2

15 points total **Distribution of points**

(a) 2 points

For correct use of a kinematic relationship to find acceleration, and correct substitution of values 1 point

$$x = x_0 + v_0 t - \frac{1}{2}at^2$$

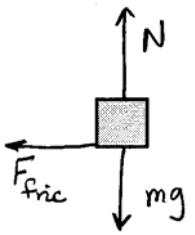
$$a = -\frac{2[(x - x_0) - v_0 t]}{t^2}$$

$$a = \frac{2[55\text{ m} - (25\text{ m/s})(3.0\text{ s})]}{(3.0\text{ s})^2}$$

For the correct final answer, regardless of sign or units 1 point

$a = -4.4\ \text{m/s}^2$

(b) 3 points



For each correct force for which the vector was correctly drawn and labeled, 1 point was awarded. 3 points

For each extraneous or incorrect force vector, 1 point was deducted with the minimum possible score being zero.

(c)

(i) 3 points

For equating the frictional force to *ma* 1 point

$\Sigma F = F_{fric} = ma$

For a correct expression for the frictional force 1 point

$F_{fric} = \mu N = \mu mg$

Substituting the expression for F_{fric} into Newton's second law

$\mu mg = ma$

$$\mu = \frac{a}{g} = \frac{4.4\ \text{m/s}^2}{9.8\ \text{m/s}^2}$$

For the correct final answer, without units 1 point

$\mu = 0.45$ ($\mu = 0.44$ for $g = 10\ \text{m/s}^2$)

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Question 2 (continued)

Distribution of points

(ii) 1 point

For indicating that the friction is static — 1 point

(d) 3 points

For correct use of a kinematic relationship to find acceleration — 1 point

$v = v_0 + at$

$a_x = \frac{v_x - v_{0x}}{t} = \frac{25 \text{ m/s} - 0 \text{ m/s}}{10 \text{ s}} = 2.5 \text{ m/s}^2$

For correct substitutions into Newton's second law — 1 point

$\Sigma F = ma = kx$

$kx = ma_x$

$x = \frac{ma}{k} = \frac{(900 \text{ kg})(2.5 \text{ m/s}^2)}{9200 \text{ N/m}}$

For the correct answer with units — 1 point

$x = 0.24$ m

(e) 3 points

For indicating that the extension of the spring is less than in part (d) — 1 point

For a correct justification — 2 points

For example: When the truck is moving at a constant speed, the crate is also moving at the same constant speed with zero acceleration. This means the net force on the crate must be zero; since the bed of the truck is frictionless, the force of the spring on the crate must also zero, and so the spring is not extended at all.

Notes: A single point could be awarded for partial justification, e.g., for either of the statements above given in the absence of the other.

The justification points could only be earned if the point was awarded for the proper extension of the spring.

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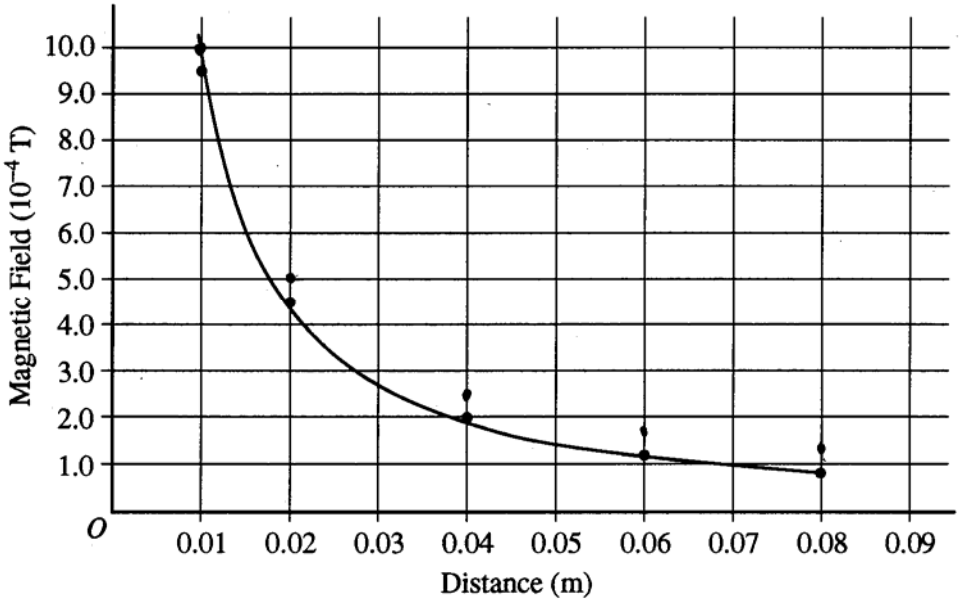
2008 SCORING GUIDELINES (Form B)

Question 3

15 points total **Distribution of points**

(a) 2 points



For each new point being above one of the points shown on the graph — 1 point

For each new point being about the same distance from the old point, a distance equal to one-half the distance between the horizontal grid lines shown — 1 point

(b) 3 points

For an attempted application of a correct relationship to find the current I — 1 point

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

$$I = \frac{2\pi rB}{\mu_0}$$

For correct substitutions using one of the new data points plotted in part (a), for example, using the point $(0.01\text{ m},\ 10.0 \times 10^{-4}\text{ T})$ — 1 point

$$I = \frac{2\pi(0.01\text{ m})\left(10.0 \times 10^{-4}\text{ T}\right)}{4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}}$$

For the correct answer — 1 point

$I = 50$ A

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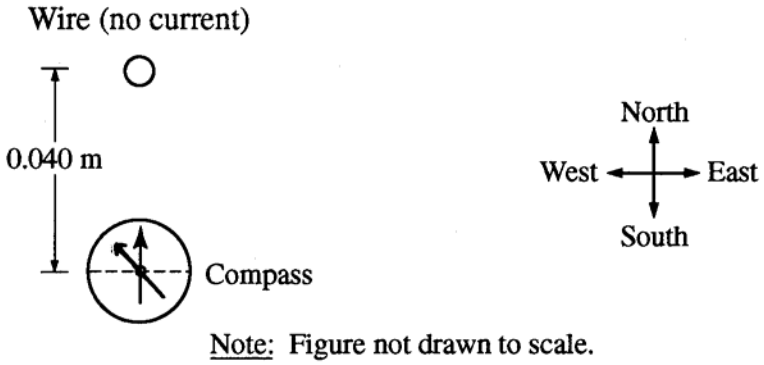
Question 3 (continued)

Distribution of points

(c) 2 points



Note: Figure not drawn to scale.

For the direction that the needle points being toward the northwest quadrant 2 points
Note: If the needle was drawn pointing directly to the west, 1 point was awarded. If the needle was drawn pointing directly to the north, no points were awarded.

(d) 4 points

For a correct relationship to find the westward component of **B**, and a correct substitution of the current determined in part (b) 1 point

$$B_w = \frac{\mu_0}{2\pi}\frac{I}{r} = \left(\frac{4\pi \times 10^{-7}\ (\text{T•m})/\text{A}}{2\pi}\right)\left(\frac{35\ \text{A}}{0.040\ \text{m}}\right)$$

For the correct answer for B_w 1 point

$B_w = 17.5 \times 10^{-5}\ \text{T}$

For a correct relationship relating the northward and westward components to the angle 1 point

$$\tan\theta = \frac{B_w}{B_n} = \frac{17.5 \times 10^{-5}\ \text{T}}{5.0 \times 10^{-5}\ \text{T}} = 3.5$$

For the correct answer 1 point
$\theta = 74°$ or 1.3 rad

(e) 2 points

For correct substitution of both values into Ohm's law 1 point
$\mathcal{E} = IR$

$$R = \frac{\mathcal{E}}{I} = \frac{120\ \text{V}}{35\ \text{A}}$$

For the correct answer including units 1 point
$R = 3.4\ \Omega$

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Question 3 (continued)

		Distribution of points
(f)	2 points	
	For correct substitution of values into a correct expression for power $P = IV$ (or $P = I^2R$ or $P = V^2/R$) $P = (35\text{ A})(120\text{ V})$	1 point
	For the correct answer including units $P = 4200\text{ W}$	1 point

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AP® PHYSICS B
2008 SCORING GUIDELINES (Form B)

Question 4

10 points total **Distribution of points**

(a) 3 points

For a correct expression for the volume flow rate I_V 1 point

$I_V = Av$

For a correct substitution for area (only if the first point was awarded) 1 point

$A = \pi r^2$

$I_V = \pi r^2 v = (3.14)(0.015 \text{ m})^2 (6.0 \text{ m/s})$

For the correct answer 1 point

$I_V = 4.2 \times 10^{-3} \text{ m}^3/\text{s}$

(b) 3 points

For a correct application of Bernoulli's equation to point 1 in the feeder pipe below ground and point 2 at the surface where the water emerges 1 point

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho {v_2}^2$

$P_1 = P_{abs}$ and $P_2 = P_{atm}$

$P_{abs} = P_{atm} + \rho g (y_2 - y_1) + \frac{1}{2}\rho \left({v_2}^2 - v_1^2\right)$

For the correct use of the equation of continuity to find v_1 1 point

$A_1 v_1 = A_2 v_2$

$v_1 = \frac{v_2 A_2}{A_1} = \frac{v_2 \pi {r_2}^2}{\pi {r_1}^2} = \frac{(6.0 \text{ m/s})(0.015 \text{ m})^2}{(0.025 \text{ m})^2} = 2.2 \text{ m/s}$

${v_2}^2 - {v_1}^2 = (6.0 \text{ m/s})^2 - (2.2 \text{ m/s})^2 = 31 \text{ m}^2/\text{s}^2$

$P_{abs} = 1.0 \times 10^5 \text{ Pa} + \left(10^3 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(2.5 \text{ m}) + \frac{1}{2}\left(10^3 \text{ kg/m}^3\right)\left(31 \text{ m}^2/\text{s}^2\right)$

For the correct answer with units 1 point

$P_{abs} = 1.4 \times 10^5 \text{ Pa}$

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Question 4 (continued)

Distribution of points

(c) 4 points

For correct use of kinematics or conservation of energy or Torricelli's theorem to find the exit speed, with correct substitution of values — 1 point

$v_2^2 = 2gh$

$v_2 = \sqrt{2gh} = \sqrt{2\left(9.8 \text{ m/s}^2\right)(4.0 \text{ m})}$

For the correct answer for the exit speed — 1 point

$v_2 = 8.9 \text{ m/s}$

For correct use of the equation of continuity to find r_{new}, with correct substitution of values — 1 point

$Av = A_{new}v_{new}$

$\pi r^2 v = \pi r_{new}^2 v_{new}$

$r_{new}^2 = r^2 \dfrac{v}{v_{new}} = (0.015 \text{ m})^2 \dfrac{(6.0 \text{ m/s})}{(8.9 \text{ m/s})}$

For the correct answer with units, consistent with the new exit speed found above — 1 point

$r_2 = 1.2 \times 10^{-2} \text{ m}$

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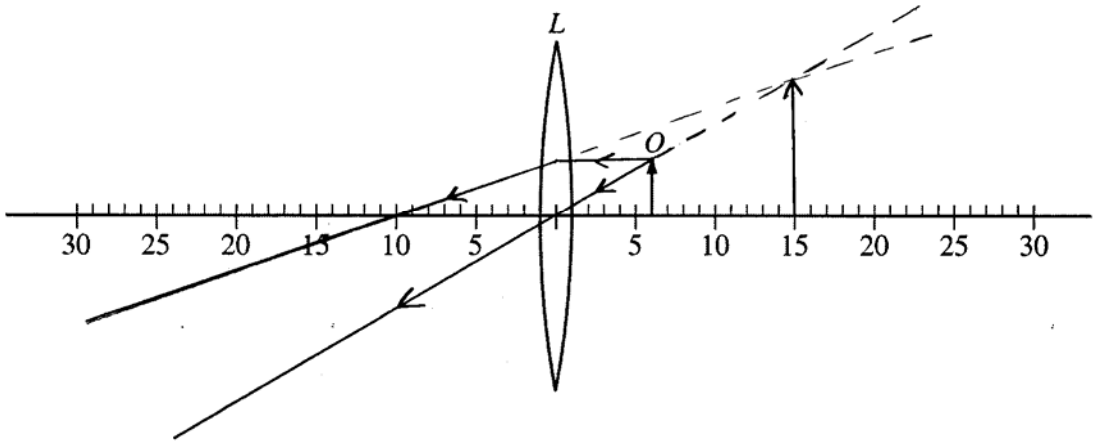
AP® PHYSICS B
2008 SCORING GUIDELINES (Form B)

Question 5

10 points total **Distribution of points**

(a) 3 points

Example:



For each correct ray from the object used to locate the image, 1 point was awarded, to a maximum of 2 points — 2 points

For the correct size and orientation of the image — 1 point

(b)

(i) 1 point

For an indication that the image is virtual — 1 point

(ii) 1 point

For a correct justification — 1 point

Example: The rays emerging from the lens did not actually converge at the image but only appear to have done so.

This point was only awarded if the point for part (b)(i) was awarded.

(c) 2 points

For correct use of the equation relating image distance to object distance and focal length, with correct substitutions — 1 point

$$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$$

$$s_i = \frac{fs_o}{s_o - f}$$

$$s_i = \frac{(10.0\text{ cm})(6.0\text{ cm})}{6.0\text{ cm} - 10.0\text{ cm}}$$

For the correct answer with the correct sign — 1 point

$s_i = -15$ cm

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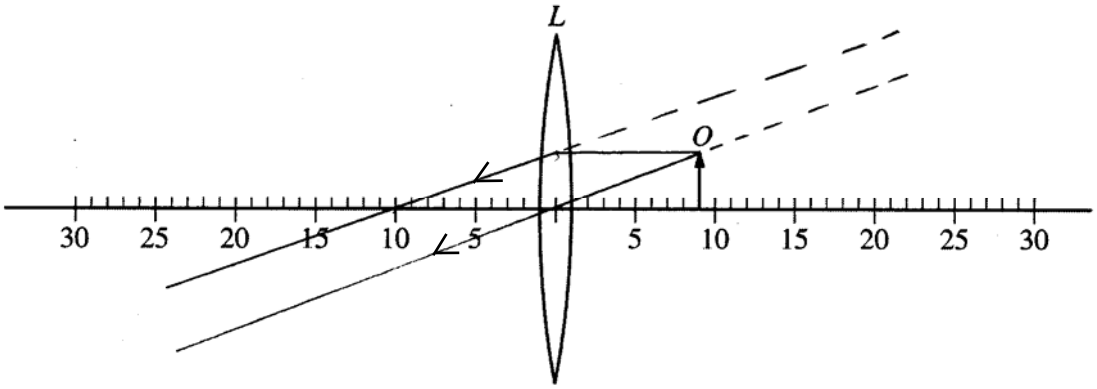
Question 5 (continued)

Distribution of points

(d) 3 points
Example:



For an indication that the height of the new image is larger — 1 point
For a correct justification (only when the previous point has been awarded) — 2 points

Justification approach 1: — 2 points
The rays passing through the lens become less diverging from each other due to the geometry. Their extensions meet further away from the lens making the image larger.

Justification approach 2: Construct a new ray diagram — 2 points
For each correct ray from the object used to locate the image, 1 point was awarded, to a maximum of 2 points. The student must explicitly refer to the diagram as the justification for the larger height in order for the diagram to be considered.

Justification approach 3: Calculate the change in magnification
For a correct calculation of the image location after the object is moved — 1 point

$$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$$

$$s_i = \frac{fs_o}{s_o - f} = \frac{(10.0\text{ cm})(9.0\text{ cm})}{9.0\text{ cm} - 10.0\text{ cm}} = -90\text{ cm}$$

For a correct calculation of the magnification both prior to moving the object and after the object is moved, leading to the conclusion that the new image is larger — 1 point

$$M_1 = -\frac{s_i}{s_o} = -\frac{-15\text{ cm}}{6\text{ cm}} = +2.5$$

$$M_2 = -\frac{s_i}{s_o} = -\frac{-90\text{ cm}}{9\text{ cm}} = +10$$

The magnification increases so the height of the new image is larger.

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AP® PHYSICS B
2008 SCORING GUIDELINES (Form B)

Question 6

10 points total **Distribution of points**

(a) 4 points

Apply the ideal gas law to pairs of points, recognizing that nR is the same at all three points.

For example, comparing points 1 and 2 and points 1 and 3

For correct use of the ideal gas law at points 1 and 2, with correct substation of values — 1 point

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$, with $V_1 = V_2$

$T_2 = \frac{T_1P_2}{P_1} = \frac{(300\text{ K})\left(500 \times 10^3\text{ Pa}\right)}{100 \times 10^3\text{ Pa}}$

For the correct temperature at point 2 — 1 point

$T_2 = 1500\text{ K}$

For correct use of the ideal gas law at points 1 and 3, with correct substitution of values — 1 point

$\frac{P_1V_1}{T_1} = \frac{P_3V_3}{T_3}$, with $P_1 = P_3$

$T_3 = \frac{T_1V_3}{V_1} = \frac{(300\text{ K})\left(6.0 \times 10^{-4}\text{ m}^3\right)}{1.0 \times 10^{-4}\text{ m}^3}$

For the correct temperature at point 3 — 1 point

$T_3 = 1800\text{ K}$

(b) 2 points

Approach 1: Calculate the area enclosed by the triangular path

For recognition that the magnitude of the work done on the gas in one cycle is equal to the area enclosed by the triangular path — 1 point

$W_{tot} = \frac{1}{2}(V_3 - V_1)(P_2 - P_1)$

For the correct answer — 1 point

$W_{tot} = \frac{1}{2}\left[(6.0 - 1.0) \times 10^{-4}\text{ m}^3\right]\left[(500 - 100) \times 10^3\text{ Pa}\right]$

$W_{tot} = 100\text{ J}$

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Question 6 (continued)

Distribution of points

(b) (continued)

Approach 2: Calculate the work done on the gas in each of the three processes and take the sum

For recognition that the work done on the gas is equal to the sum of the work done in each of the three processes — 1 point

$W_{tot} = W_{1\to2} + W_{2\to3} + W_{3\to1}$

For a correct computation of the numerical value — 1 point

$W_{1\to2} = -P_1(V_2 - V_1)$, but $V_2 = V_1$, so $W_{1\to2} = 0$

$$W_{2\to3} = -\frac{\left[(500 + 100)\times 10^3 \text{ Pa}\right]}{2}\left[(6.0 - 1.0)\times 10^{-4} \text{ m}^3\right] = -150 \text{ J}$$

$$W_{3\to1} = -P_3(V_1 - V_3) = -\left(100\times 10^3 \text{ Pa}\right)\left[(1.0 - 6.0)\times 10^{-4} \text{ m}^3\right] = +50 \text{ J}$$

$W_{3\to1} = +50$ J

$W_{tot} = W_{1\to2} + W_{2\to3} + W_{3\to1} = 0 - 150 \text{ J} + 50 \text{ J} = -100 \text{ J}$

Note: The minus sign was not necessary since the question asks only for the amount of work; the sign is asked for in part (c).

(c) 1 point

For indicating that the work done on the gas in one complete cycle is negative — 1 point

(d) 3 points

For an application of the first law of thermodynamics to process $1 \to 2$, recognizing that the work done from point 1 to point 2 is zero — 1 point

$\Delta U = Q + W$

$Q = \Delta U - W$

$Q = \Delta U$

For a correct expression for Q from point 1 to point 2, with correct substitution of values — 1 point

$$Q = \frac{3}{2}nR\Delta T = \frac{3}{2}(0.0040 \text{ mol})(8.31 \text{ J/mol•K})(1500 \text{ K} - 300 \text{ K})$$

For the correct answer — 1 point

$Q = 60$ J

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AP® PHYSICS B
2008 SCORING GUIDELINES (Form B)

Question 7

10 points total **Distribution of points**

(a) 3 points

For a correct equation relating energy and wavelength 1 point

$E_\gamma = hf = \dfrac{hc}{\lambda}$

For correct substitutions (and conversions if necessary) 1 point

$\lambda = \dfrac{hc}{E_\gamma} = \dfrac{\left(6.63 \times 10^{-34}\ \text{J·s}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)}{\left(1.02 \times 10^{6}\ \text{eV}\right)\left(1.60 \times 10^{-19}\ \text{J/eV}\right)}$ OR

$\lambda = \dfrac{hc}{E_\gamma} = \dfrac{\left(1.24 \times 10^{3}\ \text{eV·nm}\right)\left(10^{-9}\ \text{m/nm}\right)}{1.02 \times 10^{6}\ \text{eV}}$

For the correct answer with units 1 point

$\lambda = 1.22 \times 10^{-12}\ \text{m}$

(b) 2 points

For correct use of the equation relating wavelength and momentum (or energy and momentum) and correct substitution of values 1 point

$\lambda = \dfrac{h}{p_\gamma}$ (or $E = pc$)

$p_\gamma = \dfrac{h}{\lambda} = \dfrac{6.63 \times 10^{-34}\ \text{J·s}}{1.22 \times 10^{-12}\ \text{m}}$ OR $p = \dfrac{E}{c} = \dfrac{\left(1.02 \times 10^{6}\ \text{eV}\right)\left(1.6 \times 10^{-19}\ \text{J/eV}\right)}{3.0 \times 10^{8}\ \text{m/s}}$

For the correct answer with units 1 point

$p_\gamma = 5.43 \times 10^{-22}\ \text{kg·m/s}$

(c) 3 points

For an indication that momentum is conserved 1 point

$p_\gamma = p_{nuc}$

For a correct expression for the momentum of the nucleus 1 point

$p_{nuc} = m_{nuc} v_{nuc}$

For either a correct substitution from part (b) or the correct answer 1 point

$v_{nuc} = \dfrac{p_{nuc}}{m_{nuc}} = \dfrac{p_\gamma}{m_{nuc}} = \dfrac{5.43 \times 10^{-22}\ \text{kg·m/s}}{4.48 \times 10^{-26}\ \text{kg}} = 1.21 \times 10^{4}\ \text{m/s}$

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Question 7 (continued)

Distribution of points

(d) 2 points

For correct use of the expression for kinetic energy 1 point

$K_{nuc} = \frac{1}{2}mv_{nuc}^2$

For a correct substitution from part (c) 1 point

$K_{nuc} = \frac{1}{2}\left(4.48 \times 10^{-26}\ \text{kg}\right)\left(1.21 \times 10^{4}\ \text{m/s}\right)^2 = 3.28 \times 10^{-18}\ \text{J}$

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AP® Physics B
2007 Free-Response Questions

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Electron charge magnitude,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol·K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^{8}\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J·s}$
	$= 4.14 \times 10^{-15}\ \text{eV·s}$
	$hc = 1.99 \times 10^{-25}\ \text{J·m}$
	$= 1.24 \times 10^{3}\ \text{eV·nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N·m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N·m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ \text{(T·m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ \text{(T·m)/A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg·s}^2$
Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2$
	$= 1.0 \times 10^{5}\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	$\sin\theta$	$\cos\theta$	$\tan\theta$
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

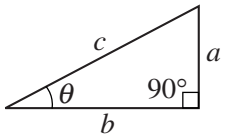
$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

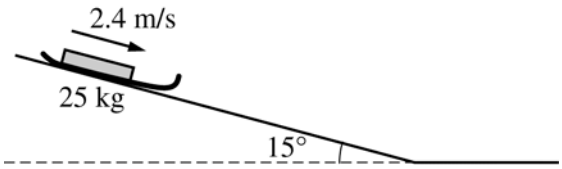
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1 and 3 and about 11 minutes for answering each of Questions 2 and 4-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.

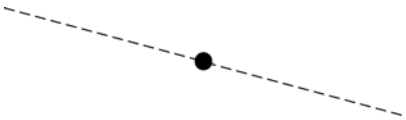


1. (15 points)

An empty sled of mass 25 kg slides down a muddy hill with a constant speed of 2.4 m/s. The slope of the hill is inclined at an angle of 15° with the horizontal as shown in the figure above.

(a) Calculate the time it takes the sled to go 21 m down the slope.

(b) On the dot below that represents the sled, draw and label a free-body diagram for the sled as it slides down the slope.



(c) Calculate the frictional force on the sled as it slides down the slope.

(d) Calculate the coefficient of friction between the sled and the muddy surface of the slope.

(e) The sled reaches the bottom of the slope and continues on the horizontal ground. Assume the same coefficient of friction.

i. In terms of velocity and acceleration, describe the motion of the sled as it travels on the horizontal ground.

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ii. On the axes below, sketch a graph of speed v versus time t for the sled. Include both the sled's travel down the slope and across the horizontal ground. Clearly indicate with the symbol t_ℓ the time at which the sled leaves the slope.



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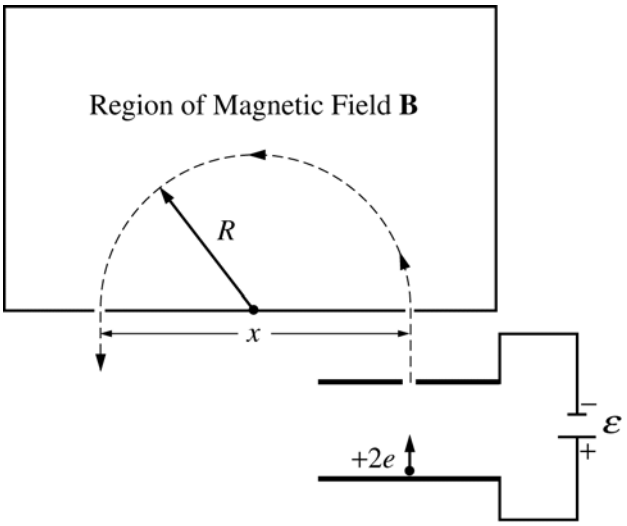

Top View

2. (10 points)

Your research director has assigned you to set up the laboratory's mass spectrometer so that it will separate strontium ions having a net charge of +2*e* from a beam of mixed ions. The spectrometer above accelerates a beam of ions from rest through a potential difference $\mathcal{E}$, after which the beam enters a region containing a uniform magnetic field **B** of constant magnitude and perpendicular to the plane of the path of the ions. The ions leave the spectrometer at a distance *x* from the entrance point. You can manually change $\mathcal{E}$.

Numerical values for this experiment:

Strontium atomic number:	38
Strontium ion mass:	1.45×10^{-25} kg
Magnitude of *B* field:	0.090 T
Desired exit distance *x*:	1.75 m

(a) In what direction must **B** point to produce the trajectory of the ions shown?

(b) The ions travel at constant speed around the semicircular path. Explain why the speed remains constant.

(c) Calculate the speed of the ions with charge +2*e* that exit at distance *x*.

(d) Calculate the accelerating voltage $\mathcal{E}$ needed for the ions with charge +2*e* to attain the speed you calculated in part (c).

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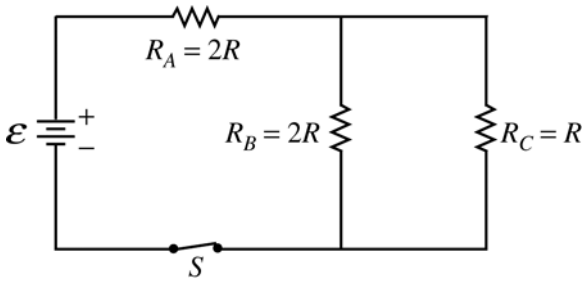

3. (15 points)

The circuit above contains a battery with negligible internal resistance, a closed switch *S*, and three resistors, each with a resistance of *R* or 2*R*.

(a)

i. Rank the currents in the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same current, give them the same ranking.

____ I_A ____ I_B ____ I_C

ii. Justify your answers.

(b)

i. Rank the voltages across the three resistors from greatest to least, with number 1 being greatest. If two resistors have the same voltage across them, give them the same ranking.

____ V_A ____ V_B ____ V_C

ii. Justify your answers.

For parts (c) through (e), use $\mathcal{E}$ = 12 V and $R = 200\ \Omega$.

(c) Calculate the equivalent resistance of the circuit.

(d) Calculate the current in resistor R_C.

(e) The switch *S* is opened, resistor R_B is removed and replaced by a capacitor of capacitance 2.0×10^{-6} F, and the switch *S* is again closed. Calculate the charge on the capacitor after all the currents have reached their final steady-state values.

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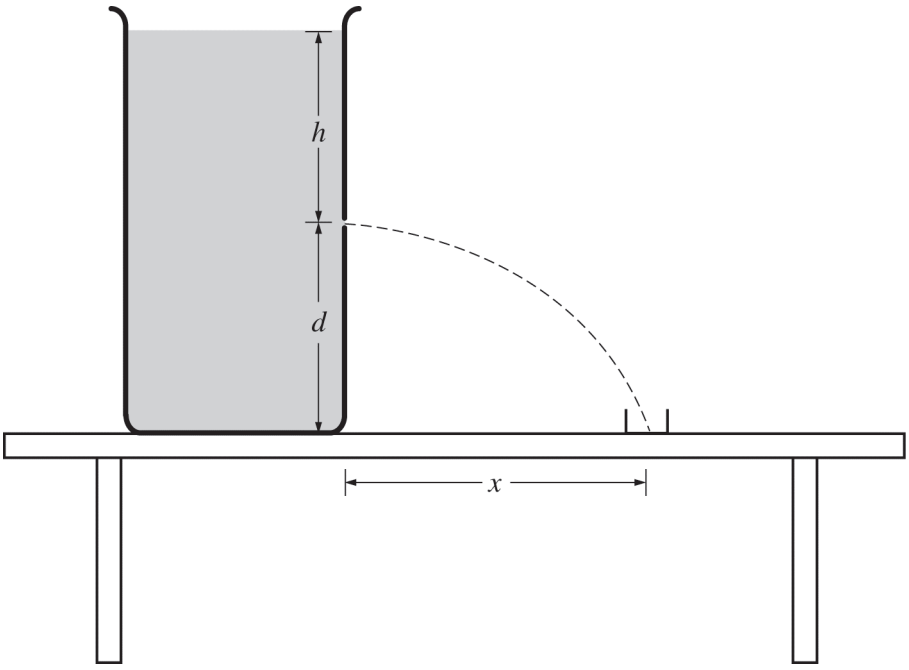

4. (10 points)

The large container shown in the cross section above is filled with a liquid of density 1.1×10^3 kg/m^3. A small hole of area 2.5×10^{-6} m^2 is opened in the side of the container a distance h below the liquid surface, which allows a stream of liquid to flow through the hole and into a beaker placed to the right of the container. At the same time, liquid is also added to the container at an appropriate rate so that h remains constant. The amount of liquid collected in the beaker in 2.0 minutes is 7.2×10^{-4} m^3.

(a) Calculate the volume rate of flow of liquid from the hole in m^3/s.

(b) Calculate the speed of the liquid as it exits from the hole.

(c) Calculate the height h of liquid needed above the hole to cause the speed you determined in part (b).

(d) Suppose that there is now less liquid in the beaker so that the height h is reduced to $h/2$. In relation to the beaker, where will the liquid hit the tabletop?

____ Left of the beaker ____ In the beaker ____ Right of the beaker

Justify your answer.

should say "container"

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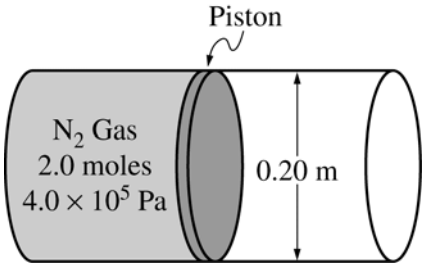

5. (10 points)

The figure above shows a 0.20 m diameter cylinder fitted with a frictionless piston, initially fixed in place. The cylinder contains 2.0 moles of nitrogen gas at an absolute pressure of 4.0×10^5 Pa . Nitrogen gas has a molar mass of 28 g/mole and it behaves as an ideal gas.

(a) Calculate the force that the nitrogen gas exerts on the piston.

(b) Calculate the volume of the gas if the temperature of the gas is 300 K.

(c) In a certain process, the piston is allowed to move, and the gas expands at constant pressure and pushes the piston out 0.15 m. Calculate how much work is done by the gas.

(d) Which of the following is true of the heat energy transferred to or from the gas, if any, in the process in part (c)?

_____ Heat is transferred to the gas.

_____ Heat is transferred from the gas.

_____ No heat is transferred in the process.

Justify your answer.

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GO ON TO THE NEXT PAGE.

6. (10 points)

You are asked to experimentally determine the focal length of a converging lens.

(a) Your teacher first asks you to estimate the focal length by using a distant tree visible through the laboratory window. Explain how you will estimate the focal length.

To verify the value of the focal length, you are to measure several object distances s_o and image distances s_i using equipment that can be set up on a tabletop in the laboratory.

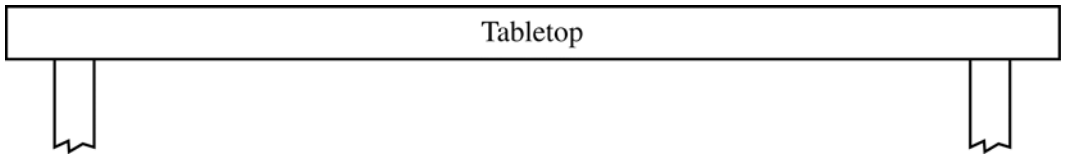
(b) In addition to the lens, which of the following equipment would you use to obtain the data?

____Lighted candle ____ Candleholder ____ Desk lamp ____ Plane mirror

____ Vernier caliper ____ Meterstick ____ Ruler ____ Lens holder

____ Stopwatch ____ Screen ____ Diffraction grating

(c) On the tabletop below, sketch the setup used to obtain the data, labeling the lens, the distances s_o and s_i, and the equipment checked in part (b).



You are to determine the focal length using a linear graph of $1/s_i$ versus $1/s_o$. Assume that you obtain the following data for object distance s_o and image distance s_i.

Trial #	s_o (m)	s_i (m)	$1/s_o$ $\left(\text{m}^{-1}\right)$	$1/s_i$ $\left(\text{m}^{-1}\right)$
1	0.40	1.10	2.5	0.91
2	0.50	0.75	2.0	1.3
3	0.60	0.60	1.7	1.7
4	0.80	0.50	1.2	2.0
5	1.20	0.38	0.83	2.6

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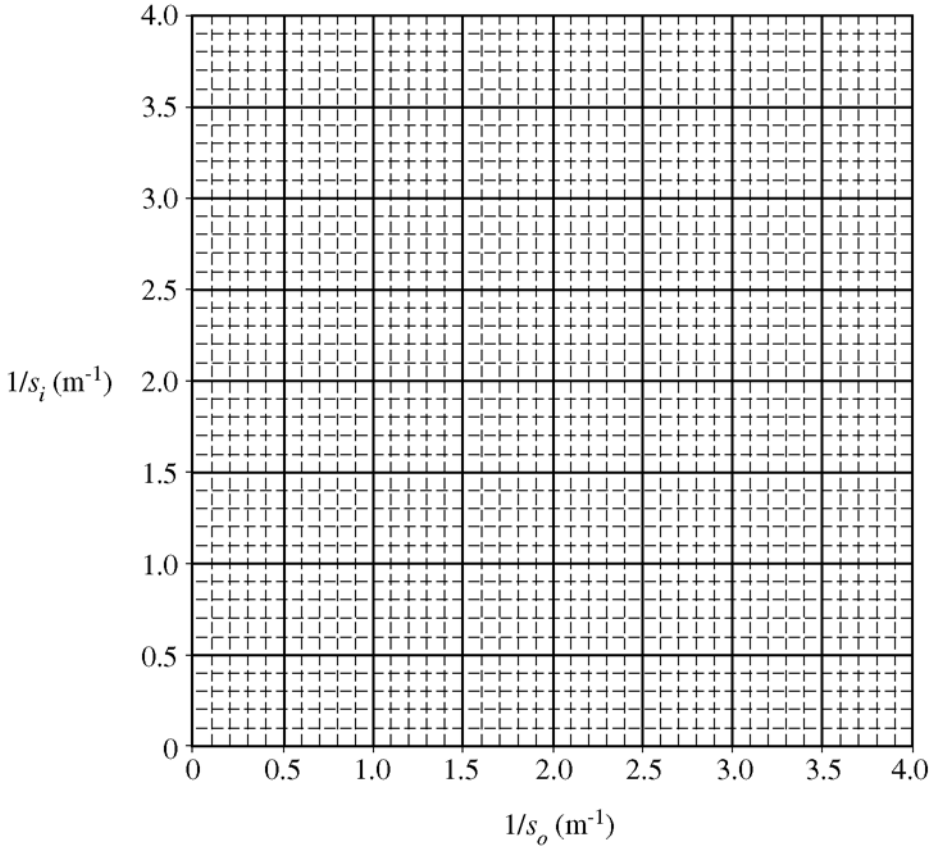
(d) On the grid below, plot the points in the last two columns of the table above and draw a best-fit line through the points.



(e) Calculate the focal length from the best-fit line.

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7. (10 points)

It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron-positron pair before annihilation is negligible compared to the energy of the photons created.

(a) Calculate, in eV, the rest energy of a positron.

(b) Determine, in eV, the energy each emitted photon must have.

(c) Calculate the wavelength of each created photon.

(d) Calculate the magnitude of the momentum of each photon.

(e) Determine the total momentum of the two-photon system.

END OF EXAM

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AP® Physics B
2007 Scoring Guidelines

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AP® PHYSICS B
2007 SCORING GUIDELINES

General Notes About 2007 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
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Question 1

15 points total **Distribution of points**

(a) 2 points

For using a correct equation relating distance, speed, and time 1 point

$x = v\Delta t$

$\Delta t = \frac{x}{v}$

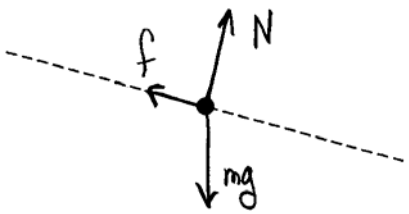
$\Delta t = \frac{21 \text{ m}}{2.4 \text{ m/s}}$

For the correct answer 1 point

$\Delta t = 8.75$ s

Note: Only 1 point was awarded for the correct answer with no supporting work.

(b) 3 points



For each correct force that is correctly labeled, is attached to the dot, and has an arrowhead pointing in the correct direction, 1 point was awarded. 3 points

For each incorrect vector, a point was deducted, with the minimum possible score being 0.

(c) 3 points

For recognizing that the sum of the forces upon the sled is zero 1 point

$\sum F = 0$

Writing the equation for the forces acting along the slope,

$\sum F = mg\sin 15° - f = 0$, where f represents the force of friction

For equating the force of kinetic friction with the component of weight that acts down the slope 1 point

$f = mg\sin 15°$

$f = (25 \text{ kg})(9.8 \text{ m/s}^2)\sin 15°$

For the correct answer 1 point

$f = 63.4$ N (64.7 N if $g = 10 \text{ m/s}^2$ is used)

Note: Only 1 point was awarded for the correct answer with no supporting work.

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Question 1 (continued)

Distribution of points

(d) 3 points

For equating the force of kinetic friction to the product of the coefficient of friction and the normal force — 1 point

$f = \mu N$

$\sum F = mg\cos 15° - N = 0$

For equating the normal force to the component of the sled's weight that is normal to the slope — 1 point

$N = mg\cos 15°$

$\mu = \frac{f}{N} = \frac{mg\sin 15°}{mg\cos 15°} = \tan 15°$

For the correct answer or for an answer consistent with the friction force obtained in (c) — 1 point

$\mu = 0.27$

Note: Only 1 point was awarded for the correct answer with no supporting work.

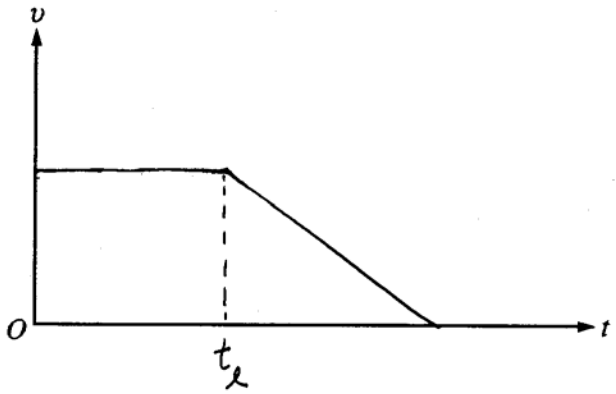
(e)

(i) 2 points

For implicitly or explicitly stating that the velocity of the sled decreases — 1 point

For explicitly stating that the acceleration of the sled is constant — 1 point

(ii) 2 points



For sketching a horizontal non-zero line — 1 point

For sketching a line of constant negative slope that begins at the right-hand end of the previously drawn horizontal line and also indicating the time t_ℓ on the graph — 1 point

Note: The second point was awarded only if the first point was awarded.

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Question 2

10 points total **Distribution of points**

(a) 1 point

For correctly indicating that the direction of the field is INTO the page or in the $-z$ direction. 1 point

(b) 2 points

For stating that the (magnetic) force is perpendicular to the velocity, or the force is centripetal, or an equivalent concept. 1 point

Note: The use of the phrase "centripetal force," without stating its source, earned no credit.

For stating that the (magnetic) force or field changes the direction of the velocity but not the speed, or an equivalent concept. 1 point

(c) 4 points

For a correct expression indicating that the magnetic force provides the centripetal force 1 point

$$\frac{mv^2}{R} = qvB$$

For a correct calculation of the radius of the trajectory 1 point

$$R = \frac{x}{2} = \frac{1.75 \text{ m}}{2} = 0.875 \text{ m}$$

For correct substitutions into a correct expression 1 point

$$v = \frac{qBR}{m} = \frac{2\left(1.60 \times 10^{-19} \text{ C}\right)(0.090 \text{ T})(0.875 \text{ m})}{1.45 \times 10^{-25} \text{ kg}}$$

For a correct answer with units 1 point

$$v = 1.74 \times 10^5 \text{ m/s}$$

(d) 3 points

For a correct expression indicating an equivalence of work and energy or electric potential energy and kinetic energy 1 point

$$q\mathcal{E} = \frac{1}{2}mv^2$$

For correct substitutions into a correct expression 1 point

$$\mathcal{E} = \frac{1}{2}\frac{m}{q}v^2 = \frac{1}{2}\frac{\left(1.45 \times 10^{-25} \text{ kg}\right)}{2\left(1.60 \times 10^{-19} \text{ C}\right)}\left(1.74 \times 10^5 \text{ m/s}\right)^2$$

For a consistent answer with units 1 point

$$\mathcal{E} = 6860 \text{ V}$$

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Question 3

15 points total **Distribution of points**

(a)

(i) 2 points

For ranking I_A as the greatest — 1 point

For ranking I_C as the second greatest and I_B as the third greatest — 1 point

(ii) 2 points

For a correct statement justifying that I_A is greatest. (For example: The total current flows through R_A and gets divided between the other two resistors.) — 1 point

For a correct statement justifying that I_C is second and I_B is third. (For example: R_B and R_C share the current in the parallel segment, and that current divides between R_B and R_C so that the smaller resistor R_C carries the most current.) — 1 point

(b)

(i) 1 point

For the correct ranking $V_A,\ V_B,\ V_C = 1,\ 2,\ 2$ — 1 point

(ii) 2 points

For a correct justification that V_A is the greatest. (For example, because no resistor is greater than R_A, and R_A has the full current through it. Or, because R_A is greater than the equivalent parallel resistance of R_B and R_C.) — 1 point

For a correct justification that $V_B = V_C$. (For example, since the voltage across the parallel resistors R_B and R_C is the same.) — 1 point

(c) 3 points

Let R_{BC} be the resistance of the parallel combination of R_B and R_C.

For one correct form for determining R_{BC} — 1 point

$$\frac{1}{R_{BC}} = \frac{1}{R_B} + \frac{1}{R_C} = \frac{1}{2R} + \frac{1}{R} = \frac{1}{400\ \Omega} + \frac{1}{200\ \Omega} = \frac{3}{400\ \Omega}$$

$$R_{BC} = \frac{2R}{3} = \frac{400\ \Omega}{3} = 133\ \Omega$$

For one correct form for determining the total resistance — 1 point

$$R_{tot} = R_A + R_{BC} = 2R + \frac{2R}{3} = 400\ \Omega + 133\ \Omega$$

For the correct numerical value — 1 point

$R_{tot} = 533\ \Omega$

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Question 3 (continued)

Distribution of points

(d) 3 points

For one correct form for the current I_A, using R_{tot} from part (c) 1 point

$$I_A = \frac{\mathcal{E}}{R_{tot}} = \frac{12\text{ V}}{533\ \Omega} = 0.0225\text{ A}$$

For the correct value of V_C 1 point

$$V_C = \mathcal{E} - V_A = \mathcal{E} - I_A R_A = 12\text{ V} - (0.0225\text{ A})(400\ \Omega) = 3.0\text{ V}$$

$$I_C = \frac{V_C}{R_C} = \frac{3\text{ V}}{200\ \Omega}$$

For the correct numerical value of I_C 1 point

$$I_C = 0.015\text{ A}$$

Alternate solution *Alternate points*

Using $R_B = 2R_C$ and $V_B = V_C$ so that $I_B R_B = I_C R_C$

$$I_C = \frac{R_B}{R_C} I_B = \frac{2R_C}{R_C} I_B = 2I_B$$

For the correct numerical value for I_{tot} *1 point*

$$I_{tot} = \mathcal{E}/R_{tot} = 0.0225\text{ A}$$

For correctly relating I_{tot} to I_C *1 point*

$$I_{tot} = I_B + I_C = \frac{I_C}{2} + I_C = \frac{3I_C}{2}$$

For the correct numerical value of I_C *1 point*

$$I_C = \frac{2I_{tot}}{3} = \frac{2}{3}(0.0225\text{ A}) = 0.015\text{ A}$$

(e) 2 points

In the new circuit, $I_B = 0$ at equilibrium, so the total current goes through each of the two resistors

$$I_{tot} = \frac{\mathcal{E}}{R_A + R_C} = \frac{\mathcal{E}}{2R + R} = \frac{\mathcal{E}}{3R} = \frac{12\text{ V}}{600\ \Omega} = 0.02\text{ A}$$

For the correct value of the voltage across the capacitor 1 point

$$V_C = I_{tot} R_C = (0.02\text{ A})(200\ \Omega) = 4.0\text{ V}$$

$$Q = CV_C$$

$$Q = \left(2.0 \times 10^{-6}\text{ F}\right)(4.0\text{ V})$$

For the correct numerical value of Q 1 point

$$Q = 8.0 \times 10^{-6}\text{ C}$$

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Question 4

10 points total **Distribution of points**

(a) 2 points

For any indication that the volume rate of flow is defined as volume/time 1 point
Define the symbol $\mathcal{V}$ for the volume flow rate

$\mathcal{V} = 7.2 \times 10^{-4}\ \text{m}^3/[(2.0\ \text{min})(60\ \text{s/min})]$

For the correct answer, including units 1 point

$\mathcal{V} = 6.0 \times 10^{-6}\ \text{m}^3/\text{s}$

(b) 2 points

For a correct relationship between volume flow rate, speed, and area 1 point

$\mathcal{V} = \upsilon A$

$\upsilon = \mathcal{V}/A$

$\upsilon = \left(6.0 \times 10^{-6}\ \text{m}^3/\text{s}\right)/\left(2.5 \times 10^{-6}\ \text{m}^2\right)$

For the correct answer, including units 1 point

$\upsilon = 2.4\ \text{m/s}$

Note: An attempt to use kinematics with the distance x and height d could earn a maximum of 1 point.

(c) 3 points

For applying Bernoulli's Equation, either to points at the top of the liquid and the hole or to points just inside and outside of the hole, and recognizing the specific conditions for one of the three variables (pressure, speed, or height) 1 point

For recognizing the conditions for the remaining two variables 1 point

Top and hole	Inside and outside
$P_t + \rho g y_t + \frac{1}{2}\rho \upsilon_t^2 = P_h + \rho g y_h + \frac{1}{2}\rho \upsilon_h^2$	$P_{\text{in}} + \rho g y_{\text{in}} + \frac{1}{2}\rho \upsilon_{\text{in}}^2 = P_{\text{out}} + \rho g y_{\text{out}} + \frac{1}{2}\rho \upsilon_{\text{out}}^2$
$P_t = P_h = P_{atm}$	$P_{\text{in}} = P_{atm} + \rho g h$, $P_{\text{out}} = P_{atm}$
$\upsilon_t = 0$	$\upsilon_{\text{in}} = 0$
$y_t = h$, $y_h = 0$	$y_{\text{in}} = y_{\text{out}} = 0$

Both cases simplify to the same equation, where υ_e is the exit speed

$\rho g h = \rho \upsilon_e^2/2$

$h = \upsilon_e^2/2g = (2.4\ \text{m/s})^2/2\left(9.8\ \text{m/s}^2\right)$

For the correct answer, including units 1 point

$h = 0.29\ \text{m}$

Notes: Solutions that begin with the equation $\rho g h = \rho \upsilon^2/2$ could earn 2 of the 3 points.

Solutions that begin with the equation $mgh = m\upsilon^2/2$ could earn 1 of the 3 points.

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Question 4 (continued)

Distribution of points

(c) (continued)

Alternate solution 1 — *Alternate points*

For explicitly stating by name that Torricelli's theorem applies — *1 point*

For writing the correct expression for the theorem — *1 point*

$v = \sqrt{2gh}$

$$h = \frac{v^2}{2g} = \frac{(2.4\ \text{m/s})^2}{2(9.8\ \text{m/s}^2)}$$

For the correct answer, including units — *1 point*

$h = 0.29$ m

Alternate solution 2 — *Alternate points*

For relating the pressure difference across the hole to the acceleration of the liquid through the hole — *1 point*

$F = ma = \Delta P\, A$

$\Delta P = \rho gh$

$a = \rho ghA/m = ghA/V$ *, where V is the volume of the hole*

For applying an appropriate kinematics equation and substituting the expression for acceleration — *1 point*

$v^2 = v_0^2 + 2a\ell$ *, where* $v_0 = 0$ *and* ℓ *is the thickness of the container wall*

$v^2 = 2(ghA/V)\ell = 2gh$

$$h = \frac{v^2}{2g} = \frac{(2.4\ \text{m/s})^2}{2(9.8\ \text{m/s}^2)}$$

For the correct answer, including units — *1 point*

$h = 0.29$ m

(d) 3 points

For correctly indicating that the liquid will hit to the left of the beaker — 1 point

For an explanation that relates the decrease in water height to a decrease in the pressure at the hole and a decrease in velocity exiting the hole — 2 points

Other explanations, such as relating force and acceleration at the hole, describing changes in potential and kinetic energy, or using a relationship from part (c), could earn full credit.

Note: In the exam booklets, the container was erroneously referred to as the beaker in this part. Answers indicating that the liquid would hit to the right of the beaker received full credit if there was an explanation indicating that the student was now using the container as the reference object.

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AP® PHYSICS B
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Question 5

10 points total **Distribution of points**

(a) 2 points

Using the relationship between pressure and force
$P = F/A$

For correctly determining the area of the piston 1 point

$A = \pi R^2 = \pi(0.20 \text{ m}/2)^2$

$F = P_{abs}A = P_{abs}\pi R^2$

For correct substitution of values for pressure and area (or for correct answer in the absence of explicitly showing the substitution) 1 point

$F = \left(4.0 \times 10^5 \text{ Pa}\right)\pi(0.20 \text{ m}/2)^2$

$F = 1.3 \times 10^4 \text{ N}$

(b) 2 points

Using the ideal gas law
$PV = nRT$

$V = \dfrac{nRT}{P}$

For correct substitution of at least three numerical values 1 point

$V = \dfrac{(2.0 \text{ mol})(8.31 \text{ J/mol}\cdot\text{K})(300 \text{ K})}{4.0 \times 10^5 \text{ Pa}}$

For the correct answer 1 point

$V = 1.2 \times 10^{-2} \text{ m}^3$

(c) 2 points

Using the expression for the work done <u>on</u> the gas
$W_{\text{on}} = -P\Delta V$

The work done <u>by</u> the gas has the opposite sign
$W_{\text{by}} = P_{abs}\,\Delta V$

For a correct expression for the change in volume 1 point

$\Delta V = Ax = \pi R^2 x$

$W_{\text{by}} = P_{abs}\pi R^2 x$

For substituting the correct pressure and a change in volume 1 point

$W_{\text{by}} = \left(4.0 \times 10^5 \text{ Pa}\right)\pi(0.20 \text{ m}/2)^2(0.15 \text{ m})$

$W_{\text{by}} = 1.9 \times 10^3 \text{ J}$

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Question 5 (continued)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

$W = Fx$

For substituting the value of force from part (a) — *1 point*

For substituting the correct value for the distance — *1 point*

$W = \left(1.3 \times 10^4 \text{ N}\right)(0.15 \text{ m})$

$W = 1.9 \times 10^3 \text{ J}$

Note: *One point was deducted for any indication that the final value of the work done by the gas is negative.*

(d) 3 points

For correctly indicating that heat is transferred to the gas. — 1 point

For any indication that because the expansion occurs under constant pressure, the temperature or internal energy of the gas increases. — 1 point

For correctly applying the first law of thermodynamics to explain why heat is transferred to the gas. For example: Since the internal energy goes up while the gas loses energy by doing work, heat must be added. — 1 point

Units point

For including correct units in at least two of the answers in (a) through (c) — 1 point

Note: *If a substitution was made using a value with units other than those given in the problem or in the Table of Information, the units used had to be explicitly stated. An exception was part (b), where the commonly used values of pressure in atmospheres and R in* $(liter)(atmospheres)/(moles)(K)$ *were acceptable.*

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AP® PHYSICS B
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Question 6

10 points total **Distribution of points**

(a) 2 points

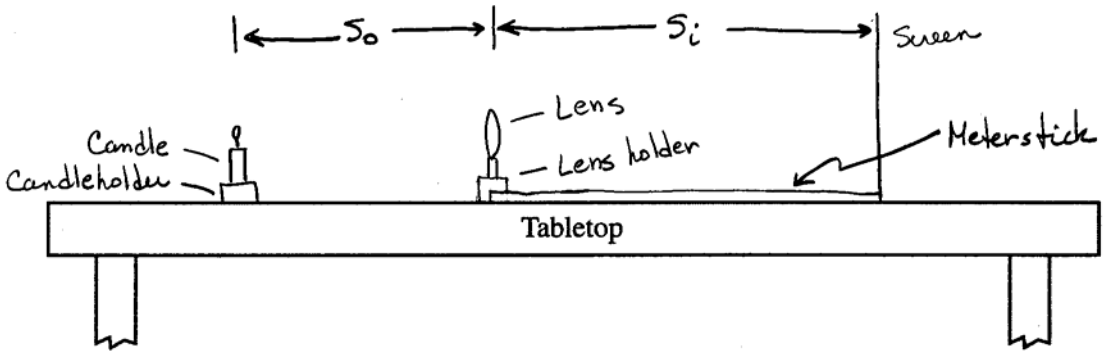
For a clear and complete method of <u>estimating</u> the focal length by focusing the image of the tree on a screen <u>and</u> stating that the distance between the image and the lens is the focal length — 2 points

<u>Partial credit:</u>

1 point only was awarded if the method above was incomplete.

1 point only was awarded if the distances s_o (tree to lens) and s_i (lens to image) were measured or estimated, and then the numbers were used in the thin lens equation to <u>calculate</u> the focal length.

(b) and (c) 3 points



For showing a functional setup involving an object, the lens, and a screen — 1 point

For having the lens and the distances s_o and s_i labeled correctly on the diagram — 1 point

For labeling on the diagram all the equipment checked in (b) (must have a functional setup to earn this point) — 1 point

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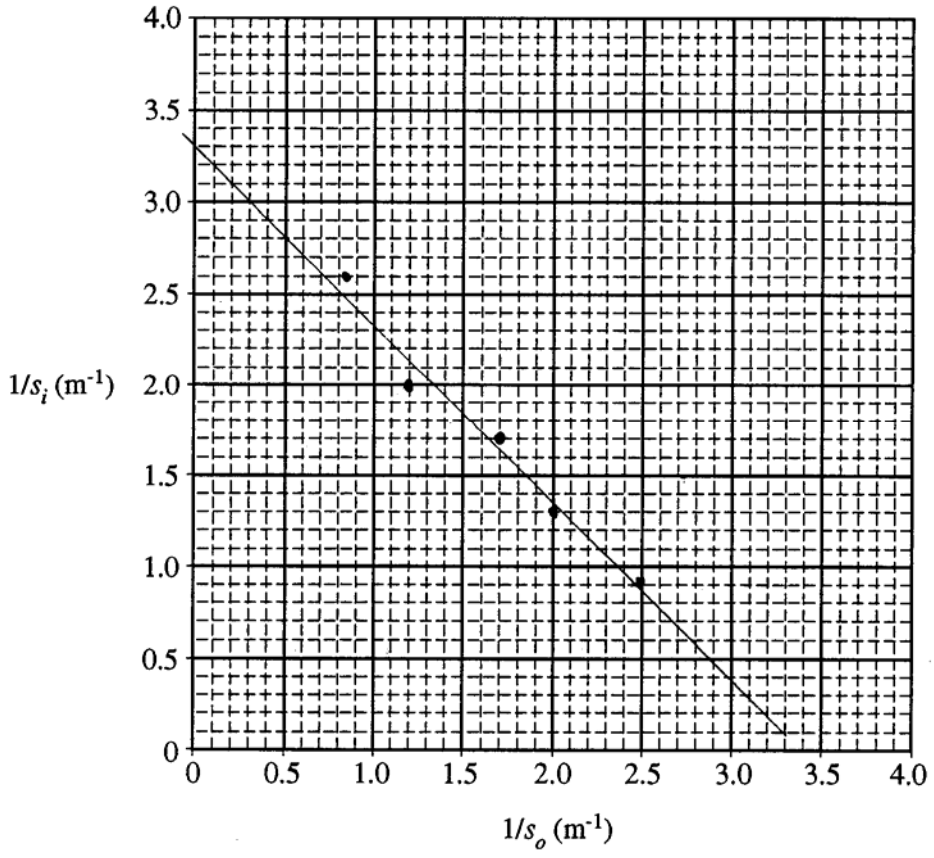
Question 6 (continued)

Distribution of points

(d) 2 points



For all data points from the table plotted correctly — 1 point

For a best-fit straight line (i.e., two points above and two points below the line and/or intercepts on axes close to $3.35\ \text{m}^{-1}$) — 1 point

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Question 6 (continued)

Distribution of points

(e) 3 points

For a clear and accurate solution with the correct answer in the range 0.28 m to 0.32 m with units (The two most common approaches to doing this are illustrated below.) 3 points

Approach 1:
Pick a point on the best-fit line (not a data point)
For example, for the graph shown in part (d), one point on the line is (1.0, 2.3).

$\frac{1}{s_o} = 1.0\ \text{m}^{-1}$, $\frac{1}{s_i} = 2.3\ \text{m}^{-1}$

$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o} = 1.0\ \text{m}^{-1} + 2.3\ \text{m}^{-1} = 3.3\ \text{m}^{-1}$

$f = \frac{1}{3.3\ \text{m}^{-1}}$

$f = 0.30\ \text{m}$

Approach 2:

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$

$\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$

So $\frac{1}{f}$ is the *y* intercept of a graph of $\frac{1}{s_i}$ versus $\frac{1}{s_o}$

For example, for the graph shown in part (d) the *y* intercept is $3.3\ \text{m}^{-1}$

So $\frac{1}{f} = 3.3\ \text{m}^{-1}$

$f = \frac{1}{3.3\ \text{m}^{-1}}$

$f = 0.30\ \text{m}$

Partial credit:

2 points only were awarded for a mostly complete solution where either units were missing or it was unclear that the best-fit line was used (e.g., not using numbers from the best-fit line if Approach 1 was used, or not showing the idea of using the intercept if Approach 2 was used).

1 point only was awarded either for a correct answer with units where it was not clear how the answer was obtained, or for using the lens equation with data from the line where there was no final answer.

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AP® PHYSICS B
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Question 7

Distribution of points

(a) 3 points

Using the relationship between mass and energy

$E = m_e c^2$

For correct substitutions of the positron mass and the speed of light — 1 point

For the correct value of energy in joules — 1 point

$E = \left(9.11 \times 10^{-31}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2 = 8.20 \times 10^{-14}\ \text{J}$

For using the correct factor to convert from joules to eVs — 1 point

$E = 8.20 \times 10^{-14}\ \text{J} / 1.60 \times 10^{-19}\ \text{J/eV}$

$E = 5.12 \times 10^{5}\ \text{eV}$

(b) 1 point

Since the electron and positron have the same mass, the energy before annihilation is twice the value found in part (a). That energy goes into creating the two photons of equal energy, so each photon has the energy equivalent of one of the particles.

For any indication that this is the same numerical answer as in part (a) — 1 point

$E_\gamma = 5.12 \times 10^{5}\ \text{eV}$

Note: Full credit was earned if the student's answer to part (a) was zero and the correct calculation shown for part (a) was done here.

(c) 3 points

For a correct equation relating energy and wavelength — 1 point

$E_\gamma = hf = \dfrac{hc}{\lambda}$

For substituting the value of energy from part (b), either in eV or joules — 1 point

For substituting a value of *h* or *hc* in units that are consistent with those of the energy used — 1 point

$\lambda = hc / E_\gamma = \left(1.24 \times 10^{3}\ \text{eV} \cdot \text{nm}\right) / \left(5.12 \times 10^{5}\ \text{eV}\right)$

$\lambda = 2.42 \times 10^{-3}\ \text{nm} = 2.42 \times 10^{-12}\ \text{m}$

Alternate solution — *Alternate points*

Using the relationship between wavelength and momentum

$\lambda = h / p$

For substituting values for h and p (but not earned if $p = mv$ was used) — *1 point*

For using the value of p from part (d) — *1 point*

For substituting a value of h in units that are consistent with those of the momentum used — *1 point*

$\lambda = \left(6.63 \times 10^{-34}\ \text{J} \cdot \text{s}\right) / \left(2.73 \times 10^{-22}\ \text{kg} \cdot \text{m/s}\right)$

$\lambda = 2.42 \times 10^{-3}\ \text{nm} = 2.42 \times 10^{-12}\ \text{m}$

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Question 7 (continued)

Distribution of points

(d) 2 points

$\lambda = h/p$

For correct substitutions, using the value of λ determined in (c) 1 point

$p = h/\lambda = \dfrac{6.63 \times 10^{-34}\ \text{J•s}}{2.42 \times 10^{-12}\ \text{m}}$ or $\dfrac{4.14 \times 10^{-5}\ \text{eV•s}}{2.42 \times 10^{-12}\ \text{m}}$

For correct units in the final answer 1 point

$p = 2.74 \times 10^{-22}\ \text{kg•m/s}$ (or N•s or J•s/m) or $0.0017\ \text{eV•s/m}$

Alternate solution *Alternate points*

$E = pc$

For substituting the value of energy from part (b) *1 point*

$p = \dfrac{E}{c} = \dfrac{\left(8.20 \times 10^{-14}\ \text{J}\right)}{3.00 \times 10^{8}\ \text{m/s}}$ *OR* $\dfrac{\left(5.12 \times 10^{5}\ \text{eV}\right)}{3.00 \times 10^{8}\ \text{m/s}}$

For correct units in the final answer *1 point*

$p = 2.73 \times 10^{-22}\ \text{kg•m/s}$ (or N•s or J•s/m) or $0.0017\ \text{eV•s/m}$

(e) 1 point

For indicating that the total momentum is zero 1 point

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AP® Physics B
2007 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Electron charge magnitude,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol•K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^{8}\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J•s}$
	$= 4.14 \times 10^{-15}\ \text{eV•s}$
	$hc = 1.99 \times 10^{-25}\ \text{J•m}$
	$= 1.24 \times 10^{3}\ \text{eV•nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N•m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N•m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ \text{(T•m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ \text{(T·m)/A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg•s}^2$
Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2$
	$= 1.0 \times 10^{5}\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon\cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

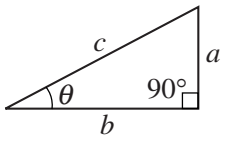
$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

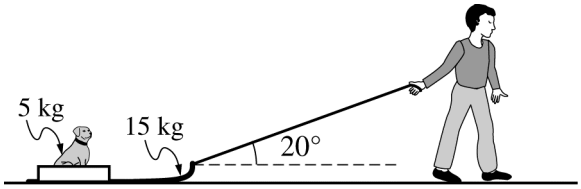
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1 and 3 and about 11 minutes for answering each of Questions 2 and 4-7. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

A child pulls a 15 kg sled containing a 5.0 kg dog along a straight path on a horizontal surface. He exerts a force of 55 N on the sled at an angle of 20º above the horizontal, as shown in the figure above. The coefficient of friction between the sled and the surface is 0.22.

(a) On the dot below that represents the sled-dog system, draw and label a free-body diagram for the system as it is pulled along the surface.

●

(b) Calculate the normal force of the surface on the system.

(c) Calculate the acceleration of the system.

(d) Calculate the work done by the child's pulling force as the system moves a distance of 7.0 m.

(e) At some later time, the dog rolls off the side of the sled. The child continues to pull with the same force. On the axes below, sketch a graph of speed v versus time t for the sled. Include both the sled's travel with and without the dog on the sled. Clearly indicate with the symbol t_r the time at which the dog rolls off.



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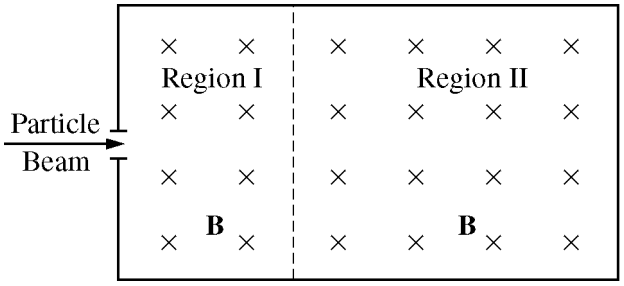


2. (10 points)

A beam of particles of charge $q = +3.2 \times 10^{-19}$ C and mass $m = 6.68 \times 10^{-26}$ kg enters region I with a range of velocities all in the direction shown in the diagram above. There is a magnetic field in region I directed into the page with magnitude $B = 0.12$ T. Charged metal plates are placed in appropriate locations to create a uniform electric field of magnitude $E = 4800$ N/C in region I. As a result, some of the charged particles pass straight through region I undeflected. Gravitational effects are negligible.

(a)

i. On the diagram above, sketch electric field lines in region I.

ii. Calculate the speed of the particles that pass straight through region I.

The particles that pass straight through enter region II in which there is no electric field and the magnetic field has the same magnitude and direction as in region I. The path of the particles in region II is a circular arc of radius R.

(b) Calculate the radius R.

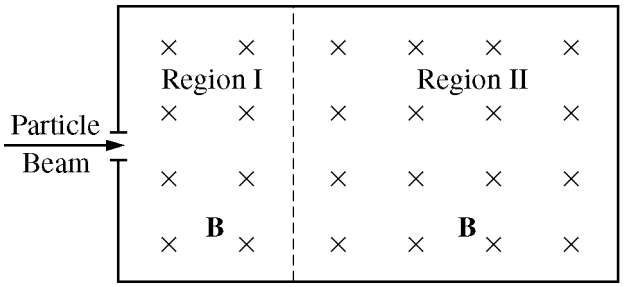
(c) Within the beam there are particles moving slower than the speed you calculated in (a)ii. In what direction is the net initial force on these particles as they enter region I?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page

____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

Justify your answer.

(d) A particle of the same mass and the same speed as in (a)ii but with charge $q = -3.2 \times 10^{-19}$ C enters region I. On the following diagram, sketch the complete resulting path of the particle.



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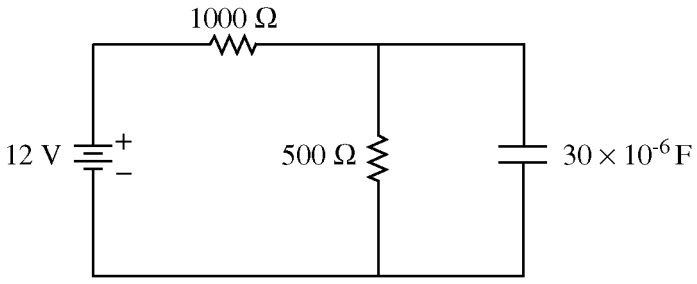

3. (15 points)

In the circuit above, a 12.0 V battery is connected to two resistors, one of resistance 1000 Ω and the other of resistance 500 Ω. A capacitor with a capacitance of 30×10^{-6} F is connected in parallel with the 500 Ω resistor. The circuit has been connected for a long time, and all currents have reached their steady states.

(a) Calculate the current in the 500 Ω resistor.

(b)

i. Draw an ammeter in the circuit above in a location such that it could measure the current in the 500 Ω resistor. Use the symbol Ⓐ to indicate the ammeter.

ii. Draw a voltmeter in the circuit above in a location such that it could measure the voltage across the 1000 Ω resistor. Use the symbol Ⓥ to indicate the voltmeter.

(c) Calculate the charge stored on the capacitor.

(d) Calculate the power dissipated in the 1000 Ω resistor.

(e) The capacitor is now discharged, and the 500 Ω resistor is removed and replaced by a resistor of greater resistance. The circuit is reconnected, and currents are again allowed to come to their steady-state values. Is the charge now stored on the capacitor larger, smaller, or the same as it was in part (c)?

____ Larger ____ Smaller ____ The same as

Justify your answer.

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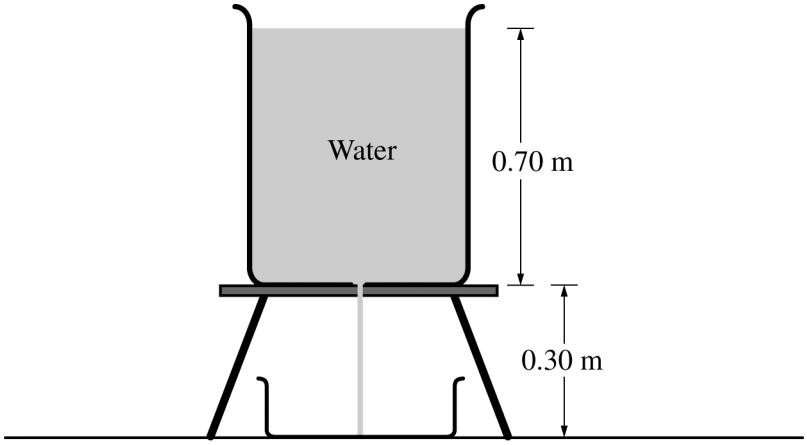

4. (10 points)

A cylindrical tank containing water of density 1000 kg/m^3 is filled to a height of 0.70 m and placed on a stand as shown in the cross section above. A hole of radius 0.0010 m in the bottom of the tank is opened. Water then flows through the hole and through an opening in the stand and is collected in a tray 0.30 m below the hole. At the same time, water is added to the tank at an appropriate rate so that the water level in the tank remains constant.

(a) Calculate the speed at which the water flows out from the hole.

(b) Calculate the volume rate at which water flows out from the hole.

(c) Calculate the volume of water collected in the tray in t = 2.0 minutes.

(d) Calculate the time it takes for a given droplet of water to fall 0.25 m from the hole.

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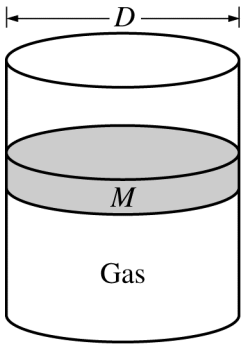

5. (10 points)

The cylinder above contains an ideal gas and has a movable, frictionless piston of diameter *D* and mass *M*. The cylinder is in a laboratory with atmospheric pressure P_{atm}. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Initially, the piston is free to move but remains in equilibrium. Determine each of the following.

i. The force that the confined gas exerts on the piston

ii. The absolute pressure of the confined gas

(b) If a net amount of heat is transferred to the confined gas when the piston is fixed, what happens to the pressure of the gas?

____ Pressure goes up. ____ Pressure goes down. ____ Pressure stays the same.

Explain your reasoning.

(c) In a certain process the absolute pressure of the confined gas remains constant as the piston moves up a distance x_0. Calculate the work done by the confined gas during the process.

6. (10 points)

A student is asked to determine the index of refraction of a glass slab. She conducts several trials for measurement of angle of incidence θ_a in the air versus angle of refraction θ_g in the glass at the surface of the slab. She records her data in the following table. The index of refraction in air is 1.0.

Trial #	θ_g (degrees)	θ_a (degrees)	Sin θ_g	Sin θ_a
1	5.0	8.0	0.09	0.14
2	15	21	0.26	0.36
3	25	39	0.42	0.63
4	35	56	0.57	0.83

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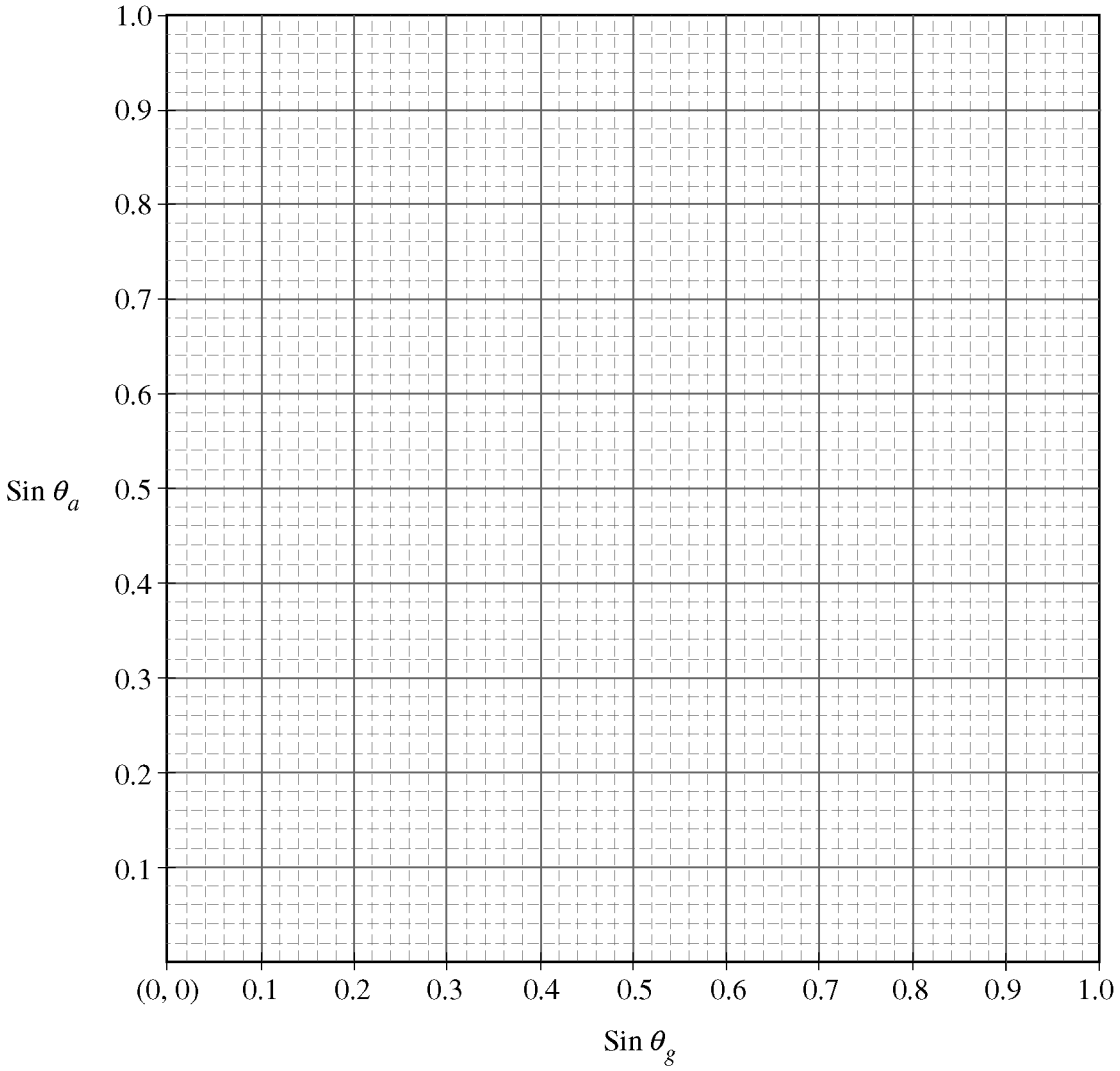
(a) Plot the data points on the axes below and draw a best-fit line through the points.



(b) Calculate the index of refraction of the glass slab from your best-fit line.

(c) Describe how you could use the graph to determine the critical angle for the glass-air interface. Do not use the answer to the part (b) for this purpose.

(d) On the graph in (a), sketch and label a line for a material of higher index of refraction.

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7. (10 points)

In the vicinity of a heavy nucleus, a high-energy photon can be converted into two particles: an electron and a positron. A positron has the same mass as the electron and equal but opposite charge. This process is called pair production.

(a) Calculate the rest energy of an electron, in eV.

(b) Determine the minimum energy, in eV, that a photon must have to give rise to pair production.

(c) Calculate the wavelength corresponding to the photon energy found in part (b).

(d) Calculate the momentum of the photon.

END OF EXAM

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AP® Physics B
2007 Scoring Guidelines
Form B

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AP® PHYSICS B (Form B)
2007 SCORING GUIDELINES

General Notes About 2007 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive and expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description* .

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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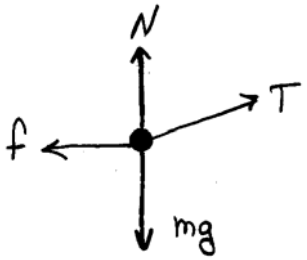
Question 1

15 points total **Distribution of points**

(a) 4 points



For each of the forces above with arrow correctly drawn and labeled, 1 point was awarded 4 points

Notes:
The force vector T could be shown in component form or as one force, but not both.
For extraneous forces, 1 point was deducted.

(b) 4 points

$\sum F_y = 0$

$N + T\sin\theta - mg = 0$

For a correct force equation 1 point

$N = mg - T\sin\theta$

For calculating the mg term correctly 1 point

For calculating the $T\sin\theta$ term correctly 1 point

$N = (15\text{ kg} + 5\text{ kg})\left(9.8\text{ m/s}^2\right) - (55\text{ N})\sin 20°$

For the correct numerical answer with units 1 point

$N = 177$ N (181 N if $g = 10\text{ m/s}^2$ is used)

(c) 3 points

$\sum F_x = ma$

For a correct Newton's second law equation involving horizontal forces 1 point

$T\cos\theta - f = ma$

$a = \dfrac{T\cos\theta - f}{m}$

For the correct relationship between the frictional and normal forces 1 point

$f = \mu N$

For correct calculation of the frictional force using the value of N from part (b) 1 point

$f = (0.22)(177\text{ N}) = 38.9\text{ N}$ (39.8 N if $g = 10\text{ m/s}^2$ is used)

$a = \dfrac{(55\text{ N})\cos 20° - 38.9\text{ N}}{20\text{ kg}}$

$a = 0.64\text{ m/s}^2$ (0.59 m/s^2 if $g = 10\text{ m/s}^2$ is used)

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Question 1 (continued)

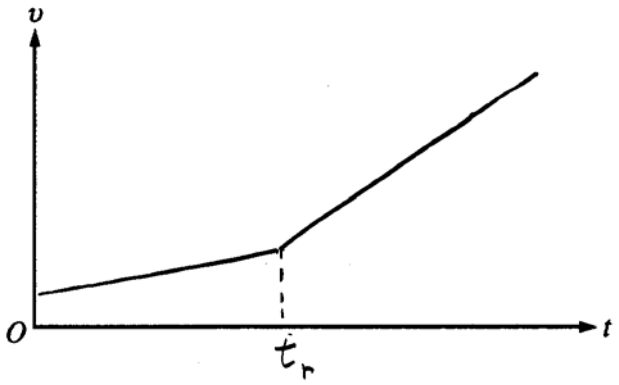
Distribution of points

(d) 2 points

For the correct work equation $W = (T\cos\theta)d$ — 1 point

For substituting the correct displacement
$W = (55\text{ N})\cos 20°(7.0\text{ m})$
$W = 360\text{ J}$ — 1 point

(e) 2 points



For each section of the graph correctly drawn as above, 1 point was awarded. — 2 points

Note: The second point was awarded only if the change at t_r was abrupt.

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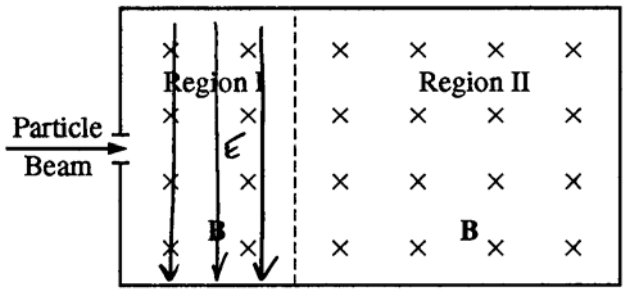
Question 2

10 points total **Distribution of points**

(a)

(i) 2 points



For at least two correct electric field lines in the right directions 1 point
For the lines going through the entire Region I from top to bottom 1 point
Note: A single line going from top to bottom could earn a maximum of 1 point.

(ii) 2 points

For either of the first two equations below 1 point

$qvB = qE$

$v = E/B$

$v = (4800\ \text{N/C})/(0.12\ \text{T})$

$v = 4.0 \times 10^4\ \text{m/s}$

For the correct answer with units 1 point

(b) 2 points

$qvB = \frac{mv^2}{r}$

For the correct equation for the radius 1 point

$r = \frac{mv}{qB}$

For correct substitutions consistent with the answer to (a)(ii) 1 point

$r = \frac{\left(6.68 \times 10^{-26}\ \text{kg}\right)\left(4.0 \times 10^4\ \text{m/s}\right)}{\left(3.2 \times 10^{-19}\ \text{C}\right)(0.12\ \text{T})}$

$r = 0.070\ \text{m}$

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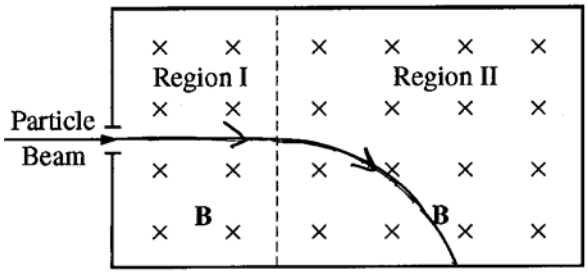
Question 2 (continued)

Distribution of points

(c) 2 points

For indicating that the initial force is "Toward the bottom of the page" 1 point
For a correct justification indicating that the magnetic force ($F_B = qvB$) decreases as velocity decreases, while the electric force ($F_E = qE$) remains the same, so $F_E > F_B$. 1 point

(d) 2 points



For the path in Region I being straight and horizontal 1 point
For the path in Region II being a circular arc, curving downward 1 point

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Question 3

15 points total **Distribution of points**

(a) 3 points

For a statement of Ohm's law, recognizing that $I_C = 0$ 1 point

$V = IR$

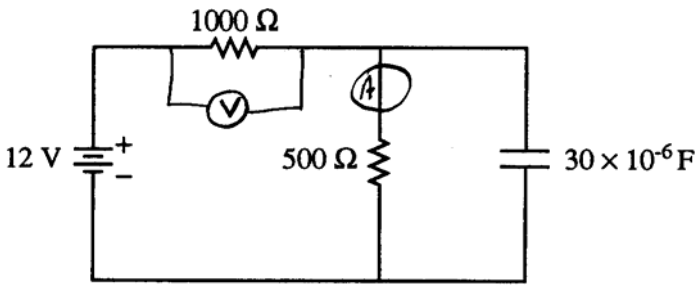
For the calculation of the total resistance 1 point

$R_{\text{total}} = 1000\ \Omega + 500\ \Omega = 1500\ \Omega$

For the correct answer, including units 1 point

$I = \dfrac{12\ \text{V}}{1500\ \Omega} = 8.0 \times 10^{-3}\ \text{A}$

(b)



(i) 2 points

For the ammeter in series anywhere in the circuit except the capacitor branch 2 points

(ii) 2 points

For the voltmeter in parallel across the $1000\ \Omega$ resistor 2 points

(c) 3 points

For a correct equation relating the charge, voltage, and capacitance 1 point

$Q = CV_C$ or $C = \dfrac{Q}{V_C}$

For recognizing that the voltage drop across the capacitor is the same as the voltage drop across the $500\ \Omega$ resistor 1 point

$V_C = IR_{500} = \left(8.0 \times 10^{-3}\ \text{A}\right)(500\ \Omega) = 4.0\ \text{V}$

For the correct answer with the correct units 1 point

$Q = \left(30 \times 10^{-6}\ \text{F}\right)(4.0\ \text{V})$

$Q = 1.2 \times 10^{-4}\ \text{C}$

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Question 3 (continued)

Distribution of points

(d) 2 points

For a correct equation for the power dissipated 1 point

$P = I^2R_{1000}$ or $V_{1000}I$ or $\frac{V_{1000}^2}{R_{1000}}$

Calculation for the second two relationships

$V_{1000} = IR_{1000} = \left(8.0 \times 10^{-3}\ \text{A}\right)(1000\ \Omega) = 8.0\ \text{V}$

For the correct substitutions 1 point

$P = \left(8.0 \times 10^{-3}\ \text{A}\right)^2(1000\ \Omega)$ or $(8.0\ \text{V})\left(8.0 \times 10^{-3}\ \text{A}\right)$ or $\frac{(8.0\ \text{V})^2}{1000\ \Omega}$

$P = 6.4 \times 10^{-2}\ \text{W}$

(e) 3 points

For choosing "Larger" 1 point

For correct justification in words or with numerical example. For example: 2 points

"Replacing the $500\ \Omega$ resistor with a larger resistor lowers the steady state current, causing the voltage across the $1000\ \Omega$ resistor to decrease and the voltage across the replacement resistor to increase." (1 point)

"The capacitor is in parallel with the replacement resistor, and so its voltage increases and therefore its charge increases since $Q = CV$." (1 point)

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Question 4

10 points total **Distribution of points**

(a) 3 points

Applying Bernoulli's equation
For example, taking point 1 to be at the top of the liquid and point 2 at the hole

$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

$$P_1 = P_2 = P_{atm}$$

$$v_1 = 0$$

$$\rho g(y_1 - y_2) = \frac{1}{2}\rho v_2^2$$

For a correct expression for the speed 1 point

$$v_2 = \sqrt{2g(y_1 - y_2)}$$

For correct substitutions 1 point

$$v_2 = \sqrt{2\left(9.8 \text{ m/s}^2\right)(0.70 \text{ m})}$$

For the correct answer, including units 1 point

$$v_2 = 3.7 \text{ m/s}$$

(b) 2 points

For any indication that the volume rate of flow is the area multiplied by the speed 1 point
Define the symbol $\mathcal{V}$ for the volume flow rate.

$$\mathcal{V} = vA$$

For correct substitutions 1 point

$$\mathcal{V} = (3.7 \text{ m})\pi(0.0010 \text{ m})^2$$

$$\mathcal{V} = 1.2 \times 10^{-5} \text{ m}^3/\text{s}$$

(c) 2 points

For any indication that the volume is the volume rate multiplied by the time 1 point

$$V = \mathcal{V}t$$

For correct substitutions 1 point

$$V = \left(1.2 \times 10^{-5} \text{ m}^3/\text{s}\right)(2 \text{ min})(60 \text{ s/min})$$

$$V = 1.4 \times 10^{-3} \text{ m}^3$$

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Question 4 (continued)

Distribution of points

(d) 3 points

For using the kinematic equation for distance as a function of time — 1 point

$y = y_0 + v_0 t + \frac{1}{2}at^2$

Taking down as the positive direction, and using $a = g$ and $y = h$

$\frac{1}{2}gt^2 + v_0 t - h = 0$

For solving the equation for t using the quadratic formula — 1 point

$t = \frac{-v_0 \pm \sqrt{{v_0}^2 + 2gh}}{g}$

For correct substitutions — 1 point

Using the + sign to avoid negative time

$t = \frac{-3.7 \text{ m/s} + \sqrt{(3.7 \text{ m/s})^2 + 2\left(9.8 \text{ m/s}^2\right)(0.25 \text{ m})}}{9.8 \text{ m/s}^2}$

$t = 0.062$ s

Alternate solution — *Alternate points*

For using the kinematic equation relating speed, acceleration, and distance — *1 point*

$v^2 = v_0^2 + 2a(x - x_0)$

For using the kinematic equation for speed as a function of time — *1 point*

$v = v_0 + at$

$t = \frac{v - v_0}{a}$

Substituting for v from the initial equation into the above equation for t

$t = \frac{\sqrt{v_0^2 + 2a(x - x_0)} - v_0}{a}$

For correct substitutions — *1 point*

$t = \frac{\sqrt{(3.7 \text{ m/s})^2 + 2\left(9.8 \text{ m/s}^2\right)(0.25 \text{ m})} - 3.7 \text{ m/s}}{9.8 \text{ m/s}^2}$

$t = 0.062$ s

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Question 5

10 points total **Distribution of points**

(a)

(i) 3 points

For recognition that one component of the force is $P_{atm}A$ 1 point

For recognition that another component of the force is Mg 1 point

$F = P_{atm}A + Mg$

For $A = \pi\left(\frac{D}{2}\right)^2 = \frac{\pi D^2}{4}$ 1 point

$F = \frac{P_{atm}\pi D^2}{4} + Mg$

(ii) 1 point

For $P = \frac{F}{A}$, with answer to (a) substituted for F 1 point

$P_{abs} = \frac{\frac{P_{atm}\pi D^2}{4} + Mg}{\frac{\pi D^2}{4}}$

$P_{abs} = P_{atm} + \frac{4Mg}{\pi D^2}$

(b) 3 points

For checking the "Pressure goes up" answer space 1 point

For a correct and complete justification, 2 points were awarded, with partial credit given where appropriate

Example:

For indicating that if heat is added, then the temperature must increase, recognizing that the volume is constant 1 point

For then using the ideal gas law to show that with the volume constant, an increase in temperature implies an increase in pressure 1 point

Alternate example *Alternate points*

For indicating that if heat is added, then the internal energy and thus the kinetic energy of the gas molecules must increase, recognizing that the volume is constant *1 point*

For then indicating that as the kinetic energy of the gas molecules increase, they exert more force on the walls of the cylinder, thus increasing the pressure *1 point*

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Question 5 (continued)

Distribution of points

(c) 3 points

For correct equation for work in terms of force and distance — 1 point

$W = Fx$

For correct substitution of x_0 for x — 1 point

$W = Fx_0$

For substitution of force from part (a)(i) — 1 point

$$W = \left(\frac{P_{atm}\pi D^2}{4} + Mg\right)x_0$$

Alternate solution — *Alternate points*

For correct equation for work in terms of pressure and volume change — *1 point*

$W = P_{abs}\,\Delta V$

For correct expression for ΔV — *1 point*

$$\Delta V = x_0 A = x_0 \frac{\pi D^2}{4}$$

$$W = P_{abs}x_0\left(\frac{\pi D^2}{4}\right)$$

For substitution of absolute pressure from part (a)(ii) — *1 point*

$$W = \left(P_{atm} + \frac{4Mg}{\pi D^2}\right)x_0\left(\frac{\pi D^2}{4}\right)$$

$$W = \left(\frac{P_{atm}\pi D^2}{4} + Mg\right)x_0$$

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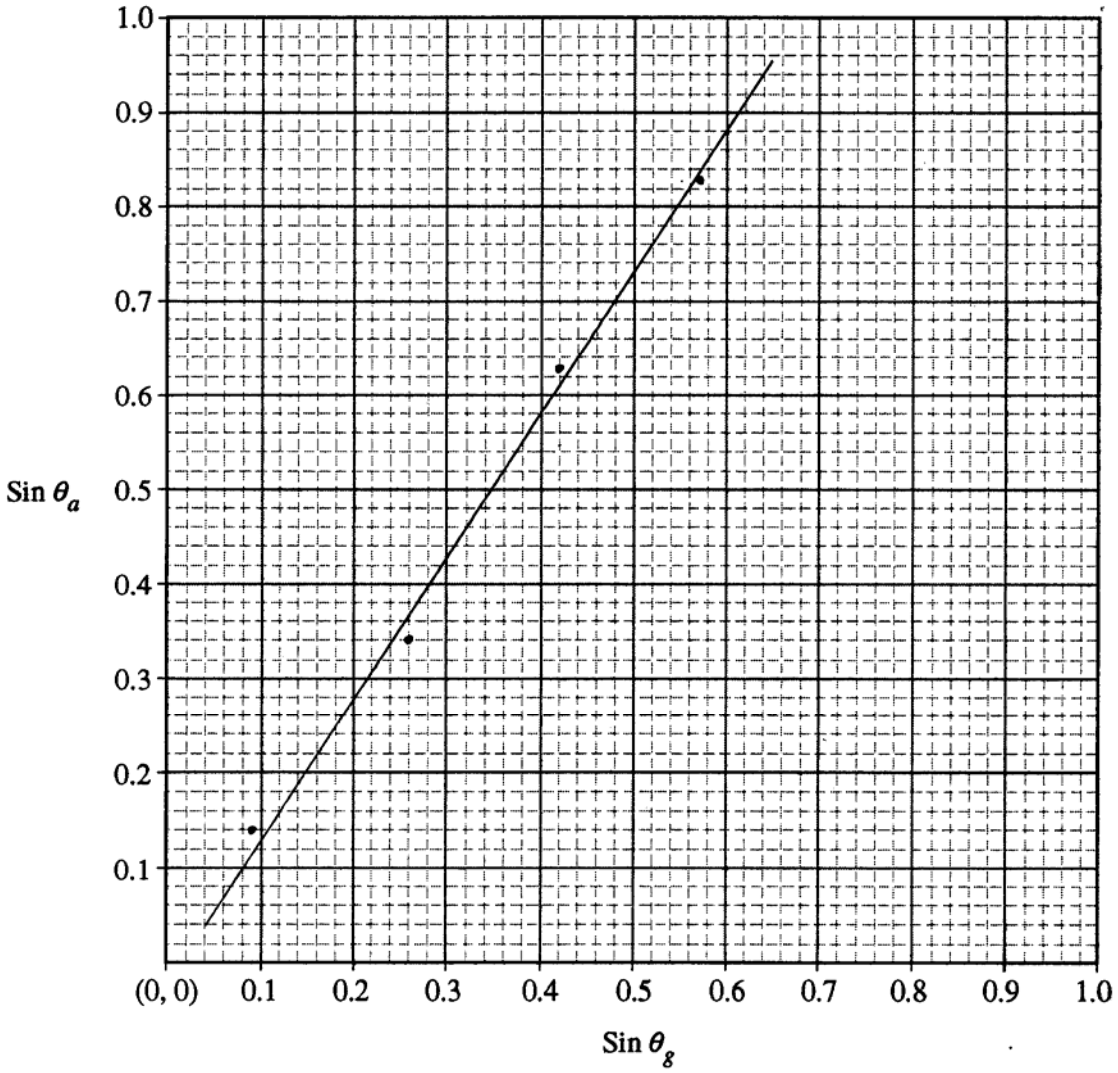
AP® PHYSICS B
2007 SCORING GUIDELINES (Form B)

Question 6

10 points total **Distribution of points**

(a) 3 points



For at least three data points plotted correctly	1 point
For a straight line drawn	1 point
For the line being a "best fit" to the data points (with equal number of points above and below the line)	1 point

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Question 6 (continued)

Distribution of points

(b) 3 points

$n_a \sin\theta_a = n_g \sin\theta_g$

$n_a = 1$

For recognizing that n_g is the slope of the graph of $\sin\theta_a$ versus $\sin\theta_g$. 1 point

$\sin\theta_a = n_g \sin\theta_g$

For using at least two widely separated points on the best-fit line (not two data points) 1 point
For example, selecting two points on the line in the graph above, such as (0.08,0.10) and (0.60,0.88)

Slope = $\frac{\Delta y}{\Delta x} = \frac{0.88 - 0.10}{0.60 - 0.08} = 1.5$

For the correct slope value, hence the value for n_g 1 point

$n_g = 1.5$

(c) 2 points

The critical angle θ_c is equal to θ_g when $\sin\theta_a = 1$

For extending the best-fit line to the point at the top of the graph where $\sin\theta_a = 1$ 1 point

For indicating that $\theta_c = \sin^{-1}(\sin\theta_g)$ at this point. (*Note: To earn this point it was not required to calculate the actual value for θ_c.*) 1 point

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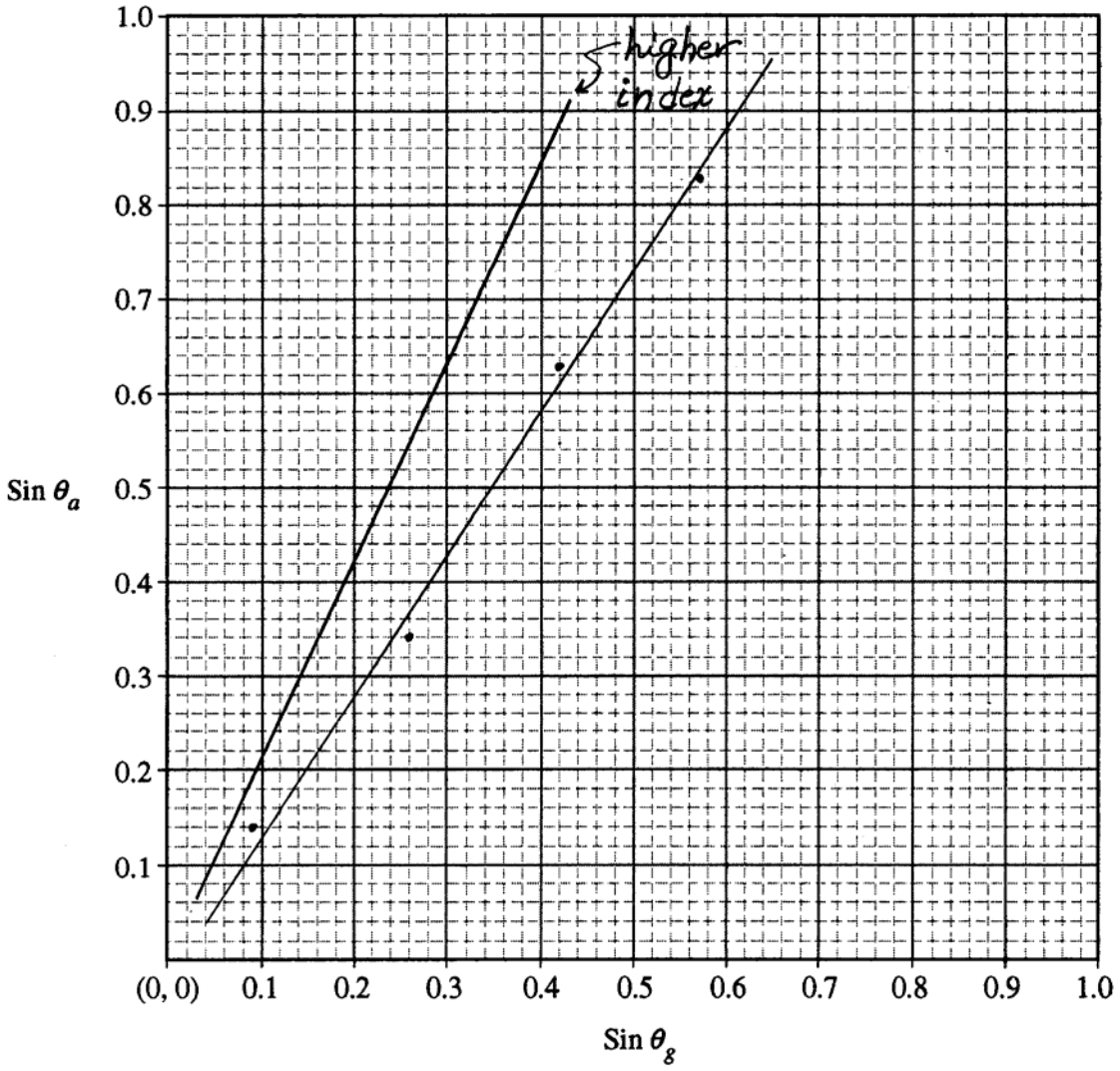
Question 6 (continued)

Distribution of points

(d) 2 points



For a line with a slope greater than the best-fit line of part (a) 1 point
For the line intercepting the origin (0,0) 1 point

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Question 7

10 points total **Distribution of points**

(a) 3 points

For using the correct equation for energy 1 point

$E_e = m_e c^2$

For a correct calculation of the energy in joules 1 point

$E_e = \left(9.11 \times 10^{-31}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2 = 8.20 \times 10^{-14}\ \text{J}$

$E_e = \left(8.20 \times 10^{-14}\ \text{J}\right)/\left(1.60 \times 10^{-19}\ \text{J/eV}\right)$

For the correct answer in eV as instructed in the question 1 point

$E_e = 5.12 \times 10^{5}\ \text{eV}$ (answers in keV and MeV also accepted)

(b) 2 points

For recognizing that the photon energy must be twice that of one of the particles 1 point

$E_\gamma = 2E_e$

For substituting the value of energy from part (a) 1 point

$E_\gamma = 2\left(5.12 \times 10^{5}\ \text{eV}\right)$

$E_\gamma = 1.02 \times 10^{6}\ \text{eV}$

(c) 2 points

For a correct relationship between photon energy and wavelength 1 point

$E_\gamma = hf = \dfrac{hc}{\lambda}$

For substituting the value of energy from part (b) 1 point

$\lambda = \dfrac{hc}{E_\gamma} = \dfrac{1.24 \times 10^{3}\ \text{eV} \cdot \text{nm}}{1.02 \times 10^{6}\ \text{eV}}$

$\lambda = 1.22 \times 10^{-3}\ \text{nm} = 1.22 \times 10^{-12}\ \text{m}$

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Question 7 (continued)

Distribution of points

(d) 3 points

For a correct relationship between photon wavelength and momentum — 1 point

$\lambda = \frac{h}{p}$

For substituting the value of wavelength from part (c) — 1 point

$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}\ \text{J}\cdot\text{s}}{1.22 \times 10^{-12}\ \text{m}}$

For the correct answer with units consistent with the values substituted — 1 point

$p = 5.43 \times 10^{-22}\ \text{kg}\cdot\text{m/s}$ or equivalent (such as $3.39 \times 10^{-3}\ \text{eV}\cdot\text{s/m}$)

Alternate solution — *Alternate points*

For a correct relationship between photon energy and momentum — *1 point*

$E_\gamma = pc$

$p = \frac{E_\gamma}{c} \quad \left(= \frac{2E_e}{c} = \frac{2m_e c^2}{c} = 2m_e c \right)$

For substituting the value of energy from part (b) — *1 point*

$p = \frac{\left(1.02 \times 10^6\ \text{eV}\right)\left(1.6 \times 10^{-19}\ \text{J/eV}\right)}{3.00 \times 10^8\ \text{m/s}} \quad \left(\text{or}\quad 2\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(3 \times 10^8\ \text{m/s}\right)\right)$

For units on the final answer consistent with the values substituted — *1 point*

$p = 5.44 \times 10^{-22}\ \text{kg}\cdot\text{m/s} \quad \left(\text{or } 5.46 \times 10^{-22}\ \text{kg}\cdot\text{m/s}\right)$ *or equivalent*

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AP® Physics B
2006 Free-Response Questions

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{ u} = 1.66\times10^{-27}\text{ kg}$
	$= 931\text{ MeV}/c^2$
Proton mass,	$m_p = 1.67\times10^{-27}\text{ kg}$
Neutron mass,	$m_n = 1.67\times10^{-27}\text{ kg}$
Electron mass,	$m_e = 9.11\times10^{-31}\text{ kg}$
Electron charge magnitude,	$e = 1.60\times10^{-19}\text{ C}$
Avogadro's number,	$N_0 = 6.02\times10^{23}\text{ mol}^{-1}$
Universal gas constant,	$R = 8.31\text{ J/(mol·K)}$
Boltzmann's constant,	$k_B = 1.38\times10^{-23}\text{ J/K}$
Speed of light,	$c = 3.00\times10^{8}\text{ m/s}$
Planck's constant,	$h = 6.63\times10^{-34}\text{ J·s}$
	$= 4.14\times10^{-15}\text{ eV·s}$
	$hc = 1.99\times10^{-25}\text{ J·m}$
	$= 1.24\times10^{3}\text{ eV·nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85\times10^{-12}\text{ C}^2/\text{N·m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0\times10^{9}\text{ N·m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi\times10^{-7}\text{ (T·m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\text{ (T·m)/A}$
Universal gravitational constant,	$G = 6.67\times10^{-11}\text{ m}^3/\text{kg·s}^2$
Acceleration due to gravity at Earth's surface,	$g = 9.8\text{ m/s}^2$
1 atmosphere pressure,	$1\text{ atm} = 1.0\times10^{5}\text{ N/m}^2$
	$= 1.0\times10^{5}\text{ Pa}$
1 electron volt,	$1\text{ eV} = 1.60\times10^{-19}\text{ J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

NEWTONIAN MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^{\,2} + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$F_{fric} \le \mu N$$

$$a_c = \frac{v^2}{r}$$

$$\tau = rF \sin\theta$$

$$\mathbf{p} = m\mathbf{v}$$

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

$$K = \frac{1}{2}mv^2$$

$$\Delta U_g = mgh$$

$$W = F\Delta r \cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = Fv\cos\theta$$

$$\mathbf{F}_s = -k\mathbf{x}$$

$$U_s = \frac{1}{2}kx^2$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$T = \frac{1}{f}$$

$$F_G = -\frac{Gm_1m_2}{r^2}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

$$C = \frac{Q}{V}$$

$$C = \frac{\epsilon_0 A}{d}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

$$R = \frac{\rho\ell}{A}$$

$$V = IR$$

$$P = IV$$

$$C_p = \sum_i C_i$$

$$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

$$F_B = qvB\sin\theta$$

$$F_B = BI\ell\sin\theta$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

$$\phi_m = BA\cos\theta$$

$$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

$$\mathcal{E} = B\ell v$$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin\theta = m\lambda$

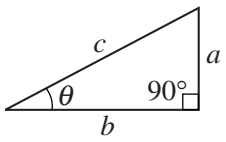
$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

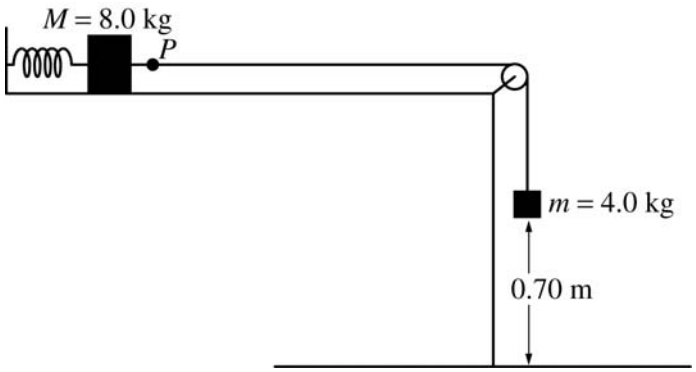
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
6 Questions

Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-4 and about 11 minutes for answering each of Questions 5-6. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (15 points)

An ideal spring of unstretched length 0.20 m is placed horizontally on a frictionless table as shown above. One end of the spring is fixed and the other end is attached to a block of mass M = 8.0 kg. The 8.0 kg block is also attached to a massless string that passes over a small frictionless pulley. A block of mass m = 4.0 kg hangs from the other end of the string. When this spring-and-blocks system is in equilibrium, the length of the spring is 0.25 m and the 4.0 kg block is 0.70 m above the floor.

(a) On the figures below, draw free-body diagrams showing and labeling the forces on each block when the system is in equilibrium.

M = 8.0 kg



m = 4.0 kg



(b) Calculate the tension in the string.

(c) Calculate the force constant of the spring.

The string is now cut at point P.

(d) Calculate the time taken by the 4.0 kg block to hit the floor.

(e) Calculate the frequency of oscillation of the 8.0 kg block.

(f) Calculate the maximum speed attained by the 8.0 kg block.

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2. (15 points)

A world-class runner can complete a 100 m dash in about 10 s. Past studies have shown that runners in such a race accelerate uniformly for a time t_u and then run at constant speed for the remainder of the race. A world-class runner is visiting your physics class. You are to develop a procedure that will allow you to determine the uniform acceleration a_u and an approximate value of t_u for the runner in a 100 m dash. By necessity your experiment will be done on a straight track and include your whole class of eleven students.

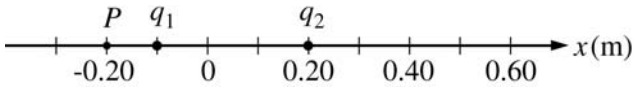
(a) By checking the line next to each appropriate item in the list below, select the equipment, other than the runner and the track, that your class will need to do the experiment.

____ Stopwatches ____ Tape measures ____ Rulers ____ Masking tape

____ Metersticks ____ Starter's pistol ____ String ____ Chalk

(b) Outline the procedure that you would use to determine a_u and t_u, including a labeled diagram of the experimental setup. Use symbols to identify carefully what measurements you would make and include in your procedure how you would use each piece of the equipment you checked in part (a).

(c) Outline the process of data analysis, including how you will identify the portion of the race that has uniform acceleration, and how you would calculate the uniform acceleration.



3. (15 points)

Two point charges, q_1 and q_2, are placed 0.30 m apart on the *x*-axis, as shown in the figure above. Charge q_1 has a value of -3.0×10^{-9} C. The net electric field at point *P* is zero.

(a) What is the sign of charge q_2?

____Positive ____ Negative

Justify your answer.

(b) Calculate the magnitude of charge q_2.

(c) Calculate the magnitude of the electric force on q_2 and indicate its direction.

(d) Determine the *x*-coordinate of the point on the line between the two charges at which the electric potential is zero.

(e) How much work must be done by an external force to bring an electron from infinity to the point at which the electric potential is zero? Explain your reasoning.

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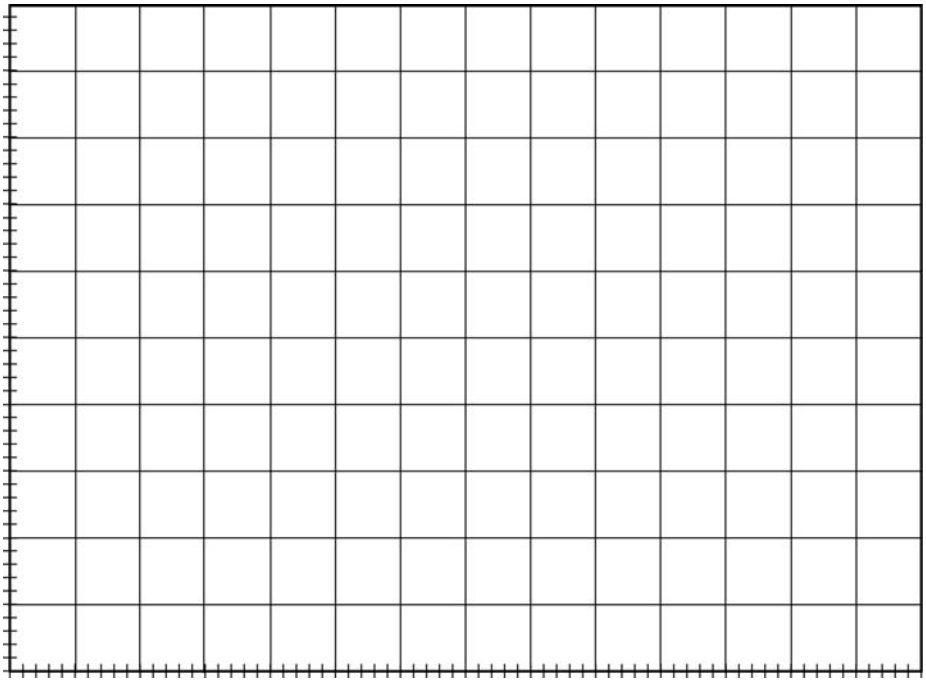
4. (15 points)

A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.

Trial	θ_i	θ_r		
1	30°	20°		
2	40°	27°		
3	50°	32°		
4	60°	37°		
5	70°	40°		

(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

(b) On the grid below, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.



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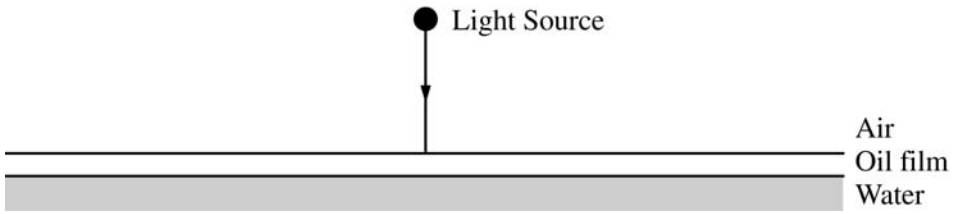
(c) Using the graph, calculate the index of refraction of the glass slab.



The student is also asked to determine the thickness of a film of oil (n = 1.43) on the surface of water (n = 1.33). Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

(d) At which of the two interfaces does the light undergo a 180º phase change on reflection?

___The air-oil interface only ___The oil-water interface only

___Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

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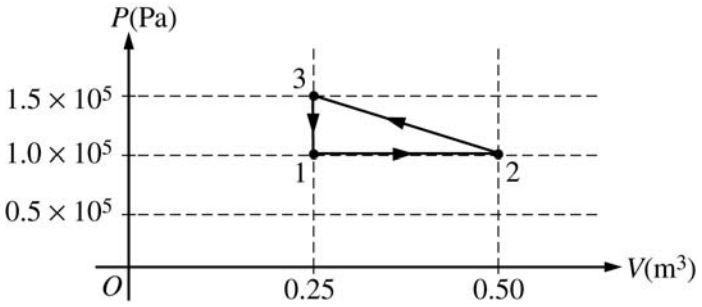

5. (10 points)

A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the *PV* diagram above.

(a) Calculate the temperature of the gas when it is in the following states.

i. State 2

ii. State 3

(b) Calculate the net work done on the gas during the cycle.

(c) Was heat added to or removed from the gas during the cycle?

____ Added ____ Removed ____ Neither added nor removed

Justify your answer.

---

6. (10 points)

A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.

(a) Calculate the energy of the photon.

(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.

(c) Describe an experiment that illustrates the wave properties of this electron.

END OF EXAM

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AP® Physics B
2006 Scoring Guidelines

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AP® PHYSICS B
2006 SCORING GUIDELINES

General Notes About 2006 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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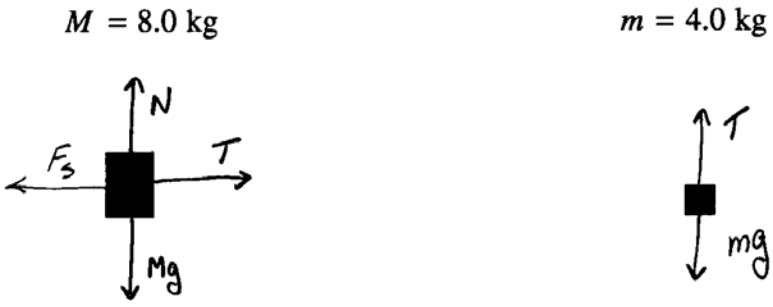
Question 1

15 points total **Distribution of points**

(a) 3 points



For the 4 kg mass:
For two correctly labeled vertical vectors, one up and one down, and no horizontal vectors — 1 point
For the 8 kg mass:
For two correctly labeled vertical vectors, one up and one down — 1 point
For two correctly labeled horizontal vectors, one left and one right — 1 point
Note: Labels could be in words, symbols, or correct numerical values. The two masses were considered independently. It was not necessary to indicate that the tension forces had the same magnitudes or that the weights were different.

(b) 2 points

For a correct approach using Newton's 2nd law and the static equilibrium condition for the 4 kg mass that leads to a relationship between tension and weight — 1 point
$T = mg$
$T = (4.0 \text{ kg})\left(9.8 \text{ m/s}^2\right)$
For the correct answer — 1 point
$T = 39$ N (40 N using $g = 10 \text{ m/s}^2$)

(c) 3 points

For a correct application of Newton's 2nd law and the static equilibrium condition for the 8 kg mass leading to a relationship between tension from part (b) and spring force — 1 point
$T = F_S = k\Delta x$
$k = T/\Delta x$
For using the correct displacement of the spring from equilibrium — 1 point
$\Delta x = 0.25 \text{ m} - 0.20 \text{ m} = 0.05 \text{ m}$
For a correct calculation leading to a positive value of k using the tension from (b) — 1 point
$k = 39 \text{ N}/0.05 \text{ m}$
$k = 780 \text{ N/m}$ (800 N/m using 40 N from part (b))

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Question 1 (continued)

Distribution of points

(d) 2 points

For a correct kinematic approach for an accelerating system applied to the 4 kg mass — 1 point

$y = \frac{1}{2}gt^2$

$t = \sqrt{2y/g}$

$t = \sqrt{2(0.70\text{ m})/(9.8\text{ m/s}^2)}$

For the correct answer — 1 point

$t = 0.38$ s (0.37 s using $g = 10\text{ m/s}^2$)

Note: *An alternate approach using conservation of energy to determine the speed at the bottom and then use of a kinematic equation for time could also earn full credit.*

(e) 2 points

For a correct approach to calculating the frequency (f or ω) of a mass-spring system — 1 point

$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ OR $\omega = \sqrt{\frac{k}{m}}$

$f = \frac{1}{2\pi}\sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}$ OR $\omega = \sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}$

For a correct value of frequency (f or ω) consistent with the value of k from part (c) — 1 point

$f = 1.6$ Hz OR $\omega = 10$ rad/s

(f) 2 points

For using conservation of energy, setting the spring potential energy equal to the kinetic energy of the block — 1 point

$\frac{1}{2}mv^2 = \frac{1}{2}kA^2$

$v = \sqrt{\frac{k}{m}}A$

$v = \sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}(0.05\text{ m})$

For a correct calculation of speed consistent with the value of k from part (c) and the correct displacement from equilibrium — 1 point

$v = 0.49$ m/s (0.50 m/s using 800 N/m from part (c))

(Global) 1 point

For correct units and a reasonable number of digits in all numerical answers obtained (must have at least one final numerical answer to earn this point) — 1 point

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Question 2

15 points total **Distribution of points**

Two general approaches were used by most of the students.

Approach A: Spread the students out every 10 meters or so. The students each start their stopwatches as the runner starts and measure the time for the runner to reach their positions.

Analysis variant 1: Make a position vs. time graph. Fit the parabolic and linear parts of the graph and establish the position and time at which the parabola makes the transition to the straight line.

Analysis variant 2: Use the position and time measurements to determine a series of average velocities ($v_{avg} = \Delta x/\Delta t$) for the intervals. Graph these velocities vs. time to obtain a horizontal line and a line with positive slope. Establish the position and time at which the sloped and horizontal lines intersect.

Analysis variant 3: Use the position and time measurements to determine a series of average accelerations $\left(\Delta x = v_0 t - at^2/2\right)$. Graph these accelerations vs. time to obtain two horizontal lines, one with a nonzero value and one at zero acceleration. Establish the position and time at which the acceleration drops to zero.

Approach B: Concentrate the students at intervals at the end of the run, in order to get a very precise value of the constant speed v_f, or at the beginning in order to get a precise value for a_u. The total distance *D* is given by $D = \left(a_u t_u^2/2\right) + v_f\left(T - t_u\right)$, where *T* is the total measured run time. In addition, $v_f = a_u t_u$. These equations can be solved for a_u and t_u (if v_f is measured directly) or v_f and t_u (if a_u is measured directly). Students may have also defined and used distances, speeds, and times for the accelerated and constant-speed portions of the run in deriving these relationships.

(a) 2 points

For checking off a distance-measuring device and describing its use in part (b) 1 point
For checking off a stopwatch and describing its use in part (b) 1 point

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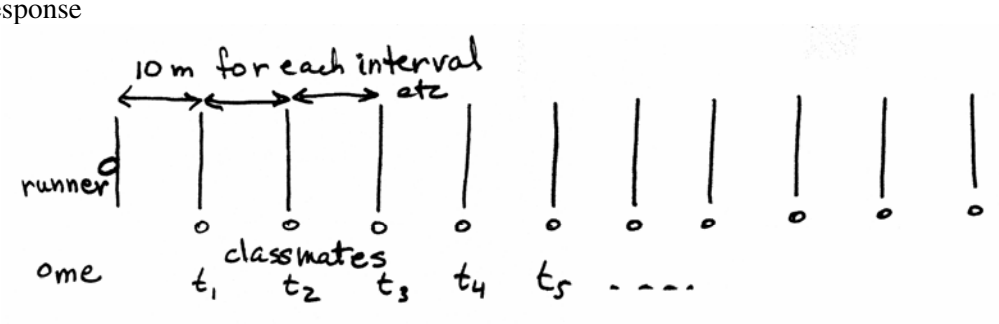
Question 2 (continued)

Distribution of points

(b) 6 points

Sample response



Use the tape measure and chalk to mark off the 100 meters in 10 meter lengths. Set a classmate with a stopwatch at marks as shown. Use the starter's pistol to signal the runner to run and the classmates to start their stopwatches. Each person turns off the stopwatch when the runner reaches his or her mark. You then have measurements of the time to reach each increment of 10 meters.

For taking distance measurements for 8 to 11 distinct fixed positions per run	1 point
For measuring time for the same 8 to 11 distinct fixed positions, consistent with the description of the experimental setup	1 point
For an experimental technique consistent with being able to determine the requested quantities	2 points
For a diagram of the experimental setup with clear labels and consistent with the technique described (awarded even if the technique is wrong)	1 point
For a technique that allows data for all positions to be taken in a single run	1 point

(c) 7 points

Approach A

For a clear and detailed explanation of the data analysis process *Note: This part of the solution was graded holistically and students could earn between 0 and 3 points depending on the clarity and completeness of their explanation.*	3 points
For equations or clear prose and use of the data to identify the two distinct regions of motion (constant acceleration and constant velocity)	1 point
For clearly and correctly identifying t_u	1 point
For clearly and correctly identifying a_u	1 point
For having the final answers correct and no incorrect statements or calculations among the correct ones	1 point

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Question 2 (continued)

	Distribution of points
(c) (continued)	
Approach B	
Students needed to clearly indicate which variable was used (acceleration or final velocity) by including the following.	
For a description or diagram that clearly defines all the variables being used	1 point
For a description or diagram showing how the needed variable (acceleration or final velocity) will be determined	1 point
For a successful transformation of the above description into equation form	2 points
For correctly solving the equations obtained	1 point
For work that would determine a correct value of a_u	1 point
For work that would determine a correct value of t_u	1 point

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Question 3

15 points total **Distribution of points**

(a) 2 points

For checking "Positive" 1 point
For a correct justification (point only awarded if "Positive" checked) 1 point
Example: At point *P*, the electric field due to charge q_1 points to the right because electric fields point toward negative charges. The field from q_2 must point to the left, i.e., away from the charge, to cancel the field from q_1. So q_2 must be positive.
Point is not awarded if the justification is "*charges cancel each other out.*"

(b) 4 points

For a correct equation for electric field strength of a point charge 1 point

$$E = \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_i^2}$$

For showing that the sum of the electric fields at *P* is zero 1 point

$$0 = \frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2}$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2} = -\frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2}$$

$$q_2 = -\frac{d_2^2}{d_1^2}q_1$$

For correct substitution of values 1 point

$$q_2 = -\frac{(0.40\text{ m})^2}{(0.10\text{ m})^2}\left(-3.0\times10^{-9}\text{ C}\right)$$

For the correct answer 1 point

$$q_2 = +4.8\times10^{-8}\text{ C}$$

(c) 3 points

For writing Coulomb's law 1 point

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

For correct substitution of given values and the charge found in part (b) 1 point

$$F_2 = \left(9.0\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\frac{\left(3.0\times10^{-9}\text{ C}\right)\left(48\times10^{-9}\text{ C}\right)}{(0.30\text{ m})^2}$$

$$F_2 = 1.4\times10^{-5}\text{ N}$$

For a direction consistent with the answer to part (a) 1 point
The electric force on q_2 is to the left (or to the right if the answer to part (a) is "Negative")

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Question 3 (continued)

Distribution of points

(d) 4 points

For showing that the sum of the potentials is zero — 1 point
$V_1 + V_2 = 0$

For using the point charge formula for electric potential — 1 point

$V = \dfrac{q}{4\pi\epsilon_0 r}$ OR $V = k\dfrac{q}{r}$

$$\frac{1}{4\pi\epsilon_0}\frac{q_1}{r_1} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{r_2} = 0$$

For correctly substituting values into the equation above, including q_1, the value of q_2 from part (b), and distances in the denominators that sum to 0.3 m and include a valid distance variable — 1 point

Example:

$$\frac{1}{4\pi\epsilon_0}\frac{-3.0\times10^{-9}\text{ C}}{(0.30\text{ m} - d)} + \frac{1}{4\pi\epsilon_0}\frac{48\times10^{-9}\text{ C}}{d} = 0$$

$$d\left(-3.0\times10^{-9}\text{ C}\right) = -(0.30\text{ m} - d)\left(48\times10^{-9}\text{ C}\right)$$

$$d\left(3.0\times10^{-9}\text{ C}\right) = (0.30\text{ m} - d)\left(48\times10^{-9}\text{ C}\right)$$

$$\left(48\times10^{-9}\text{ C} + 3.0\times10^{-9}\text{ C}\right)d = (0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)$$

$$d = \frac{(0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)}{\left(48\times10^{-9}\text{ C} + 3.0\times10^{-9}\text{ C}\right)}$$

$d = 0.28$ m

For finding a value for x within the range $-0.1\text{ m} < x < 0.2\text{ m}$ — 1 point

<u>Note</u>: *This point was only awarded if the substitution point was awarded*

$x = 0.20\text{ m} - 0.28\text{ m} = -0.08$

(e) 2 points

For stating that net work done is zero — 1 point

For a correct justification — 1 point

Example:

$W = \Delta U = q\,\Delta V$. Since the potential is zero at infinity and is also zero at the final position, $\Delta V = 0$. Therefore $W = 0$.

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Question 4

15 points total **Distribution of points**

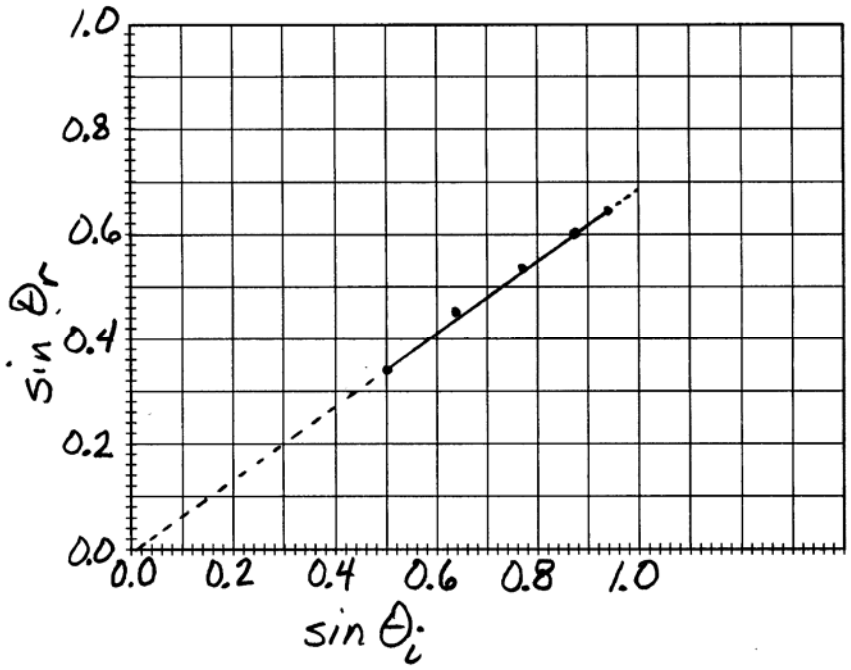
(a) 2 points

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	0.50	0.34
2	40°	27°	0.64	0.45
3	50°	32°	0.77	0.53
4	60°	37°	0.87	0.60
5	70°	40°	0.94	0.64

For identifying that both quantities to be graphed are the sines of the angles 1 point
For correctly calculating the sines using degrees 1 point

(b) 4 points

Example:



For correctly labeling both axes with the sines of the angles 1 point
For correctly labeling both axes with appropriate numerical scales 1 point
For plotting the five points 1 point
For correctly drawing a best fit line that includes the entire range of data points and may extend beyond them 1 point

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Question 4 (continued)

Distribution of points

(c) 4 points

For a statement or implicit use of Snell's Law — 1 point
$n_1 \sin\theta_i = n_2 \sin\theta_r$ (or $\sin\theta_i = n_2 \sin\theta_r$ since $n_1 = n_{air} = 1$)

For indicating that the index of refraction n can be obtained from the slope or inverse of the slope depending on choice of variable plotted on each axis — 1 point
Example using graph above
$$n = \frac{\sin\theta_i}{\sin\theta_r} = \frac{1}{\text{slope}}$$

For using two sets of points directly from the line to find the slope — 1 point
$$\text{slope} = \frac{0.53 - 0.41}{0.78 - 0.60} = 0.67$$

For a correct calculation of the index of refraction consistent with the slope of the graph — 1 point
$n = 1/0.67 = 1.5$

(d) 1 point

For checking "The air-oil interface only" — 1 point

(e) 4 points

For indicating that the optical path difference between the waves reflecting off the air-oil interface and the oil-water interface is one-half wavelength — 1 point
$\Delta\ell = \lambda/2$

For indicating that the wave reflecting off the oil-water interface travels a distance equal to twice the thickness of the oil — 1 point
$\Delta\ell = 2t$

For indicating that the wavelength of the light in the oil film is different from the wavelength of the light in air — 1 point
$\lambda_{film} = \lambda_{air}/n_{film}$

The three equations above are combined to relate the film thickness to the wavelength.
$2t = \lambda_{film}/2 = \lambda_{air}/2n_{film}$
$t = \lambda_{air}/4n_{film}$
$t = 6.0 \times 10^{-7}\,\text{m}/4(1.43)$

For the correct answer with appropriate units — 1 point
$t = 1.05 \times 10^{-7}\,\text{m} = 105\ \text{nm}$

<u>Notes</u>:
A student who checked "The oil-water interface only" *in part (d) and then correctly calculated a wavelength of 105 nm for the thickness of the oil was awarded full credit.*
A student who checked "Both interfaces" *or* "Neither interface" *in part (d) and then correctly calculated a wavelength of 210 nm for the thickness of the oil was awarded full credit.*

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Question 5

10 points total **Distribution of points**

(a)

(i) 2 points

From the ideal gas law

$PV = nRT$

For recognizing that $\frac{PV}{T}$ is constant throughout the cycle 1 point

Using the fact that pressure is the same for states 1 and 2

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$T_2 = \frac{V_2 T_1}{V_1}$

For substituting correct values into a correct expression 1 point

$T_2 = \left(0.50 \text{ m}^3\right)(373 \text{ K}) \big/ \left(0.25 \text{ m}^3\right)$

$T_2 = 746 \text{ K}$

Note: Some students earned the first point by correctly calculating the value of n or the product nR using the given conditions in state 1. The student could have then proceeded to the correct substitutions in both parts (i) and (ii).

(ii) 1 point

Using the fact that volume is the same for states 1 and 3

$\frac{P_1}{T_1} = \frac{P_3}{T_3}$

$T_3 = \frac{P_3 T_1}{P_1}$

For substituting correct values into a correct expression 1 point

$T_3 = \left(1.5 \times 10^5 \text{ Pa}\right)(373 \text{ K}) \big/ \left(1.0 \times 10^5 \text{ Pa}\right)$

$T_3 = 560 \text{ K}$

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Question 5 (continued)

Distribution of points

(b) 4 points

Calculate the work done on the gas in each of the three processes making up the cycle.
For calculating the work done from state 1 to state 2 given constant pressure — 1 point
$W_{1\to2} = -P\Delta V = -(1.0\times10^5\ \text{Pa})(0.25\ \text{m}^3) = -25000\ \text{J}$ (negative sign not required)
For calculating the work done from state 2 to state 3 using average pressure — 1 point
$W_{2\to3} = -P_{avg}\Delta V = -(1.25\times10^5\ \text{Pa})(-0.25\ \text{m}^3) = +31250\ \text{J}$ (positive sign not required)
Note: A student that correctly calculated the area under the curve for either process earned the point for that process.
For noting that no work is done going from state 1 to state 3 or for indicating net work is only contributed in going from state 1 to 2 and state 2 to 3 — 1 point
$W_{3\to1} = 0$ or $W_{net} = W_{1\to2} + W_{2\to3}$
For the correct answer with the correct sign — 1 point
$W_{net} = +6250\ \text{J}$

Alternate solution — *Alternate points*
For stating that the net work done is the area of the triangle or for implying such by using the expression for the area of a triangle, $A = \frac{1}{2}\text{base}\bullet\text{height}$ — *1 point*
For correctly substituting the base value from the graph — *1 point*
For correctly substituting the height value from the graph — *1 point*
$W = \frac{1}{2}\left(1.5\times10^5\ \text{Pa} - 1.0\times10^5\ \text{Pa}\right)\left(0.50\ \text{m}^3 - 0.25\ \text{m}^3\right)$
For the correct answer with the correct sign — *1 point*
$W_{net} = +6250\ \text{J}$

(c) 3 points

For checking "Removed" — 1 point
Note: Checking the box consistent with the sign of the net work calculated in part (b) earned full credit, but checking the incorrect option resulted in no additional credit.
For referring to the first law of thermodynamics implicitly or explicitly — 1 point
$\Delta U = Q + W$
For noting that the consequence of the closed thermodynamic cycle is that the internal energy does not change (since the gas ends at the same temperature at which it started), and/or that the heat transferred equals the opposite of the work done on gas — 1 point
$\Delta U = 0$ or $Q = -W$
This can also be expressed in words.
Example: Work is done on the gas, which would add energy to the gas. Heat must be removed in order for the internal energy to be unchanged after one cycle.

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Question 6

10 points total **Distribution of points**

(a) 3 points

For correctly expressing frequency in terms of speed of light and wavelength, either with symbols or numerical values 1 point

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^{8}\ \text{m/s}}{1.5 \times 10^{-8}\ \text{m}} = 2.0 \times 10^{16}\,\text{Hz}$$

For substituting the expression for frequency into the equation for the energy of a photon 1 point

$$E = hf = (6.63 \times 10^{-34}\,\text{J} \cdot \text{s})(2.0 \times 10^{16}\,\text{Hz})$$

For the correct answer with correct units 1 point

$$E = 1.33 \times 10^{-17}\,\text{J} = 82.7\,\text{eV}$$

Alternate solution *Alternate points*

For correctly expressing the momentum of the photon in terms of Planck's constant and the wavelength, either with symbols or numerical values *1 point*

$$\lambda = \frac{h}{p} \quad \text{or} \quad p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}\,\text{J} \cdot \text{s}}{1.5 \times 10^{-8}\,\text{m}} = 4.42 \times 10^{-26}\ \text{kg•m/s}$$

For substituting the expression for the momentum into the energy-momentum relationship for a photon *1 point*

$$E = pc = (4.42 \times 10^{-26}\,\text{N} \cdot \text{s})(3.0 \times 10^{8}\,\text{m/s})$$

For the correct answer with correct units *1 point*

$$E = 1.33 \times 10^{-17}\,\text{J} = 82.7\,\text{eV}$$

(b) 4 points

The kinetic energy of a massive particle is given by

$$K = \frac{1}{2}mv^2$$

For substituting the energy in joules from part (a) as the kinetic energy to calculate the speed of the electron 1 point

$$1.33 \times 10^{-17}\,\text{J} = \frac{1}{2}(9.11 \times 10^{-31}\,\text{kg})v^2$$

$$v = 5.4 \times 10^{6}\,\text{m/s}$$

For calculating the momentum of the electron using the speed calculated above 1 point

$$p = mv = (9.11 \times 10^{-31}\,\text{kg})(5.4 \times 10^{6}\,\text{m/s})$$

For substituting the momentum into the equation for the deBroglie wavelength 1 point

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}\,\text{J•s}}{(9.11 \times 10^{-31}\,\text{kg})(5.4 \times 10^{6}\,\text{m/s})}$$

For the correct answer with correct units 1 point

$$\lambda = 1.35 \times 10^{-10}\,\text{m}$$

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Question 6 (continued)

Distribution of points

(c) 3 points

The expected answer is a description of an experiment in which a beam of electrons is aimed at either a single slit, a double slit, a diffraction grating, or a crystal. The student must also describe the interference pattern of maxima and minima appearing on a screen as evidence of the wave nature of the electron.

For using a beam of electrons (NOT a single electron) 1 point

For aiming the electron beam at one of the objects noted above 1 point

For indicating that the resultant is an interference pattern (a drawing was acceptable) 1 point

Notes:

If the experiment description is completely correct except that it includes a beam of light instead of electrons, it earned two of the three possible points.

No points were earned for merely naming an experiment, either in reference to commonly known experimenters ("Davisson–Germer experiment") or pieces of equipment ("double-slit experiment").

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AP® Physics B
2006 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{ u} = 1.66\times10^{-27}\text{ kg}$
	$= 931\text{ MeV}/c^2$
Proton mass,	$m_p = 1.67\times10^{-27}\text{ kg}$
Neutron mass,	$m_n = 1.67\times10^{-27}\text{ kg}$
Electron mass,	$m_e = 9.11\times10^{-31}\text{ kg}$
Electron charge magnitude,	$e = 1.60\times10^{-19}\text{ C}$
Avogadro's number,	$N_0 = 6.02\times10^{23}\text{ mol}^{-1}$
Universal gas constant,	$R = 8.31\text{ J/(mol•K)}$
Boltzmann's constant,	$k_B = 1.38\times10^{-23}\text{ J/K}$
Speed of light,	$c = 3.00\times10^{8}\text{ m/s}$
Planck's constant,	$h = 6.63\times10^{-34}\text{ J•s}$
	$= 4.14\times10^{-15}\text{ eV•s}$
	$hc = 1.99\times10^{-25}\text{ J•m}$
	$= 1.24\times10^{3}\text{ eV•nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85\times10^{-12}\text{ C}^2/\text{N•m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0\times10^{9}\text{ N•m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi\times10^{-7}\text{ (T•m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\text{ (T·m)/A}$
Universal gravitational constant,	$G = 6.67\times10^{-11}\text{ m}^3/\text{kg•s}^2$
Acceleration due to gravity at Earth's surface,	$g = 9.8\text{ m/s}^2$
1 atmosphere pressure,	$1\text{ atm} = 1.0\times10^{5}\text{ N/m}^2$
	$= 1.0\times10^{5}\text{ Pa}$
1 electron volt,	$1\text{ eV} = 1.60\times10^{-19}\text{ J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \le \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2}m\upsilon^2$

$\Delta U_g = mgh$

$W = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = F\upsilon\cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

$\phi_m = BA\cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho g y + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2}k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

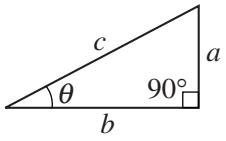
$x_m \sim \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

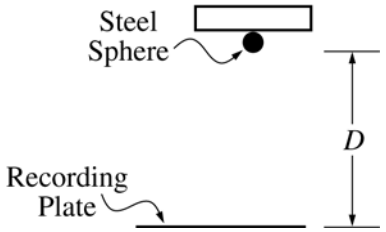
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell w h$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
6 Questions

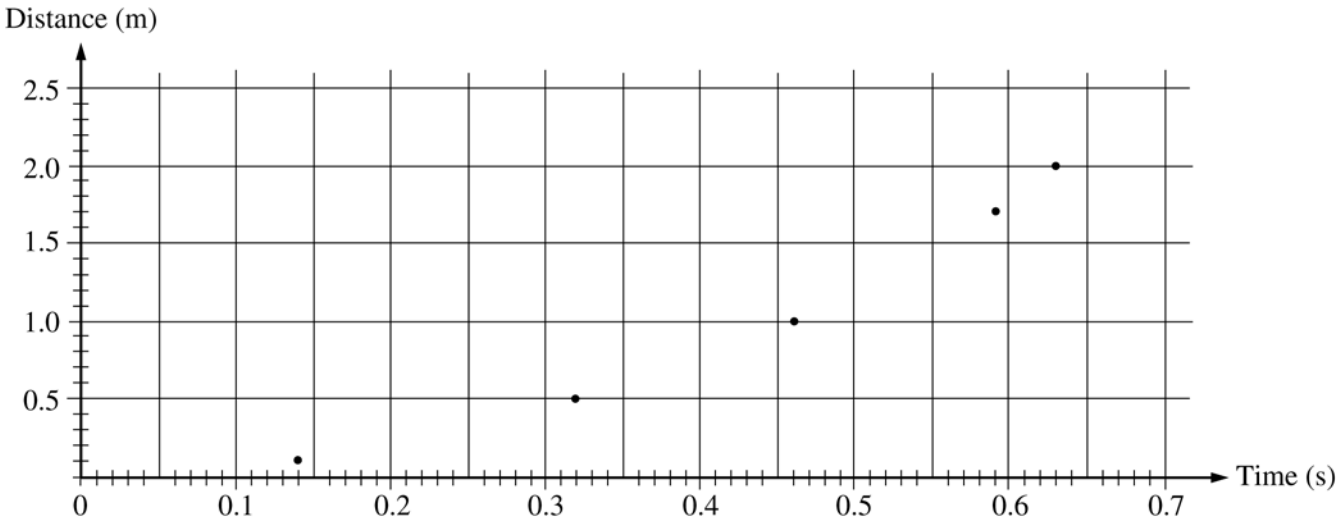
Directions: Answer all six questions, which are weighted according to the points indicated. The suggested time is about 17 minutes for answering each of questions 1-4, and about 11 minutes for answering each of questions 5-6. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

A student wishing to determine experimentally the acceleration g due to gravity has an apparatus that holds a small steel sphere above a recording plate, as shown above. When the sphere is released, a timer automatically begins recording the time of fall. The timer automatically stops when the sphere strikes the recording plate. The student measures the time of fall for different values of the distance D shown above and records the data in the table below. These data points are also plotted on the graph.

Distance of Fall (m)	0.10	0.50	1.00	1.70	2.00
Time of Fall (s)	0.14	0.32	0.46	0.59	0.63



(a) On the grid above, sketch the smooth curve that best represents the student's data.

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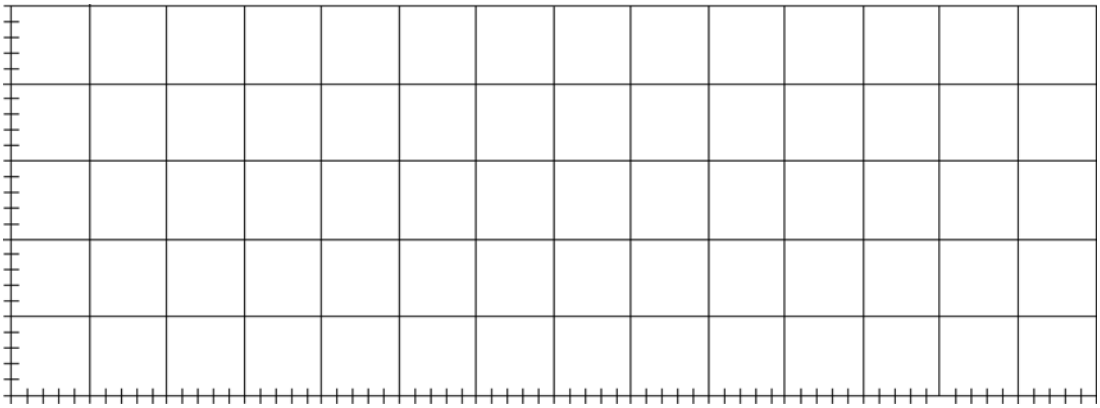
The student can use these data for distance D and time t to produce a second graph from which the acceleration g due to gravity can be determined.

(b) If only the variables D and t are used, what quantities should the student graph in order to produce a linear relationship between the two quantities?

(c) On the grid below, plot the data points for the quantities you have identified in part (b), and sketch the best straight-line fit to the points. Label your axes and show the scale that you have chosen for the graph.



(d) Using the slope of your graph in part (c), calculate the acceleration g due to gravity in this experiment.

(e) State one way in which the student could improve the accuracy of the results if the experiment were to be performed again. Explain why this would improve the accuracy.

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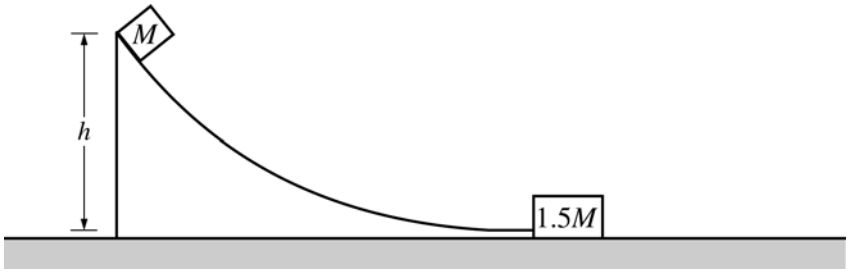

2. (15 points)

A small block of mass M is released from rest at the top of the curved frictionless ramp shown above. The block slides down the ramp and is moving with a speed $3.5v_0$ when it collides with a larger block of mass $1.5M$ at rest at the bottom of the incline. The larger block moves to the right at a speed $2v_0$ immediately after the collision. Express your answers to the following questions in terms of the given quantities and fundamental constants.

(a) Determine the height h of the ramp from which the small block was released.

(b) Determine the speed of the small block after the collision.

(c) The larger block slides a distance D before coming to rest. Determine the value of the coefficient of kinetic friction μ between the larger block and the surface on which it slides.

(d) Indicate whether the collision between the two blocks is elastic or inelastic. Justify your answer.

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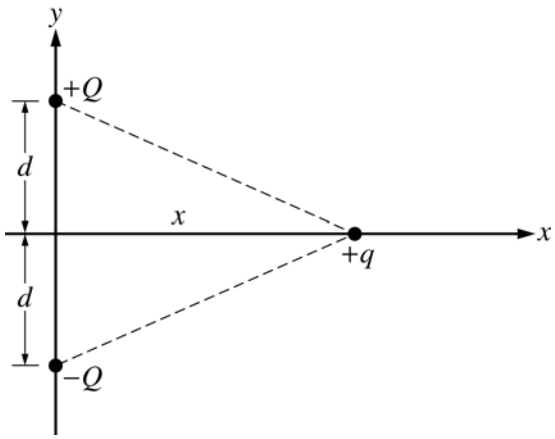

3. (15 points)

Three electric charges are arranged on an x-y coordinate system, as shown above. Express all algebraic answers to the following parts in terms of Q, q, x, d, and fundamental constants.

(a) On the diagram, draw vectors representing the forces F_1 and F_2 exerted on the $+q$ charge by the $+Q$ and $-Q$ charges, respectively.

(b) Determine the magnitude and direction of the total electric force on the $+q$ charge.

(c) Determine the electric field (magnitude and direction) at the position of the $+q$ charge due to the other two charges.

(d) Calculate the electric potential at the position of the $+q$ charge due to the other two charges.

(e) Charge $+q$ is now moved along the positive x-axis to a very large distance from the other two charges. The magnitude of the force on the $+q$ charge at this large distance now varies as $1/x^3$. Explain why this happens.

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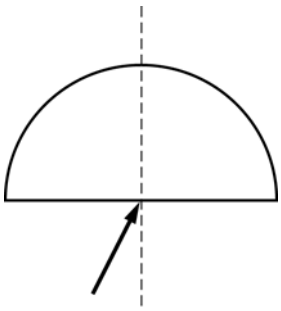


4. (15 points)

A ray of red light in air ($\lambda = 650$ nm) is incident on a semicircular block of clear plastic ($n = 1.51$ for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.

i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.

ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.

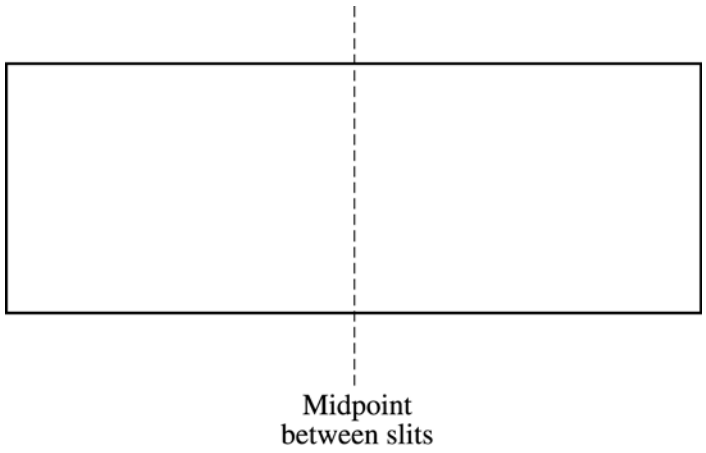
iii. Determine the speed of the light in the plastic block.

iv. Determine the wavelength of the light in the plastic block.

(b) The source of red light is replaced with one that produces blue light ($\lambda = 450$ nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.



ii. Calculate the distance between two adjacent bright fringes.

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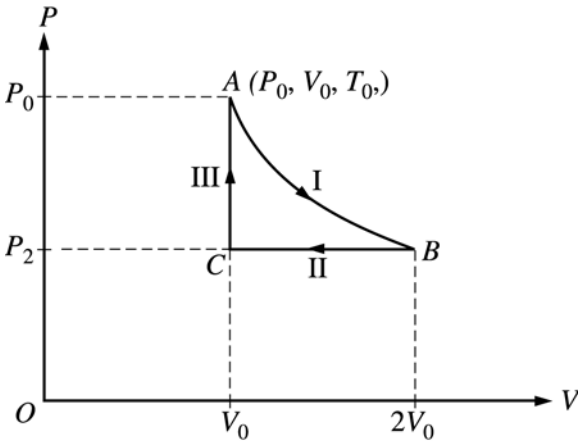

5. (10 points)

A sample of ideal gas is taken through steps I, II, and III in a closed cycle, as shown on the pressure P versus volume V diagram above, so that the gas returns to its original state. The steps in the cycle are as follows.

I. An isothermal expansion occurs from point A to point B, and the volume of the gas doubles.

II. An isobaric compression occurs from point B to point C, and the gas returns to its original volume.

III. A constant volume addition of heat occurs from point C to point A and the gas returns to its original pressure.

(a) Determine numerical values for the following ratios, justifying your answers in the spaces next to each ratio.

i. $\frac{P_B}{P_A} =$

ii. $\frac{P_C}{P_A} =$

iii. $\frac{T_B}{T_A} =$

iv. $\frac{T_C}{T_A} =$

(b) During step I, the change in internal energy is zero. Explain why.

(c) During step III, the work done on the gas is zero. Explain why.

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6. (10 points)

An electron of mass m is initially moving with a constant speed v, where $v << c$. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the kinetic energy of the electron.

(b) Determine the de Broglie wavelength of the electron.

The electron encounters a particle with the same mass and opposite charge (a positron) moving with the same speed in the opposite direction. The two particles undergo a head-on collision, which results in the disappearance of both particles and the production of two photons of the same energy.

(c) Determine the energy of each photon.

(d) Determine the wavelength of each photon.

(e) Explain why there must be two photons produced instead of just one.

END OF EXAM

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AP® Physics B
2006 Scoring Guidelines
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AP® PHYSICS B
2006 SCORING GUIDELINES (Form B)

General Notes About 2006 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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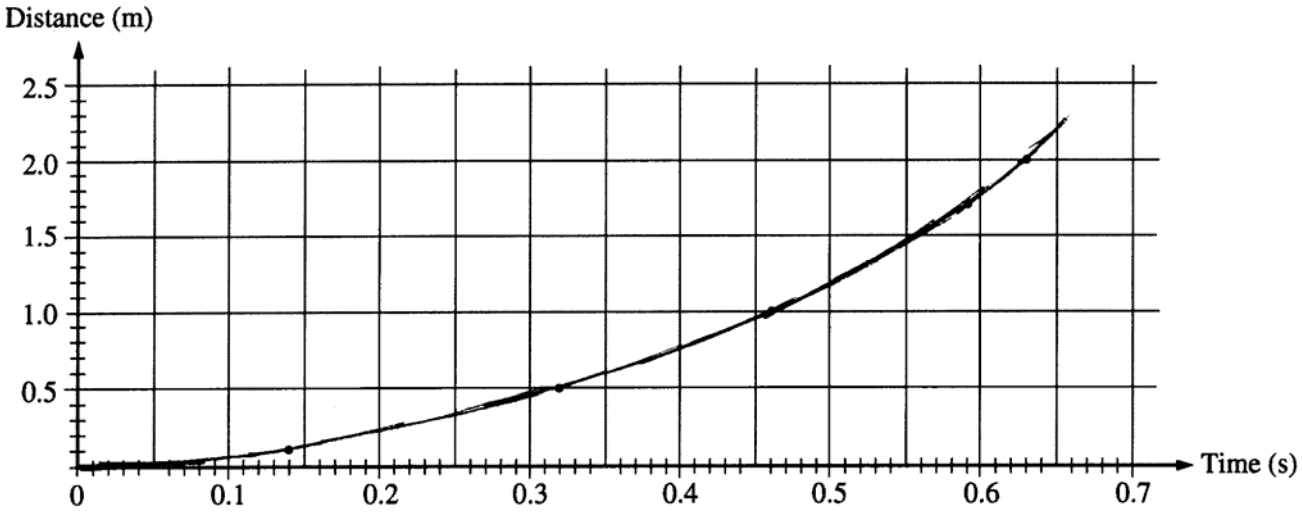
Question 1

15 points total **Distribution of points**

(a) 3 points



For a line that is close to all of the data points 1 point
For a smooth curve 1 point
For a nonlinear curve that is concave up 1 point

(b) 2 points

Distance and time are related by the equation $D = \frac{1}{2}gt^2$

For a correct pair of quantities, expressed in terms of D and t, that will yield a straight line 2 points
Examples: D and t^2 OR $\sqrt{D}$ and t

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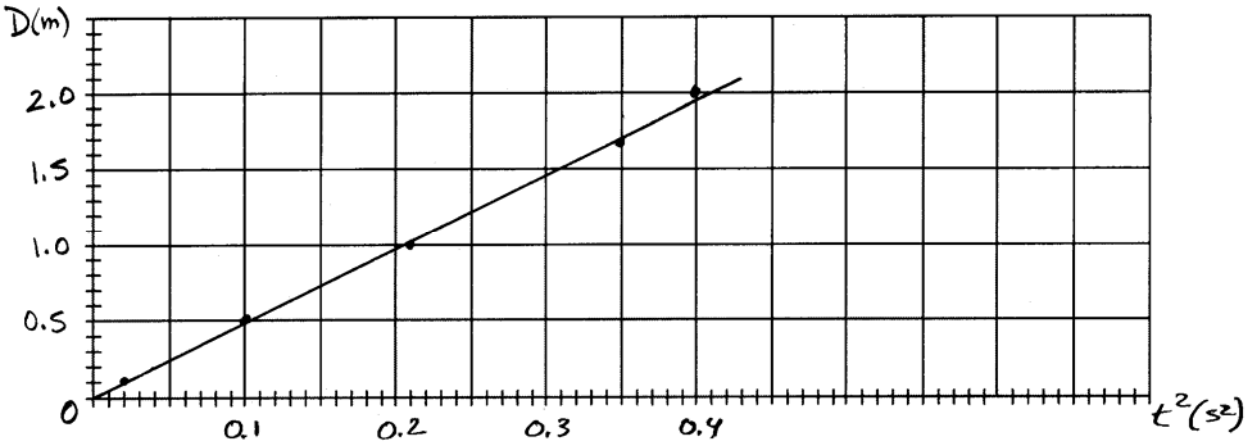
Question 1 (continued)

Distribution of points

(c) 4 points

For correctly scaling and labeling the horizontal axis for a quantity cited in part (b) — 1 point
For correctly scaling and labeling the vertical axis for a quantity cited in part (b) — 1 point
For a reasonably correct plotting of the data — 1 point
For a reasonably straight line through the data points — 1 point

Example graphing D versus t^2:



Note: If part (b) contains incorrect variables and they are correctly graphed in part (c), a maximum of 2 points could be earned.

(d) 3 points

For determining the slope of the line drawn on the graph — 1 point

Using the example graph above, $\text{slope} = \dfrac{(2.0 - 0.1)\ \text{m}}{(0.41 - 0.02)\ \text{s}^2} = \dfrac{1.9\ \text{m}}{0.39\ \text{s}^2} = 4.9\ \text{m/s}^2$

For an expression relating g to the slope — 1 point

In the example given, $D = \frac{1}{2}gt^2$, so $\frac{1}{2}g = \text{slope}$

For a value of g in the range $9\text{-}11\ \text{m/s}^2$ — 1 point

In the example given, $g = 2\left(4.9\ \text{m/s}^2\right) = 9.8\ \text{m/s}^2$

(e) 3 points

For a good, specific improvement — 2 points
For an explanation of how this would improve accuracy — 1 point
Example: Do several trials for each value of D and take averages. This reduces personal and random error.
One point could be earned for less appropriate or less specific answers, for example "do trials in a vacuum" or "cut down on air resistance."

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AP® PHYSICS B
2006 SCORING GUIDELINES (Form B)

Question 2

15 points total **Distribution of points**

(a) 4 points

For any use of conservation of energy — 1 point

For example, initially the small block has only potential energy, and it is all converted to kinetic energy when it reaches the bottom of the ramp.

For a correct expression for the initial potential energy — 1 point

For a correct expression for the kinetic energy at the bottom of the ramp — 1 point

$Mgh = \frac{1}{2}M(3.5v_0)^2$

For the correct answer — 1 point

$h = \frac{3.5^2}{2}\frac{v_0^2}{g}$ or equivalent

(b) 4 points

For any use of conservation of momentum — 1 point

For a correct expression for the initial momentum of the blocks — 1 point

For a correct expression for the final momentum of the blocks — 1 point

$M(3.5v_0) = Mv + (1.5M)(2v_0)$

$v = 3.5v_0 - 3v_0$

For the correct answer — 1 point

$v = 0.5v_0$

(c) 4 points

For a correct relationship between friction and the acceleration of the block — 1 point

$\sum F = ma = f_{fric}$

For a correct kinematic equation relating acceleration and distance that does not contain time — 1 point

$v_f^2 = v_i^2 - 2aD$

For using the correct initial speed of the block — 1 point

$0 = 4v_0^2 - 2aD$

$a = 2v_0^2/D$

Substituting expressions for a and f into the first equation above

$(1.5M)2v_0^2/D = \mu(1.5M)g$

For the correct answer — 1 point

$\mu = 2v_0^2/Dg$

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Question 2 (continued)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

For any indication that the work done on the block as it slides is equal to its initial kinetic energy — *1 point*

$f_{fric}d = \frac{1}{2}mv_i^2$

For a correct expression for the work done on the block — *1 point*

For a correct expression for the initial kinetic energy of the block — *1 point*

$\mu(1.5M)gD = \frac{1}{2}(1.5M)(2v_0)^2$

For the correct answer — *1 point*

$\mu = \frac{2v_0^2}{Dg}$

(d) 3 points

For indicating that the collision is inelastic — 1 point

For indicating that the reason it is inelastic is because the change in kinetic energy is not zero, or because kinetic energy is lost in the collision — 1 point

For showing that the change in kinetic energy is not zero — 1 point

$\Delta K = K_f - K_i = \left[\frac{1}{2}M(0.5v_0)^2 + \frac{1}{2}(1.5M)(2v_0)^2\right] - \frac{1}{2}M(3.5v_0)^2$

$\Delta K = -3Mv_0^2$

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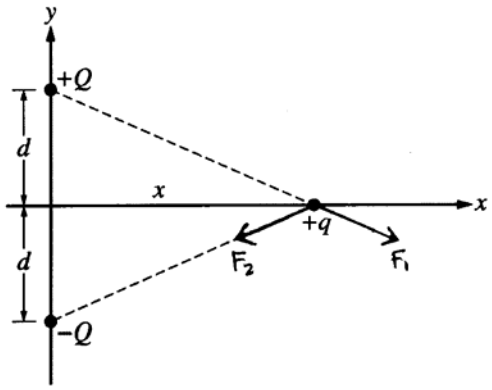
Question 3

15 points total **Distribution of points**

(a) 2 points



For indicating the correct direction for the force due to the $+Q$ charge (F_1 as drawn above) 1 point

For indicating the correct direction for the force due to the $-Q$ charge (F_2 as drawn above) 1 point

(b) 6 points

For any indication that the magnitudes of F_1 and F_2 are the same 1 point

The x-components of F_1 and F_2 cancel.

For any indication that the magnitude of the net force is the sum of the y-components of F_1 and F_2, which are equal 1 point

Example: $F_{total} = F_1\cos\theta + F_2\cos\theta = 2F\cos\theta$, where θ is the angle between the y-axis and the dashed lines in the figure

For a correct expression for $\cos\theta$ 1 point

$$\cos\theta = \frac{d}{\sqrt{x^2 + d^2}}$$

For a correct substitution for F into the above expression for F_{total} 1 point

$$F = \frac{kqQ}{r^2} = \frac{kqQ}{x^2 + d^2}$$

$$F_{total} = 2\frac{kqQ}{x^2 + d^2}\frac{d}{\sqrt{x^2 + d^2}}$$

For the correct magnitude of the total force 1 point

$$F_{total} = \frac{2kqQd}{\left(x^2 + d^2\right)^{3/2}} \quad \text{or equivalent}$$

For indicating the correct direction for the total force, e.g., negative y-direction, toward the bottom of the page, etc. 1 point

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Question 3 (continued)

Distribution of points

(c) 2 points

The field can be found from the force.

$E = F_{total}/q$

For the correct magnitude of the electric field — 1 point

$$E = \frac{2kQd}{\left(x^2 + d^2\right)^{3/2}}$$

For indicating the correct direction for the electric field, e.g., negative y-direction, toward the bottom of the page, etc. — 1 point

(d) 2 points

The total potential is the sum of the individual point charge potentials.

$$V = V_1 + V_2 = \frac{kQ}{\sqrt{x^2 + d^2}} + \frac{-kQ}{\sqrt{x^2 + d^2}}$$

For indicating that the electric potential is zero — 2 points

Note: One point partial credit could be earned for only recognizing that the potentials from the two charges must be added.

(e) 3 points

For any indication that as x gets large, the hypotenuse and x are approximately equal or d is negligible compared to x — 1 point

For indicating that the above implies that $\sqrt{x^2 + d^2} \approx x$ — 1 point

For indicating that substituting the approximate equality into the answer from part (b) yields $F_{total} = \frac{2kqQd}{x^3}$ — 1 point

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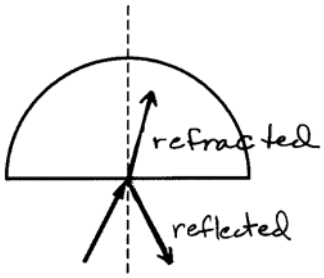
Question 4

15 points total **Distribution of points**

(a)



(i) 2 points

For drawing a reflected ray at approximately the same angle to the normal as the incident ray — 1 point

For clearly indicating that this is the reflected ray — 1 point

(ii) 4 points

Snell's law is used to find the angle of refraction

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

For correctly substituting values into Snell's law — 1 point

$1.0 \sin 27° = 1.51 \sin\theta_2$

$\sin\theta_2 = \sin 27°/1.51 = 0.30$

For the correct value of the angle — 1 point

$\theta_2 = 17.5°$

For drawing a ray at approximately the correct angle — 1 point

For clearly indicating that this is the refracted ray — 1 point

(iii) 1 point

The speed in the block can be determined using the definition of index of refraction.

$v = c/n = \left(3.00 \times 10^8 \text{ m/s}\right)/1.51$

For the correct answer — 1 point

$v = 1.99 \times 10^8 \text{ m/s}$

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Question 4 (continued)

Distribution of points

(a) (continued)

(iv) 2 points

For a statement that the frequency is the same in the two materials, or an equation that is an application of that fact — 1 point

$$f = \frac{v_{\text{air}}}{\lambda_{\text{air}}} = \frac{v_{\text{plastic}}}{\lambda_{\text{plastic}}} \qquad \lambda_{\text{plastic}} = \frac{v_{\text{plastic}}\lambda_{\text{air}}}{v_{\text{air}}}$$

OR $\lambda_{plastic} = \frac{\lambda_{air}}{n}$

$$\lambda_{\text{plastic}} = \frac{1.99 \times 10^8 \text{ m/s}}{3 \times 10^8 \text{ m/s}}(650 \text{ nm}) \quad \text{OR} \quad \lambda_{plastic} = \frac{650 \text{ nm}}{1.51}$$

For the correct answer with units — 1 point

λ_{plastic} = 431 nm OR 430 nm

(b) 2 points

The following points were only awarded if rays were shown or described in part (a)

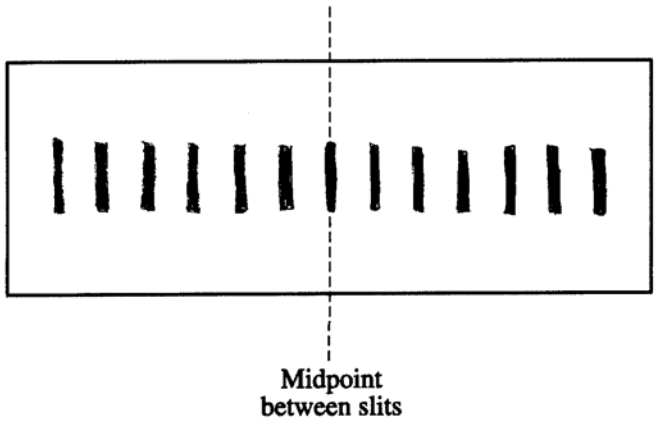
For indicating that the angle of reflection does not change — 1 point

For indicating that the angle of refraction becomes smaller — 1 point

(c)

(i) 2 points

Example in which the dark lines in the drawn pattern represent the bright bands of blue light



For indicating a central peak in the pattern — 1 point

For having approximately even spacing between maxima — 1 point

A sketch of the intensity graph was also acceptable

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Question 4 (continued)

Distribution of points

(c) (continued)

(ii) 2 points

For using an appropriate formula (or combination of formulas) and correctly substituting — 1 point

For example

$$x_m \approx \frac{m\lambda L}{d}$$

$$x_m \approx \frac{(1)\left(450 \times 10^{-9}\ \text{m}\right)(1.4\ \text{m})}{0.15 \times 10^{-3}\ \text{m}}$$

For the correct answer — 1 point

$x = 4.2$ mm

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Question 5

10 points total **Distribution of points**

(a)

(i) 2 points

From the ideal gas law, $PV/T =$ a constant

Points A and B are on the isothermal, so they are at the same temperature.

Therefore, $P_B V_B = P_A V_A$

$P_B 2V_0 = P_A V_0$

For the correct answer 1 point

$\frac{P_B}{P_A} = \frac{1}{2}$

For a correct justification (such as the reasoning shown above) 1 point

(ii) 2 points

Points C and B are at the same pressure.

Therefore, $\frac{P_C}{P_A} = \frac{P_B}{P_A}$

For the correct answer 1 point

$\frac{P_C}{P_A} = \frac{1}{2}$

For a correct justification (such as the reasoning shown above) 1 point

(iii) 2 points

Points A and B are on the isothermal, so they are at the same temperature.

For the correct answer 1 point

$\frac{T_B}{T_A} = 1$

For a correct justification (such as the reasoning shown above) 1 point

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Question 5 (continued)

Distribution of points

(a) (continued)

(iv) 2 points

Points C and A are at the same volume.

Therefore, from the ideal gas law $\frac{P_C}{P_A} = \frac{T_C}{T_A}$.

$\frac{P_C}{P_A} = \frac{1}{2}$, which was determined in part (ii) above

For the correct answer 1 point

$\frac{T_C}{T_A} = \frac{1}{2}$

For a correct justification (such as the reasoning shown above) 1 point

(b) 1 point

For a correct explanation 1 point

Internal energy depends only on the temperature. Since step I is isothermal there is no change in temperature and thus no change in internal energy

(c) 1 point

For a correct explanation 1 point

$W = -P\Delta V$. In step III there is no change in volume, and thus no work done.

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Question 6

10 points total **Distribution of points**

(a) 1 point

For a correct expression for kinetic energy 1 point
$K = mv^2/2$
Note: This point was only awarded if no extraneous energy formulas were used.

(b) 2 points

For using the correct expression for de Broglie wavelength 1 point
$\lambda = h/p$
For the correct answer in terms of the given quantities 1 point
$\lambda = h/mv$

(c) 2 points

For a correct expression for the total energy of the electron and positron 1 point
$E_{total} = 2\left(mv^2/2 + mc^2\right)$
Can also add that since $v << c$, $E_{total} \approx 2mc^2$
The two photons share this energy equally.
For the correct answer 1 point
$E_{photon} = mv^2/2 + mc^2$ OR $E_{photon} \approx mc^2$

(d) 3 points

For using the given expression for the photon energy 1 point
$E_{photon} = hf$
For expressing the energy in terms of the wavelength 1 point
$f = c/\lambda$ so $E_{photon} = hc/\lambda$
Substituting the energy obtained in part (c)
$mv^2/2 + mc^2 = hc/\lambda$ OR $mc^2 = hc/\lambda$
For the correct answer 1 point
$\lambda = 2hc/\left(mv^2 + 2mc^2\right)$ OR $\lambda = h/mc$

(e) 2 points

For any indication that conservation of momentum applies 1 point
For a correct explanation of why conservation of momentum requires two photons 1 point
Example: since the total momentum of the electron and positron was zero, the total momentum of the products must be zero. Since a photon cannot have zero momentum, two photons traveling in opposite directions are required.
Note: Only 1 point total was awarded for attempts to explain using Newton's third law.

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AP® Physics B
2005 Free-Response Questions

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TABLE OF INFORMATION FOR 2005

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}(\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}(\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta\mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P + \rho gy + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$P = \frac{F}{A}$

$PV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
ℓ = length
M = molar mass
n = number of moles
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$\sin \theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin \theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

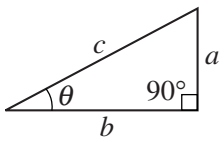
$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

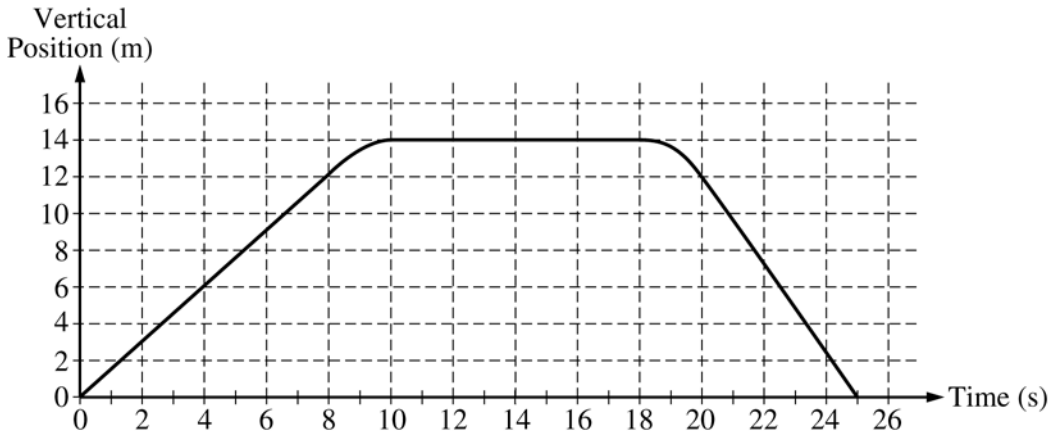
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin \theta = \frac{a}{c}$
$\cos \theta = \frac{b}{c}$
$\tan \theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
7 Questions

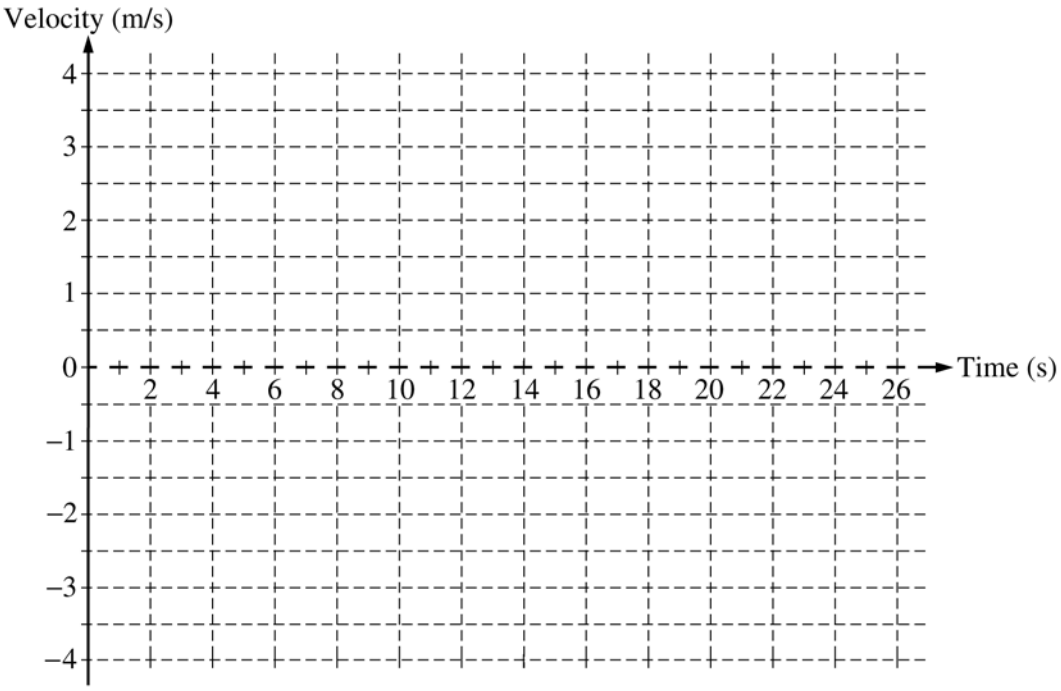
Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 11 minutes for answering each of questions 1-2 and 5-7, and about 17 minutes for answering each of questions 3-4. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (10 points)

The vertical position of an elevator as a function of time is shown above.

(a) On the grid below, graph the velocity of the elevator as a function of time.



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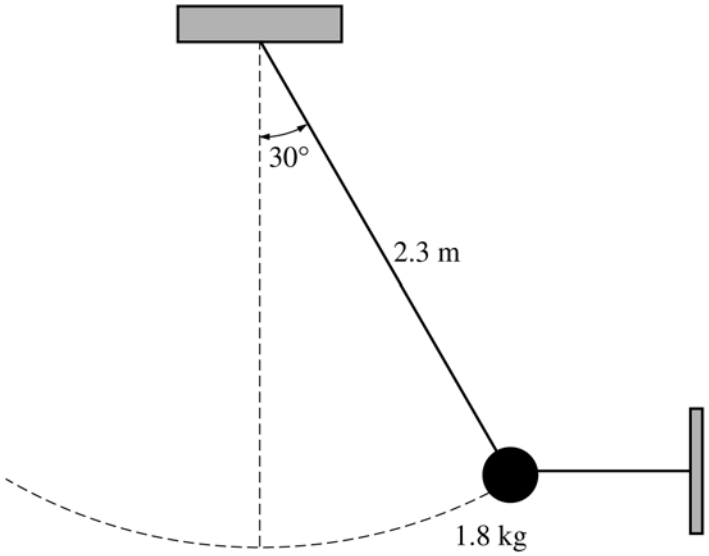
(b)

i. Calculate the average acceleration for the time period $t = 8$ s to $t = 10$ s.

ii. On the box below that represents the elevator, draw a vector to represent the direction of this average acceleration.



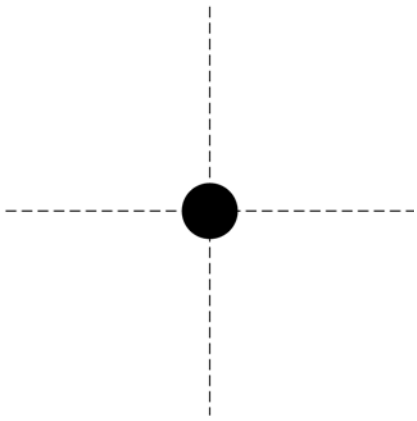
(c) Suppose that there is a passenger of mass 70 kg in the elevator. Calculate the apparent weight of the passenger at time $t = 4$ s.



2. (10 points)

A simple pendulum consists of a bob of mass 1.8 kg attached to a string of length 2.3 m. The pendulum is held at an angle of 30° from the vertical by a light horizontal string attached to a wall, as shown above.

(a) On the figure below, draw a free-body diagram showing and labeling the forces on the bob in the position shown above.



(b) Calculate the tension in the horizontal string.

(c) The horizontal string is now cut close to the bob, and the pendulum swings down. Calculate the speed of the bob at its lowest position.

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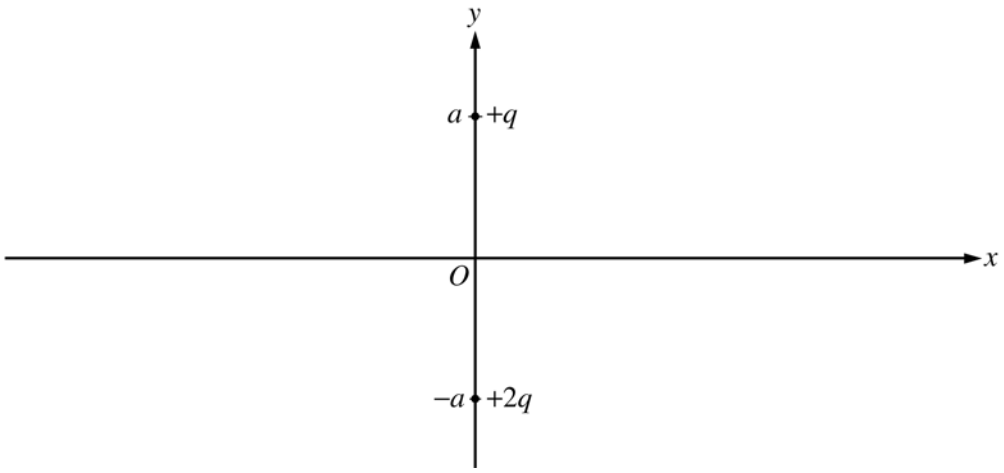


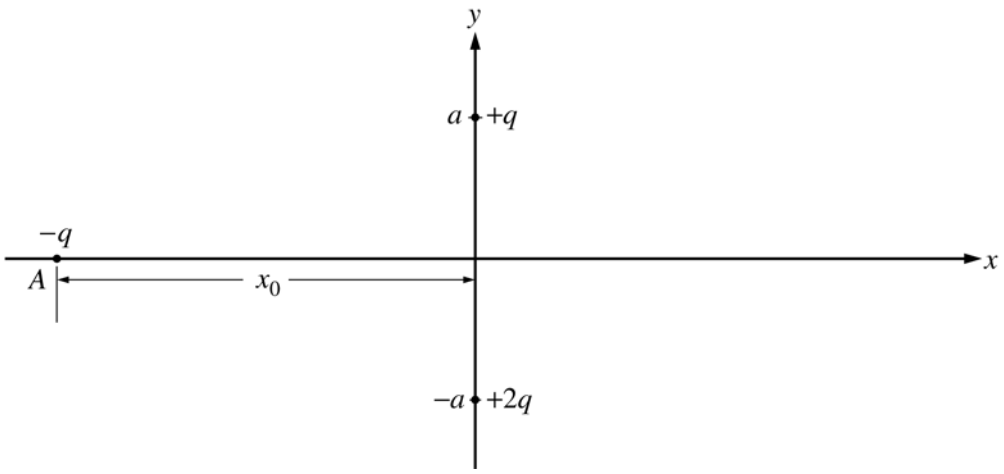
3. (15 points)

Two point charges are fixed on the y-axis at the locations shown in the figure above. A charge of $+q$ is located at $y = +a$ and a charge of $+2q$ is located at $y = -a$. Express your answers to parts (a) and (b) in terms of q, a, and fundamental constants.

(a) Determine the magnitude and direction of the electric field at the origin.

(b) Determine the electric potential at the origin.

A third charge of $-q$ is first placed at an arbitrary point A ($x = -x_0$) on the x-axis as shown in the figure below.



(c) Write expressions in terms of q, a, x_0, and fundamental constants for the magnitudes of the forces on the $-q$ charge at point A caused by each of the following.

i. The $+q$ charge

ii. The $+2q$ charge

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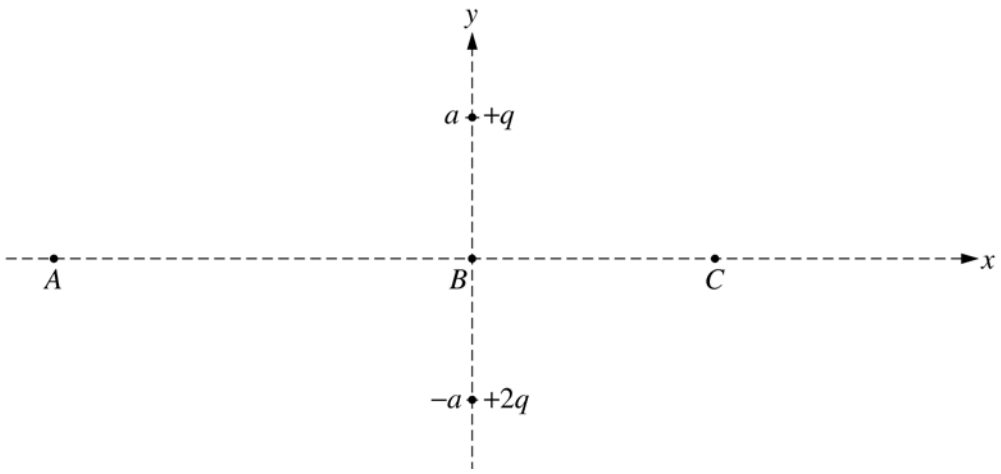
(d) The $-q$ charge can also be placed at other points on the x-axis. At each of the labeled points (A, B, and C) in the following diagram, draw a vector to represent the direction of the net force on the $-q$ charge due to the other two charges when it is at those points.



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4. (15 points)

Your teacher gives you a slide with two closely spaced slits on it. She also gives you a laser with a wavelength $\lambda = 632$ nm. The laboratory task that you are assigned asks you to determine the spacing between the slits. These slits are so close together that you cannot measure their spacing with a typical measuring device.

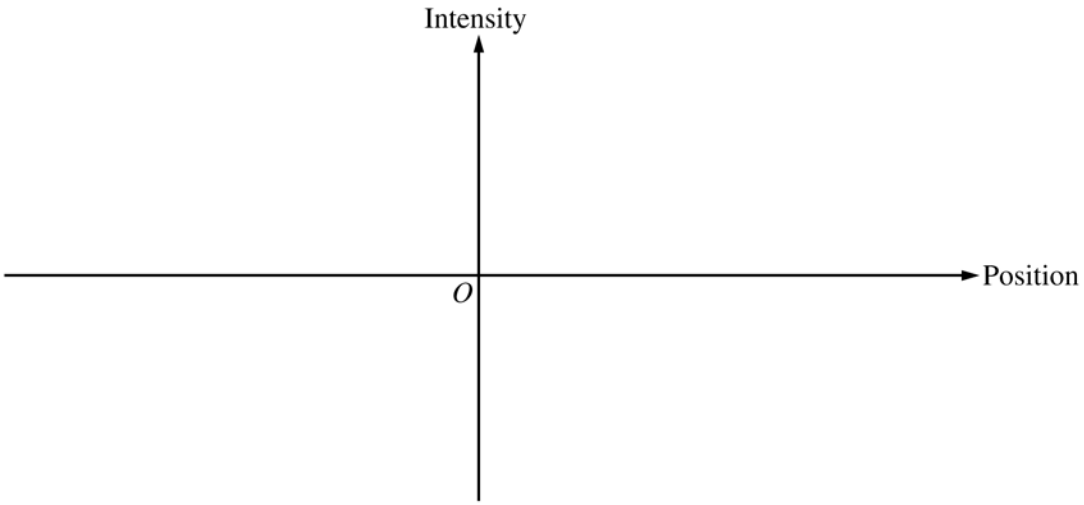
(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.

___ Meterstick ___ Ruler ___ Tape measure ___ Light-intensity meter

___ Large screen ___ Paper ___ Slide holder ___ Stopwatch

(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify carefully what measurements you will need to make.

(c) On the axes below, sketch a graph of intensity versus position that would be produced by your setup, assuming that the slits are very narrow compared to their separation.



(d) Outline the procedure that you would use to make the needed measurements, including how you would use each piece of the additional equipment you checked in (a).

(e) Using equations, show explicitly how you would use your measurements to calculate the slit spacing.

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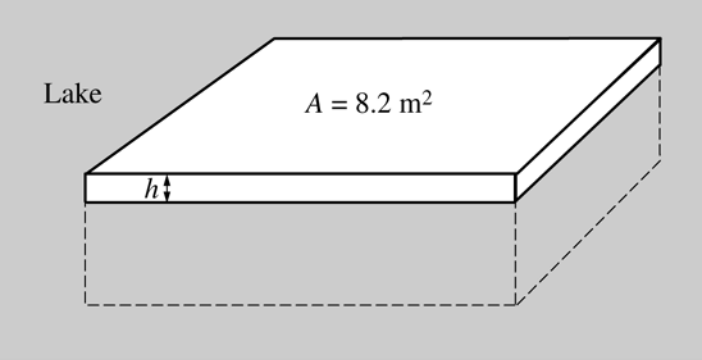

Note: Figure not drawn to scale.

5. (10 points)

A large rectangular raft (density 650 kg/m^3) is floating on a lake. The surface area of the top of the raft is 8.2 m^2 and its volume is 1.80 m^3. The density of the lake water is 1000 kg/m^3.

(a) Calculate the height h of the portion of the raft that is above the surrounding water.

(b) Calculate the magnitude of the buoyant force on the raft and state its direction.

(c) If the average mass of a person is 75 kg, calculate the maximum number of people that can be on the raft without the top of the raft sinking below the surface of the water. (Assume that the people are evenly distributed on the raft.)

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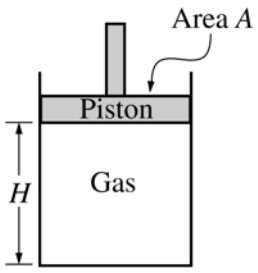


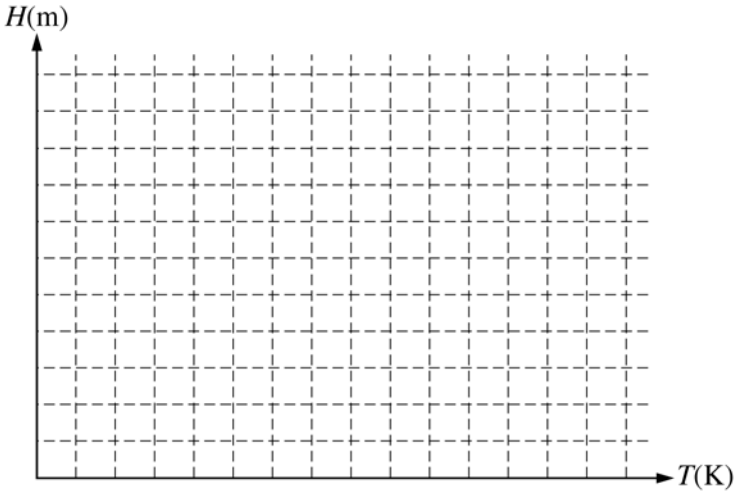
6. (10 points)

An experiment is performed to determine the number n of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area A. The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure P remains constant. Measurements are made of the temperature T of the gas and the height H of the bottom of the piston above the base of the cylinder and are recorded in the table below. Assume that the thermal expansion of the apparatus can be ignored.

T (K)	H (m)
300	1.11
325	1.19
355	1.29
375	1.37
405	1.47

(a) Write a relationship between the quantities T and H, in terms of the given quantities and fundamental constants, that will allow you to determine n.

(b) Plot the data on the axes below so that you will be able to determine n from the relationship in part (a). Label the axes with appropriate numbers to show the scale.



(c) Using your graph and the values $A = 0.027$ m^2 and $P = 1.0$ atmosphere, determine the experimental value of n.

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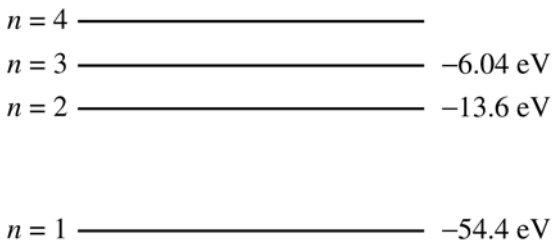

Note: Energy levels not drawn to scale.

7. (10 points)

The diagram above shows the lowest four discrete energy levels of an atom. An electron in the $n = 4$ state makes a transition to the $n = 2$ state, emitting a photon of wavelength 121.9 nm.

(a) Calculate the energy level of the $n = 4$ state.

(b) Calculate the momentum of the photon.

The photon is then incident on a silver surface in a photoelectric experiment, and the surface emits an electron with maximum possible kinetic energy. The work function of silver is 4.7 eV.

(c) Calculate the kinetic energy, in eV, of the emitted electron.

(d) Determine the stopping potential for the emitted electron.

END OF EXAM

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AP® Physics B
2005 Scoring Guidelines

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AP® PHYSICS B
2005 SCORING GUIDELINES

General Notes About 2005 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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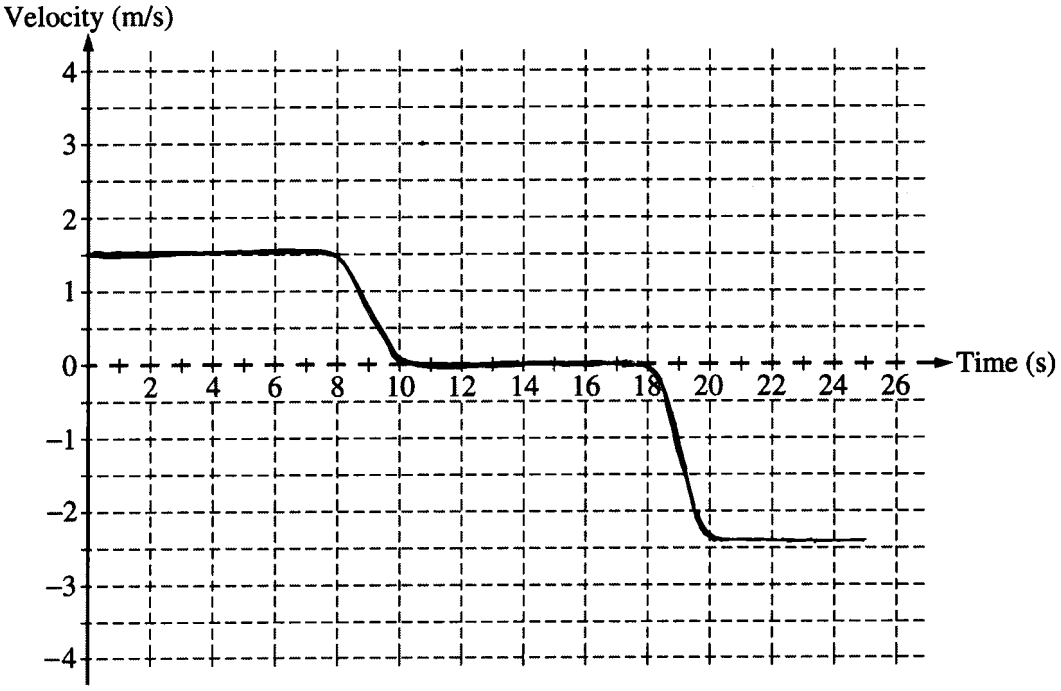
Question 1

10 points total **Distribution of points**

(a) 4 points



The velocities can be found from the slope of the position graph.

For showing a positive velocity of magnitude 1.5 m/s (i.e., 12 m/8 s) between 0 s and 8 s inclusive — 1 point

For showing zero velocity between 10 s and 18 s inclusive — 1 point

For showing a negative velocity of magnitude 2.4 m/s (i.e., 12 m/5 s) between 20 s and 25 s inclusive — 1 point

For showing two nonvertical transition regions; between t = 8 s and 10 s and between t = 18 s and 20 s — 1 point

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Question 1 (continued)

Distribution of points

(b)

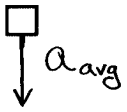
(i) 3 points

For a definition or equation for average acceleration — 1 point
$a_{avg} = \Delta v/\Delta t$ OR $v = v_0 + at$

For the correct substitution from part (a) — 1 point
$a_{avg} = (0 - 1.5 \text{ m/s})/2 \text{ s}$

For the correct answer including units and sign — 1 point
$a_{avg} = -0.75 \text{ m/s}^2$

(ii) 1 point



For a correctly drawn vector, with or without a label — 1 point

(c) 2 points

The acceleration is zero, so the normal force (apparent weight) is equal to the gravitational force.

For a correct relationship leading to a calculation of apparent weight — 1 point
$N = W = mg$ OR $N - W = ma$
$W_{app} = (70 \text{ kg})(9.8 \text{ m/s}^2)$

For the correct answer with units — 1 point
$W_{app} = 686 \text{ N}$ (or 700 N using $g = 10 \text{ m/s}^2$)

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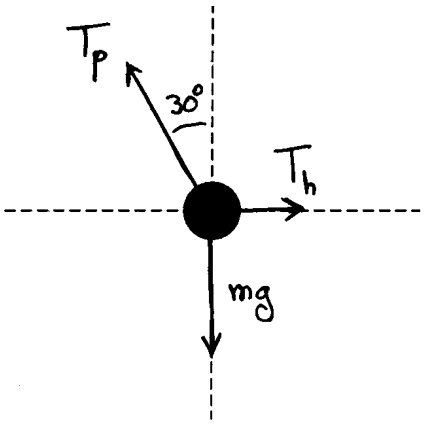
Question 2

10 points total **Distribution of points**

(a) 2 points



For each correctly drawn and labeled tension, with arrowhead in right direction — 1 point each

One point was deducted for each of the following until score reached zero:
- No force of gravity
- Each extraneous force
- Any missing labels

Drawing all forces along correct lines with labels but no arrowheads received only one point.

Components of the tension in the pendulum string could be included in addition to or instead of the net tension, as long as they were clearly labeled as such.

(b) 4 points

For any indication that the net force is zero — 1 point

For an attempt to determine the components of the tension in the pendulum string — 1 point

For correctly determining these components — 1 point

$T_h = T_p \sin 30°$

$mg = T_p \cos 30°$

$\frac{T_h}{mg} = \frac{\sin 30°}{\cos 30°} = \tan 30°$

$T_h = mg \tan 30°$

$T_h = (1.8 \text{ kg})\left(9.8 \text{ m/s}^2\right)\tan 30°$

For the correct answer with units — 1 point

$T_h = 10 \text{ N}$

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Question 2 (continued)

Distribution of points

(b) (continued)

Alternate solution — *Alternate points*

For indicating that the addition of the three force vectors gives a 30-60-90 right triangle — *2 points*

For a correct trigonometric relationship between forces — *1 point*

$\frac{T_h}{mg} = \tan 30°$

For the correct answer with units — *1 point*

$T_h = 10$ N

If no forces were drawn in part (a), one point could be earned for writing the component equations $T = mg\sin\theta$ and $T = mg\cos\theta$, and two points for $T = mg\tan\theta$.

(c) 4 points

For any indication of conservation of energy — 1 point

For any indication of the need to use a change in height — 1 point

$mgh_0 + \frac{1}{2}mv_0^2 = mgh_f + \frac{1}{2}mv_f^2$

For setting $v_0 = 0$ — 1 point

$\frac{1}{2}mv_f^2 = mg\,\Delta h$

$v_f = \sqrt{2g\,\Delta h}$

$\Delta h = L - L\cos 30°$

$v_f = \sqrt{2gL(1-\cos 30°)}$

$v_f = \sqrt{2\left(9.8\ \text{m/s}^2\right)(2.3\ \text{m})(1-\cos 30°)}$

For the correct answer, with units — 1 point

$v_f = 2.5$ m/s

A solution that used the kinematic equation $v_f^2 = v_0^2 + 2as$ could only receive full credit if the student explained how the equation is equivalent to conservation of energy.

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Question 3

15 points total **Distribution of points**

(a) 4 points

For use of the correct formula for the electric field E 1 point

$E = k\frac{q}{r^2}$ OR $E = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$

For adding the two E vectors from the charges 1 point

$E_O = \left|\left(+k\frac{2q}{a^2}\right) + \left(-k\frac{q}{a^2}\right)\right|$

For the correct (positive) expression for the magnitude of the field 1 point

$E_O = k\frac{q}{a^2}$

For any indication that the field is in the +y-direction 1 point

(b) 3 points

For use of the correct formula for the potential V 1 point

$V = k\frac{q}{r}$ OR $V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$

For adding the two potentials 1 point

$V_O = \left|k\frac{2q}{a} + k\frac{q}{a}\right|$

For the correct (positive) answer 1 point

$V_O = \frac{3kq}{a}$

(c) (i) and (ii) 4 points

For determining the distance r between charges in terms of x_0 and a in either part (i) or (ii) 1 point

$r = \sqrt{x_0^2 + a^2}$

For use of Coulomb's law in either part (i) or (ii) 1 point

$F = k\frac{q_1 q_2}{r^2}$

For *both* correct substitution of charges into Coulomb's law *and* correct substitution of the previously determined expression for r in either part (i) or (ii) 1 point

For correct (positive) answer for both part (i) and (ii) 1 point

For part (i): $F_q = \left|k\frac{(-q)(q)}{x_0^2 + a^2}\right| = k\frac{q^2}{x_0^2 + a^2}$

For part (ii): $F_q = \left|k\frac{(-q)(2q)}{x_0^2 + a^2}\right| = k\frac{2q^2}{x_0^2 + a^2}$

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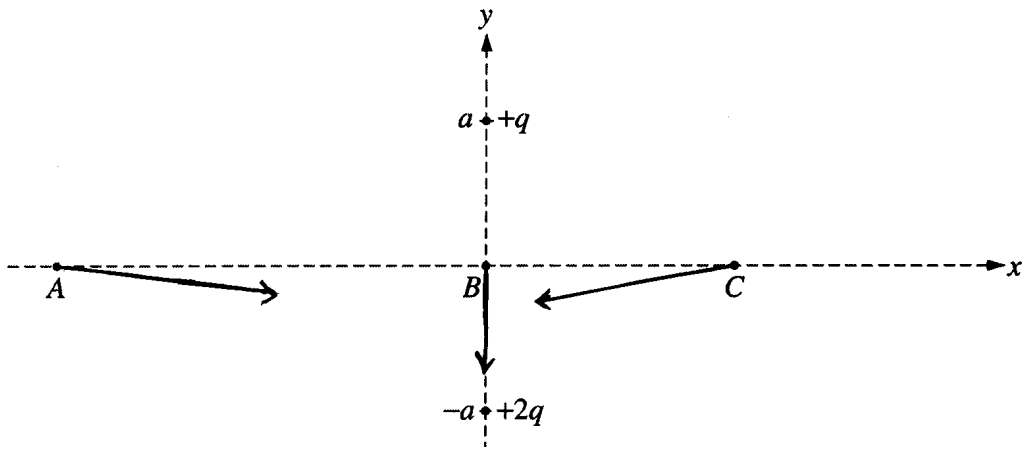
Question 3 (continued)

Distribution of points

(d) 4 points



For having all three vectors on the same side of the *x*-axis (i.e., recognizing that the vertical components should all be in the same direction) 1 point

For a single resultant vector from *A* pointing down and to the right, toward a point below the *x*-axis and above +2*q* 1 point

For a single resultant vector from *C* pointing down and to the left, toward a point below the *x*-axis and above +2*q* 1 point

For a single resultant vector pointing straight down from *B* 1 point

Magnitudes of the vectors and any components that may have been drawn were not evaluated.

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AP® PHYSICS B
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Question 4

15 points total **Distribution of points**

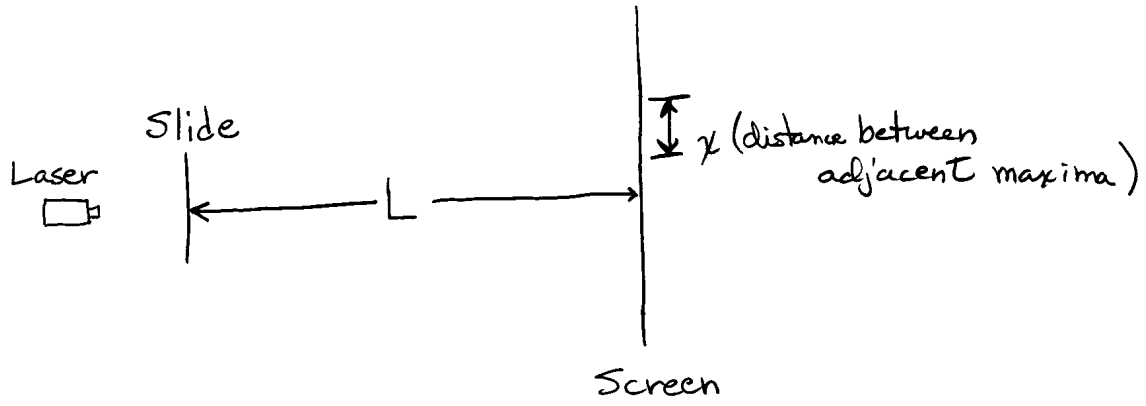
(a) 2 points

For checking any length-measuring device and not the stopwatch 2 points
Only one point was awarded for checking any length-measuring device and the stopwatch.
No points were awarded if no length-measuring device was checked or all the equipment was checked.

(b) 3 points

For a diagram including at least a laser, a slide, and a screen 1 point
For correctly labeling the equipment 1 point
For correctly identifying the two distances to be measured, with symbols 1 point

Example diagram:



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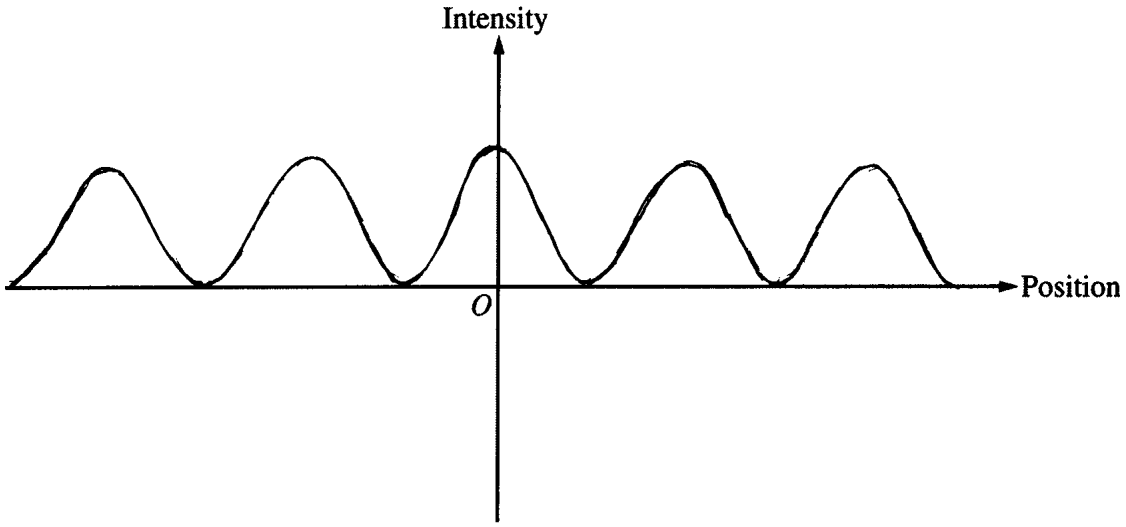
Question 4 (continued)

Distribution of points

(c) 3 points



Points could only be earned in the following order, with each successive point dependent on earning the previous point.

For a central maximum	1 point
For a continuous graph with approximately equally spaced maxima	1 point
For nothing else incorrect (e.g., no negative intensity)	1 point

(d) 4 points

For appropriate use of equipment (including all items checked in (a))	1 point
For indicating a measurement of the distance from the slits to the screen	1 point
For indicating appropriate measurements of the maxima (e.g., the distance between adjacent maxima or the distance of successive maxima from the center)	1 point
For a complete and clear description	1 point

For example:

Set up the laser to shine on the slide, and set the screen far away on the other side of the slide.

Measure the distance L from the slide to the screen with the tape measure.

Use the ruler to measure the distance x between adjacent maxima.

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Question 4 (continued)

Distribution of points

(e) 3 points

Points could only be earned in the following order, with each successive point dependent on earning the previous point.

For using appropriate equations 1 point

For explicitly identifying, in some other part of the question, the symbols used here 1 point

For correct correlation of symbols in equations to symbols in diagram in part (b) 1 point

$x_m \approx \frac{m\lambda L}{d}$ OR $d \sin = m\lambda$ and $\tan\theta = \frac{x_m}{L}$ (since $\sin\theta \approx \tan\theta$ for small angles), where m is an integer, x_m is the distance of a maximum of order m from the central maximum, λ is the wavelength, L is the distance between slits and the screen, and d is the slit separation

Solving for d

$d \approx \frac{\lambda L}{x}$ using distances x between adjacent maxima and $\Delta m = 1$

OR $d \approx \frac{m\lambda L}{x_m}$ using distances from center of pattern

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Question 5

10 points total **Distribution of points**

(a) 3 points

For an equation that uses the ratio of densities ρ_r / ρ_w to find the fraction of the total volume (or height) submerged 1 point

The weight of the raft equals the weight of the displaced water.

$W_r = W_w$

$m_r g = m_w g$

$\rho_r V_r g = \rho_w V_w g$

Solving for the volume of displaced water, which equals the submerged volume of the raft

$$V_w = \frac{\rho_r}{\rho_w} V_r$$

For recognizing that the submerged volume (or height) must be subtracted from the total volume (or height) 1 point

$V_{submerged} = Ah = V_r - V_w$

$$Ah = V_r - \frac{\rho_r}{\rho_w} V_r = V_r \left(1 - \frac{\rho_r}{\rho_w}\right)$$

$$h = \frac{V_r}{A}\left(1 - \frac{\rho_r}{\rho_w}\right)$$

$$h = \frac{1.8 \text{ m}^3}{8.2 \text{ m}^2}\left(1 - \frac{650 \text{ kg/m}^3}{1000 \text{ kg/m}^3}\right)$$

For the correct answer 1 point

$h = 0.077$ m

Some students misinterpreted the statement about the volume of the raft, taking it to mean the volume of the part above the water instead of the total volume. If the solution to part (b) showed work that demonstrated understanding of the concepts needed for part (a), appropriate credit for this part was awarded.

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Question 5 (continued)

Distribution of points

(b) 4 points

For indicating that the buoyant force is equal to the weight of the raft — 1 point

$F_{buoy} = W_r$

For correct substitutions for calculating the buoyant force, either by directly calculating the raft's weight or calculating the weight of the displaced water — 1 point

$F_{buoy} = \rho_r V_r g = \left(650\ \text{kg/m}^3\right)\left(1.80\ \text{m}^3\right)\left(9.8\ \text{m/s}^2\right)$

OR $F_{buoy} = \rho_w V_w g = \left(1000\ \text{kg/m}^3\right)\left(1.17\ \text{m}^3\right)\left(9.8\ \text{m/s}^2\right)$

For the correct answer with units — 1 point

$F_{buoy} = 1.15 \times 10^4\ \text{N}$ (or $1.17 \times 10^4\ \text{N}$ using $g = 10\ \text{m/s}^2$)

For indicating that the direction of the buoyant force is up — 1 point

(c) 3 points

The additional weight that can be carried is equal to the weight of water displaced by the part of the raft now above water.

For indicating a correct equation for the net force — 1 point

$W_{addl} = W_{extra\ water}$ OR $W_{addl} = F_{buoyNEW} - W_{raft}$

The first equation above yields $W_{addl} = \rho_w V_{top} g = \rho_w A h g$

Substituting the algebraic expression for h from part (a) and simplifying yields $W_{addl} = \rho_w V_r g - \rho_r V_r g = V_r g\left(\rho_w - \rho_r\right)$, which is equivalent to substitution into the second equation above.

For correct numerical substitutions to get the weight (or mass) of the top of the raft — 1 point

$W_{addl} = \left(1.80\ \text{m}^3\right)\left(9.8\ \text{m/s}^2\right)\left(1000\ \text{kg/m}^3 - 650\ \text{kg/m}^3\right)$

$W_{addl} = 6200\ \text{N}$ (variation due to rounding earlier on was accepted)

For dividing the total weight (or mass) by the weight (or mass) of a person and indicating the correct number of people that the raft can carry. (The final answer must indicate a *whole* number of people.) — 1 point

$$n = \frac{W_{addl}}{m_p g} = \frac{6200\ \text{N}}{(75\ \text{kg})\left(9.8\ \text{m/s}^2\right)} = 8.4$$

A maximum of 8 people can be on the raft.

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Question 6

10 points total **Distribution of points**

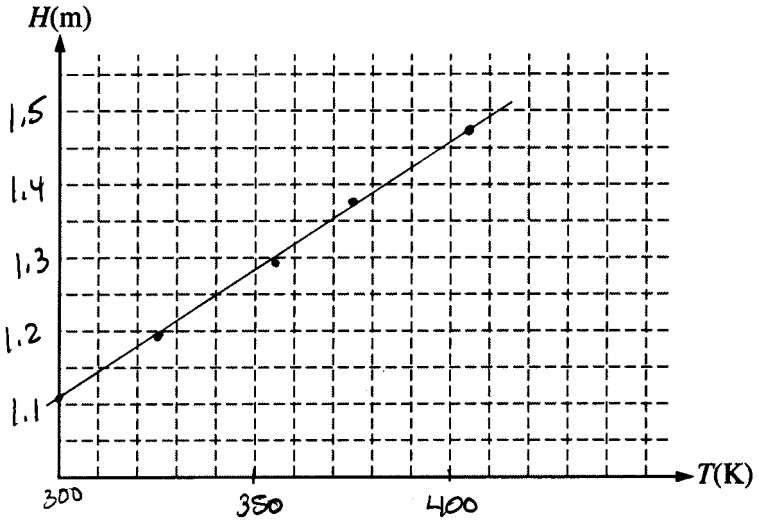
(a) 2 points

For writing the ideal gas equation of state 1 point
$PV = nRT$
For an indication that $V = AH$ 1 point
$PAH = nRT$
$H = \frac{nR}{PA}T$
Note: Simply writing $PAH = nRT$ or the equivalent earned both points. If the student tried to rearrange the equation, algebra mistakes were not penalized in this part.

(b) 4 points

For labeling both axes with linear numerical scales 1 point
For having neither axis labeled with its scale starting at zero (no penalty for showing zero at the end of an axis and a "break" in the axis) 1 point
For accurately plotting five data points that closely fit a straight line with a positive slope 2 points
One point was lost if some points were inaccurately plotted.
Both points were lost if the data points were not visible, even if a line was drawn.

Example answer shown below. The question did not ask for a best-fit line, and it was not required for this part. However, a line is shown in the example, since it could be used in the determination of *n*.



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Question 6 (continued)

Distribution of points

(c) 4 points

From part (a), $H = \frac{nR}{PA}T$

For any clear indication that the student used more than one data point — 1 point

For example: Setting up a slope calculation using subtraction, averaging calculated values for n or the ratio H/T, or using a linear regression on the calculator

For the correct slope of a best-fit line through the data points (this point not awarded if slope method not used) — 1 point

For correct substitutions into a correct expression containing n using consistent units for the values of P, R, A, and H — 1 point

Example using the line shown above, which happens to go through the first and last data points

$$\text{Slope of line} = \frac{nR}{PA}$$

$$\text{Slope} = \frac{(1.47 - 1.11)\text{m}}{(405 - 300)\text{K}} = \frac{0.36\text{ m}}{105\text{ K}}$$

$$n = \frac{PA}{R}(\text{slope})$$

$$n = \frac{\left(1 \times 10^5\text{ Pa}\right)\left(0.027\text{ m}^2\right)}{8.31\text{ J/(mol•K)}}\left(\frac{0.36\text{ m}}{105\text{ K}}\right)$$

For a numerical answer that follows from substitutions into the correct expression above — 1 point

$n = 1.11$ moles

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Question 7

10 points total **Distribution of points**

(a) 4 points

For a correct calculation of the photon frequency 1 point

$f = \frac{c}{\lambda}$

$f = \left(3.00 \times 10^{8}\ \text{m/s}\right) / \left(1.219 \times 10^{-7}\,\text{m}\right) = 2.46 \times 10^{15}\,\text{Hz}$

For correct calculation of the photon energy in electron-volts or joules 1 point

$E_{\text{ph}} = hf = \left(4.14 \times 10^{-15}\ \text{eV•s}\right)\left(2.46 \times 10^{15}\ \text{Hz}\right) = 10.2\ \text{eV}$ OR $1.63 \times 10^{-18}\ \text{J}$

The two points above were also awarded for correctly using $E = hc/\lambda$ or using $E = pc$ and the answer from part (b).

For indicating that the photon energy is the difference between the two energy levels 1 point

$E_4 = E_2 + E_{\text{ph}}$

$E_4 = -13.6\ \text{eV} + 10.2\ \text{eV}$

For the correct numerical answer 1 point

$E_4 = -3.4\ \text{eV}$ OR $-5.44 \times 10^{-19}\ \text{J}$

Alternate solution *Alternate points*

For use of energy levels and the Bohr model* *1 point*

$E_n = E_1 / n^2$

For identifying the ground state energy *1 point*

$E_1 = -54.4\ \text{eV}$

For using the correct quantum number *1 point*

$n = 4$

For the correct answer *1 point*

$E_4 = -3.4\ \text{eV}$

*Note: This equation is not on the equation sheet, nor is the Bohr model part of the Physics B curriculum. However, students were given credit for this correct solution.

(b) 2 points

$p = h/\lambda$ OR $p = E/c$

For substitution of appropriate values into either of the above equations 1 point

$p = \left(6.63 \times 10^{-34}\ \text{J•s}\right) / \left(121.9 \times 10^{-9}\,\text{m}\right)$ OR $p = \left(1.63 \times 10^{-18}\,\text{J}\right) / \left(3.00 \times 10^{8}\,\text{m/s}\right)$

For the correct answer with correct units 1 point

$p = 5.44 \times 10^{-27}\ \text{kg•m/s}$ (or $3.40 \times 10^{-8}\ \text{eV•s/m}$)

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Question 7 (continued)

Distribution of points

(c) 2 points

$K_{max} = E_{ph} - \phi$

For correct substitution of photon energy from part (a), or a calculation of it — 1 point

$K_{max} = 10.2 \text{ eV} - 4.7 \text{ eV}$

For the correct answer in eV — 1 point

$K_{max} = 5.5 \text{ eV}$

(d) 2 points

$K_{max} = W = qV$

For using the definition of an eV as the work required to move a charge e through a 1-volt potential difference — 1 point

For the correct answer with units of volts — 1 point

$V = 5.5 \text{ V}$

Alternate solution — *Alternate points*

For understanding the relationship between electrical potential and energy — *1 point*

$V = K_{max}/q$

$V = (5.5 \text{ eV})\left(1.6 \times 10^{-19} \text{ J/eV}\right)/\left(1.6 \times 10^{-19} \text{ C}\right)$

For the correct answer with units of volts — *1 point*

$V = 5.5 \text{ V}$

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AP® Physics B
2005 Free-Response Questions
Form B

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CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, W represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta \mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta \phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P + \rho gy + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$P = \frac{F}{A}$

$PV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
ℓ = length
M = molar mass
n = number of moles
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$\sin \theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin \theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

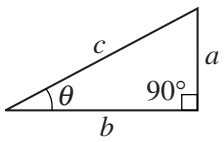
$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin \theta = \frac{a}{c}$
$\cos \theta = \frac{b}{c}$
$\tan \theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



2005 AP® PHYSICS B FREE-RESPONSE QUESTIONS (Form B)

PHYSICS B

SECTION II

Time—90 minutes

7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 11 minutes for answering each of questions 1-2 and 5-7, and about 17 minutes for answering each of questions 3-4. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.

1. (10 points)

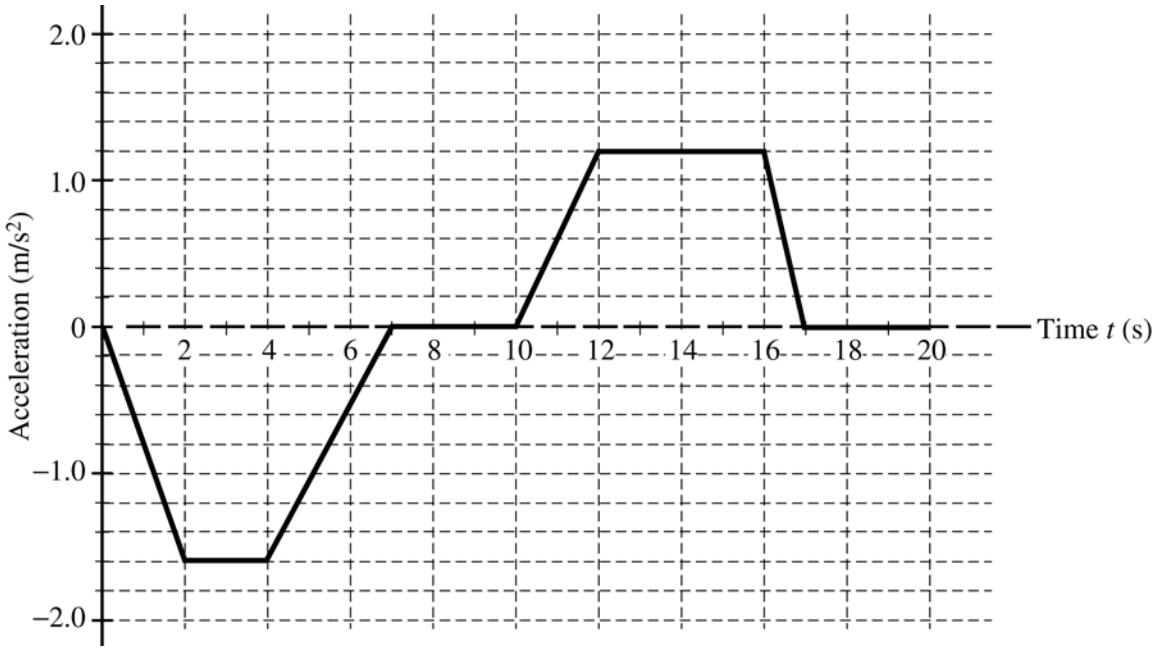
   A student of mass m stands on a platform scale in an elevator in a tall building. The positive direction for all vector quantities is upward.

   (a) Draw a free-body diagram showing and labeling all the forces acting on the student, who is represented by the dot below.

   ●

   (b) Derive an expression for the reading on the scale in terms of the acceleration a of the elevator, the mass m of the student, and fundamental constants.

   An inspector provides the student with the following graph showing the acceleration a of the elevator as a function of time t.



   (c)

   i. During what time interval(s) is the force exerted by the platform scale on the student a maximum value?

   ii. Calculate the magnitude of that maximum force for a 45 kg student.

   (d) During what time interval(s) is the speed of the elevator constant?

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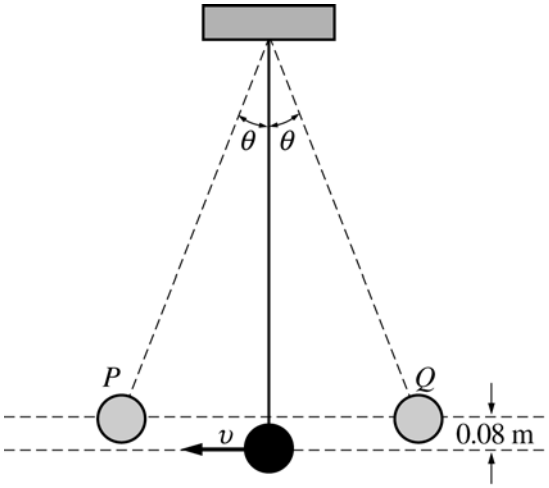
2. (10 points)

A simple pendulum consists of a bob of mass 0.085 kg attached to a string of length 1.5 m. The pendulum is raised to point Q, which is 0.08 m above its lowest position, and released so that it oscillates with small amplitude θ between the points P and Q as shown below.



Note: Figure not drawn to scale.

(a) On the figures below, draw free-body diagrams showing and labeling the forces acting on the bob in each of the situations described.

i. When it is at point P



ii. When it is in motion at its lowest position



(b) Calculate the speed v of the bob at its lowest position.

(c) Calculate the tension in the string when the bob is passing through its lowest position.

(d) Describe one modification that could be made to double the period of oscillation.

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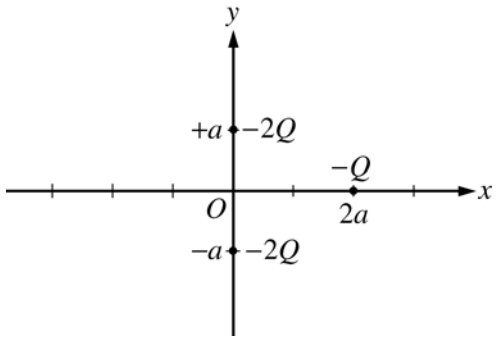


3. (15 points)

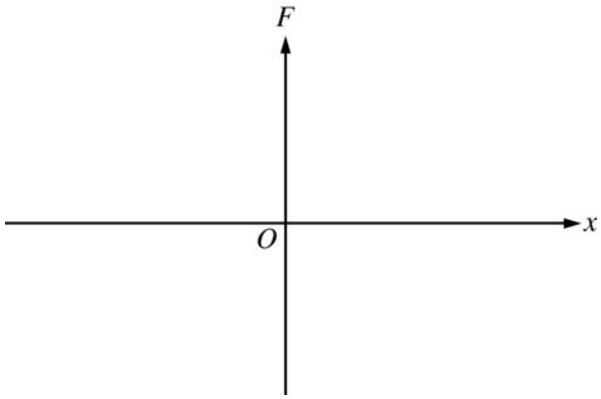
The figure above shows two point charges, each of charge –2Q, fixed on the y-axis at $y = +a$ and at $y = -a$. A third point charge of charge $-Q$ is placed on the x-axis at $x = 2a$. Express all algebraic answers in terms of Q, a, and fundamental constants.

(a) Derive an expression for the magnitude of the net force on the charge $-Q$ due to the other two charges, and state its direction.

(b) Derive an expression for the magnitude of the net electric field at the origin due to all three charges, and state its direction.

(c) Derive an expression for the electrical potential at the origin due to all three charges.

(d) On the axes below, sketch a graph of the force F on the $-Q$ charge caused by the other two charges as it is moved along the x-axis from a large positive position to a large negative position. Let the force be positive when it acts to the right and negative when it acts to the left.



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4. (15 points)

Your teacher gives you two speakers that are in phase and are emitting the same frequency of sound, which is between 5000 and 10,000 Hz. She asks you to determine this frequency more precisely. She does not have a frequency or wavelength meter in the lab, so she asks you to design an interference experiment to determine the frequency. The speed of sound is 340 m/s at the temperature of the lab room.

(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.

___ Speaker stand ___ Meterstick ___ Ruler ___Tape measure

___ Stopwatch ___ Sound-level meter

(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify what measurements you will need to make.

(c) Briefly outline the procedure that you would use to make the needed measurements, including how you would use each piece of equipment you checked in (a).

(d) Using equations, show explicitly how you would use your measurements to calculate the frequency of the sound produced by the speakers.

(e) If the frequency is decreased, describe how this would affect your measurements.

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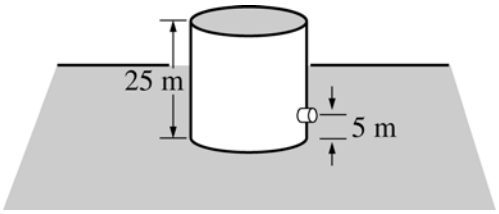

5. (10 points)

A large tank, 25 m in height and open at the top, is completely filled with saltwater (density 1025 kg/m^3). A small drain plug with a cross-sectional area of 4.0×10^{-5} m^2 is located 5.0 m from the bottom of the tank. The plug breaks loose from the tank, and water flows from the drain.

(a) Calculate the force exerted by the water on the plug before the plug breaks free.

(b) Calculate the speed of the water as it leaves the hole in the side of the tank.

(c) Calculate the volume flow rate of the water from the hole.

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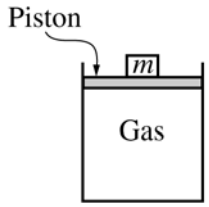


Note: Figure not drawn to scale.

6. (10 points)

You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

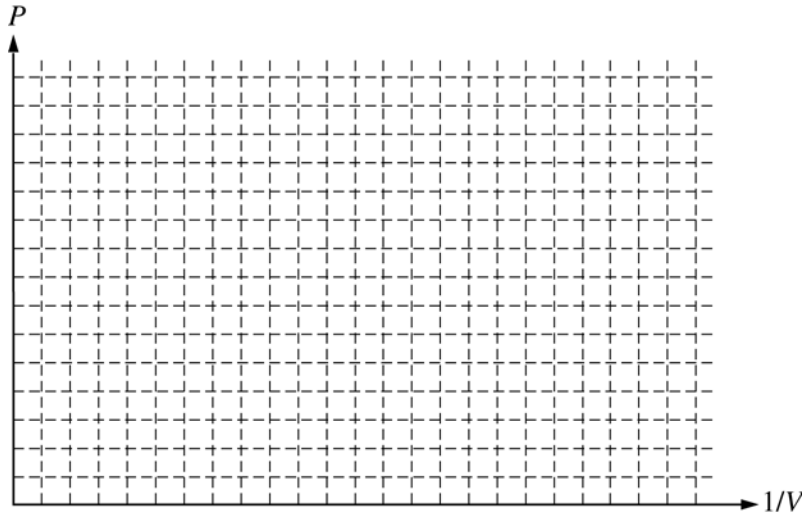
m (kg)	$V\left(\text{m}^3\right)$	$1/V\ \left(\text{m}^{-3}\right)$	P (Pa)
0	6.0×10^{-5}	1.7×10^{4}	
1	4.5×10^{-5}	2.2×10^{4}	
2	3.6×10^{-5}	2.8×10^{4}	
3	3.0×10^{-5}	3.3×10^{4}	
4	2.6×10^{-5}	3.8×10^{4}	

(a) Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

You also determine that $A = 3.0 \times 10^{-4}\ \text{m}^2$ and $T = 300$ K.

(b) Calculate the value of P for each value of m and record your values in the data table above.

(c) Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



(d) Using your graph in part (c), calculate the experimental value of n .

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7. (10 points)

A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.

(b) Calculate the number of photons emitted by the source in 5 minutes.

The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

(c) Calculate the maximum speed of the emitted electrons.

(d) Calculate the de Broglie wavelength of the most energetic electrons.

END OF EXAM

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AP® Physics B
2005 Scoring Guidelines
Form B

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AP® PHYSICS B
2005 SCORING GUIDELINES (Form B)

General Notes About 2005 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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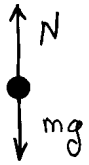
AP® PHYSICS B
2005 SCORING GUIDELINES (Form B)

Question 1

10 points total **Distribution of points**

(a) 2 points



For an upward force with a label indicating a normal force or a force from the scale 1 point
For a downward force with a label appropriate for a weight 1 point
One point was deducted for each extraneous force until the net score was zero.

(b) 3 points

The scale reading is the magnitude of the normal force on the student.
For starting with Newton's second law 1 point
$F_{net} = ma$
For correctly expressing the net force 1 point
$N - mg = ma$
For correctly solving for the normal force 1 point
$N = m(g + a)$

(c)

(i) 2 points

The normal force exerted by the scale is maximum when the acceleration has its maximum positive value.
The force is maximum from 12 to 16 seconds.
For an interval beginning at 12 seconds 1 point
For an interval ending at 16 seconds 1 point
One point was deducted for each interval with no correct endpoints until the net score was zero.

(ii) 1 point

Using the expression for the normal force from part (b)
$N = m(g + a)$
$N = (45 \text{ kg})\left(9.8 \text{ m/s}^2 + 1.2 \text{ m/s}^2\right)$
$N = (45 \text{ kg})\left(11.0 \text{ m/s}^2\right)$
For the correct answer with units 1 point
$N = 500$ N

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Question 1 (continued)

Distribution of points

(d) 2 points

The speed of the elevator is constant when the acceleration is zero.
This occurs from 7 to 10 seconds and from 17 to 20 seconds.
For each correct interval 1 point each
One point was deducted for each extraneous interval until the net score was zero.
One point was awarded if the scale was misread for both intervals and the response was given as both 6.5 to 10 and 16.5 to 20.

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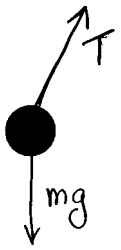
Question 2

10 points total **Distribution of points**

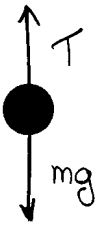
(a)

(i) 2 points



For each correctly drawn and labeled force 1 point each
One point was deducted if any extraneous forces were shown.

(ii) 2 points



For each correctly drawn and labeled force 1 point each
One point was deducted if any extraneous forces were shown.

(b) 2 points

For correctly applying conservation of energy 1 point

$\frac{1}{2}mv^2 = mg\,\Delta h$

$v = \sqrt{2g\,\Delta h}$

$v = \sqrt{2\left(9.8\ \text{m/s}^2\right)(0.08\ \text{m})} = \sqrt{1.568}\ \text{m/s}$

For the correct answer 1 point

$v = 1.3\ \text{m/s}$

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Question 2 (continued)

Distribution of points

(c) 3 points

For using $\sum \mathbf{F} = m\mathbf{a}$ 1 point

For a correct expression for the net force that is equated to a centripetal force 1 point

$T - mg = mv^2/r$

$T = m\left(g + v^2/r\right)$

$T = (0.085 \text{ kg})\left[9.8 \text{ m/s}^2 + (1.3 \text{ m/s})^2/(1.5 \text{ m})\right]$

For the correct answer with units 1 point

$T = 0.93$ N (or equivalent answer depending on rounding or use of $g = 10 \text{ m/s}^2$)

(d) 1 point

For a correct modification 1 point

For example: Make the string four times longer.

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Question 3

15 points total **Distribution of points**

(a) 4 points

For any mathematical statement indicating that the force on the $-Q$ charge is obtained by the addition of forces due to the other two charges — 1 point

For any of the following three statements or expressions — 1 point

- The y components of the forces due to the two $-2Q$ charges cancel.
- The magnitude of the net force equals the sum of the magnitudes of the x components.
- $r_{+a} = r_{-a} = \sqrt{a^2 + (2a)^2} = \sqrt{5}a$

$$F_x = 2\frac{kQ(2Q)}{r^2}\cos\theta$$

$$\cos\theta = \frac{2a}{r} = \frac{2a}{\sqrt{5}a} = \frac{2}{\sqrt{5}}$$

$$F_x = 2\frac{kQ(2Q)}{5a^2}\frac{2}{\sqrt{5}}$$

For the correct expression for the magnitude of the net force — 1 point

$$F_x = \frac{8kQ^2}{5\sqrt{5}a^2}$$

For the correct indication of direction — 1 point

Force is directed to the right, OR force is in the $+x$ direction, OR explicit use of an arrow to show direction.

(b) 3 points

For any indication that the contributions to the field from the $-2Q$ charges cancel — 1 point

For the correct expression for the magnitude of the field due to the $-Q$ charge — 1 point

$$E = \left|\frac{kq}{r^2}\right| = \left|\frac{k(-Q)}{(2a)^2}\right|$$

$E = \dfrac{kQ}{4a^2}$ (point awarded even with a minus sign)

For the correct indication of direction — 1 point

Field is directed to the right, OR field is in the $+x$ direction, OR explicit use of an arrow to show direction.

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Question 3 (continued)

Distribution of points

(c) 5 points

$$V = k\sum_i \frac{q_i}{r_i}$$

For any indication of the need to use superposition for the electrical potential (or showing three terms in the expression) 1 point

One point awarded for each correct term, including the minus sign, in the following expression 3 points

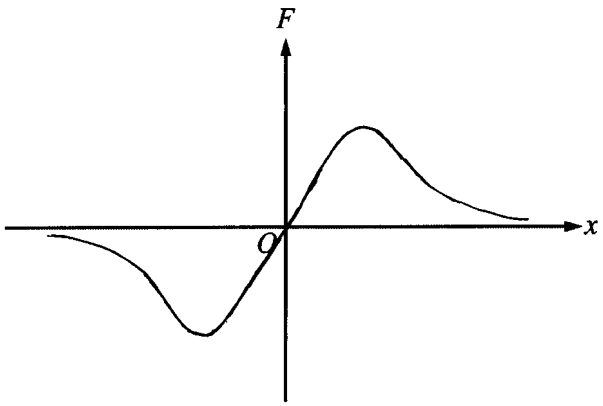
$$V = \frac{k(-2Q)}{a} + \frac{k(-2Q)}{a} + \frac{k(-Q)}{2a}$$

$$V = -\frac{4kQ}{a} - \frac{kQ}{2a} = -\frac{8kQ}{2a} - \frac{kQ}{2a}$$

For the correct simplified answer with correct sign 1 point

$$V = -\frac{9kQ}{2a}$$

(d) 3 points



For having $F = 0$ at $x = 0$ with $|F|$ increasing gradually going away from the origin 1 point
This point was not given for a spike function at the origin.

For having the graph positive on the right and negative on the left 1 point

For having a single maximum of $|F|$ on each side of the origin and having the curve monotonically and asymptotically decreasing to zero as $x \to \infty$ 1 point

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Question 4

15 points total **Distribution of points**

Credit for each part of this problem was awarded if the response, when judged holistically, showed reasonable understanding of a correct experimental method. Responses that showed little understanding could not receive full credit.

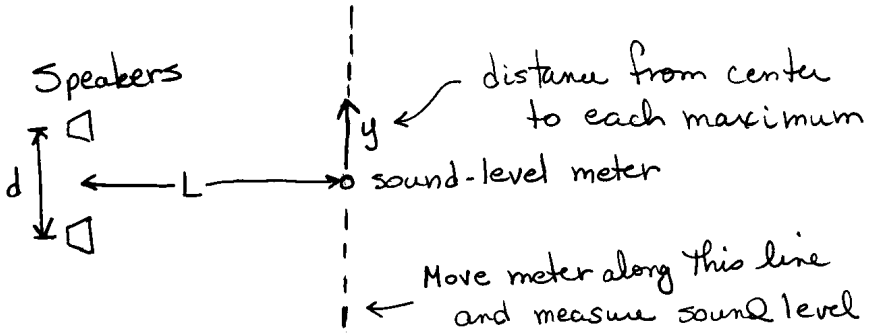
(a) 2 points

For using in parts (b) and (c) every piece of equipment marked in part (a) 1 point
For marking every piece of equipment used in parts (b) and (c) 1 point

(b) 4 points

For drawing an appropriate setup 1 point
For completely labeling the equipment 1 point
For indicating the measurements to be made 1 point
For complete labeling of the measurements, including symbols for them 1 point

Sample response



(c) 4 points

For a description of the setup of equipment 2 points
For a description of how to determine maxima or minima in the interference pattern 1 point
For indicating what measurements to take 1 point
Example response for the figure above:
Set the speakers a fixed distance *d* apart, pointing perpendicular to the line along which *d* is measured.
Determine a line parallel to the speaker line and a distance *L* away.
Use the sound meter to locate the maxima of the interference pattern along this line.
Record the locations of these maxima along the line.

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Question 4 (continued)

Distribution of points

(d) 4 points

The solution shown below is for the example given above. Solutions for other methods also received appropriate credit.

For the condition for a maximum — 1 point

$m\lambda = d\sin\theta$

For using the condition for small angles and eliminating θ — 1 point

$\sin\theta \approx y/L$

$m\lambda \approx dy/L$

For using successive maxima (i.e., $\Delta m = 1$) to get $\lambda \approx d\,\Delta y/L$ — 1 point

For an appropriate expression for frequency — 1 point

$f = v_{\text{sound}}/\lambda$

$f \approx Lv_{\text{sound}}/d\,\Delta y$

(e) 1 point

For a correct description — 1 point

For the example given:

Decreasing frequency results in increasing wavelength. Thus the distance between successive maxima will increase.

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Question 5

10 points total **Distribution of points**

(a) 4 points

For including atmospheric pressure in the expression for total pressure 1 point

For the correct expression for the term for the pressure due to the saltwater 1 point

$P = P_{atm} + \rho_{sw} gh$

$P = 1 \times 10^5 \text{ Pa} + \left(1025 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(20 \text{ m})$

$P = 1 \times 10^5 \text{ Pa} + 2.0 \times 10^5 \text{ Pa}$

$P = 3.0 \times 10^5 \text{ Pa} \quad (\text{or } 3.1 \times 10^5 \text{ Pa using } g = 10 \text{ m/s}^2)$

For the correct relationship between force and pressure 1 point

$F = PA$

$F = \left(3.0 \times 10^5 \text{ Pa}\right)\left(4.0 \times 10^{-5} \text{ m}^2\right)$

For the correct answer with units 1 point

$F = 12 \text{ N}$

(b) 4 points

For applying Bernoulli's principle at the top of the tank and the height of the drain 1 point

$P_{0top} + \rho g y_{top} + \frac{1}{2}\rho v_{top}^2 = P_{0drain} + \rho g y_{drain} + \frac{1}{2}\rho v_{drain}^2$

For realizing that $P_{0top} = P_{0drain} = P_{atm}$ 1 point

For realizing that $v_{top} = 0$ 1 point

Substituting and simplifying

$\rho g y_{top} = \rho g y_{drain} + \frac{1}{2}\rho v_{drain}^2$

$\frac{1}{2}\rho v_{drain}^2 = \rho g y_{drain} - \rho g y_{top} = \rho g\left(y_{drain} - y_{top}\right)$

$v_{drain} = \sqrt{2g\left(y_{drain} - y_{top}\right)}$

$v_{drain} = \sqrt{2\left(9.8 \text{ m/s}^2\right)(20 \text{ m})}$

$v_{drain} = \sqrt{392} \text{ m/s}$

For the correct answer with units 1 point

$v_{drain} = 20 \text{ m/s}$

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Question 5 (continued)

Distribution of points

(c) 2 points

For a correct expression for the volume rate of flow 1 point

$V/t = vA$

$V/t = (20\ \text{m/s})\left(4.0 \times 10^{-5}\ \text{m}^2\right)$

For the correct answer with units 1 point

$V/t = 8.0 \times 10^{-4}\ \text{m}^3/\text{s}$

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AP® PHYSICS B
2005 SCORING GUIDELINES (Form B)

Question 6

10 points total **Distribution of points**

(a) 1 point

For a correct expression relating P and V 1 point

$PV = nRT$ OR $P = nRT\frac{1}{V}$

(b) 2 points

The total pressure is atmospheric pressure plus the pressure due to the added mass.

$P = P_{atm} + \frac{mg}{A}$

$P = 1.0 \times 10^5 \text{ Pa} + \frac{m\left(9.8 \text{ m/s}^2\right)}{3.0 \times 10^{-4} \text{ m}^2}$

m (kg)	$V\left(\text{m}^3\right)$	$1/V\ \left(\text{m}^{-3}\right)$	P (Pa)
0	6.0×10^{-5}	1.7×10^4	1.0×10^5
1	4.5×10^{-5}	2.2×10^4	1.3×10^5
2	3.6×10^{-5}	2.8×10^4	1.7×10^5
3	3.0×10^{-5}	3.3×10^4	2.0×10^5
4	2.6×10^{-5}	3.8×10^4	2.3×10^5

For two or three correct values of pressure 1 point
For an additional one or two correct values (i.e., four or five correct received two points) 1 point
If atmospheric pressure was left out, only one point could be earned.

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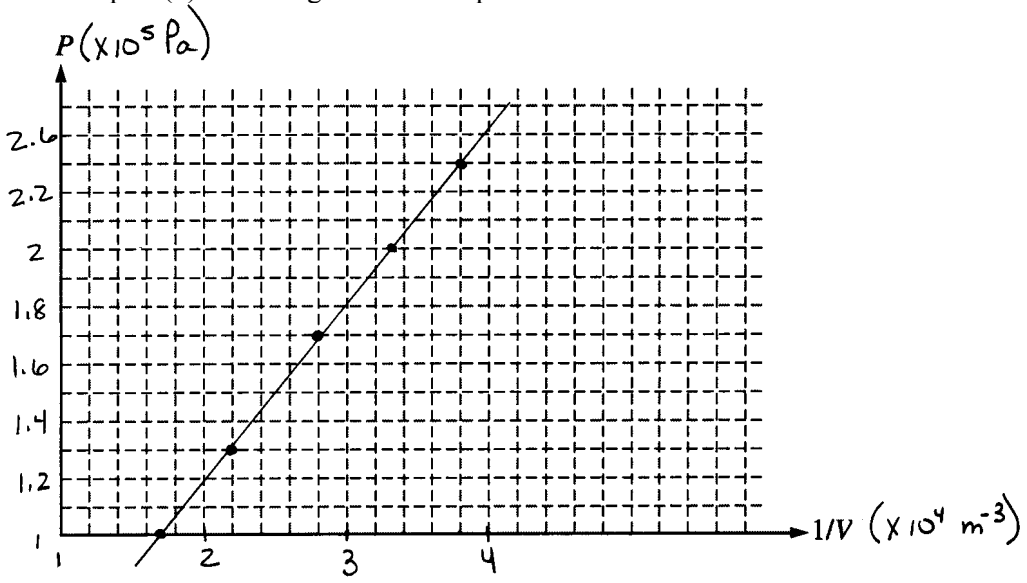
Question 6 (continued)

Distribution of points

(c) 3 points

For correctly labeling the horizontal axis 1 point
For correctly labeling the vertical axis 1 point
For accurately plotting the points 1 point
Full credit could be earned for correctly plotting incorrect data from the table.

Example answer shown below. This part of the question did not ask for the best-fit line, but it was needed for part (d) and was graded in that part.



(d) 4 points

For drawing a reasonable best-fit line through the data, given that the data could yield a value for n 1 point

$P = nRT(1/V)$

For calculating the slope of the line 1 point
From the example graph shown above, where the line goes through the first and last data points

$$\text{slope} = \frac{\left(2.3 \times 10^5 - 1.0 \times 10^5\right) \text{ Pa}}{\left(3.8 \times 10^4 - 1.7 \times 10^4\right) \text{ m}^{-3}}$$

For a reasonable value for the slope 1 point

For the values shown above, slope = 6.19 kPa $\cdot$m^3

$n = \text{slope}/RT$

$$n = \frac{6.19 \text{ kPa} \cdot \text{m}^3}{(8.31 \text{ J/(mol}\cdot\text{K)})(300 \text{ K})}$$

For the correct answer 1 point

$n = 0.0025$ mol

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Question 7

10 points total **Distribution of points**

(a) 2 points

For a correct expression for the energy of a photon 1 point

$E = hf$ OR $E = hc/\lambda$

Substituting into the second equation

$E = \left(1.99 \times 10^{-25}\ \text{J•m}\right)/\left(450 \times 10^{-9}\ \text{m}\right)$ OR $\left(1.24 \times 10^{3}\ \text{eV•nm}\right)/(450\ \text{nm})$

For the correct answer with units 1 point

$E = 4.4 \times 10^{-19}\ \text{J}$ (or 2.8 eV)

(b) 3 points

For a correct relationship for the number of photons N 1 point

$$N = \frac{(\text{energy emitted in 5 minutes})}{(\text{energy per photon})}$$

For correct substitutions 1 point

$$N = \frac{(\text{power})(\text{time})}{(\text{energy per photon})} = \frac{\left(2.5 \times 10^{-3}\ \text{J/s}\right)(5\ \text{min})(60\ \text{s/min})}{4.4 \times 10^{-19}\ \text{J}}$$

For the correct answer 1 point

$N = 1.7 \times 10^{18}$

(c) 3 points

For relating the maximum kinetic energy of an electron to the stopping potential (i.e., 0.86 eV or qV) 1 point

$\frac{1}{2}mv_{\max}^2 = qV$

For obtaining the correct expression for the maximum speed 1 point

$v_{\max} = \sqrt{2qV/m}$

$v_{\max} = \sqrt{2\left(1.6 \times 10^{-19}\ \text{C}\right)(0.86\ \text{V})/\left(9.11 \times 10^{-31}\ \text{kg}\right)}$

For the correct answer with units 1 point

$v_{\max} = 5.5 \times 10^{5}\ \text{m/s}$

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Question 7 (continued)

Distribution of points

(d) 2 points

For a correct relationship for the wavelength 1 point

$$\lambda = \frac{h}{p_{\max}}$$

$$\lambda = \frac{h}{m\upsilon_{\max}}$$

$$\lambda = \frac{6.63 \times 10^{34}\ \text{J•s}}{\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(5.5 \times 10^{5}\ \text{m/s}\right)}$$

For the correct answer with units 1 point

$\lambda = 1.3$ nm

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CollegeBoard
Advanced Placement Program

AP® Physics B
2004 Free-Response Questions

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TABLE OF INFORMATION FOR 2004 and 2005

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta \mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_C = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta \phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P + \rho gy + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$P = \frac{F}{A}$

$PV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
ℓ = length
M = molar mass
n = number of moles
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$\sin \theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin \theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

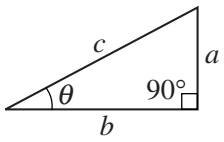
$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin \theta = \frac{a}{c}$
$\cos \theta = \frac{b}{c}$
$\tan \theta = \frac{a}{b}$

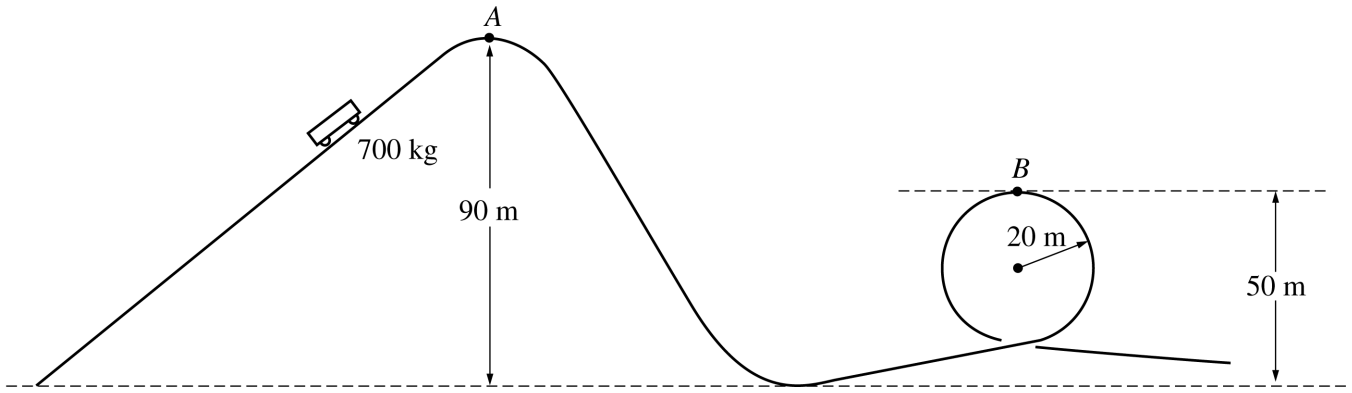
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



2004 AP® PHYSICS B FREE-RESPONSE QUESTIONS

PHYSICS B
SECTION II
Time—90 minutes
6 Questions

Directions: Answer all six questions, which are weighted according to the points indicated. The suggested time is about 17 minutes for answering each of questions 1-4, and about 11 minutes for answering each of questions 5-6. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (15 points)

A roller coaster ride at an amusement park lifts a car of mass 700 kg to point A at a height of 90 m above the lowest point on the track, as shown above. The car starts from rest at point A, rolls with negligible friction down the incline and follows the track around a loop of radius 20 m. Point B, the highest point on the loop, is at a height of 50 m above the lowest point on the track.

(a)

i. Indicate on the figure the point P at which the maximum speed of the car is attained.

ii. Calculate the value v_{max} of this maximum speed.

(b) Calculate the speed v_B of the car at point B.

(c)

i. On the figure of the car below, draw and label vectors to represent the forces acting on the car when it is upside down at point B.



ii. Calculate the magnitude of all the forces identified in (c)i.

(d) Now suppose that friction is not negligible. How could the loop be modified to maintain the same speed at the top of the loop as found in (b)? Justify your answer.

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GO ON TO THE NEXT PAGE.

2. (15 points)

While exploring a sunken ocean liner, the principal researcher found the absolute pressure on the robot observation submarine at the level of the ship to be about 413 atmospheres. The density of seawater is $1025\ \text{kg/m}^3$.

(a) Calculate the gauge pressure p_g on the sunken ocean liner.

(b) Calculate the depth D of the sunken ocean liner.

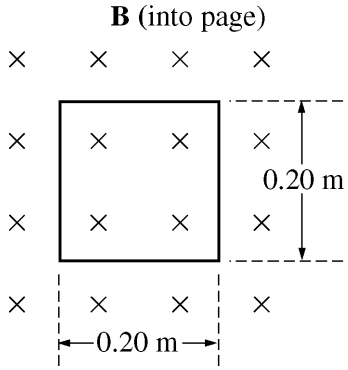
(c) Calculate the magnitude F of the force due to the water on a viewing port of the submarine at this depth if the viewing port has a surface area of $0.0100\ \text{m}^2$.

Suppose that the ocean liner came to rest at the surface of the ocean before it started to sink. Due to the resistance of the seawater, the sinking ocean liner then reached a terminal velocity of $10.0\,\text{m/s}$ after falling for 30.0 s.

(d) Determine the magnitude a of the average acceleration of the ocean liner during this period of time.

(e) Assuming the acceleration was constant, calculate the distance d below the surface at which the ocean liner reached this terminal velocity.

(f) Calculate the time t it took the ocean liner to sink from the surface to the bottom of the ocean.



3. (15 points)

A square loop of wire of side 0.20 m has a total resistance of $0.60\ \Omega$. The loop is positioned in a uniform magnetic field **B** of 0.030 T. The field is directed into the page, perpendicular to the plane of the loop, as shown above.

(a) Calculate the magnetic flux ϕ through the loop.

The field strength now increases uniformly to 0.20 T in 0.50 s.

(b) Calculate the emf $\mathcal{E}$ induced in the loop during this period.

(c)

i. Calculate the magnitude I of the current in the loop during this period.

ii. What is the direction of the current in the loop?

_____ Clockwise _____ Counterclockwise

Justify your answer.

(d) Describe a method by which you could induce a current in the loop if the magnetic field remained constant.

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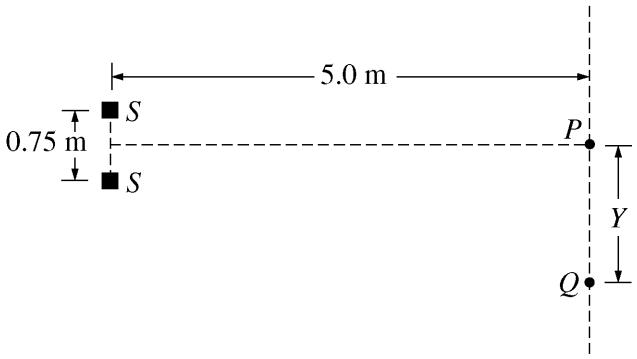

Note: Figure not drawn to scale.

4. (15 points)

Two small speakers S are positioned a distance of 0.75 m from each other, as shown in the diagram above. The two speakers are each emitting a constant 2500 Hz tone, and the sound waves from the speakers are in phase with each other. A student is standing at point P, which is a distance of 5.0 m from the midpoint between the speakers, and hears a maximum as expected. Assume that reflections from nearby objects are negligible. Use 343 m/s for the speed of sound.

(a) Calculate the wavelength of these sound waves.

(b) The student moves a distance Y to point Q and notices that the sound intensity has decreased to a minimum. Calculate the shortest distance the student could have moved to hear this minimum.

(c) Identify another location on the line that passes through P and Q where the student could stand in order to observe a minimum. Justify your answer.

(d)

i. How would your answer to (b) change if the two speakers were moved closer together? Justify your answer.

ii. How would your answer to (b) change if the frequency emitted by the two speakers was increased? Justify your answer.

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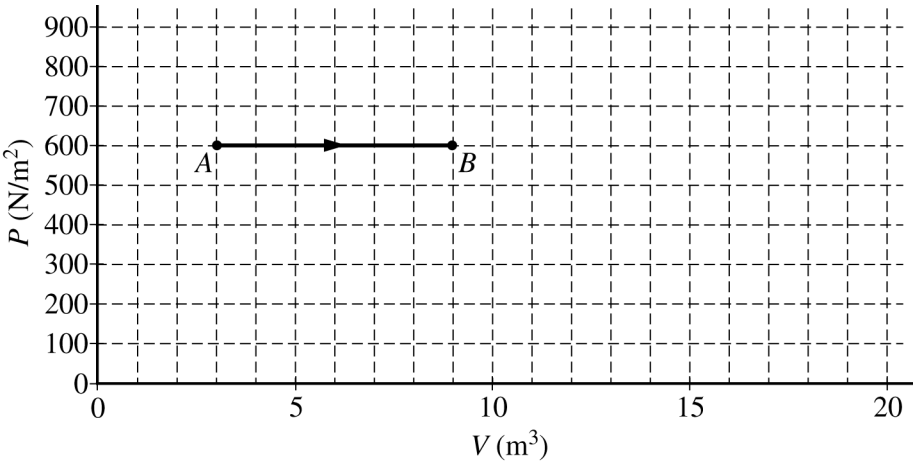

5. (10 points)

The diagram above of pressure P versus volume V shows the expansion of 2.0 moles of a monatomic ideal gas from state A to state B. As shown in the diagram, $P_A = P_B = 600\ \text{N/m}^2$, $V_A = 3.0\ \text{m}^3$, and $V_B = 9.0\ \text{m}^3$.

(a)

i. Calculate the work done <u>by the gas</u> as it expands.

ii. Calculate the change in internal energy of the gas as it expands.

iii. Calculate the heat added to or removed from the gas during this expansion.

(b) The pressure is then reduced to $200\ \text{N/m}^2$ without changing the volume as the gas is taken from state B to state C. Label state C on the diagram and draw a line or curve to represent the process from state B to state C.

(c) The gas is then compressed isothermally back to state A.

i. Draw a line or curve on the diagram to represent this process.

ii. Is heat added to or removed from the gas during this isothermal compression?

____ added to ____ removed from

Justify your answer.

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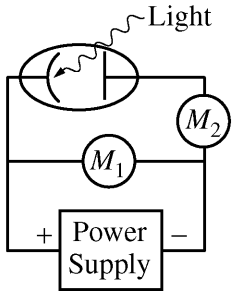


6. (10 points)

A student performs a photoelectric effect experiment in which light of various frequencies is incident on a photosensitive metal plate. This plate, a second metal plate, and a power supply are connected in a circuit, which also contains two meters, M_1 and M_2, as shown above.

The student shines light of a specific wavelength λ onto the plate. The voltage on the power supply is then adjusted until there is no more current in the circuit, and this voltage is recorded as the stopping potential V_S.

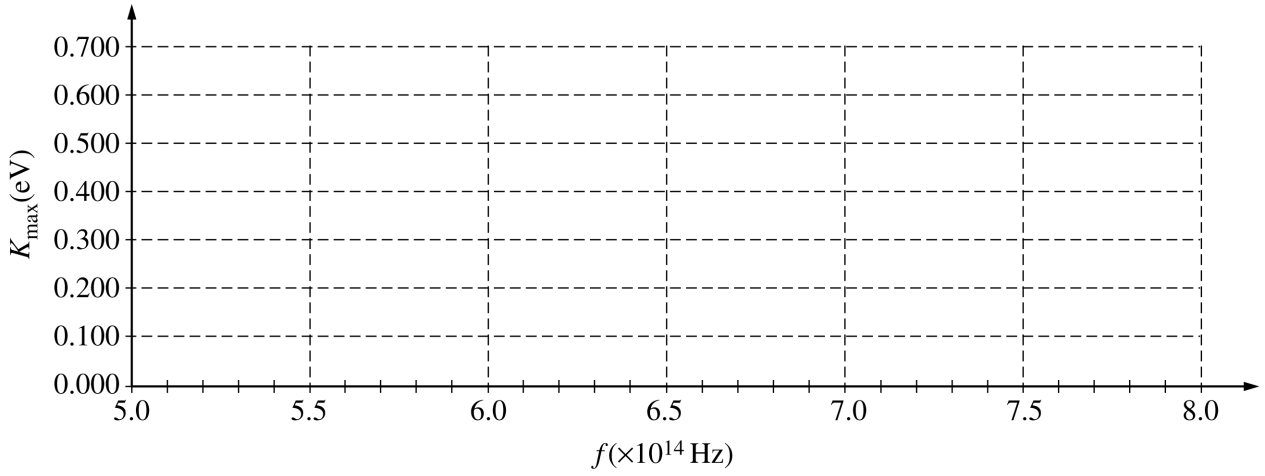
The student then repeats the experiment several more times with different wavelengths of light. The data, along with other values calculated from it, are recorded in the table below.

λ (m)	4.00×10^{-7}	4.25×10^{-7}	4.50×10^{-7}	4.75×10^{-7}
V_S (volts)	0.65	0.45	0.30	0.15
f (Hz)	7.50×10^{14}	7.06×10^{14}	6.67×10^{14}	6.32×10^{14}
K_{max} (eV)	0.65	0.45	0.30	0.15

(a) Indicate which meter is used as an ammeter and which meter is used as a voltmeter by checking the appropriate spaces below.

	M_1	M_2
Ammeter	_____	_____
Voltmeter	_____	_____

(b) Use the data above to plot a graph of K_{max} versus f on the axes below, and sketch a best-fit line through the data.



(c) Use the best-fit line you sketched in part (b) to calculate an experimental value for Planck's constant.

(d) If the student had used a different metal with a larger work function, how would the graph you sketched in part (b) be different? Explain your reasoning.

END OF EXAMINATION

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Advanced Placement Program

AP® Physics B
2004 Scoring Guidelines

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General Notes about 2004 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g. a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g. 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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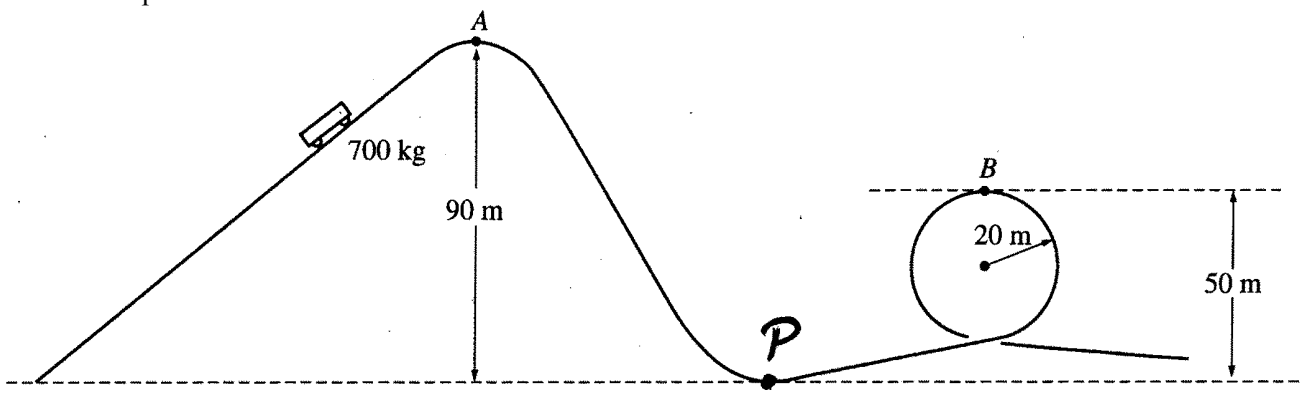
Question 1

15 points total **Distribution of points**

(a)

i. 1 point



For correctly locating point P at the low point between the hill and the loop 1 point

ii. 3 points

For any indication that energy is conserved 1 point

Setting the kinetic energy at P equal to the potential energy at A:

$$\frac{1}{2}mv_{max} = mgy_A$$

$$v_{max} = \sqrt{2gy_A}$$

For correct substitution 1 point

$$v_{max} = \sqrt{2\left(9.8 \text{ m/s}^2\right)(90 \text{ m})}$$

For the correct answer 1 point

$v_{max} = 42$ m/s (or 42.4 m/s using $g = 10$ m/s^2)

A maximum of 2 points could be earned for applying the kinematics equation $v_{max}^2 = v_A^2 + 2a\,\Delta y$ without an explicit statement that since energy is conserved, anything "falling" from A to P will achieve the same speed as something that is dropped.

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Question 1 (continued)

Distribution of points

(b) 3 points

For any indication that energy is conserved — 1 point

Equating the total energy at point B to the potential energy at point A:

$$\frac{1}{2}mv_B + mgy_B = mgy_A$$

Solving for the speed at point B:

$$v_B = \sqrt{2g(y_A - y_B)}$$

For correct substitution — 1 point

$$v_B = \sqrt{2\left(9.8\ \text{m/s}^2\right)(90\ \text{m} - 50\ \text{m})}$$

For the correct answer — 1 point

$v_B = 28$ m/s (or 28.3 m/s using $g = 10\ \text{m/s}^2$)

As in (a) ii above, a maximum of 2 points could be earned for using the kinematics equation.

(c)

i. 3 points



For each correctly drawn and labeled vector — 1 pt each

For no extraneous vectors, given that the two vectors above are drawn correctly — 1 point

ii. 3 points

For determining the correct value of the weight — 1 point

$$mg = (700\ \text{kg})\left(9.8\ \text{m/s}^2\right)$$

$mg = 6860$ N (or 7000 N using $g = 10\ \text{m/s}^2$)

For indicating there is a centripetal force on the car, either separately or by setting the sum of the forces equal to the centripetal force — 1 point

$$N + mg = \frac{mv_B^2}{r}$$

$$N = \frac{mv_B^2}{r} - mg = \frac{(700\ \text{kg})(28\ \text{m/s})^2}{20\ \text{m}} - 6860\ \text{N}$$

For the correct answer — 1 point

$N = 20{,}580$ N (or 21,000 N using $g = 10\ \text{m/s}^2$)

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Question 1 (continued)

Distribution of points

(d) 2 points

For any clear description of both a modification that will lower the height of point *B* and a correct justification — 2 points

For example: Flatten out the track on either side of the loop so the bottom of the loop is on the ground, and thus point *B* is lower. The work done by friction will reduce the total mechanical energy available at point *B*, so if the kinetic energy at point *B* is to remain the same, the potential energy at that point must be reduced.

Only one point was awarded for an answer that showed some understanding but was not totally clear or complete.

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Question 2

15 points total **Distribution of points**

(a) 2 points

For work showing $p_{absolute} - p_{atm}$ in an appropriate equation or calculation 1 point

$p_g = p_{absolute} - p_{atm}$

$p_g = 413 \text{ atm} - 1 \text{ atm}$

For the correct answer 1 point

$p_g = 412 \text{ atm}$

Note: An answer with no work shown only received 1 point total

(b) 3 points

For showing $p = \rho gh$ in any of the following equations or during calculation 1 point

$p = p_0 + \rho gh$ OR $p_g = \Delta p = \rho gh$ OR $p = \rho gh$

For correct substitutions in any of these equations 1 point

For example, $D = \dfrac{p_g}{\rho g} = \dfrac{(412 \text{ atm})\left(1 \times 10^5 \text{ N}/\left(\text{m}^2 \cdot \text{atm}\right)\right)}{\left(1025 \text{ kg}/\text{m}^3\right)\left(9.8 \text{ m}/\text{s}^2\right)}$

For answer consistent with (a), with a reasonable number of significant figures (1 to 4) 1 point

$D = 4100$ m (or 4020 m using $g = 10 \text{ m}/\text{s}^2$). Any negative sign was ignored.

Note: A range of answers was possible depending on the value used for g (9.8 or $10 \text{ m}/\text{s}^2$) and on the conversion factor used to convert atmospheres to N/m^2 (the approximate value in the equation sheet or the more precise value found in some calculators).

(c) 2 points

For correct substitution of numerical values into a correct relationship 1 point

$F = p_g A = (412 \text{ atm})\left(1 \times 10^5 \text{ N}/\left(\text{m}^2 \cdot \text{atm}\right)\right)\left(0.0100 \text{ m}^2\right)$

Note: Since "force due to the water" might have been interpreted as due to the total pressure instead of the gauge pressure, 413 atm was also accepted for the pressure.

For the correct answer with units consistent with calculation using 412 atm, 413 atm, or answer to (a) 1 point

$F = 4.12 \times 10^5$ N

Note: In the absence of explicit indication of numerical substitution, a correct answer with a correct equation could earn 2 points.

Also accepted was $F = \rho Vg$, where $\rho = 1025 \text{ kg/m}^3$ and $V = \left(0.0100 \text{ m}^3\right)$(answer to (b))

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Question 2 (continued)

Distribution of points

(d) 2 points

For substitution in the correct equation OR for the correct numerical answer 1 point
Negative sign was ignored.
For a correct numerical answer with correct units 1 point
$a = \Delta v/t = (10.0 \text{ m/s} - 0 \text{ m/s})/(30.0 \text{ s})$
$a = 0.333 \text{ m/s}^2$

(e) 2 points

For correct substitution into a correct equation 1 point
For correct answer (using acceleration from (d) in the first two of the following solutions) 1 point
$v^2 = v_0^2 + 2a\Delta x$
$d = v_f^2/2a = (10.0 \text{ m/s})^2/2(0.333 \text{ m/s}) = 150 \text{ m}$

OR

$d = \frac{1}{2}at^2$
$d = \frac{1}{2}(0.333 \text{ m/s}^2)(30.0 \text{ s})^2 = 150 \text{ m}$

OR

$v_{\text{avg}} = \Delta x/t$
$d = v_{avg}t = (30 \text{ s})(10.0 \text{ m/s} + 0 \text{ m/s})/2 = 150 \text{ m}$

Note: In the absence of explicit indication of numerical substitution, a correct answer with a correct equation could earn 2 points. Negative sign was ignored.

(f) 4 points

For computing the distance Δy that the ship falls at constant velocity using D from part (b) and d from part (e) 1 point
$\Delta y = D - d = 4100 \text{ m} - 150 \text{ m}$
$\Delta y = 3950 \text{ m}$
For consistent substitution in a correct equation to find t_2, the time the ship falls at constant velocity 1 point
$\Delta y = v_f t_2$
$t_2 = \Delta y/v_f = (3950 \text{ m})/(10 \text{ m/s}) = 395 \text{ s}$
For finding the total time by adding t_2 to the given time t_1 to reach terminal velocity 1 point
$t_{\text{tot}} = t_2 + t_1 = 395 \text{ s} + 30 \text{ s}$
For the correct total time 1 point
$t = 425 \text{ s}$ (or answer consistent with previous answers)

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Question 3

15 points total **Distribution of points**

(a) 3 points

For using the correct expression for the magnetic flux 1 point
$\phi = BA$

For correct substitution 1 point
$\phi = (0.030\ \text{T})(0.20\ \text{m})^2$

For the correct answer
$\phi = 1.2 \times 10^{-3}\ \text{T}\cdot\text{m}^2$ 1 point

(b) 4 points

For using the correct expression for the magnitude of the emf 1 point
$\mathcal{E} = \dfrac{\Delta\phi}{\Delta t}$

For recognizing that one needs to calculate a change in the magnetic field or the flux 1 point

For a correct determination of the change in magnetic field or the flux 1 point
$\mathcal{E} = \dfrac{\Delta B\, A}{\Delta t}$

$\mathcal{E} = \dfrac{(0.20\ \text{T} - 0.030\ \text{T})(0.20\ \text{m})^2}{0.50\ \text{s}}$

For the correct answer 1 point
$\mathcal{E} = 0.014\ \text{V}$ (with or without a negative sign)

(c)

i. 2 points

For using a correct expression for Ohm's law 1 point
$I = \mathcal{E}/R$

For correct substitution 1 point
$I = (0.014\ \text{V})/(0.60\ \Omega)$
$I = 0.023\ \text{A}$

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Question 3 (continued)

Distribution of points

(c) (continued)

ii. 3 points

For correctly indicating that the current is counterclockwise 1 point

The remaining points were only awarded if the point above was earned

For indicating that Lenz's law or a hand rule applies 1 point

For correctly explaining how Lenz's law or a hand rule leads to the answer 1 point

For example: The magnetic field is increasing into the page. Current will be induced to oppose that change. By the right-hand rule, to create a field out of the page the current must be counterclockwise.

(d) 2 points

For any description of a correct method to induce a current in a constant magnetic field 2 points

For example: Change the area of the loop
Pull the loop out of the field
Rotate the loop about an axis in the plane of the loop

No points were awarded if items such as batteries, capacitors, etc. were added to the loop

Units: 1 point

For correct units on at least two of the three answers to parts (a), (b), and (c) 1 point

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Question 4

15 points total **Distribution of points**

(a) 3 points

For a correct equation 1 point

$v = f\lambda$

$\lambda = v/f$

For correct substitutions 1 point

$\lambda = (343 \text{ m/s})/(2500 \text{ Hz})$

For the correct answer with units 1 point

$\lambda = 0.1372 \text{ m} \approx 0.14 \text{ m}$

(b) 3 points

For demonstrating a correct approach to the problem using any of the following methods. 1 point

Method 1

$$x_m \approx \frac{m\lambda L}{d} = \frac{\frac{1}{2}\lambda L}{d} = \frac{\frac{1}{2}(0.1372 \text{ m})(5.0 \text{ m})}{0.75 \text{ m}}$$

$Y = x_m = 0.457 \text{ m}$

Method 2

$d\sin\theta = m\lambda$ and $Y = L\tan\theta$

$$\theta = \sin^{-1}\left(\frac{m\lambda}{d}\right) = \sin^{-1}\left(\frac{\frac{1}{2}(0.1372 \text{ m})}{0.75 \text{ m}}\right) = 5.25°$$

$Y = L\tan\theta = (5.0 \text{ m})\tan(5.25°) = 0.459 \text{ m}$

Method 3

Computing the actual path difference and setting it equal to $\lambda/2$:

$$\sqrt{\left(Y + \frac{d}{2}\right)^2 + L^2} - \sqrt{\left(Y - \frac{d}{2}\right)^2 + L^2} = \frac{\lambda}{2}$$

$$\sqrt{(Y + 0.375 \text{ m})^2 + (5 \text{ m})^2} - \sqrt{(Y - 0.375 \text{ m})^2 + (5 \text{ m})^2} = \frac{0.1372 \text{ m}}{2}$$

By algebraic solution or by using a calculator

$Y = 0.460 \text{ m}$

Assignment of points for each of the three methods:

For using $m = 1/2$ or for using path difference $= \lambda/2$ 1 point

For substitution of λ from (a), $d = 0.75$ m, and $L = 5.0$ m 1 point

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Question 4 (continued)

Distribution of points

(c) 3 points

For correct identification of another minimum — 1 point
Examples:
$Y = 0.46$ m along the line PQ but on the opposite side of P than Q
OR
At 3, 5, 7, … times the answer from (b) along the line PQ. Could be on either side of P, but it was not necessary to mention which side.

For a complete explanation of the placement of the minimum cited — 2 points
This explanation may include a clear statement of the symmetry of the problem, a description of the path differences for sound from the speakers, or a mathematical derivation of the new distance from P to the new minimum. One point only was awarded for justifications that were not complete or less clear.

(d)

i. 3 points

For an indication that Y increases — 1 point
For a clear correct justification — 2 points
Examples:
A statement that the distance d between the speakers decreases and Y is inversely proportional to the separation of the speakers
OR
A mathematical calculation of the value of Y for a value of $d < 0.75$ m
Note: The justification points were awarded based on the quality of the explanation. One point only was awarded for justifications that were not complete or less clear.

ii. 3 points

For an indication that Y decreases — 1 point
For a clear correct justification — 2 points
Examples:
A statement that includes the inverse proportion between wavelength and frequency and the direct proportion between Y and wavelength
OR
A mathematical calculation that demonstrates these relationships starting with $f > 2500$ Hz and ending with $Y < 0.46$ m.
Note: The justification points were awarded based on the quality of the explanation. One point only was awarded for justifications that were not complete or less clear.

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Question 5

10 points total **Distribution of points**

(a)

i. 2 points

For a correct calculation of the work done on the gas 1 point

$W_{on} = -P\Delta V$

$W_{on} = -\left(600\ \text{N/m}^2\right)\left(9.0\ \text{m}^3 - 3.0\ \text{m}^3\right)$

$W_{on} = -3600\ \text{J}$

For recognition that the work done by the gas is the negative of the work done on the gas 1 point

$W_{by} = 3600\ \text{J}$

ii. 3 points

For a correct expression or derivation of the expression for ΔU 1 point

$\Delta U = \frac{3}{2} nR\ \Delta T$

For correct calculation of T's or ΔT using the ideal gas law, $PV = nRT$ 1 point

$\Delta U = \frac{3}{2}(2\ \text{moles})\left(8.31 \frac{\text{J}}{\text{mol K}}\right)(325\ \text{K} - 108\ \text{K})$

OR since $P\ \Delta V = nR\ \Delta T$, $\Delta U = \frac{3}{2} P\ \Delta V = \frac{3}{2}\left(600\ \text{N/m}^2\right)\left(9\ \text{m}^3 - 3\ \text{m}^3\right)$

For the correct answer 1 point

$\Delta U = 5400\ \text{J}$

Note: The equation $\Delta U = \frac{3}{2} nR\ \Delta T$ can be derived from the expressions for K_{avg} and υ_{rms} found in the equation sheet as follows:

$U = NK_{avg}$, where N = number of molecules in the gas = nN_0

$U = nN_0 \frac{3}{2} k_B T$

$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$, so $\frac{R}{M} = \frac{k_b}{\mu}$

$R = k_B \frac{M}{\mu} = k_B N_0$

$U = \frac{3}{2} nRT$

$\Delta U = \frac{3}{2} nR\ \Delta T$

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Question 5 (continued)

Distribution of points

(a) continued

iii. 1 point

For correct substitution of answers from parts i. and ii. into the first law of thermodynamics — 1 point

$\Delta U = Q + W_{on}$

$Q = \Delta U - W_{on}$

$Q = 5400 \text{ J} - (-3600 \text{ J})$

$Q = 9000 \text{ J}$

Alternate Solutions for parts ii. and iii. — *Alternate points*

Solving part iii. first:

$$Q = nc_P \Delta T = n\frac{5}{2}R\,\Delta T = (2 \text{ moles})\frac{5}{2}\left(8.31\frac{\text{J}}{\text{mol K}}\right)(325 \text{ K} - 108 \text{ K}) = 9000 \text{ J}$$

For a correct equation — *1 point*

For correct calculation of T's or ΔT — *1 point*

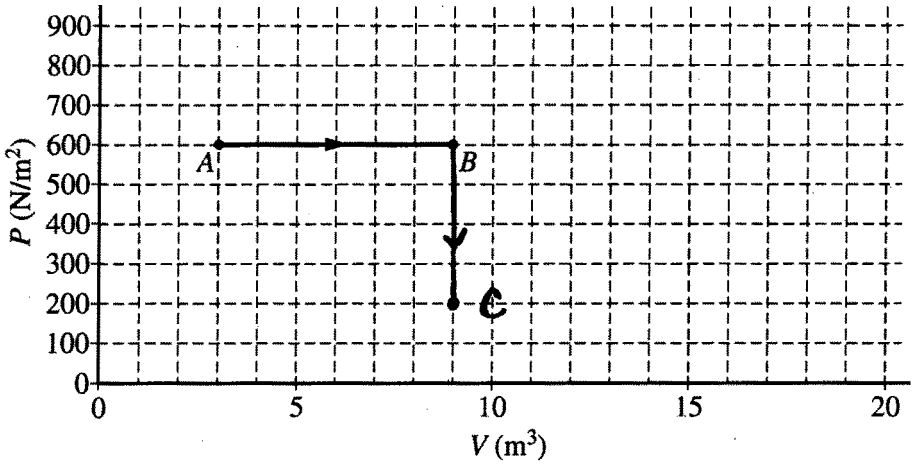
For the correct answer — *1 point*

Returning to solve part ii.:

$\Delta U = Q + W_{on} = 9000 \text{ J} + (-3600 \text{ J}) = 5400 \text{ J}$

For correct substitutions into the first law of thermodynamics of answers from parts i. and iii. — *1 point*

(b) 1 point



For point C plotted and labeled correctly as above, and for a correct straight line from point B to point C — 1 point

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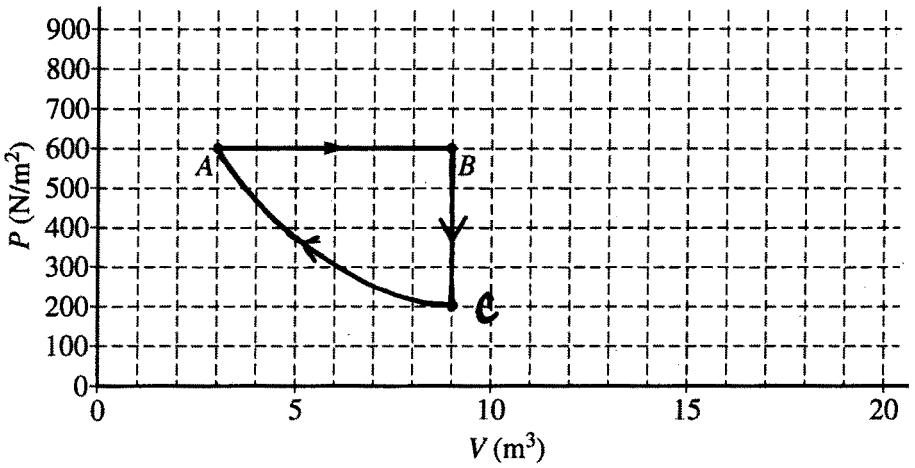
Question 5 (continued)

Distribution of points

(c)

i. 1 point



For a correct curve from point *C* to point *A*. Curve must be concave upward. 1 point

ii. 2 points

For correctly indicating that heat is removed from the gas 1 point

For a correct justification such as explaining in words or symbols that the change in internal energy is zero, so from first law of thermodynamics $Q = -W$. Since the work done on the gas is greater than zero, Q is negative. Therefore heat is removed from the gas. 1 point

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Question 6

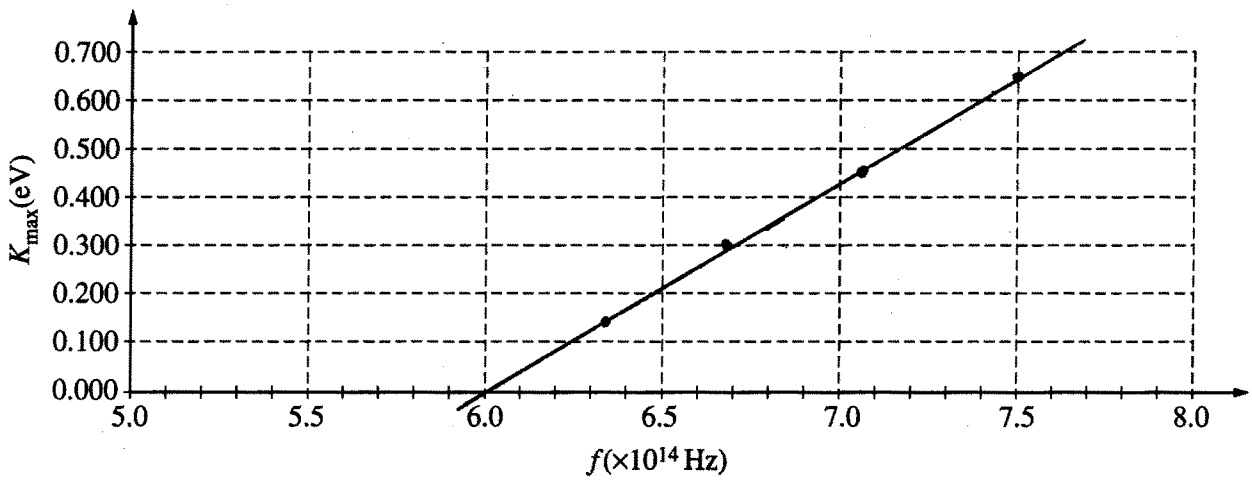
10 points total **Distribution of points**

(a) 2 points

For indicating that the ammeter is M_2 1 point

For indicating that the voltmeter is M_1 1 point

(b) 2 points



For correctly plotting all 4 points 1 point

For a correct straight line based on the points that were plotted 1 point

(c) 2 points

$K_{max} = hf - \phi$, so h equals the slope of the line

Taking two points from the graph, for example

$(6 \times 10^{14}\ \text{Hz}, 0\ \text{eV})$ and $(7.5 \times 10^{14}\ \text{Hz}, 0.65\ \text{eV})$:

$$h = \frac{\Delta y}{\Delta x} = \frac{\Delta K_{max}}{\Delta f} = \frac{0.65\ \text{eV} - 0\ \text{eV}}{7.5 \times 10^{14}\ \text{Hz} - 6.0 \times 10^{14}\ \text{Hz}}$$

$h = 4.3 \times 10^{-15}$ eV•s

For any indication of $\frac{\Delta y}{\Delta x}$ or $\frac{\Delta K_{max}}{\Delta f}$ or $\frac{y}{x}$ or $\frac{K_{max}}{f}$ 1 point

For a value of h consistent with the plotted data. 1 point

Note: For correctly plotted points, a range of values from 3.73×10^{-15} eV•s to 4.55×10^{-15} eV•s was accepted. This range is ±10% of the actual value of h.

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Question 6 (continued)

Distribution of points

(c) (continued)

Alternate Solutions *Alternate points*

Method 1 By simultaneous equations
Set up two equations with two unknowns using $K_{\max} = hf - \phi$ and two points on the graph. Solve the equations for *h*.
For indicating $K_{\max} = hf - \phi$ *1 point*
For the correct value of *h* from the two equations *1 point*

Method 2 By calculator program
Enter the data into a calculator and run a program to determine the best-fit line for $K_{\max}$ as a function of *f*. Then recognize that *h* is the coefficient of f in the equation.
For the correct equation $y \approx 4.2 \times 10^{-15} x - 2.51$ or $K_{\max} \approx 4.2 \times 10^{-15} f - 2.51$ (*1 point*)
For the statement that $h = 4.2 \times 10^{-15}$ eV•s from the equation (*1 point*)

(d) 4 points

For a statement that the graph moves to the right or down, OR for a sketch of a second parallel line to the right of the first graph and labeled as the second graph. 2 points
Note: 1 point was deducted for an indication that the slope of the graph changes.
For a correct explanation that relates to a graph or to the physical situation, such as one of the following: 2 points

- A larger work function means a larger *y*-intercept (no penalty for not including a minus sign before the *y*-intercept)
- A larger work function means a larger *x*-intercept or threshold frequency
- A larger work function means that greater energy is needed in order for an electron to escape from the surface

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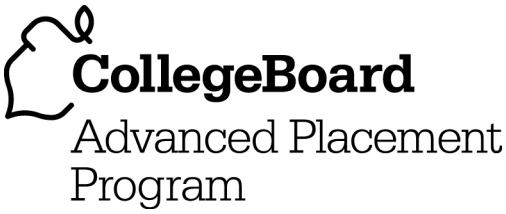

AP® Physics B
2004 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2004 and 2005

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta \mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_C = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta \phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2004 and 2005

FLUID MECHANICS AND THERMAL PHYSICS

$P = P_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P + \rho gy + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$P = \frac{F}{A}$

$PV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
ℓ = length
M = molar mass
n = number of moles
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$\sin \theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin \theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

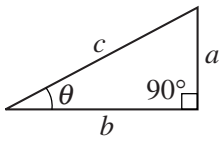
$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

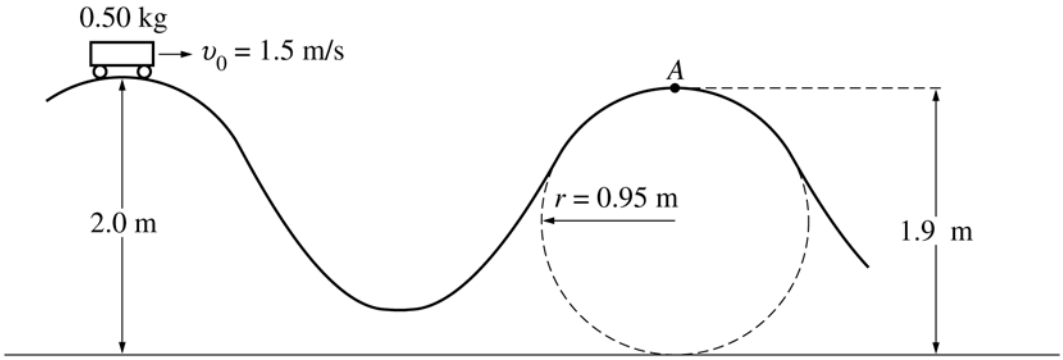
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin \theta = \frac{a}{c}$
$\cos \theta = \frac{b}{c}$
$\tan \theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



PHYSICS B
SECTION II
Time—90 minutes
6 Questions

Directions: Answer all six questions, which are weighted according to the points indicated. The suggested time is about 17 minutes for answering each of questions 1-4, and about 11 minutes for answering each of questions 5-6. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

A designer is working on a new roller coaster, and she begins by making a scale model. On this model, a car of total mass 0.50 kg moves with negligible friction along the track shown in the figure above. The car is given an initial speed $v_0 = 1.5$ m/s at the top of the first hill of height 2.0 m. Point A is located at a height of 1.9 m at the top of the second hill, the upper part of which is a circular arc of radius 0.95 m.

(a) Calculate the speed of the car at point A.

(b) On the figure of the car below, draw and label vectors to represent the forces on the car at point A.



(c) Calculate the magnitude of the force of the track on the car at point A.

(d) In order to stop the car at point A, some friction must be introduced. Calculate the work that must be done by the friction force in order to stop the car at point A.

(e) Explain how to modify the track design to cause the car to lose contact with the track at point A before descending down the track. Justify your answer.

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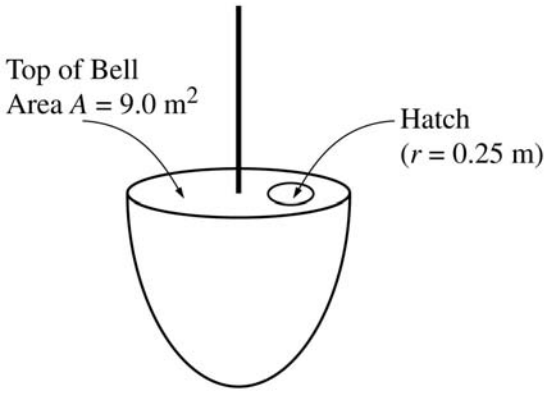

2. (15 points)

The experimental diving bell shown above is lowered from rest at the ocean's surface and reaches a maximum depth of 80 m. Initially it accelerates downward at a rate of $0.10\ \text{m/s}^2$ until it reaches a speed of $2.0\ \text{m/s}$, which then remains constant. During the descent, the pressure inside the bell remains constant at 1 atmosphere. The top of the bell has a cross-sectional area $A = 9.0\ \text{m}^2$. The density of seawater is $1025\ \text{kg/m}^3$.

(a) Calculate the total time it takes the bell to reach the maximum depth of 80 m.

(b) Calculate the weight of the water on the top of the bell when it is at the maximum depth.

(c) Calculate the absolute pressure on the top of the bell at the maximum depth.

On the top of the bell there is a circular hatch of radius $r = 0.25$ m.

(d) Calculate the minimum force necessary to lift open the hatch of the bell at the maximum depth.

(e) What could you do to reduce the force necessary to open the hatch at this depth? Justify your answer.

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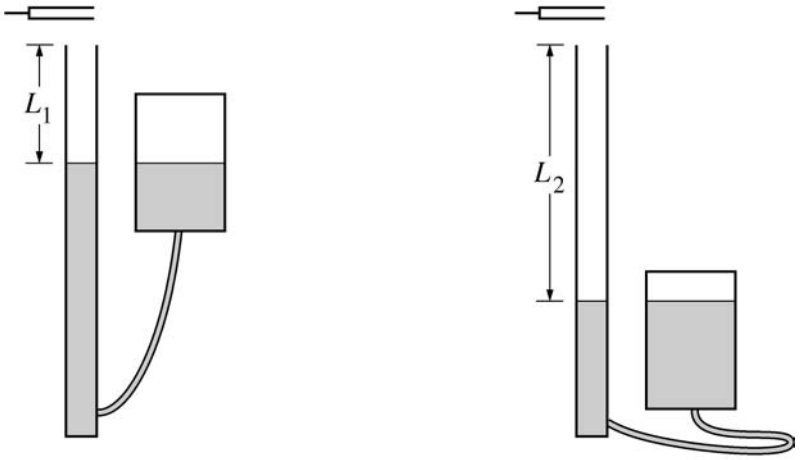

Note: Figure not drawn to scale.

3. (15 points)

A vibrating tuning fork is held above a column of air, as shown in the diagrams above. The reservoir is raised and lowered to change the water level, and thus the length of the column of air. The shortest length of air column that produces a resonance is $L_1 = 0.25$ m , and the next resonance is heard when the air column is $L_2 = 0.80$ m long. The speed of sound in air at 20°C is 343 m/s and the speed of sound in water is 1490 m/s.

(a) Calculate the wavelength of the standing sound wave produced by this tuning fork.

(b) Calculate the frequency of the tuning fork that produces the standing wave, assuming the air is at 20°C.

(c) Calculate the wavelength of the sound waves produced by this tuning fork in the water.

(d) The water level is lowered again until a third resonance is heard. Calculate the length L_3 of the air column that produces this third resonance.

(e) The student performing this experiment determines that the temperature of the room is actually slightly higher than 20°C. Is the calculation of the frequency in part (b) too high, too low, or still correct?

_____ Too high _____ Too low _____ Still correct

Justify your answer.

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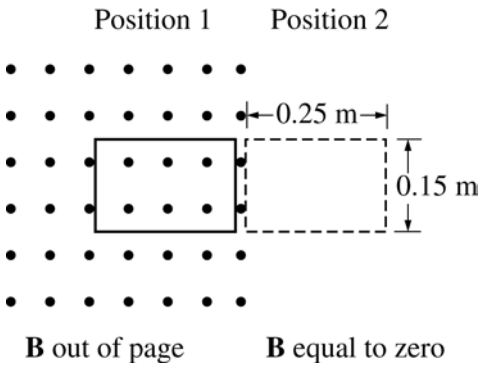

4. (15 points)

A 20-turn wire coil in the shape of a rectangle, 0.25 m by 0.15 m, has a resistance of $5.0\ \Omega$. In position 1 shown above, the loop is in a uniform magnetic field **B** of 0.20 T. The field is directed out of the page, perpendicular to the plane of the loop. The loop is pulled to the right at a constant velocity, reaching position 2 in 0.50 s, where **B** is equal to zero.

(a) Calculate the average emf induced in the 20-turn coil during this period.

(b) Calculate the magnitude of the current induced in the 20-turn coil and state its direction.

(c) Calculate the power dissipated in the 20-turn coil.

(d) Calculate the magnitude of the average force necessary to remove the 20-turn coil from the magnetic field.

(e) Identical wire is used to add 20 more turns of wire to the original coil. How does this affect the current in the coil? Justify your answer.

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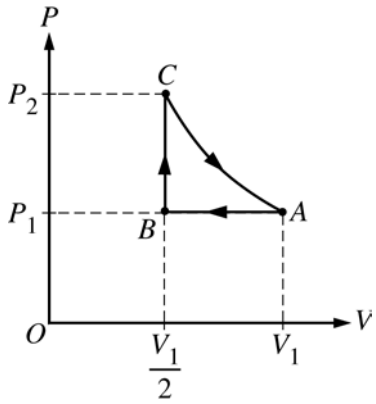

5. (10 points)

One mole of an ideal gas is initially at pressure P_1, volume V_1, and temperature T_1, represented by point A on the PV diagram above. The gas is taken around cycle $ABCA$ shown. Process AB is isobaric, process BC is isochoric, and process CA is isothermal.

(a) Calculate the temperature T_2 at the end of process AB in terms of temperature T_1.

(b) Calculate the pressure P_2 at the end of process BC in terms of pressure P_1.

(c) Calculate the net work done on the gas when it is taken from A to B to C. Express your answer in terms of P_1 and V_1.

(d) Indicate below all of the processes that result in heat being added to the gas.

____ AB ____BC ____CA

Justify your answer.

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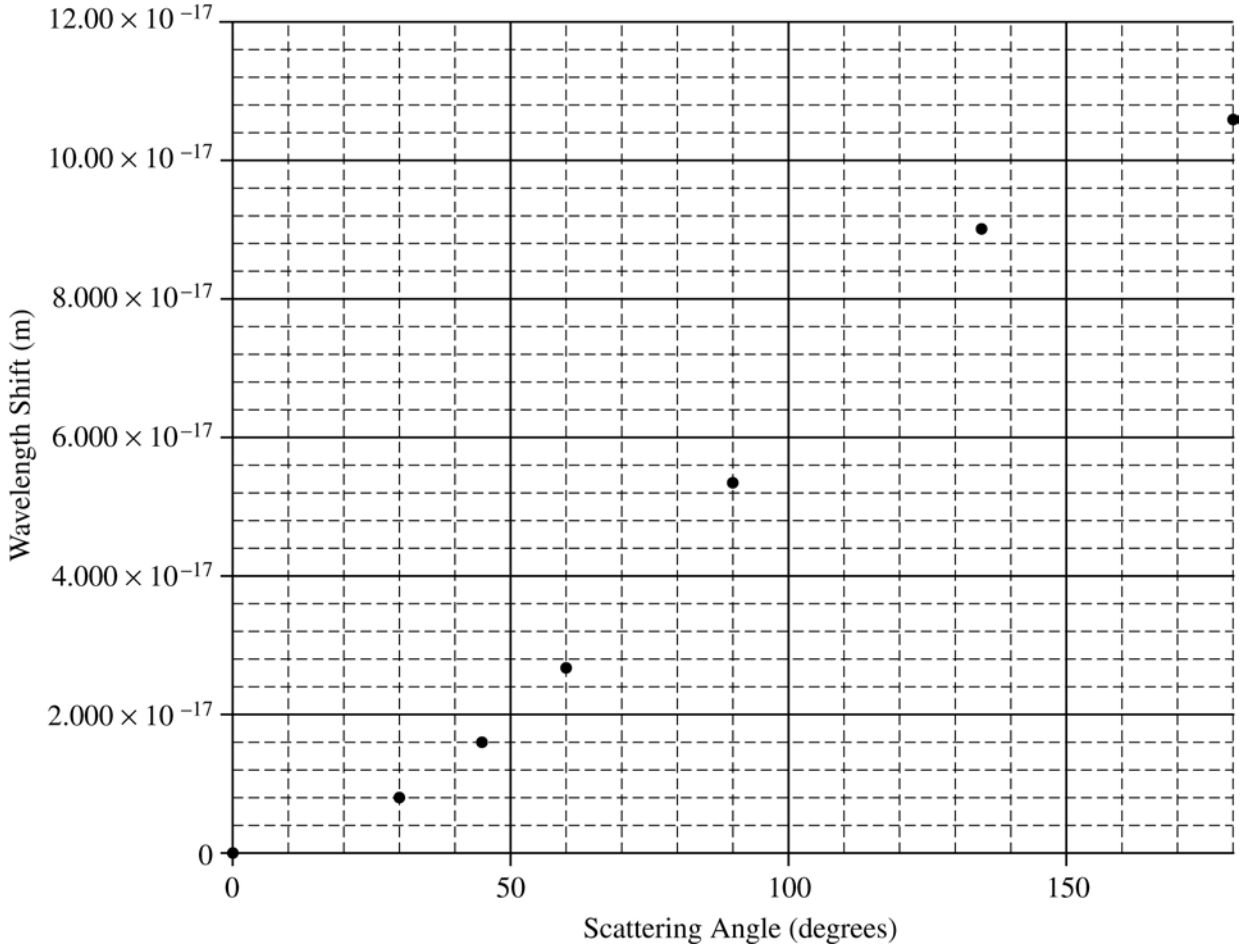
6. (10 points)

An incident gamma ray photon of wavelength 1.400×10^{-14} m is scattered off a stationary nucleus. The shift in wavelength of the photon is measured for various scattering angles, and the results are plotted on the graph shown below.



(a) On the graph, sketch a best-fit curve to the data.

In one of the trials, the photon is scattered at an angle of 120° with its original direction.

(b) Calculate the wavelength of this photon after it is scattered off the nucleus.

(c) Calculate the momentum of this scattered photon.

(d) Calculate the energy that this scattering event imparts to the recoiling nucleus.

END OF EXAMINATION

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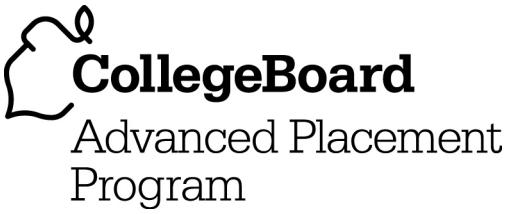

AP® Physics B
2004 Scoring Guidelines
Form B

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AP® PHYSICS B
2004 SCORING GUIDELINES (Form B)

General Notes about 2004 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g. a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g. 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS B
2004 SCORING GUIDELINES (Form B)

Question 1

15 points total **Distribution of points**

(a) 4 points

For any indication of conservation of energy 1 point
For a correct conservation equation for this situation 1 point

$$\frac{1}{2}mv_0^2 + mgh_0 = \frac{1}{2}mv_A^2 + mgh_A$$

$$v_A^2 = v_0^2 + 2g(h_0 - h_A)$$

For the correct substitutions 1 point

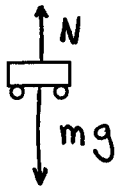
$$v_A^2 = (1.5 \text{ m/s})^2 + 2\left(9.8 \text{ m/s}^2\right)(2.0 \text{ m} - 1.9 \text{ m})$$

$$v_A^2 = 4.2(\text{m/s})^2 \quad (\text{or } 4.3(\text{m/s})^2 \text{ using } g = 10 \text{ m/s}^2)$$

For the correct answer 1 point

$v_A = 2.0$ m/s (or 2.1 m/s if v_A^2 was not rounded or if $g = 10$ m/s^2 was used)

(b) 2 points



For each correctly drawn and labeled force 1 pt each
One point earned for correct forces was deducted for having any extraneous forces.

(c) 3 points

For indicating that the sum of the forces equals the centripetal force 1 point

$$\sum F = \frac{mv_A^2}{r}$$

For having the correct relative signs in the application of the above equation 1 point

$$mg - N = \frac{mv_A^2}{r}$$

For solving for the normal force, substituting, and solving correctly 1 point

$$N = mg - \frac{mv_A^2}{r}$$

$$N = (0.50 \text{ kg})\left(9.8 \text{ m/s}^2\right) - \frac{(0.50 \text{ kg})\left(4.21(\text{m/s})^2\right)}{0.95 \text{ m}}$$

$$N = 2.7 \text{ N}$$

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Question 1 (continued)

Distribution of points

(d) 3 points

For any indication that the work done must equal the kinetic energy at point A in the absence of friction — 1 point

$W_{\text{friction}} = -\frac{1}{2}mv_A^2$

For correct substitution — 1 point

$W_{\text{friction}} = -\frac{1}{2}(0.50\text{ kg})\left(4.2(\text{m/s})^2\right)$

For the correct answer, including the negative sign — 1 point

$W_{\text{friction}} = -1.1\text{ J}$

(e) 3 points

Method 1:

For indicating that one should decrease the radius of the curve of the second hill — 1 point

The cart will lose contact when $mg - \frac{mv_A^2}{r} \le 0$. Decreasing the radius of the curve will cause the second term to increase and thus meet the condition.

For referring to the equation $N = mg - \frac{mv_A^2}{r}$ — 1 point

For indicating that the cart will loose contact when $N \le 0$ — 1 point

Method 2:

For indicating that one should make the initial hill higher or the second hill lower — (1 point)

The cart will loose contact when $mg - \frac{mv_A^2}{r} \le 0$. Increasing the difference in heights will cause the speed at A to increase, and thus the second term will increase and the condition will be met.

For referring to the equation $N = mg - \frac{mv_A^2}{r}$ and indicating that the cart will loose contact when $N \le 0$ — (1 point)

For indicating that the speed at A will increase — (1 point)

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Question 2

15 points total **Distribution of points**

(a) 4 points

For calculating the length of time t_1 that the diving bell is accelerating (i.e. the time it takes to reach the constant speed v_c) 1 point

$v_c = at_1$

$t_1 = v_c / a$

$t_1 = (2.0 \text{ m/s}) / (0.10 \text{ m/s}^2) = 20 \text{ s}$

For calculating the distance the bell descends while accelerating 1 point

$d_1 = \frac{1}{2} a t_1^2$

$d_1 = \frac{1}{2}(0.10 \text{ m/s}^2)(20 \text{ s})^2 = 20 \text{ m}$

The bell therefore descends a distance $d_2 = 80 \text{ m} - 20 \text{ m} = 60 \text{ m}$ at the constant speed.

For calculating the time to descend this 60 m 1 point

$d_2 = v_c t_2$

$t_2 = d_2 / v_c$

$t_2 = (60 \text{ m})/(2.0 \text{ m/s}) = 30 \text{ s}$

For calculating the total time 1 point

$t_{\text{tot}} = t_1 + t_2 = 20 \text{ s} + 30 \text{ s}$

$t_{\text{tot}} = 50 \text{ s}$

(b) 3 points

For a correct expression for the weight of the water above the cross-sectional area A 1 point

$w = \rho V g = \rho A h g$

For correct substitution 1 point

$w = (1025 \text{ kg/m}^3)(9.0 \text{ m}^2)(80 \text{ m})(9.8 \text{ m/s}^2)$

For the correct answer, including units 1 point

$w = 7.2 \times 10^6 \text{ N}$ (or $7.4 \times 10^6 \text{ N}$ using $g = 10 \text{ m/s}^2$)

Full credit could also be earned for determining the pressure due to the water alone, and using $F = PA$ to determine the weight

A maximum of 2 points could be earned for only determining the mass of the water, or for calculating the absolute pressure and using $F = PA$.

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Question 2 (continued)

Distribution of points

(c) 3 points

For indicating that the pressure at a depth h has a term ρgh, or using $P = w/A$ and the value of the weight from part (b) — 1 point

For indicating that the atmospheric pressure must be added (in correct SI units – otherwise the ρgh term must be converted to atmospheres for full credit) — 1 point

$P = (w/A) + P_{atm}$

$P = \left(7.2 \times 10^6 \text{ N}/9.0 \text{ m}^2\right) + 1.0 \times 10^5 \text{ N}/\text{m}^2$

For the correct answer, including units — 1 point

$P = 9.0 \times 10^5 \text{ N}/\text{m}^2$ (or $9.2 \times 10^5 \text{ N}/\text{m}^2$ using $g = 10 \text{ m}/\text{s}^2$)

(d) 3 points

For a correct expression for the force on an area A_{hatch} — 1 point

$F = PA_{\text{hatch}}$

For a correct expression for the area of the hatch — 1 point

$A_{\text{hatch}} = \pi r^2$

Since there is one atmosphere pressure inside the diving bell, the net pressure corresponding to the minimum applied force is that from the water only.

$F_{\text{min}} = \rho ghA_{\text{hatch}}$

Substituting:

$F_{\text{min}} = \left(1025 \text{ kg}/\text{m}^3\right)\left(9.8 \text{ m}/\text{s}^2\right)(80 \text{ m})\left(\pi (0.25 \text{ m})^2\right)$

For the correct answer — 1 point

$F_{\text{min}} = 1.6 \times 10^5 \text{ N}$

Since the question could have been interpreted as asking for the minimum total force required, full credit was awarded for including atmospheric pressure.

(e) 2 points

For a correct modification that would reduce the force necessary to open the hatch — 1 point

For a correct justification — 1 point

Examples:

Increase the pressure inside the diving bell. The internal pressure would then compensate for atmospheric pressure plus some of the pressure of the water, reducing the force needed.

Reduce the size of the hatch. Pressure times a smaller area yields a smaller force.

Use a tool that gives a mechanical advantage, such as a lever. Such a tool is designed so that one exerts a smaller force over a larger distance than one would without it.

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AP® PHYSICS B
2004 SCORING GUIDELINES (Form B)

Question 3

15 points total **Distribution of points**

(a) 4 points

There must be a node at the liquid surface and an antinode near the top of the tube, so the length of consecutive resonances differ by a half wavelength.

For equating the difference in air column lengths to the difference in the number of wavelengths 3 points

$L_2 - L_1 = \frac{\lambda}{2}$

$\lambda = 2(L_2 - L_1)$

For correct substitution and answer 1 point

$\lambda = 2(0.80 \text{ m} - 0.25 \text{ m})$

$\lambda = 1.1 \text{ m}$

A maximum of 3 points was awarded for using only one of the air column lengths to calculate a wavelength

A maximum of 2 points was awarded for equating the difference in air column lengths to one or one-quarter wavelength

(b) 2 points

For using the relationship between wavelength, speed, and frequency 1 point

$f = v_{\text{air}}/\lambda$

For correct substitutions (using λ from part (a)) and a corresponding correct answer 1 point

$f = (343 \text{ m/s})/(1.1 \text{ m})$

$f = 312 \text{ Hz}$

(c) 3 points

For indicating the need to use the values of the wave properties appropriate for water 1 point

$\lambda_{\text{water}} = v_{\text{water}}/f_{\text{water}}$

For indicating that the frequency in water is the same as in air 1 point

For correct substitution and answer 1 point

$\lambda_{\text{water}} = \frac{(1490 \text{ m/s})}{312 \text{ Hz}}$

$\lambda_{\text{water}} = 4.8 \text{ m}$

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Question 3 (continued)

Distribution of points

(d) 3 points

L_3 is approximately $1\frac{1}{4}$ wavelengths, which is one-half wavelength longer than L_2

For any indication that L_3 equals $L_2 + \lambda/2$ or $L_1 + \lambda$ — 2 points

$L_3 = 0.80 \text{ m} + \frac{1.1 \text{ m}}{2}$

For the correct answer (using whatever wavelength was determined previously) — 1 point

$L_3 = 1.35 \text{ m}$

A maximum of 2 points were awarded for using $L_3 = 5\lambda/2$ or $L_3 = L_2 + \lambda$

One point was awarded for a good drawing of the standing wave in the air column with no calculation.

(e) 3 points

For indicating that the calculation of frequency was too low — 2 points

For a correct justification — 1 point

For example: As temperature increases, the speed of sound in air increases, so the speed used in part (b) was too low. Since $f = v_{\text{air}}/\lambda$, that lower speed of sound yielded a frequency that was too low.

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Question 4

15 points total **Distribution of points**

(a) 4 points

For a correct expression for the magnitude of the emf per turn in the coil 1 point

$\mathcal{E} = \frac{\Delta\phi}{\Delta t}$ OR $\mathcal{E} = B\ell v$

$\mathcal{E} = \frac{A\Delta B}{\Delta t} = \frac{w\ell(B-0)}{\Delta t}$ OR $\mathcal{E} = \frac{B\ell w}{\Delta t}$

For correct substitutions in either equation (both yield the same value) 1 point

$\mathcal{E} = \frac{(0.25\text{ m})(0.15\text{ m})(0.20\text{ T})}{0.50\text{ s}}$

For correct calculation 1 point

$\mathcal{E} = 0.015$ V per turn

For recognizing that with 20 turns the total emf in the coil is 20 times the emf per turn 1 point

$\mathcal{E}_{\text{tot}} = 20(0.015\text{ V per turn}) = 0.30\text{ V}$

(b) 2 points

For correct expression for Ohm's law, substitution from part (a), and magnitude 1 point

$V = IR$

$I = \frac{V}{R} = \frac{0.30\text{ V}}{5.0\,\Omega} = 0.06\text{ A}$

For correct direction, i.e., counterclockwise 1 point

(c) 3 points

For a correct expression for the power dissipated in the coil 1 point

$P = IV$ OR $P = I^2R$ OR $P = V^2/R$

For correct substitution of answers from (a) and/or (b) into one of these expressions 1 point

(Must recognize that $V = \mathcal{E}_{\text{tot}}$)

For example, $P = (0.06\text{ A})(0.30\text{ V})$

For correct calculation including correct units 1 point

$P = 0.018$ W

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Question 4 (continued)

Distribution of points

(d) 3 points

The force on the right side is zero, and forces on the top and bottom sides cancel, so the net force is that on the left side.

For the correct expression for the force on a straight wire (force per turn in this situation) in a magnetic field — 1 point

$F = BI\ell\sin\theta$ OR $F = BI\ell$ (recognizing that the wire is perpendicular to the field)

For correct substitutions — 1 point

$F = (0.20\text{ T})(0.60\text{ A})(0.15\text{ m})$

$F = 0.0018\text{ N}$

For recognizing that with 20 turns the total force on the left side of the coil is 20 times the force per turn — 1 point

$F_{tot} = 0.036\text{ N}$

Alternate Solution — *Alternate points*

For using one of the equations $P = Fv\sin\theta$ OR $P = \frac{W}{t} = \frac{Fd}{t}$ — *1 point*

$F = \frac{P}{v\sin\theta}$ OR $F = \frac{Pt}{d}$

For correct substitutions (both approaches yield same value) — *1 point*

$F_{tot} = \frac{(0.018\text{ W})(0.50\text{ s})}{0.25\text{ m}}$

For correct answer — *1 point*

$F_{tot} = 0.036\text{ N}$

(e) 3 points

For recognition that doubling the number of turns doubles the total emf, which would tend to increase the current — 1 point

For recognition that doubling the number of turns doubles the total resistance, which would tend to decrease the current — 1 point

For putting these together to show that the current is unchanged — 1 point

$$I_f = \frac{\mathcal{E}_f}{R_f} = \frac{2\mathcal{E}_i}{2R_i} = \frac{\mathcal{E}_i}{R_i} = I_i$$

Note: The third point was awarded for an indication that the current is unchanged, even if the justification was wrong.

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AP® PHYSICS B
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Question 5

10 points total **Distribution of points**

(a) 2 points

For recognizing that $P_A = P_B$ 1 point

At point A: $P_1 V_1 = nRT_1$

At point B: $P_1 \frac{V_1}{2} = nRT_2$

Dividing these equations and solving for T_2:

$$\frac{P_1 V_1}{P_1 \frac{V_1}{2}} = \frac{T_1}{T_2}$$

$$2 = \frac{T_1}{T_2}$$

For the correct answer 1 point

$T_2 = T_1/2$

(b) 2 points

Answer can be obtained by either comparing points B & C or points A & C using the ideal gas law at each point

For recognizing that $T_C = 2T_B$ OR $T_C = T_A$ 1point

<u>Comparing points B & C</u>

At point B: $P_1 \frac{V_1}{2} = nR\frac{T_1}{2}$

At point C: $P_2 \frac{V_1}{2} = nRT_1$

Dividing the equations and solving for P_2:

$$\frac{P_1 \frac{V_1}{2}}{P_2 \frac{V_1}{2}} = \frac{nR\frac{T_1}{2}}{nRT_1}$$

$$\frac{P_1}{P_2} = \frac{1}{2}$$

For the correct answer

$P_2 = 2P_1$

<u>Comparing points C & A</u>

At point A: $P_1 V_1 = nRT_1$

At point C: $P_2 \frac{V_1}{2} = nRT_1$

Dividing the equations and solving for P_2:

$$\frac{P_1 V_1}{P_2 \frac{V_1}{2}} = 1$$

$$\frac{2P_1}{P_2} = 1$$

For the correct answer 1 point

$P_2 = 2P_1$

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Question 5 (continued)

Distribution of points

(c) 2 points

For correct equation for work done on the gas (regardless of sign) OR for recognition that work is the area under the line *AB* on the graph. (No work is done from *B* to *C* because the change in volume is zero.) — 1 point

$W = -P\,\Delta V$

$W = -P_1\left(\frac{V_1}{2} - V_1\right)$

For the correct answer including correct sign — 1 point

$W = \frac{P_1 V_1}{2}$

(d) 4 points

Heat was added to the gas in processes *BC* and *CA*, but not in *AB*.

For two or three correct indications of whether or not heat was added to the gas in each process (The absence of a check mark was taken as in indication that heat was not added.) — 1 point

For a reasonable justification for process *AB*. This point was awarded only if this process was indicated correctly (i.e., not checked) — 1 point

Example: The volume decreases so the work done on the gas is positive. The temperature decreases so the change in internal energy is negative. Therefore $Q = \Delta U - W$ is negative. Heat is expelled from the gas. (Note: Answer must mention work for credit.)

For a reasonable justification for process *BC*. This point was awarded only if this process was indicated correctly (i.e., checked) — 1 point

Example: There is no change in volume so no work is done. The temperature increases so the internal energy increases. Therefore $Q = \Delta U - W$ is positive. (This point also awarded for only referring to increasing temperature or for referring to increasing speed of the molecules.)

For a reasonable justification for process *CA*. This point was awarded only if this process was indicated correctly (i.e., checked). — 1 point

Example: There is no change in temperature or internal energy. The volume increases so work is done by the gas. Heat needs to be added to the gas to do this work.

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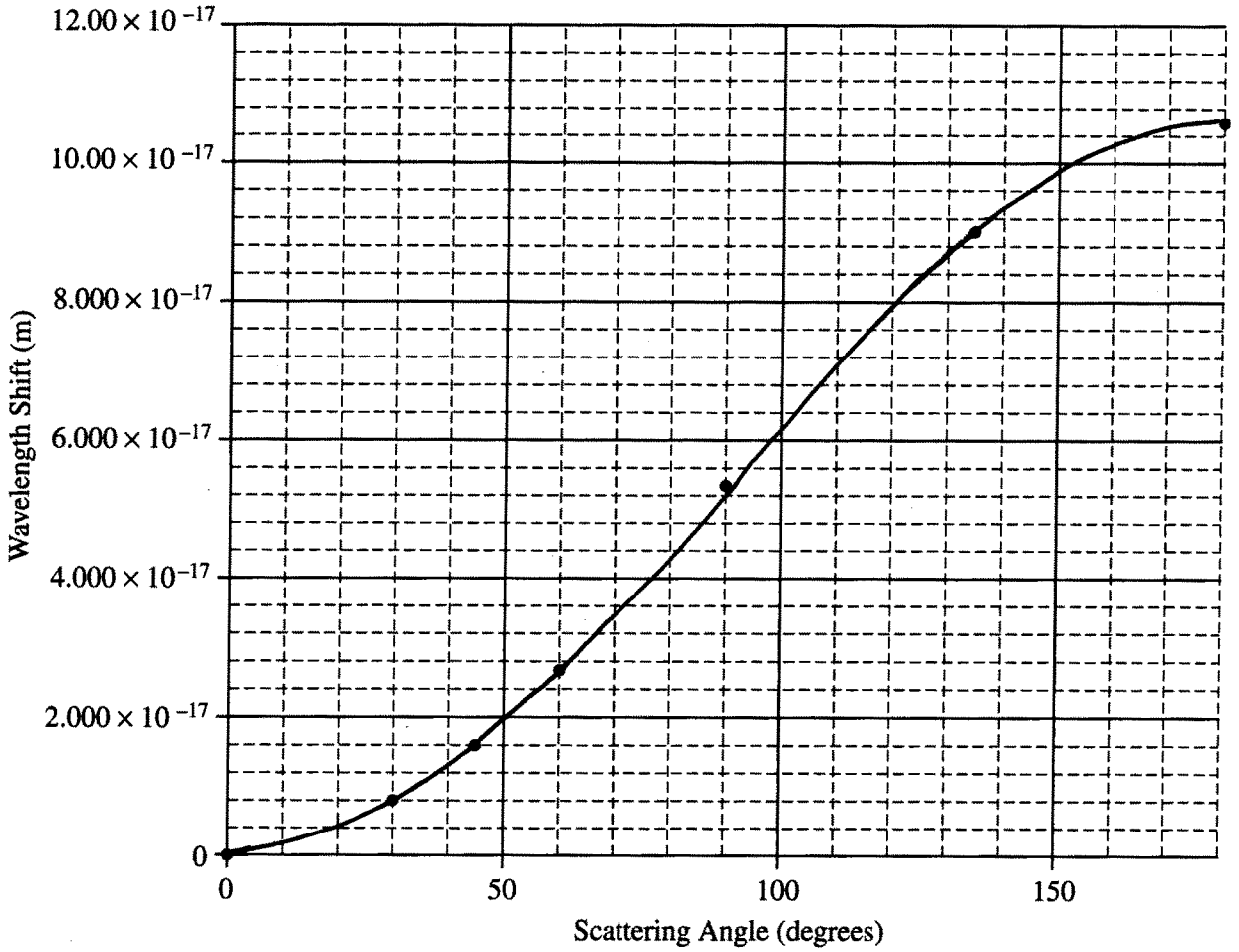
Question 6

10 points total **Distribution of points**

(a) 3 points



For a smooth curve passing through or very close to all plotted points 3 points
Partial credit points could be awarded for curves of lesser quality.
For example:
Showing all the data points connected by straight-line segments earned 2 points.
Curves that generally fit the data points at small angles, but are concave upward for the whole range earned 1 or 2 points depending on how badly the curve misses the points at higher angles.
A single straight "best fit" line or really bad curve earned 1 point.
A curve that was monotonically decreasing earned no points.

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Question 6 (continued)

Distribution of points

(b) 3 points

For reading the wavelength shift from the graph 1 point

From the graph shown, the wavelength shift at $120°$ is 8.000×10^{-17} m.
The photon loses energy, which means the wavelength increases.

For adding (not subtracting) the wavelength shift to the original wavelength 1 point

$\lambda_s = 1.400 \times 10^{-14}\ \text{m} + 8.000 \times 10^{-17}\ \text{m}$

For correct answer 1 point

$\lambda_s = 140.8 \times 10^{-16}\ \text{m} = 1.41 \times 10^{-14}\ \text{m}$

(c) 2 points

For using the de Broglie equation to calculate momentum (even if a value from (b) that was actually $\Delta\lambda$ was substituted) 1 point

$\lambda_s = h/p_s$ OR $p = h/\lambda$

$p_s = h/\lambda_s$

$p_s = \left(6.63 \times 10^{-34}\ \text{J•s}\right)/\left(1.408 \times 10^{-14}\ \text{m}\right)$

For consistent answer including correct units 1 point

$p_s = 4.71 \times 10^{-20}\ \text{kg•m/s}$

Note: The answer point could also be awarded if the value of $\lambda_s = \lambda_i - \Delta\lambda$ was used instead of the correct relationship.

(d) 2 points

For use of conservation of energy 1 point

$\Delta E_{nuc} = -\Delta E_{photon}$

$\Delta E_{photon} = \Delta(hf) = \Delta\left(\frac{hc}{\lambda}\right)$ OR $\Delta E_{photon} = \Delta(pc) = \Delta\left(\frac{hc}{\lambda}\right)$

$\Delta E_{nuc} = -\left(\frac{hc}{\lambda_s} - \frac{hc}{\lambda_i}\right) = hc\left(\frac{1}{\lambda_i} - \frac{1}{\lambda_s}\right)$

$\Delta E_{nuc} = \left(1.99 \times 10^{-25}\ \text{J} \cdot \text{m}\right)\left(\frac{1}{1.400 \times 10^{-14}\ \text{m}} - \frac{1}{1.408 \times 10^{-14}\ \text{m}}\right)$

For the correct answer 1 point

$\Delta E_{nuc} = 8.08 \times 10^{-14}\ \text{J}$ (or 510 keV)

Note: The answer point was awarded for correct use of whatever λ_s was obtained from part (b), but not for using the value of $\Delta\lambda$.

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AP® Physics B
2003 Free-Response Questions

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CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2003

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta\mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2003

FLUID MECHANICS AND THERMAL PHYSICS

$p = p_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$p + \rho gy + \frac{1}{2}\rho v^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$Q = mL$

$Q = mc\Delta T$

$p = \frac{F}{A}$

$pV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q + W$

$\Delta U = nc_V \Delta T$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

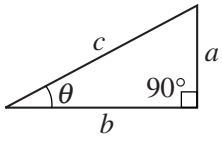
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$

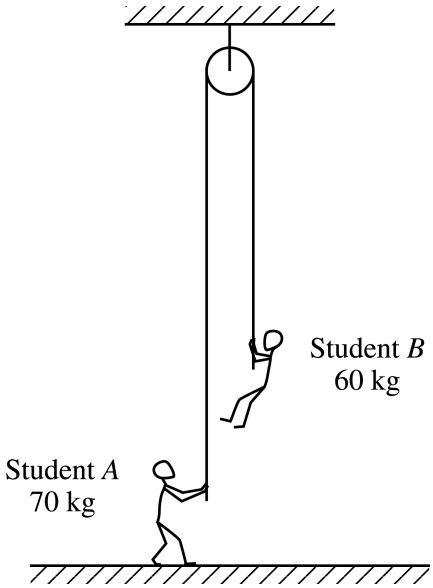


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2003 AP® PHYSICS B FREE-RESPONSE QUESTIONS

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



1. (15 points)
A rope of negligible mass passes over a pulley of negligible mass attached to the ceiling, as shown above. One end of the rope is held by Student *A* of mass 70 kg, who is at rest on the floor. The opposite end of the rope is held by Student *B* of mass 60 kg, who is suspended at rest above the floor.

   (a) On the dots below that represent the students, draw and label free-body diagrams showing the forces on Student *A* and on Student *B*.

   ● *B*

   ● *A*

   (b) Calculate the magnitude of the force exerted by the floor on Student *A*.

   Student *B* now climbs up the rope at a constant acceleration of 0.25 m/s^2 with respect to the floor.

   (c) Calculate the tension in the rope while Student *B* is accelerating.

   (d) As Student *B* is accelerating, is Student *A* pulled upward off the floor? Justify your answer.

   (e) With what minimum acceleration must Student *B* climb up the rope to lift Student *A* upward off the floor?

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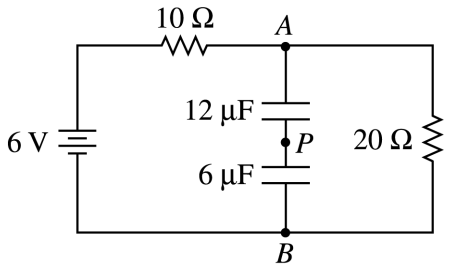

2. (15 points)
A circuit contains two resistors (10 Ω and 20 Ω) and two capacitors (12 μF and 6 μF) connected to a 6 V battery, as shown in the diagram above. The circuit has been connected for a long time.

(a) Calculate the total capacitance of the circuit.

(b) Calculate the current in the 10 Ω resistor.

(c) Calculate the potential difference between points A and B.

(d) Calculate the charge stored on one plate of the 6 μF capacitor.

(e) The wire is cut at point P. Will the potential difference between points A and B increase, decrease, or remain the same?

____ increase ____ decrease ____ remain the same

Justify your answer.

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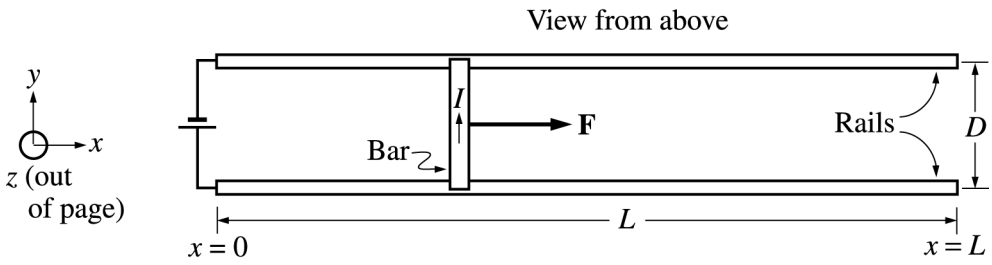

3. (15 points)
A rail gun is a device that propels a projectile using a magnetic force. A simplified diagram of this device is shown above. The projectile in the picture is a bar of mass M and length D, which has a constant current I flowing through it in the +y-direction, as shown. The space between the thin frictionless rails contains a uniform magnetic field **B**, perpendicular to the plane of the page. The magnetic field and rails extend for a distance L. The magnetic field exerts a constant force **F** on the projectile, as shown.

Express all algebraic answers to the following parts in terms of the magnitude F of the constant magnetic force, other quantities given above, and fundamental constants.

(a) Determine the position x of the projectile as a function of time t while it is on the rail if the projectile starts from rest at $x = 0$ when $t = 0$.

(b) Determine the speed of the projectile as it leaves the right-hand end of the track.

(c) Determine the energy supplied to the projectile by the rail gun.

(d) In what direction must the magnetic field **B** point in order to create the force **F** ? Explain your reasoning.

(e) Calculate the speed of the bar when it reaches the end of the rail given the following values.

$B = 5$ T $L = 10$ m $I = 200$ A $M = 0.5$ kg $D = 10$ cm

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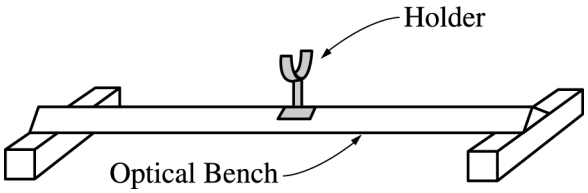
4. (15 points)
In your physics lab, you have a concave mirror with radius of curvature $r = 60$ cm. You are assigned the task of finding experimentally the location of a lit candle such that the mirror will produce an image that is 4 times the height of the lit candle.



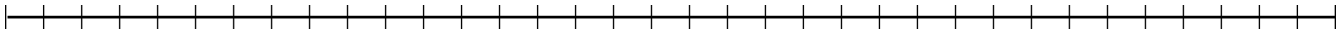
You have an optical bench, which is a long straight track as shown above. Objects in holders can be attached at any location along the bench. In addition to the concave mirror and the lit candle in holders, you also have the following equipment.

____ convex mirror in holder	____ concave lens in holder	____ convex lens in holder
____ meter stick	____ ruler	____ screen in holder

(a) Briefly list the steps in your procedure that will lead you to the location of the lit candle that produces the desired image. Include definitions of any parameters that you will measure.

(b) On the list of equipment before part (a) place check marks beside each additional piece of equipment you will need to do this experiment.

(c) On the scale below, draw a ray diagram of your lab setup in part (a) to show the locations of the candle, the mirror, and the image.



(d) Check the appropriate spaces below to indicate the characteristics of your image.

____ real	____ upright	____ larger than object
____ virtual	____ inverted	____ smaller than object

(e) You complete your assignment and turn in your results to your teacher. She tells you that another student, using equipment from the same list, has found a different location for the lit candle. However, she tells both of you that the labs were done correctly and that neither experiment need be repeated. Explain why both experiments can be correct.

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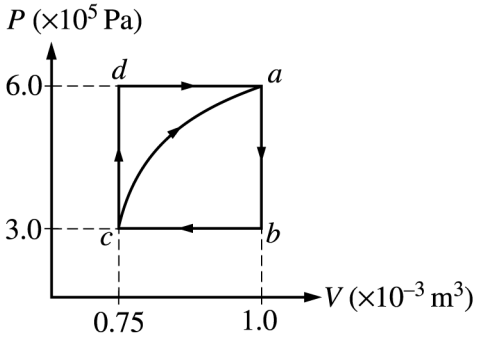

5. (10 points)
A cylinder with a movable piston contains 0.1 mole of a monatomic ideal gas. The gas, initially at state *a,* can be taken through either of two cycles, *abca* or *abcda*, as shown on the *PV* diagram above. The following information is known about this system.

$Q_{c\to a} =$ 685 J along the curved path

$W_{c\to a} = -120$ J along the curved path

$U_a - U_b = 450$ J

$W_{a\to b\to c} = 75$ J

(a) Determine the change in internal energy, $U_a - U_c$, between states a and c.

(b) i. Is heat added to or removed from the gas when the gas is taken along the path *abc* ?

___ added to the gas ____ removed from the gas

ii. Calculate the amount added or removed.

(c) How much work is done on the gas in the process *cda*?

(d) Is heat added to or removed from the gas when the gas is taken along the path *cda*?

___ added to the gas ____ removed from the gas

Explain your reasoning.

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6. (10 points)

A diver descends from a salvage ship to the ocean floor at a depth of 35 m below the surface. The density of ocean water is 1.025×10^3 kg/m^3.

(a) Calculate the gauge pressure on the diver on the ocean floor.

(b) Calculate the absolute pressure on the diver on the ocean floor.

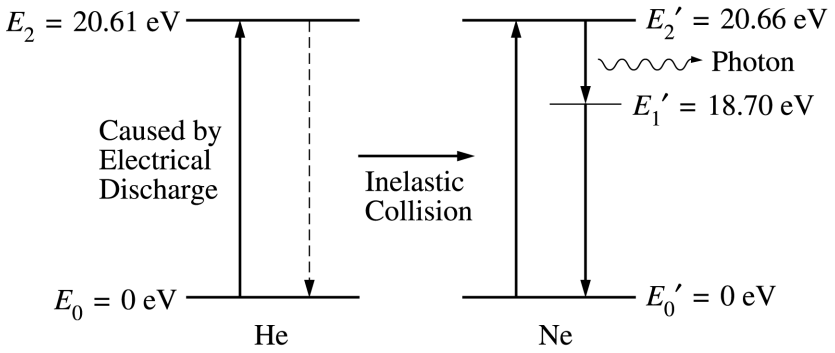
The diver finds a rectangular aluminum plate having dimensions 1.0 m × 2.0 m × 0.03 m. A hoisting cable is lowered from the ship and the diver connects it to the plate. The density of aluminum is 2.7×10^3 kg/m^3. Ignore the effects of viscosity.

(c) Calculate the tension in the cable if it lifts the plate upward at a slow, constant velocity.

(d) Will the tension in the hoisting cable increase, decrease, or remain the same if the plate accelerates upward at 0.05 m/s^2?

____ increase ____ decrease ____ remain the same

Explain your reasoning.



7. (10 points)

Energy-level diagrams for atoms that comprise a helium-neon laser are given above. As indicated on the left, the helium atom is excited by an electrical discharge and an electron jumps from energy level E_0 to energy level E_2. The helium atom (atomic mass 4) then collides inelastically with a neon atom (atomic mass 20), and the helium atom falls to the ground state, giving the neon atom enough energy to raise an electron from E_0' to E_2'. The laser emits light when an electron in the neon atom falls from energy level E_2' to energy level E_1'.

(a) Calculate the minimum speed the helium atom must have in order to raise the neon electron from E_0' to E_2'.

(b) Calculate the DeBroglie wavelength of the helium atom when it has the speed determined in (a).

(c) The excited neon electron then falls from E_2' to E_1' and emits a photon of laser light. Calculate the wavelength of this light.

(d) This laser light is now used to repair a detached retina in a patient's eye. The laser puts out pulses of length 20×10^{-3} s that average 0.50 W output per pulse. How many photons does each pulse contain?

END OF EXAMINATION

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AP® Physics B
2003 Scoring Guidelines

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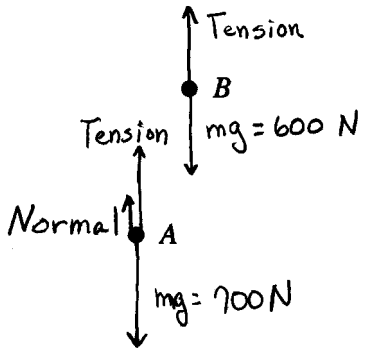
AP® PHYSICS B
2003 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 3 points



For a free body diagram that includes any one of the three forces on Student *A* (weight, normal, or tension) 1 point

For correctly including the other two forces on Student *A* 1 point

For a correct free-body diagram for Student *B* (including both weight and tension) 1 point

One point was deducted for each extraneous vector, up to a maximum of the number of point already earned

(b) 3 points

For equating the tension in the rope to the weight of Student *B* 1 point

$T = m_B g$

For a correct expression for the sum of the forces on Student *A* 1 point

$\Sigma F_A = T + N - m_A g = 0$

Eliminating *T* and solving for *N*

$N = m_A g - m_B g$

$N = (70\ \text{kg} - 60\ \text{kg})(9.8\ \text{m/s}^2) = 686\ \text{N} - 588\ \text{N}$

For the correct answer 1 point

$N = 98\ \text{N}$ (or 100 N using $g = 10\ \text{m/s}^2$)

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Question 1 (continued)

Distribution of points

(c) 3 points

For applying Newton's 2nd law to Student *B* — 1 point
$\Sigma F_B = m_B a$

For a correct expression for the sum of the forces on Student *B* — 1 point
$\Sigma F_B = T - m_B g$

Solving for *T* and substituting:
$T = m_B g + m_B a = 588 \text{ N} + (60 \text{ kg})(0.25 \text{ m/s}^2)$

For the correct answer — 1 point
$T = 603 \text{ N}$ (or 615 N using $g = 10 \text{ m/s}^2$)

(d) 2 points

For a correct response of "No" — 1 point
For a reasonable explanation — 1 point
Example: To lift student *A* off the floor, the tension must be greater than the students' weight of (70 kg)*g*

An answer of "Yes" was acceptable IF the answer to (c) was greater than the weight of Student *A* AND the justification was consistent.

(e) 3 points

For applying Newton's 2nd Law to Student *B* — 1 point
$\Sigma F_B = m_B a$

For a correct expression for the sum of the forces on Student *B* — 1 point
$\Sigma F_B = T - m_B g$

Solving for *a*
$a = \dfrac{T}{m_b} - g$

The minimum tension required to lift Student *A* is the student's weight
Substituting:
$a = \dfrac{686 \text{ N}}{60 \text{ kg}} - 9.8 \text{ m/s}^2$

For the correct answer — 1 point
$a = 1.63 \text{ m/s}^2$ (or 1.67 m/s^2 using $g = 10 \text{ m/s}^2$)

For indicating correct units in parts (b), (c) and (e) — 1 point

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AP® PHYSICS B
2003 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**

(a) 3 points

For the correct formula for total capacitance in series 1 point

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ OR $C_T = \frac{C_1 C_2}{C_1 + C_2}$

For correct substitution 1 point

$\frac{1}{C_T} = \frac{1}{12\,\mu\text{F}} + \frac{1}{6\,\mu\text{F}}$ OR $C_T = \frac{(12\,\mu\text{F})(6\,\mu\text{F})}{12\,\mu\text{F} + 6\,\mu\text{F}}$

For the correct numerical answer 1 point

$C_T = 4\,\mu\text{F}$

(b) 3 points

The capacitors are fully charged so current flows through the resistors but not the capacitors.

For calculating the total resistance in series 1 point

$R_T = R_1 + R_2 = 10\,\Omega + 20\,\Omega = 30\,\Omega$

For use of correct form of Ohm's law 1 point

$I = \frac{V}{R} = \frac{6\text{ V}}{30\,\Omega}$

For the correct answer 1 point

$I = 0.2$ A

(c) 3 points

Potential difference between A and B is the voltage across the 20 Ω resistor

For a correct form of Ohm's law 1 point

$V = IR$

For correct substitutions for I from part (b) and for R 1 point

$V = (0.2\text{ A})(20\,\Omega)$

For the correct answer 1 point

$V = 4$ V

Note: 1 point was subtracted for indicating a wrong unit.

Alternately, full credit could be obtained for finding the voltage across the 10 Ω resistor and subtracting it from 6 V *or* for recognizing that the voltages across the 20 Ω and 10 Ω resistors would add to 6 V and be in a 2/1 ratio, and using this to obtain the correct answer.

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Question 2 (continued)

Distribution of points

(d) 4 points

For using the correct formula to determine the charge — 1 point
$Q = CV$

For correct substitution of value of C from part (a) — 1 point

For correct substitution of value of V from part (c) — 1 point
$Q = \left(4 \times 10^{-6}\ \text{F}\right)\left(4\ \text{V}\right)$

For the correct answer — 1 point
$Q = 16 \times 10^{-6}\ \text{C} = 16\ \mu\text{C}$

Alternately, full credit could be obtained by first determining the voltage across the 6 μF capacitor (which can be done one way by recognizing that the voltages across the two capacitors are in a 2/1 ratio and sum to 4 V) and substituting this value for V and the value for C of 6 μF into the equation $Q = CV$.

(e) 2 points

For checking the box "remains the same" — 1 point

For a reasonable justification — 1 point

Example: No current is flowing from A to P to B. Therefore breaking the circuit at point P does not affect the current in the outer loop, and therefore will not affect the potential difference between A and B (or across the 20 Ω resistor).

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Question 3

15 points total **Distribution of points**

(a) 3 points

For using the correct kinematic equation 1 point

$x - x_0 = v_0 t + \frac{1}{2}at^2$

For using Newton's second law to determine the acceleration 1 point

$F = ma$, so $a = F/m$

Both x_0 and v_0 equal zero.

For the correct answer 1 point

$x = Ft^2/2M$ (or $IDBt^2/2M$ using $F = IDB$)

(b) 3 points

For an appropriate kinematic or momentum equation 1 point

$v^2 = v_0^2 + 2a(x - x_0)$ (or other kinematic equations) OR $M\,\Delta v = Ft$

If an equation containing *t* was used, the expression from part (a) can be used to find *t*

For indicating the correct distance 1 point

$x - x_0 = L$

Substituting

$v^2 = 0 + 2(F/M)L$ OR $Mv = F\sqrt{2(x - x_0)/a} = F\sqrt{2LM/F}$

For the correct answer 1 point

$v = \sqrt{2FL/M}$ (or $\sqrt{2IDBL/M}$ using $F = IDB$)

Alternately, full credit was also awarded for using conservation of energy and directly relating the change in kinetic energy to the work done, i.e. $\frac{1}{2}mv^2 = FL$.

(c) 3 points

For indicating that the energy supplied equals the final kinetic energy 1 point

$E = \frac{1}{2}mv^2$

For substituting the value of v determined in part (b) 1 point

$E = \frac{1}{2}m\left(\sqrt{2FL/M}\right)^2$

For the correct answer 1 point

$E = FL$ (or $IDBL$ using $F = IDB$)

Full credit could also be earned for using the work-energy theorem and indicating that the work equals *FL*

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Question 3 (continued)

Distribution of points

(d) 2 points

For indicating that the magnetic field points out of the plane of the page, or in the +z-direction — 1 point

For a correct explanation — 1 point
For example, referencing the right-hand rule or giving a verbal explanation of how it applies to the situation

(e) 4 points

For using the expression for v determined in part (b) — 1 point
$v = \sqrt{2FL/M}$ OR $\sqrt{2IDBL/M}$

For an indication that $F = I\ell B$ — 1 point

For an indication that $\ell = D$ — 1 point

For correctly substituting the values of D and L, and obtaining the correct answer, with units — 1 point
$v = \sqrt{2(200\text{ A})(0.1\text{ m})(5\text{ T})(10\text{ m})/(0.5\text{ kg})} = 63\text{ m/s}$
(or 60 m/s with the correct number of significant figures)

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Question 4

15 points total **Distribution of points**

Two possible situations fit the requirements: one forms a real image and the other a virtual image.

(a) 3 points

For placing the concave mirror on the optical bench 1 point
For a very good description of a procedure for locating the image 2 points
For example: "Place the mirror at one end of the bench and the candle more than 30 cm from the mirror. Place the screen out beyond the candle and reposition it to get an image. Measure the height of the image. Reposition candle and screen until image height is four times object height."

No points were awarded if there was no reference to use of a mirror
Only one point could be earned if student used a convex mirror instead of a concave mirror
An imperfect or incomplete description of a useful procedure received 1 point

(b) 2 points

For checking a meter stick and/or ruler, plus everything else that they used in part (a) 1 point
For having no checks on items that they did not use in part (a) 1 point

If part (a) is blank or earned no points, then part (b) earned no points.
If part (a) only earned 1 point, then part (b) could not earn more than 1 point.
If everything or nothing is checked, then part (b) earned no points.

(c) 6 points

Note: Diagrams are drawn with curvature of mirror not to scale, in order to clearly illustrate the situation.

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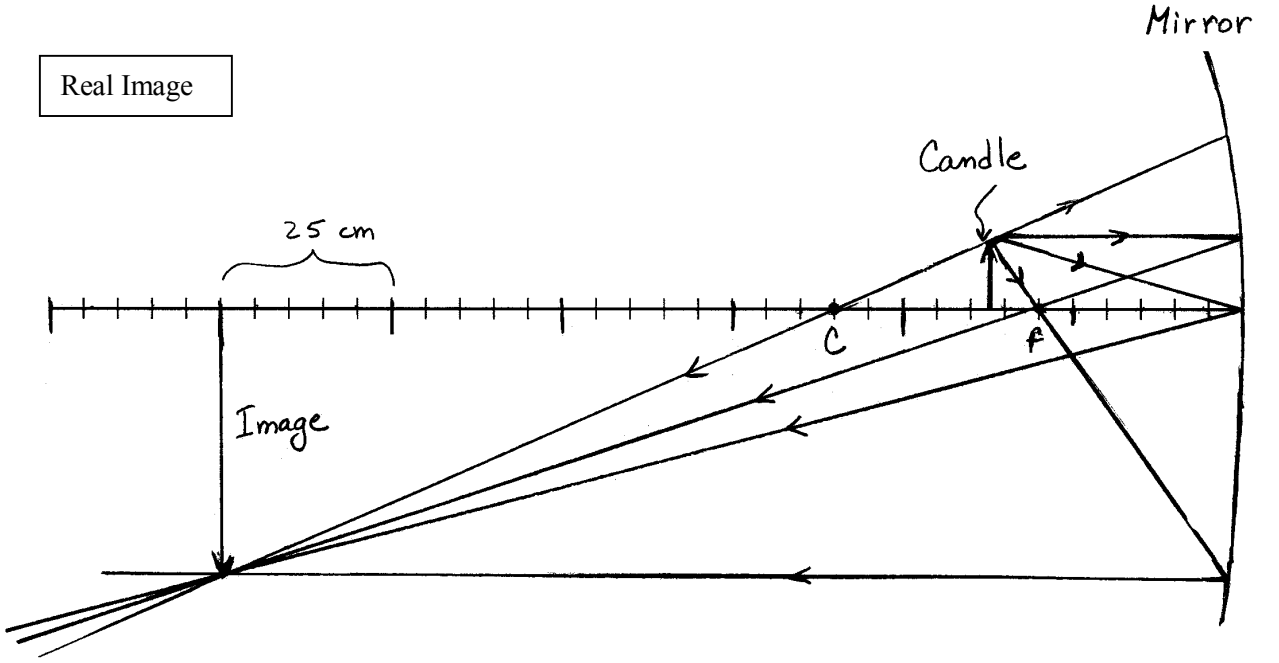
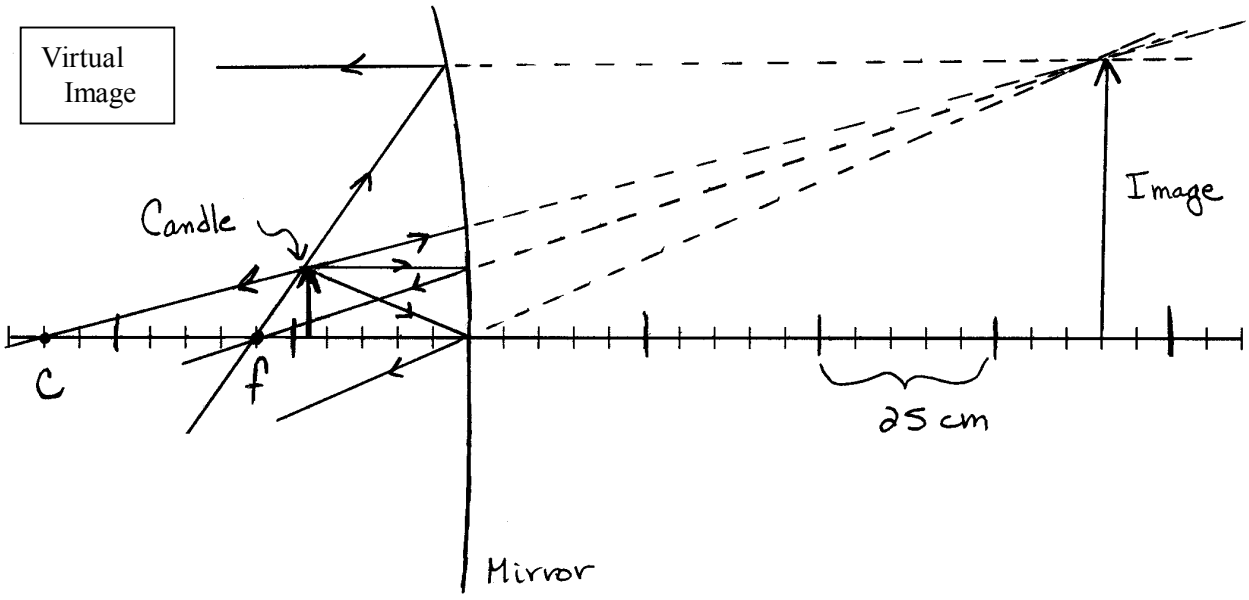
Question 4 (continued)

Distribution of points



(c) (continued)



For showing the concave mirror 1 point

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Question 4 (continued)

	Distribution of points
At least one ray from the candle is shown reflecting from the mirror	1 point
One point each for up to two correctly drawn principal rays	2 points
For showing the intersection of principal rays at a location such that the image distance is larger than the object distance (This point was only awarded if the correct mirror and rays were present.)	1 point
For a correctly oriented image drawn at the intersection of the principal rays (This point was only awarded if the fifth point was earned.)	1 point

No points were awarded if there was no curved mirror used in the diagram. The curved mirror could be indicated by drawing it curved, or labeling it, or showing rays consistent with a curved mirror.

Only one point was awarded for using a convex mirror instead of a concave mirror.

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Question 4 (continued)

Distribution of points

(d) 3 points

If the student drew at least one ray AND an image in part (c) that made it possible to interpret the drawing, then part (d) was graded on the basis of a literal interpretation of the drawing. All answers had to be consistent with the drawing.

For correct indication of the image as real or virtual — 1 point

For correct indication of the image as upright or inverted (the orientation must be clearly indicated by the image drawn) — 1 point

For correct indication of the image as larger or smaller — 1 point

If part (c) was blank or didn't have both an image and at least one ray, then part (d) was graded of the basis of the two possible CORRECT answers. The first two points above could be earned by indicating one of the correct pairs of answers: real & inverted OR virtual & upright. The last point could be earned only by indicating that the image is larger.

(e) 1 point

For an answer that said another type of image could be formed (e.g., virtual versus real and/or upright versus inverted) or some other answer (e.g., adding a lens to the concave-mirror system) that went beyond simply restating the premise. — 1 point

If student gave the correct explanation and one or more wrong explanations, zero points were awarded.

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Question 5

10 points total **Distribution of points**

(a) 1 point

For a correct calculation of the change in internal energy 1 point

$U_a - U_c = \Delta U_{c\to a} = Q_{c\to a} + W_{c\to a}$

$\Delta U_{c\to a} = 685\text{ J} - 120\text{ J}$

$\Delta U_{c\to a} = 565\text{ J}$

(b) 3 points

i. (1 point)

For correct choice of heat removed from the gas 1 point

ii. (2 points)

For recognition that the change in internal energy is opposite in sign from part (a) answer 1 point

$\Delta U_{a\to b\to c} = -\Delta U_{c\to a} = -565\text{ J}$

Calculating the heat:

$Q_{c\to d\to a} = \Delta U_{c\to d\to a} - W_{c\to d\to a}$

$Q_{c\to d\to a} = -565\text{ J} - 75\text{ J}$

For the correct answer 1 point

$Q_{c\to d\to a} = -640\text{ J}$

(c) 3 points

The total work done is the sum of the work for the two sections of the path

$W_{c\to d\to a} = W_{c\to d} + W_{d\to a}$

For some indication that the work done along path $c \to d$ is zero 1 point

The work done along path $d \to a$ is the area under the curve

$W_{c\to d\to a} = 0 - P\,\Delta V$

For correct substitution 1 point

$W_{c\to d\to a} = -(6.0\times10^5\text{ Pa})(1.0\times10^{-3}\text{ m}^3 - 0.75\times10^{-3}\text{ m}^3)$

For the correct answer 1 point

$W_{c\to d\to a} = -150\text{ J}$

(d) 3 points

For correct choice of heat added to the gas 1 point

For a complete explanation that references the first law 2 points

Example: Since $\Delta U_{c\to d\to a}$ is positive (i.e. 565 J) and work is done (i.e. -150 J), Q must be positive.

An incomplete argument with correct relevant assertions and no mistakes earned 1 point.

An incomplete argument with irrelevant or incorrect assertions earned no points.

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Question 6

10 points total **Distribution of points**

(a) 2 points

For any correct indication of the relation between pressure difference and depth in either part (a) or part (b) 1 point

$P - P_0 = \rho g h$

Gauge pressure is equal to the pressure difference from the surface to the given depth

$P_{\text{gauge}} = \left(1.025\times10^3 \ \frac{\text{kg}}{\text{m}^3}\right)\left(9.8 \ \frac{\text{m}}{\text{s}^2}\right)(35 \text{ m})$

For the correct answer 1 point

$P_{gauge} = 3.5\times10^5$ Pa.

(b) 1 point

For any indication, in words or with a calculation, that absolute pressure is the gauge pressure calculated above plus atmospheric pressure 1 point

$P_{\text{abs}} = P_{\text{gauge}} + P_{\text{atm}} = 3.5\times10^5 \text{ Pa} + 1.0\times10^5 \text{ Pa} = 4.5\times10^5 \text{ Pa}$

(c) 5 points

For any indication that the plate is in equilibrium 1 point

$T + F_{buoy} - mg = 0$ (other statements such as $a = 0$ or $\Sigma F = 0$ also acceptable)

For substituting correct values into the relations for the mass or weight of the plate 1 point

$m = \rho V = \left(2.7\times10^3 \ \frac{\text{kg}}{\text{m}^3}\right)\left(1.0\times2.0\times0.03 \text{ m}^3\right) = 1.6\times10^2 \text{ kg}$ OR $mg = \rho V g = 1.6\times10^3 \text{ N}$

For indicating the existence of an upward buoyant force, using a diagram, an arrow, or an equation in which the buoyant force has the opposite sign of the plate's weight 1 point

For substituting the density of the fluid into the appropriate relation for the mass of the displaced fluid or the buoyant force 1 point

$F_{bouy} = \rho_{\text{fluid}} V g = \left(1.025\times10^3 \ \frac{\text{kg}}{\text{m}^3}\right)\left(0.06 \text{ m}^3\right)\left(9.8 \ \frac{\text{m}}{\text{s}^2}\right) = (61.5 \text{ kg})\left(9.8 \ \frac{\text{m}}{\text{s}^2}\right) = 6.0\times10^2 \text{ N}$

Solving for the tension and substituting:

$T = mg - F_{bouy} = 1.6\times10^3 \text{ N} - 6.0\times10^2 \text{ N}$

For the correct answer 1 point

$T = 1.0\times10^3$ N (or 9.9×10^2 N using $g = 10 \text{ m/s}^2$)

Notes:

Full credit was awarded for a correct answer with relevant work that did not explicitly show all of the steps above.

One point was deducted for one incorrect numerical calculation with all other work correct.

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Question 6 (continued)

Distribution of points

(d) 2 points

For checking "increase" 1 point
For a valid explanation 1 point
Example: In (c) the net force is zero, but to accelerate there must be a non-zero net force. Since the weight and the buoyant force are fixed, the tension must be greater to have a non-zero net force upward.

Note: A valid explanation is not one that merely restates the conclusion that the tension increases when the plate accelerates. It must go further by referring to Newton's second law and the fact that the net force must be upward when the plate accelerates upward.

Alternate interpretation
Some students clearly interpreted the question to be referring to a change in the tension over time, rather than a change with respect to the situation in part (c). If the student checked "remains the same" and gave an explanation stating that a constant acceleration implies a constant force, they were awarded 2 points.

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Question 7

10 points total **Distribution of points**

(a) 2 points

For any indication of conservation of energy 1 point

$\frac{1}{2}m_{\text{He}}v_0^{\,2} = \frac{1}{2}m_{\text{He}}v_1^{\,2} + \frac{1}{2}m_{\text{Ne}}v_2^{\,2} + \left(E_2' - E_2\right)$, where v_0 is the minimum speed of the helium atom before the collision, and v_1 and v_2 are the speeds of the helium and neon atoms after the collision, respectively

The point is awarded for any of the following assumptions for v_1 and v_2:

a. $v_1 = 0$ and $v_2 = 0$

b. $v_1 = 0$, $v_2 \neq 0$

c. $v_1 \neq 0$, $v_2 \neq 0$, and $v_1 \neq v_2$

d. $v_1 = v_2 \neq 0$

For any indication of conservation of momentum 1 point

$m_{\text{He}}v_0 = \pm m_{\text{He}}v_1 + m_{\text{Ne}}v_2$

The point is awarded for recognizing conservation of momentum, with any of the following assumptions for v_1 and v_2:

e. $v_1 = 0$, $v_2 \neq 0$

f. $v_1 \neq 0$, $v_2 \neq 0$, and $v_1 \neq v_2$

g. $v_1 = v_2 \neq 0$

To earn both points, assumptions for the two equations must be the same

The value of the final answer depends on the assumption used.

(b) 2 points

Using the expression for the DeBroglie wavelength

$\lambda = \frac{h}{p} = \frac{h}{mv}$

For correctly substituting the answer obtained for v_0 from part (a) 1 point

For correctly substituting m_{He}, including correct units 1 point

Students did not have to show conversions of units that would be needed to complete the calculation correctly.

Both points were awarded if a value for momentum calculated in part (a) was substituted directly.

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Question 7 (continued)

Distribution of points

(c) 3 points

Using the equation relating energy and frequency for a photon:
$f = E/h$

For substituting the correct difference in neon energy levels for the energy of the photon — 1 point

$$f = \frac{20.66 \text{ eV} - 18.70 \text{ eV}}{4.14 \times 10^{-15} \text{ eV} \cdot \text{s}} = 4.73 \times 10^{14} \text{ Hz}$$

Using the equation relating wavelength and frequency
$\lambda = c/f$

For substituting the calculated value of f and the correct value for the speed of light into the above equation — 1 point

$\lambda = \left(3 \times 10^8 \text{ m/s}\right)/4.73 \times 10^{14} \text{ Hz}$

For the correct answer, including units — 1 point

$\lambda = 634$ nm (or 633 nm if values are substituted directly into the equation $\lambda = hc/E$, using the value of hc in $\text{eV} \cdot \text{nm}$ from the Table of Information)

Alternate solution — *Alternate points*

For using the equation relating momentum and energy of a photon, including the correct difference in neon energy levels — *1 point*

$$p = E/c = \left(E_2' - E_1'\right)/c$$

$$p = \left(20.66 \text{ eV} - 18.70 \text{ eV}\right)/3 \times 10^8 \text{ m/s} = 6.53 \times 10^{-9} \text{ eV} \cdot \text{s/m}$$

For using the equation relating wavelength and momentum, and substituting the value of momentum obtained above — *1 point*

$\lambda = h/p = \left(4.14 \times 10^{-15} \text{ eV} \cdot \text{s}\right)/\left(6.53 \times 10^{-9} \text{ eV} \cdot \text{s/m}\right)$

For the correct answer, including units — *1 point*

$\lambda = 634$ nm (or 633 nm as explained above)

(d) 3 points

The total energy per pulse equals the power times the duration of the pulse
$E = P\,\Delta t$

For substituting the values into the equation above — 1 point

$$E = \left(0.50 \text{ W}\right)\left(20 \times 10^{-3} \text{ s}\right) = 1 \times 10^{-2} \text{ J} = 6.25 \times 10^{16} \text{ eV}$$

The number of photons equals the total energy per pulse divided by the energy per photon

$$N = E/\left(E_2' - E_1'\right)$$

For correctly substituting the values of E_1' and E_2' into the equation above — 1 point

$$N = 6.25 \times 10^{16} \text{ eV}/\left(20.66 \text{ eV} - 18.70 \text{ eV}\right)$$

For the correct answer — 1 point

$N = 3.19 \times 10^{16}$

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AP® Physics B
2003 Free-Response Questions
Form B

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CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2003

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta\mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2003

FLUID MECHANICS AND THERMAL PHYSICS

$p = p_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$p + \rho gy + \frac{1}{2}\rho v^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$Q = mL$

$Q = mc\Delta T$

$p = \frac{F}{A}$

$pV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q + W$

$\Delta U = nc_V \Delta T$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

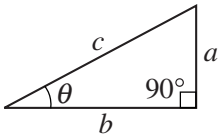
Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

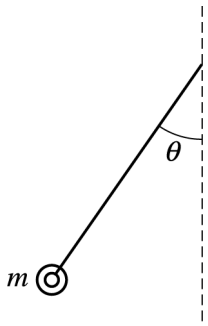
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

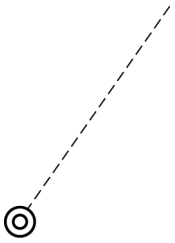
PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)
An airplane accelerates uniformly from rest. A physicist passenger holds up a thin string of negligible mass to which she has tied her ring, which has a mass m. She notices that as the plane accelerates down the runway, the string makes an angle θ with the vertical as shown above.

(a) In the space below, draw a free-body diagram of the ring, showing and labeling all the forces present.



The plane reaches a takeoff speed of 65 m/s after accelerating for a total of 30 s.

(b) Determine the minimum length of the runway needed.

(c) Determine the angle θ that the string makes with the vertical during the acceleration of the plane before it leaves the ground.

(d) What additional information would be needed in order to estimate the mechanical energy of the airplane at the instant of takeoff? Explain your answer.

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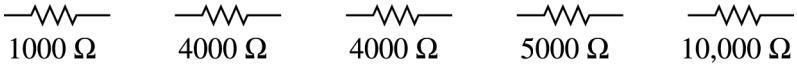
2. (15 points)
A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.

(a) Determine the power to be supplied to the motor.

(b) Determine the electrical energy to be supplied to the motor in 60 s.

(c) Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.

To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



(d) In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.



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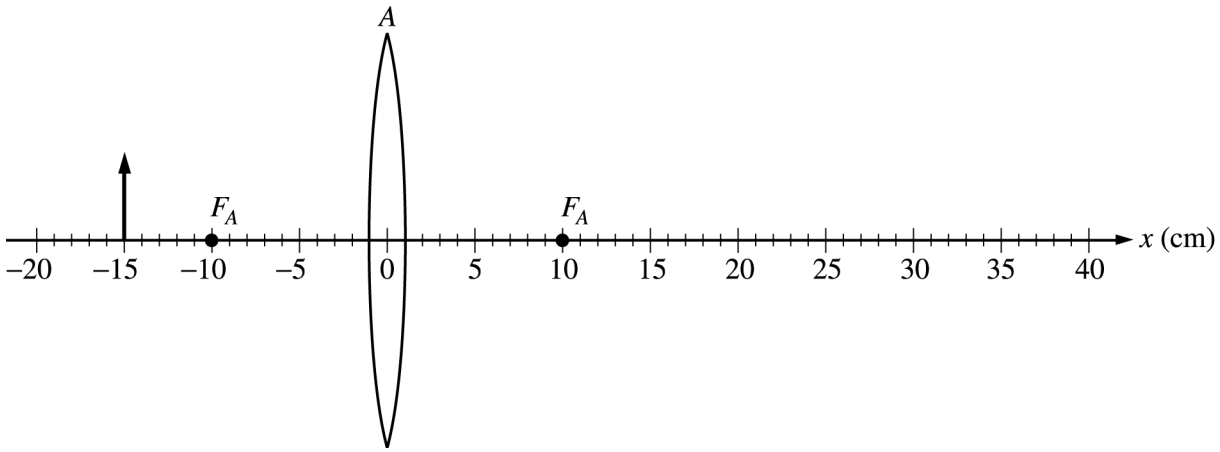
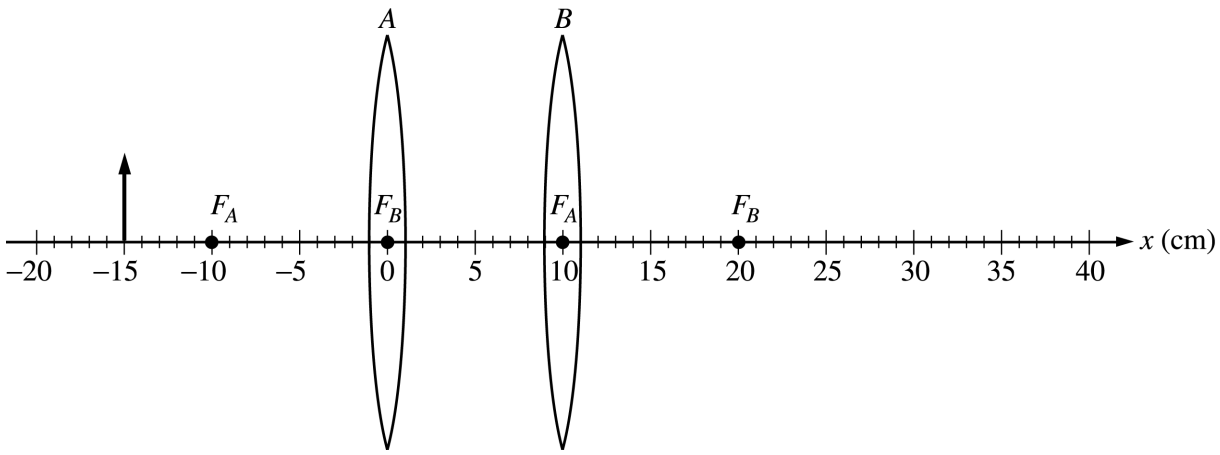


3. (15 points)
A thin convex lens A of focal length $f_A = 10$ cm is positioned on an x-axis as shown above. An object of height 5 cm, represented by the arrow, is positioned 15 cm to the left of lens A.

(a) On the figure above, draw necessary rays and sketch the image produced by lens A.

(b) Calculate the location of the image produced by lens A.

(c) Calculate the height of the image produced by lens A.



A second thin convex lens B of focal length $f_B = 10$ cm is now positioned 10 cm to the right of lens A, as shown above.

(d) Determine the location on the x-axis given above of the final image produced by the combination of lenses.

(e) Check the appropriate spaces below to indicate the characteristics of the final image produced by the combination of lenses.

____ inverted ____ larger than the original object

____ upright ____ smaller than the original object

Explain your answers.

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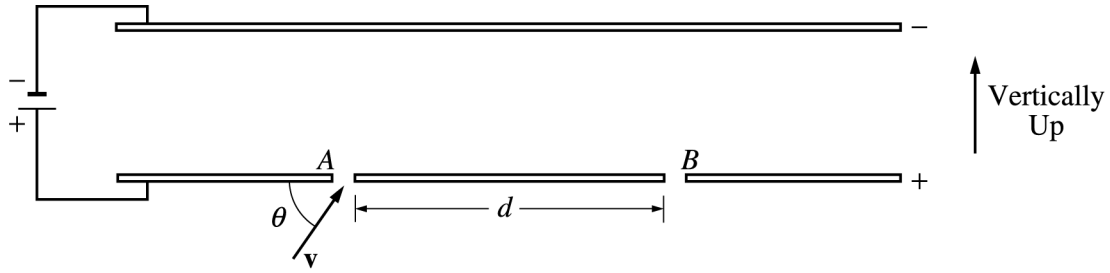

4. (15 points)
An electric field **E** exists in the region between the two electrically charged parallel plates shown above. A beam of electrons of mass m, charge q, and velocity **v** enters the region through a small hole at position A. The electrons exit the region between the plates through a small hole at position B. Express your answers to the following questions in terms of the quantities m, q, **E**, θ, and **v**. Ignore the effects of gravity.

(a) i. On the diagram of the parallel plates above, draw and label a vector to show the direction of the electric field **E** between the plates.

ii. On the following diagram, show the direction of the force(s) acting on an electron after it enters the region between the plates.

●

iii. On the diagram of the parallel plates above, show the trajectory of an electron that will exit through the small hole at position B.

(b) Determine the magnitude of the acceleration of an electron after it has entered the region between the parallel plates.

(c) Determine the total time that it takes the electrons to go from position A to position B.

(d) Determine the distance d between positions A and B.

(e) Now assume that the effects of gravity cannot be ignored in this problem. How would the distance d change for an electron entering the region at A and leaving at B? Explain your reasoning.

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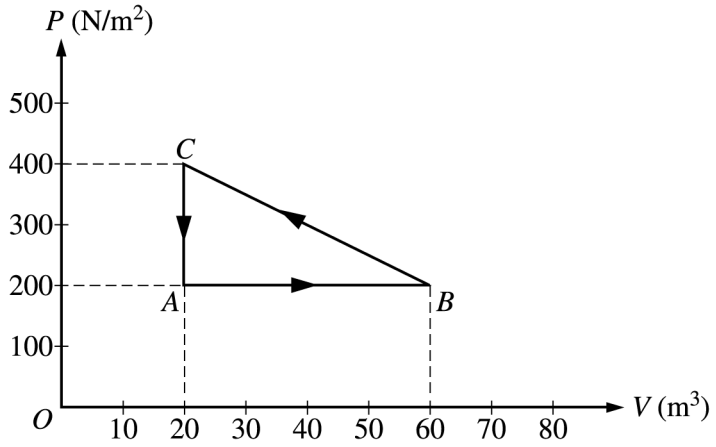

5. (10 points)

One mole of an ideal gas is taken around the cycle $A \rightarrow B \rightarrow C \rightarrow A$ as shown on the PV diagram above.

(a) Calculate the temperature of the gas at point A.

(b) Calculate the net work done on the gas during one complete cycle.

(c) i. Is heat added to or removed from the gas during one complete cycle?

____ added to the gas ____ removed from the gas

ii. Calculate the heat added to or removed from the gas during one complete cycle.

(d) After one complete cycle, is the internal energy of the gas greater, less, or the same as before?

____ greater ____ less ____ the same

Justify your answer.

(e) After one complete cycle, is the entropy of the gas greater, less, or the same as before?

____ greater ____ less ____ the same

Justify your answer.

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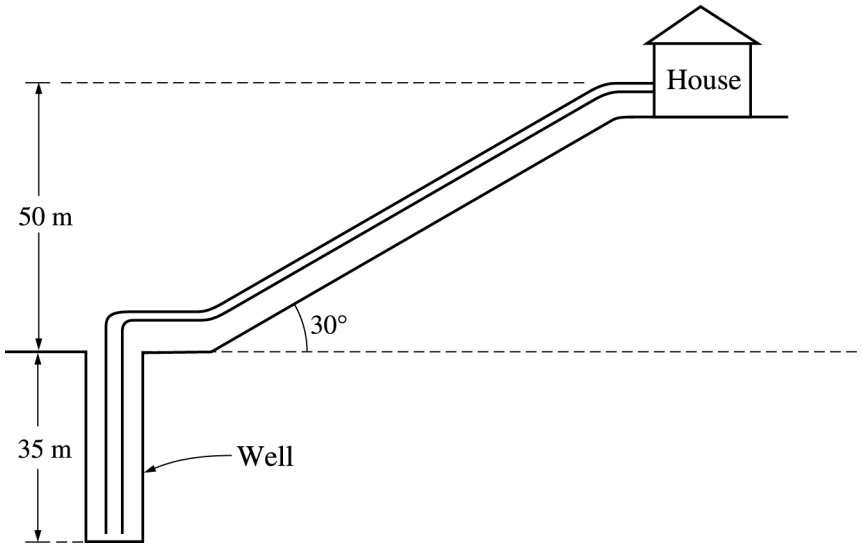

6. (10 points)

A pump, submerged at the bottom of a well that is 35 m deep, is used to pump water uphill to a house that is 50 m above the top of the well, as shown above. The density of water is 1,000 kg/m^3. All pressures are gauge pressures. Neglect the effects of friction, turbulence, and viscosity.

(a) Residents of the house use 0.35 m^3 of water per day. The day's pumping is completed in 2 hours during the day.

i. Calculate the minimum work required to pump the water used per day

ii. Calculate the minimum power rating of the pump.

(b) The average pressure the pump actually produces is 9.20×10^5 N/m^2. Within the well the water flows at 0.50 m/s and the pipe has a diameter of 3.0 cm. At the house the pipe diameter is 1.25 cm.

i. Calculate the flow velocity when a faucet in the house is open.

ii. Explain how you would calculate the minimum pressure at the faucet.

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7. (10 points)

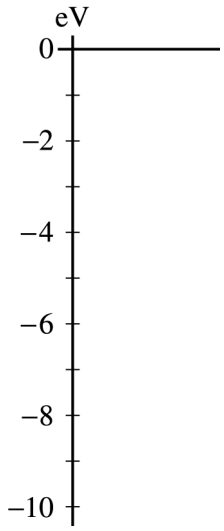
An experiment is performed on a sample of atoms known to have a ground state of −5.0 eV. The gas is illuminated with "white light" (400 - 700 nm). A spectrometer capable of analyzing radiation in this range is used to measure the radiation. The sample is observed to absorb light at only 400 nm. After the "white light" is turned off, the sample is observed to emit visible radiation of 400 nm and 600 nm.

(a) In the space below, determine the values of the energy levels and on the following scale sketch an energy-level diagram showing the energy values in eVs and the relative positions of:

i. the ground state

ii. the energy level to which the system was first excited

iii. one other energy level that the experiment suggests may exist



(b) What is the wavelength of any other radiation, if any, that might have been emitted in the experiment? Why was it not observed?

END OF EXAMINATION

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AP® Physics B
2003 Scoring Guidelines
Form B

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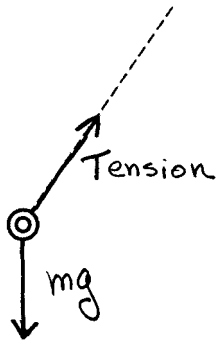
AP® PHYSICS B
2003 SCORING GUIDELINES (Form B)

Question 1

15 points total **Distribution of points**

(a) 3 points



One point for each correctly drawn and appropriately labeled force — 2 points
For no incorrect forces — 1 point

(b) 5 points

For use of the correct equation relating acceleration and velocity — 1 point
$\mathbf{a} = \Delta\mathbf{v}/t$

For correctly calculating the magnitude of the acceleration — 1 point
$a = \dfrac{65 \text{ m/s} - 0}{30 \text{ s}} = \dfrac{13}{6} \text{ m/s}^2 \quad (\text{or } 2.17 \text{ m/s}^2)$

For using an equation relating distance and acceleration — 1 point
$d = d_0 + v_0 t + \dfrac{1}{2} a t^2 \quad \text{OR} \quad v^2 = v_0^2 + 2a\,\Delta d$

For substituting the calculated acceleration — 1 point
$d = \dfrac{1}{2}\left(\dfrac{13}{6} \text{ m/s}^2\right)(30 \text{ s})^2 \quad \text{OR} \quad d = (65 \text{ m/s})^2 \Big/ 2\left(\dfrac{13}{6} \text{ m/s}^2\right)$

For the correct answer — 1 point
$d = 975 \text{ m}$

Alternate solution — *Alternate points*

For use of the correct equation for average speed — *1 point*
$v_{\text{avg}} = (v_f + v_0)/2$

For correctly calculating the average speed — *1 point*
$v_{\text{avg}} = (65 \text{ m/s} + 0)/2 = 32.5 \text{ m/s}$

For using the appropriate equation relating distance to speed — *1 point*
$d = v_{\text{avg}} t$

For substituting v_{avg} into the equation — *1 point*
$d = (32.5 \text{ m/s})(30 \text{ s})$

For the correct answer — *1 point*
$d = 975 \text{ m}$

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Question 1 (continued)

Distribution of points

(c) 5 points

For using the correct x and y components of the tension — 1 point
$T_x = T\sin\theta$ and $T_y = T\cos\theta$

For the correct equation relating the forces along the x-axis — 1 point
$T\sin\theta = ma$

For the correct equation relating the forces along the y-axis — 1 point
$T\cos\theta = mg$

For combining these two equations to eliminate the tension — 1 point
$\tan\theta = a/g$
$\tan\theta = (2.17\ \text{m/s}^2)/(9.8\ \text{m/s}^2)$

For the correct answer — 1 point
$\theta = 12.5°$ (or $12.2°$ using $g = 10\ \text{m/s}^2$)

(d) 2 points

For indicating that one would need to know the mass of the airplane, with some attempt to give an explanation that relates to the mass. — 1 point

For a correct explanation — 1 point
Example: The kinetic energy is the only form of mechanical energy in this case. The velocity is known, but you need the mass to calculate the kinetic energy.

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Question 2

15 points total **Distribution of points**

(a) 3 points

For correct equation for power 1 point
$P = IV$
For the correct answer 2 points
P = 3 mW (or 0.003 W)
One point was subtracted for incorrect or missing unit

(b) 3 points

For the correct equation for work or energy 1 point
W (or energy) = Pt
For correct substitution of power from part (a) 1 point
W (or energy) = (0.003 W)(60 s)
For the correct answer consistent with substitution of power from part (a), with correct units 1 point
W (or energy) = 0.180 J

(c) 5 points

For the correct efficiency equation 1 point
$\text{efficiency} = \dfrac{W_o}{W_i}$
For correct substitution of W_i (work done in 60 s) from part (b) 1 point
For indicating that the work output W_o equals the change in gravitational potential energy 1 point
$W_o = mg\Delta h$
For correct calculation of work output in 60 s 1 point
$W_o = (0.012\text{ kg})(9.8\text{ m/s}^2)(1\text{ m}) = 0.12\text{ J}$ (or same answer using $g = 10\text{ m/s}^2$)
For correct calculation of efficiency consistent with calculation made in part (b). 1 point
$\text{efficiency} = \dfrac{0.12\text{ J}}{0.18\text{ J}} = 66.7\%$ (or 65.3% using $g = 9.8\text{ m/s}^2$ and unrounded value for W_o)

Alternately, full credit could also be obtained by calculating efficiency using the ratio of power output to power input, in which case

$$\text{eff} = \frac{P_o}{P_i} = \frac{(0.012\text{ kg})(9.8\text{ m/s}^2)(1\text{ m})/60\text{ s}}{0.003\text{ W}} = 65.3\% \text{ (or 66.7\% using } g = 10\text{ m/s}^2)$$

Similar point allocations were assigned using this method.

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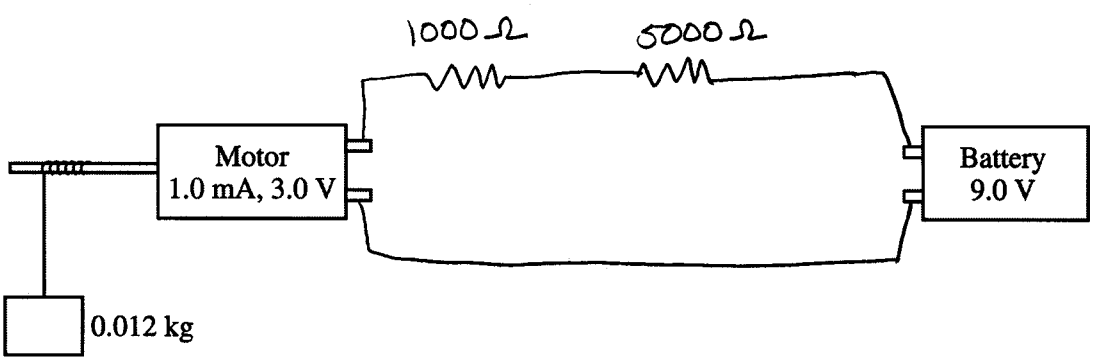
Question 2 (continued)

Distribution of points

(d) 4 points



For a calculation or notation that 6 V was the voltage drop across the resistor needed in order to reduce the voltage across the motor from 9 V to 3 V. 1 point

Series resistance needed to produce this voltage drop = $\frac{6.0\text{ V}}{1.0\text{ mA}} = 6000\ \Omega$

For the selection of a 1000 Ω and a 5000 Ω resistor 1 point

For the placement of the 1000 Ω and 5000 Ω resistor in series 1 point

For an appropriate sketch of the system with appropriate symbols and labels for resistors 1 point

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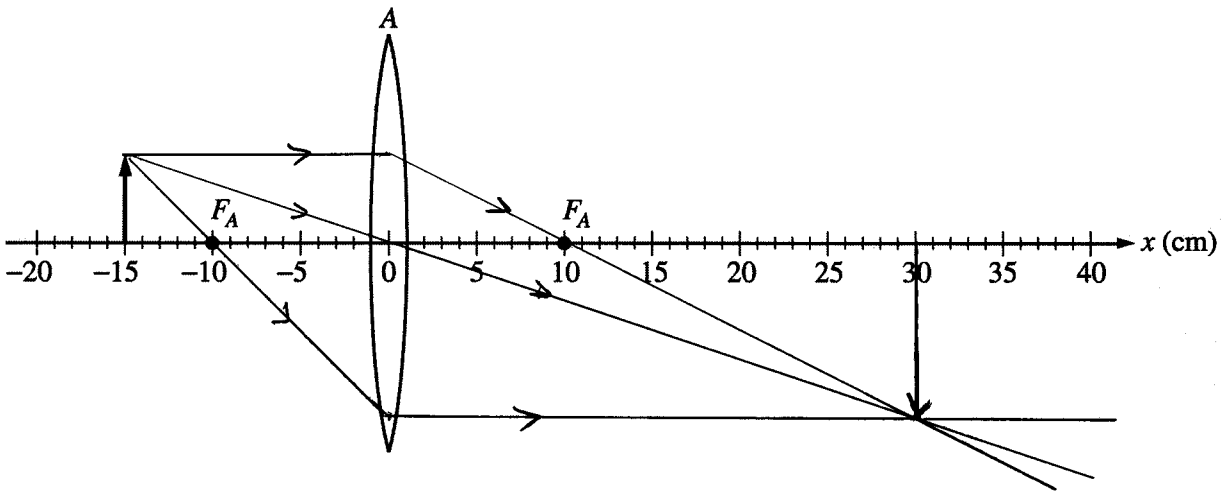
Question 3

15 points total **Distribution of points**

(a) 4 points



One point for each correctly drawn ray passing through the lens (maximum of 2 points)	2 points
For the intersection of the rays occurring at 30 cm ± 5 cm	1 point
For correctly drawing the image	1 point

(b) 3 points

For using the lens equation $\frac{1}{s_o}+\frac{1}{s_i}=\frac{1}{f}$	1 point
For correct substitutions $\frac{1}{15\text{ cm}}+\frac{1}{s_i}=\frac{1}{10\text{ cm}}$	1 point
For answer consistent with substitutions $s_i = 30\text{ cm}$	1 point

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Question 3 (continued)

Distribution of points

(c) 3 points

For correct equation relating ratio of image to object heights to ratio of image to object distances — 1 point

$\frac{h_i}{h_o} = -\frac{s_i}{s_o}$ OR $\frac{|h_i|}{|h_o|} = \frac{|s_i|}{|s_o|}$

For consistent substitution — 1 point

$\frac{h_i}{5\text{ cm}} = -\frac{30\text{ cm}}{15\text{ cm}}$ OR $\frac{|h_i|}{5\text{ cm}} = \frac{30\text{ cm}}{15\text{ cm}}$

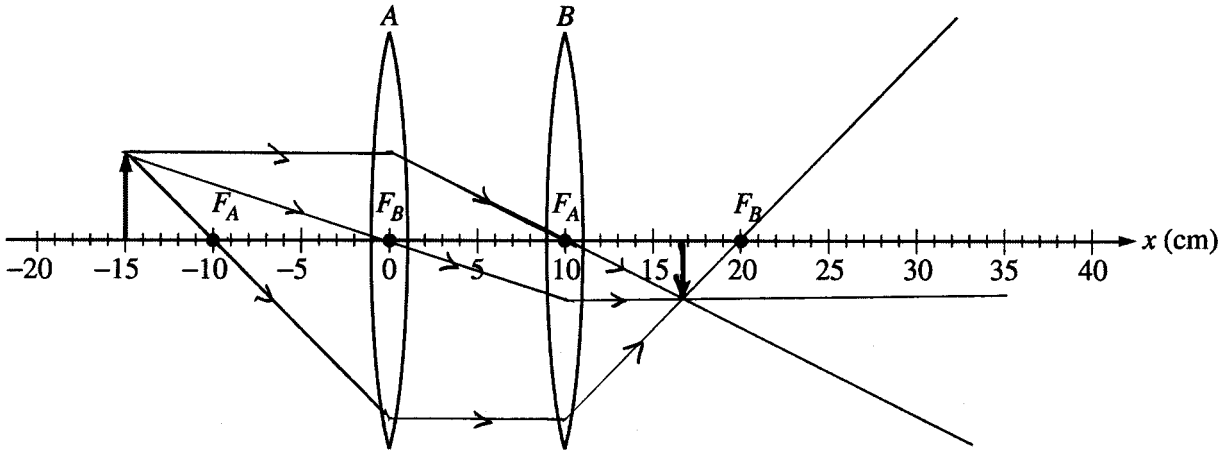
For answer consistent with substitutions — 1 point

$h_i = -10$ cm OR $|h_i| = 10$ cm

Note: Since the minus sign in the first answer just indicates the image is inverted, it was not necessary for full credit, since the question could be interpreted as asking only for the actual size of the image.

(d) 3 points

Method 1: Ray diagram



One point for each correctly drawn ray passing through both lenses (maximum of 2 points) — 2 points

For the image location at 16.6 cm ± 3 cm — 1 point

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Question 3 (continued)

Distribution of points

Method 2: Mathematical approach using the lens equation

The image produced by the first lens becomes the virtual object for the second lens.
For the correct object distance to substitute into the lens equation for the second lens — 1 point

$s_o' = -(30\text{ cm} - 10\text{ cm}) = -20\text{ cm}$ (The minus indicates that the object is virtual.)

$$\frac{1}{s_o'} + \frac{1}{s_i'} = \frac{1}{f}$$

$$\frac{1}{-20\text{ cm}} + \frac{1}{s_i'} = \frac{1}{10\text{ cm}}$$

For the final image location with respect to the second lens — 1 point

$s_i' = 6.7\text{ cm}$

For the final image location on the scale shown — 1 point

$x_i = s_i' + 10\text{ cm} = 16.7\text{ cm}$

(e) 2 points

For checking spaces consistent with answer to part (d) and a correct explanation — 2 points
Explanation had to either refer to ray diagram, or, if a mathematical approach was used in part (d), had to be consistent with answer to part (d).
No points were awarded for students who checked spaces without any explanations.

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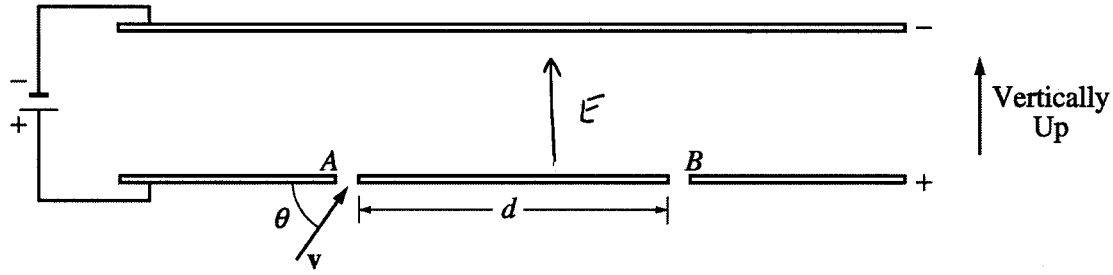
AP® PHYSICS B
2003 SCORING GUIDELINES (Form B)

Question 4

15 points total **Distribution of points**

(a) 4 points

i. (1 point)



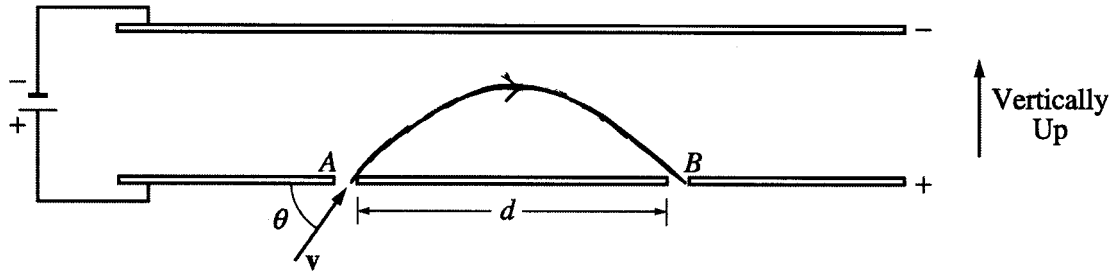
For a correctly drawn and labeled vector for **E**, directed vertically upward as shown in the diagram above — 1 point

ii. (1point)



For a vector directed vertically downward representing the force on an electron in the field, as shown in the diagram above — 1 point

iii. (2 points)



For a curved path from *A* to *B* — 1 point
For the path being symmetrical about the midpoint of *d* — 1 point

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Question 4 (continued)

Distribution of points

(b) 2 points

For using the equation that relates the force on a charged particle to the electric field 1 point
$F = qE$
Equating this force to the net force in Newton's second law, $F_{net} = ma$
$qE = ma$
For the correct answer 1 point
$a = \frac{qE}{m}$

(c) 4 points

In the electric field the electron is accelerated vertically downward.
$v_y(t) = v_y - at$, where v_y is the vertical component of the electron's velocity at point *A*
The time t_1 to reach maximum vertical displacement occurs when $v_y(t_1) = 0$. Solving for t_1:
$t_1 = \frac{v_y}{a}$
For using the correct component for v_y 1 point
$v_y = v\sin\theta$
For indicating that the total time is twice t_1 1 point
$t_{tot} = 2t_1 = \frac{2v\sin\theta}{a}$
For correct substitution of *a* from part (b) 1 point
$t_{tot} = \frac{2v\sin\theta}{\frac{qE}{m}}$
For the correct answer 1 point
$t_{tot} = \frac{2mv\sin\theta}{qE}$

Alternately, the kinematic equations $v_y(t) = v\sin\theta - at$ OR $y(t) = y_0 + (v\sin\theta)t - \frac{1}{2}at^2$ could be used. When the electron reaches *B* at time t_{tot}, $v_y(t_{tot}) = -v\sin\theta$, and $y(t_{tot}) = y_0$. Substituting these values and the expression for *a* from part (b) into the respective equations above and solving either equation for t_{tot} gives the answer, $t_{tot} = \frac{2mv\sin\theta}{qE}$. This approach also received full credit with awarding of points similar to those above.

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Question 4 (continued)

Distribution of points

(d) 3 points

While the electron is in the field the horizontal component of its velocity is constant.

For the correct equation relating distance to time — 1 point

$d = v_x t_{tot}$

For using the correct component for v_x — 1 point

$v_x = v\cos\theta$

For correct substitutions for v_x and total time — 1 point

$$d = (v\cos\theta)\left(\frac{2mv\sin\theta}{qE}\right)$$

$$d = \frac{2mv^2\sin\theta\cos\theta}{qE}$$

(e) 2 points

For an indication that the distance d would be less — 1 point

For any reasonable explanation — 1 point

Example: The additional gravitational force downward would increase the downward acceleration thus decreasing the total time the electron would be in the field.

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AP® PHYSICS B
2003 SCORING GUIDELINES (Form B)

Question 5

10 points total **Distribution of points**

(a) 2 points

For a statement of the ideal gas law 1 point

$pV = nRT$

$\left(200\ \text{N/m}^2\right)\left(20\ \text{m}^3\right) = \left(1\ \text{mol}\right)\left(8.32\ \text{J/}\left(\text{mol}\cdot\text{K}\right)\right)T$

For the correct answer 1 point

$T = 481$ K

(b) 2 points

For indicating that the work W done on the gas is equal to the area enclosed by the cycle or for $W = -p\Delta V$ 1 point

W = area of triangle enclosed by cycle $= \frac{1}{2}bh = \frac{1}{2}\left(60\ \text{m}^3 - 20\ \text{m}^3\right)\left(400\ \text{N/m}^2 - 200\ \text{N/m}^2\right)$

For the correct answer 1 point

$W = 4000$ J

(c) 2 points

i. (1 point)

For indicating that heat is removed from the gas during one complete cycle 1 point

ii. (1 point)

Using the first law of thermodynamics

$\Delta U = Q + W$

Recognizing that $\Delta U = 0$ for a closed cycle

$Q = -W$

For the correct answer consistent with part (b) 1 point

$Q = -4000$ J

Note: Since the question could be interpreted as asking for the magnitude of the heat added to or remove from, the minus sign was not necessary for full credit.

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Question 5 (continued)

Distribution of points

(d) 2 points

For indicating that the internal energy of the gas after one cycle is the same as before — 1 point
For a reasonable justification — 1 point
Example: The internal energy of the gas is a function of the temperature and the temperature is the same at the beginning and end of each cycle.

(e) 2 points

For indicating that the entropy of the gas after one cycle is the same as before — 1 point
For a reasonable justification — 1 point
Example: The entropy is a function of the state of the gas, and after one complete cycle the gas has returned to its original state.

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AP® PHYSICS B
2003 SCORING GUIDELINES (Form B)

Question 6

10 points total **Distribution of points**

(a) 6 points

i. (3 points)

For correct use of the equation relating work to the distance raised 1 point

$W = mgh$

For correct use of the equation relating mass to density and volume 1 point

$m = \rho V$

Combining the two relationships

$W = \rho Vgh = \left(1000 \text{ kg/m}^3\right)\left(0.35 \text{ m}^3\right)\left(9.8 \text{ m/s}^2\right)\left(50 \text{ m} + 35 \text{ m}\right)$

For the correct answer 1 point

$W = 290{,}000$ J (or 300,000 J using $g = 10 \text{ m/s}^2$)

ii. (2 points)

For correct use of the equation relating power to work and time 1 point

$$P = \frac{W}{\Delta t}$$

$$P = \frac{290{,}000 \text{ W}}{\left(2 \text{ hr}\right)\left(60 \text{ min/hr}\right)\left(60 \text{ s/min}\right)}$$

For the correct answer 1 point

$P = 40$ W (or 41 W using $g = 10 \text{ m/s}^2$)

(b) 4 points

i. (3 points)

For correct use of equation of continuity 1 point

$v_1 A_1 = v_2 A_2$

For using the radius of each pipe as half the diameter 1 point

Substituting the given values:

$$\left(0.50 \text{ m/s}\right)\pi\left(\frac{0.03 \text{ m}}{2}\right)^2 = v_2\pi\left(\frac{0.0125 \text{ m}}{2}\right)^2$$

For the correct answer 1 point

$v_2 = 2.88$ m/s

ii. (2 points)

For indicating the need to use Bernoulli's equation 1 point

For an explanation of how to use Bernoulli's equation 1 point

Example: $p_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = p_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2$

If the subscript 1 represents quantities at the pump and subscript 2 represent quantities at the house, then all the quantities are known except the pressure at the house, so the equation can be solved for this pressure.

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AP® PHYSICS B
2003 SCORING GUIDELINES (Form B)

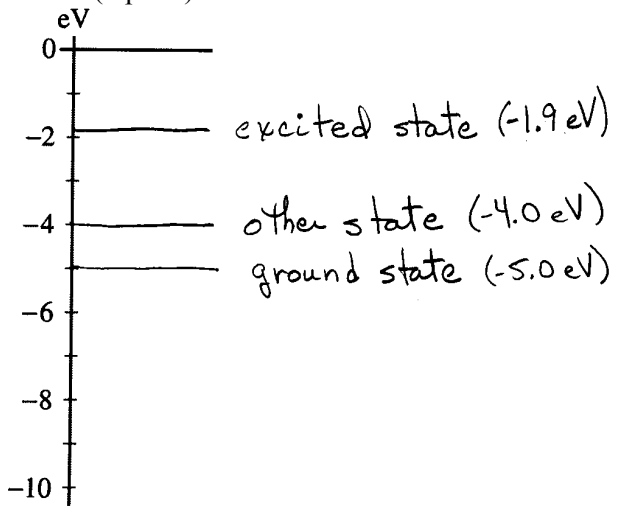
Question 7

10 points total **Distribution of points**

(a) 7 points

There were two possible "other" or intermediate energy levels asked for in part iii., so there were two possible correct energy level diagrams depending on which "other" energy level was used.

i. (1 point)



For drawing a horizontal line on the diagram at −5 eV — 1 point

ii. (3 points)

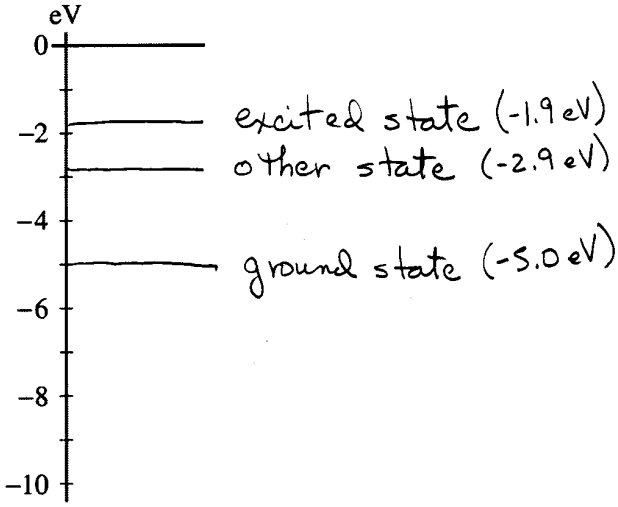
For correct equation(s) to calculate the energy of a 400 nm photon — 1 point
$E = hf$ and $f = c/\lambda$, so
$E = hc/\lambda$
$E = \left(1.24 \times 10^3 \text{ eV} \cdot \text{nm}\right) / \left(400 \text{ nm}\right)$

For the correct answer — 1 point
$E = 3.1$ eV

For drawing a horizontal line on the diagram at −1.9 eV to represent the first excited state, which is 3.1 eV above the ground state — 1 point

OR

iii. (3 points)



Using the same equations to calculate the energy of a 600 nm photon:

$$E = \frac{hc}{\lambda} = \frac{1.24 \times 10^3 \text{ eV} \cdot \text{nm}}{600 \text{ nm}}$$

For the correct answer — 1 point
$E = 2.1$ eV

This photon could represent a transition from the first excited state to an intermediate state, in which case the intermediate state is at $E = -4.0$ eV. Or the photon could represent a transition from an intermediate state to the ground state, in which case the intermediate state is at −2.9 eV. — 1 point

For drawing a horizontal line on the diagram at either −4.0 eV or −2.9 eV — 1 point

Note: Although the value of *hc* is given in the table of information, many students substituted *h* and *c* separately.

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Question 7 (continued)

Distribution of points

(b) 3 points

If the intermediate state is at −4.0 eV, then the transition from the intermediate state to the ground level at −5.0 eV is 1.0 eV. If the intermediate state is at −2.9 eV, then the transition from the first excited state at −1.9 eV to the intermediate state is 1.0 eV.

For calculation of 1.0 eV by subtraction of energy levels — 1 point

Since $E = \frac{hc}{\lambda}$

$$\lambda = \frac{hc}{E} = \frac{1.24 \times 10^3 \text{ eV} \cdot \text{nm}}{1.0 \text{ eV}}$$

For calculation of wavelength — 1 point

$\lambda = 1240$ nm

For statement that this wavelength is not seen because it is in the infrared or outside the range of wavelengths for "white light" given in the problem — 1 point

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AP® Physics B
2002 Free-Response Questions

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CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta \mathbf{r} = F\Delta r \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = Fv \cos \theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta \phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

FLUID MECHANICS AND THERMAL PHYSICS

$p = p_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$p + \rho gy + \frac{1}{2}\rho v^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$Q = mL$

$Q = mc\Delta T$

$p = \frac{F}{A}$

$pV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q + W$

$\Delta U = nc_V \Delta T$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

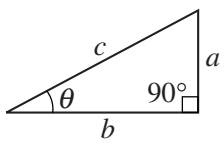
$d \sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

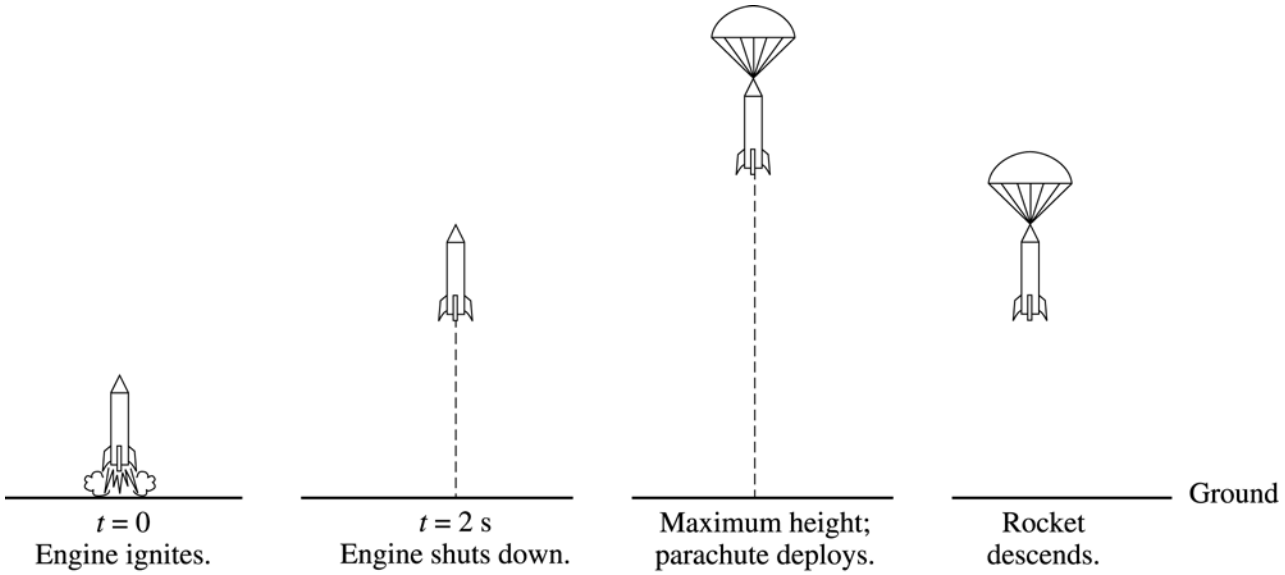
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.



Note: Figures not drawn to scale.

1. (15 points)

A model rocket of mass 0.250 kg is launched vertically with an engine that is ignited at time $t = 0$, as shown above. The engine provides an impulse of 20.0 N•s by firing for 2.0 s. Upon reaching its maximum height, the rocket deploys a parachute, and then descends vertically to the ground.

(a) On the figures below, draw and label a free-body diagram for the rocket during each of the following intervals.

i. While the engine is firing

ii. After the engine stops, but before the parachute is deployed

iii. After the parachute is deployed



(b) Determine the magnitude of the average acceleration of the rocket during the 2 s firing of the engine.

(c) What maximum height will the rocket reach?

(d) At what time after $t = 0$ will the maximum height be reached?

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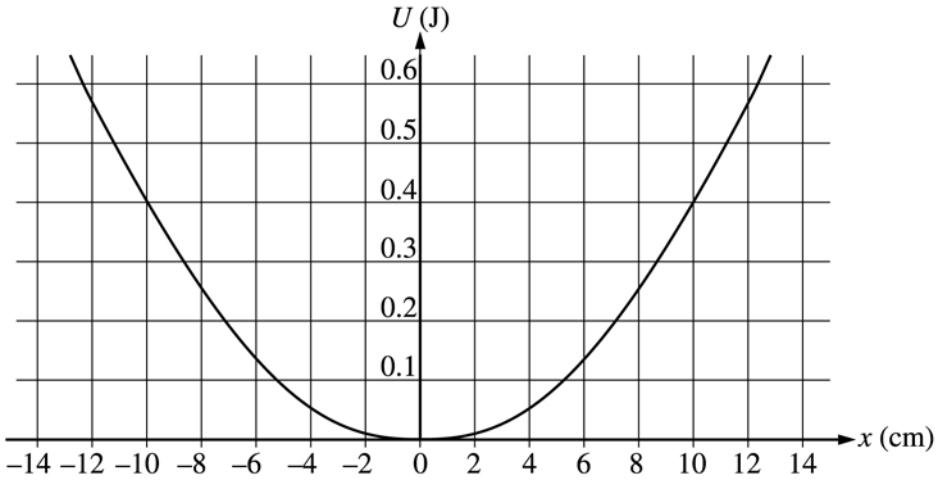


2. (15 points)

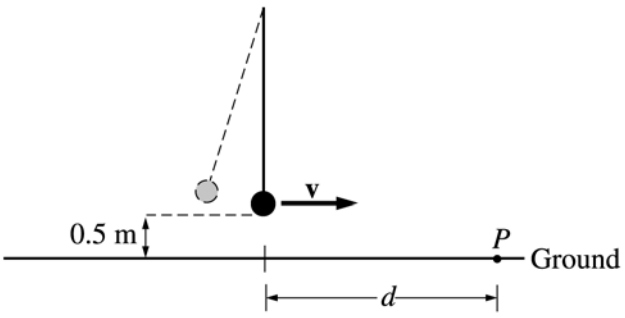
A 3.0 kg object subject to a restoring force F is undergoing simple harmonic motion with a small amplitude. The potential energy U of the object as a function of distance x from its equilibrium position is shown above. This particular object has a total energy E of 0.4 J.

(a) What is the object's potential energy when its displacement is +4 cm from its equilibrium position?

(b) What is the farthest the object moves along the x-axis in the positive direction? Explain your reasoning.

(c) Determine the object's kinetic energy when its displacement is –7 cm.

(d) What is the object's speed at $x = 0$?



Note: Figure not drawn to scale.

(e) Suppose the object undergoes this motion because it is the bob of a simple pendulum as shown above. If the object breaks loose from the string at the instant the pendulum reaches its lowest point and hits the ground at point P shown, what is the horizontal distance d that it travels?

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3. (15 points)

Two lightbulbs, one rated 30 W at 120 V and another rated 40 W at 120 V, are arranged in two different circuits.

(a) The two bulbs are first connected in parallel to a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(b) The bulbs are now connected in series with each other and a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(c) In the spaces below, number the bulbs in each situation described, in order of their brightness. (1 = brightest, 4 = dimmest)

____30 W bulb in the parallel circuit

____40 W bulb in the parallel circuit

____30 W bulb in the series circuit

____40 W bulb in the series circuit

(d) Calculate the total power dissipated by the two bulbs in each of the following cases.

i. The parallel circuit

ii. The series circuit

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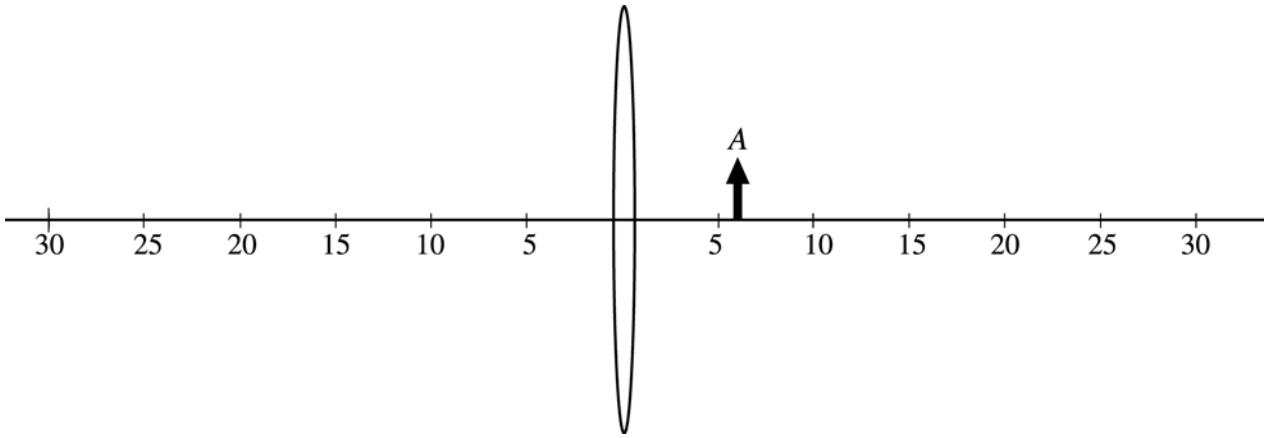
4. (15 points)

A thin converging lens of focal length 10 cm is used as a simple magnifier to examine an object A that is held 6 cm from the lens.

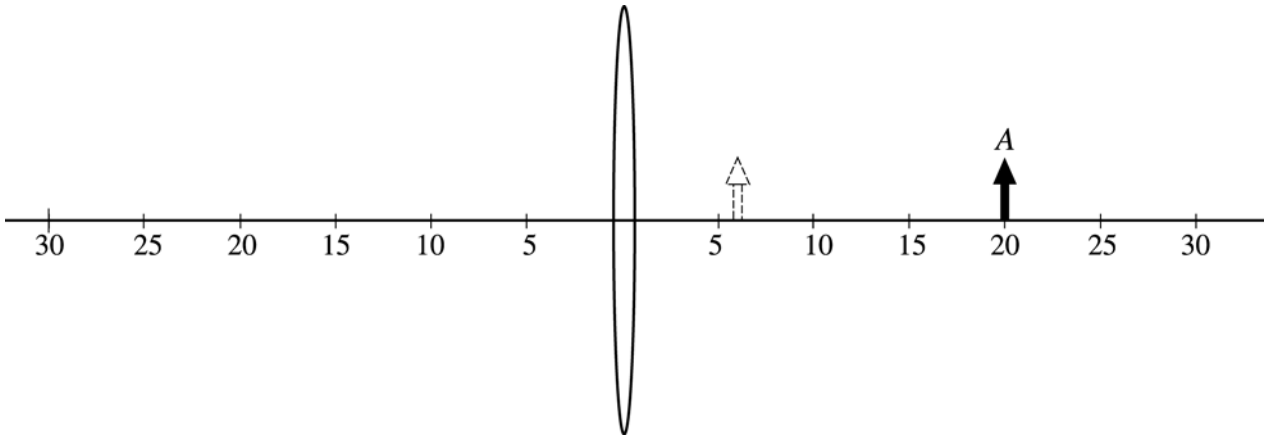
(a) On the figure below, draw a ray diagram showing the position and size of the image formed.



(b) State whether the image is real or virtual. Explain your reasoning.

(c) Calculate the distance of the image from the center of the lens.

(d) Calculate the ratio of the image size to the object size.



(e) The object A is now moved to the right from $x = 6$ cm to a position of $x = 20$ cm, as shown above. Describe the image position, size, and orientation when the object is at $x = 20$ cm.

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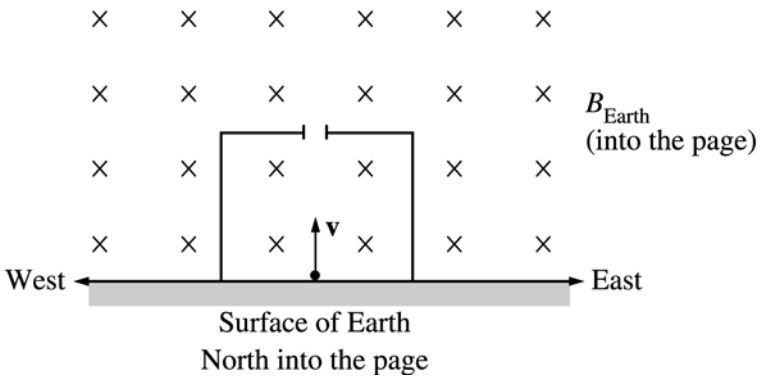

5. (10 points)

A proton of mass m_p and charge e is in a box that contains an electric field E, and the box is located in Earth's magnetic field B_{Earth}. The proton moves with an initial velocity **v** vertically upward from the surface of Earth. Assume gravity is negligible.

(a) On the diagram above, indicate the direction of the electric field inside the box so that there is no change in the trajectory of the proton while it moves upward in the box. Explain your reasoning.

(b) Determine the speed of the proton while in the box if it continues to move vertically upward. Express your answer in terms of the fields and the given quantities.

The proton now exits the box through the opening at the top.

(c) On the figure on the previous page, sketch the path of the proton after it leaves the box.

(d) Determine the magnitude of the acceleration a of the proton just after it leaves the box, in terms of the given quantities and fundamental constants.

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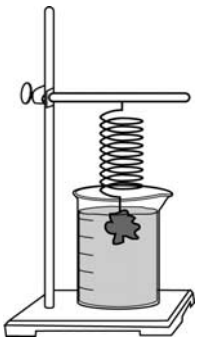
6. (10 points)

In the laboratory, you are given a cylindrical beaker containing a fluid and you are asked to determine the density ρ of the fluid. You are to use a spring of negligible mass and unknown spring constant k attached to a stand. An irregularly shaped object of known mass m and density D $(D >> \rho)$ hangs from the spring. You may also choose from among the following items to complete the task.

- A metric ruler
- A stopwatch
- String

(a) Explain how you could experimentally determine the spring constant k.



(b) The spring-object system is now arranged so that the object (but none of the spring) is immersed in the unknown fluid, as shown above. Describe any changes that are observed in the spring-object system and explain why they occur.

(c) Explain how you could experimentally determine the density of the fluid.

(d) Show explicitly, using equations, how you will use your measurements to calculate the fluid density ρ. Start by identifying any symbols you use in your equations.

Symbol	Physical quantity

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7. (10 points)

A photon of wavelength 2.0×10^{-11} m strikes a free electron of mass m_e that is initially at rest, as shown above left. After the collision, the photon is shifted in wavelength by an amount $\Delta\lambda = 2h/m_e c$, and reversed in direction, as shown above right.

(a) Determine the energy in joules of the incident photon.

(b) Determine the magnitude of the momentum of the incident photon.

(c) Indicate below whether the photon wavelength is increased or decreased by the interaction.

____Increased ____Decreased

Explain your reasoning.

(d) Determine the magnitude of the momentum acquired by the electron.

END OF EXAMINATION

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AP® Physics B
2002 Scoring Guidelines

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General Notes About
2002 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded.
   One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the approximate value $g = 10 \text{ m/s}^2$ for ease of calculation, but use of 9.8 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, in calculations of mass differences in a nuclear reaction, rounding to too few digits can lose the accuracy required to determine a mass difference.

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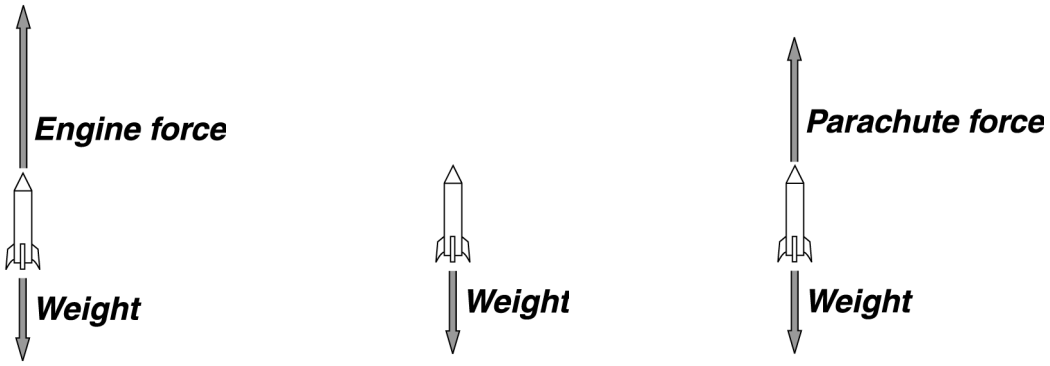
AP® PHYSICS B
2002 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 5 points

i. ii. iii.



1 point for each properly drawn force with an appropriate and clear label, such as those above or letter labels like *mg*, *W*, F_e, or F_p — Total 5 points

For each diagram, one point was deducted for any incorrect forces or other vectors

(b & c) 7 points

These parts were scored together.
In solving parts (b) and (c), there were two frequently used methods of determining the average acceleration *a* while the engine is firing and the speed v_f attained when the engine stops. Both methods begin with determining the net force while the engine is firing, as shown below. They then determine the acceleration and velocity in different orders (methods 1 and 2 on the next page).

For applying the relationship between force and impulse to correctly determine the force exerted by the engine — 1 point

$J = F\ \Delta t$

$F_{engine} = J/\Delta t = (20.0\ \text{N}\cdot\text{s})/(2.0\ \text{s})$

$F_{engine} = 10\ \text{N}$

For subtracting to determine the net force on the rocket — 1 point

$F_{net} = F_{engine} - mg = 10\ \text{N} - (0.250\ \text{kg})(10\,\text{m/s}^2)$

$F_{net} = 7.5\ \text{N}$

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Question 1 (cont'd.)

(b & c) continued

Distribution of points

Method 1 - Determining first the velocity at the end of engine firing, then the average acceleration

Equating the total impulse to the change in momentum:

$F\ \Delta t = m\ \Delta v = m\left(v_f - v_i\right)$

(If a solution started with this expression but used an incorrect net force, one point was earned for applying the relationship between force and impulse)

$v_f - v_i = F\ \Delta t / m$

$v_f - 0 = (7.5\text{ N})(2.0\text{ s})/(0.250\text{ kg})$

For the correct value of the final velocity — 1 point

$v_f = 60\text{ m/s}$

For using the kinematic equation for velocity to determine the acceleration — 1 point

$v_f = v_i + at$

$a = \left(v_f - v_i\right)/t$

$a = (60\text{ m/s} - 0)/(2.0\text{ s})$

$a = 30\text{ m/s}^2$

Method 2 - Determining first the average acceleration, then the velocity at the end of engine firing

For setting *ma* equal to the net force or some physical force in the problem — *1 point*

$F_{net} = ma$

$a = F_{net}/m = (7.5\text{ N})/(0.250\text{ kg})$

$a = 30\text{ m/s}^2$

Using the kinematic equation for velocity:

$v_f = v_i + at$

$v_f = 0 + \left(30\text{ m/s}^2\right)(2.0\text{ s})$

For the correct value of the final velocity — *1 point*

$v_f = 60\text{ m/s}$

For using a correct kinematic equation to determine the height y_1 reached when the engine stops firing and for making correct substitutions — 1 point

$y_1 = y_i + v_i t + \frac{1}{2}at^2$ or $v_f^2 = v_i^2 + 2a\ \Delta y$

$y_1 = 0 + 0 + \frac{1}{2}\left(30\text{ m/s}^2\right)(2\text{ s})^2$ $\quad y_1 = \frac{v_f^2 - v_i^2}{2a} + y_i$

$y_1 = 60\text{ m}$ $\quad y_1 = \frac{(60\text{ m/s})^2 - 0}{2\left(30\text{ m/s}^2\right)} + 0$

$y_1 = 60\text{ m}$

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Question 1 (cont'd.)

Distribution of points

(b & c) continued

For using a correct kinematic equation to determine the height y_2 traveled from when the engine stops firing to when the maximum height is attained, and making correct substitutions — 1 point
(This point could also be earned for correctly applying conservation of energy.)

$$v_f^2 = v_i^2 + 2g\,\Delta y$$

$$y_2 = \frac{v_f^2 - v_i^2}{2g} + y_i$$

$$y_2 = \frac{0 - (60\ \text{m/s})^2}{2(-10\ \text{m/s}^2)} + 0$$

$$y_2 = 180\ \text{m}$$

For adding the two distances to get the total height — 1 point

$$y_{total} = y_1 + y_2 = 60\ \text{m} + 180\ \text{m}$$

$$y_{total} = 240\ \text{m}$$

(d) 3 points

For using a correct kinematic equation to determine the time of travel from when the engine stops firing to when the maximum height is attained, and making correct substitutions — 1 point

$$v_f = v_i - gt_2$$

$$t_2 = \frac{v_f - v_i}{-g} = \frac{0 - 60\ \text{m/s}}{\text{-}10\ \text{m/s}^2}$$

$$t_2 = 6.0\ \text{s}$$

For adding the above to the time the rocket was firing — 1 point

$$t_{total} = t_1 + t_2 = 2.0\ \text{s} + 6.0\ \text{s}$$

For the correct value for the total time (i.e. the answer obtained from a completely correct solution to the entire problem) — 1 point

$$t_{total} = 8.0\ \text{s}$$

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Question 2

15 points total | **Distribution of points**

(a) 1 point

For a reasonable value of U read from the graph — 1 point
$U \approx 0.05$ J

Alternate solution — *Alternate points*
Using the equation for the potential energy of simple harmonic motion:
$U = \frac{1}{2}kx^2$
Using the distance of 10 cm at which the maximum value of 0.4 J for U occurs allows determination of the force constant k.
$0.4 \text{ J} = \frac{1}{2}k(0.1 \text{ m})^2$
$k = 80 \text{ N/m}$
For determining the value of U at 4 cm — *1 point*
$U = \frac{1}{2}(80 \text{ N/m})(0.04 \text{ m})^2$
$U = 0.06$ J

(b) 3 points

For indicating that the maximum possible position in the $+x$-direction is 10 cm — 1 point
For a complete explanation — 2 points
A full-credit explanation would indicate either of the following:
1) The particle stops at this point (or that the kinetic energy is zero here) because all of the energy is in the form of potential energy.
2) The maximum potential energy cannot be greater than the total energy.
Incomplete explanations (such as only saying that the potential energy is 0.4 J at 10 cm) received one point. However, only saying that the total energy is 0.4 J received no credit, since this is just a restatement of given information.

(c) 3 points

For a reasonable value of U read from the graph (between 0.18 J and 0.22 J) — 1 point
This point was also awarded for a correct calculation of U using the force constant determined in part (a).
For subtracting this value of U from the total energy to obtain the kinetic energy — 1 point
For a consistent final answer — 1 point
$K \approx 0.2$ J

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Question 2 (cont'd.)

Distribution of points

(d) 4 points

For any indication that the potential energy is zero at $x = 0$ — 1 point

For setting the kinetic energy equal to the total energy — 1 point

$K = \frac{1}{2}mv^2 = E_{total}$

$v = \sqrt{2E_{total}/m}$

For correctly substituting the energy and mass into the above equation — 1 point

$v = \sqrt{2(0.4\text{ J})/(3.0\text{ kg})}$

For the correct answer — 1 point

$v = 0.5\text{ m/s}$

(e) 4 points

Using the kinematic equation for the vertical motion:

$y_f = y_i + v_{0y}t - \frac{1}{2}gt^2$

For correctly substituting $v_{0y} = 0$ — 1 point

Setting y_f also equal to zero and solving for *t*:

$t = \sqrt{2y_i/g} = \sqrt{2(0.5\text{ m})/(10\text{ m/s}^2)}$

For the correct value of *t* — 1 point

$t = 0.3\text{ s}$

Using the equation for the horizontal distance:

$d = v_x t$

For correctly substituting the value of *t* above and the value of v_x from part (d) — 1 point

$d = (0.5\text{ m/s})(0.3\text{ s})$

For the correct answer — 1 point

$d = 0.2\text{ m}$

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Question 3

15 points total **Distribution of points**

(a) i. 3 points

For both a correct power formula and Ohm's law, either shown explicitly or applied 1 point
For a correct calculation of resistance 1 point
For a correct calculation of current 1 point
This point was awarded if an incorrect value for resistance was correctly used with 120 V.

The calculations can be done in slightly different ways and in different orders.
One example follows:

$P = IV$ and $I = \frac{V}{R}$, so $P = \frac{V^2}{R}$

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{30\ \text{W}} = 480\ \Omega$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{480\ \Omega} = 0.25\ \text{A}$$

(a) ii. 2 points

For a correct calculation of resistance 1 point
For a correct calculation of current 1 point
This point was awarded if an incorrect value for resistance was correctly used with 120 V.

Again, the calculations can be done in slightly different ways and in different orders.
One example follows:

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{40\ \text{W}} = 360\ \Omega$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{360\ \Omega} = 0.33\ \text{A}$$

(b) i. and ii. 4 points

These two parts were scored as a unit.
For showing by calculation or by statement that the resistance in part (b)i is assumed to be the same as in part (a)i, and the resistance in part (b)ii is assumed to be the same as in part (a)ii 1 point
This point could also be awarded to students who recognized the bulbs as non-ohmic and stated this clearly, specifying lower resistances to be used in the solution.

$R_{\text{"30"}} = 480\ \Omega$

$R_{\text{"40"}} = 360\ \Omega$

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Question 3 (cont'd.)

Distribution of points

(b) i. and ii. continued

For adding both resistances to calculate the total series resistance R_{tot} used in the Ohm's law calculation of current — 1 point
$R_{tot} = 480\ \Omega + 360\ \Omega = 840\ \Omega$

For calculating the correct current in part (b)i, or for a current consistent with the total resistance calculated — 1 point
$I_{"30"} = I_{tot} = \frac{V}{R_{tot}} = \frac{120\ \text{V}}{840\ \Omega} = 0.14\ \text{A}$

For stating that the current in part (b)ii is the same as in part (b)i, whether or not the (b)i current is correct — 1 point
$I_{"40"} = I_{"30"} = I_{tot} = 0.14\ \text{A}$

(c) 3 points

__2__ 30 W bulb in the parallel circuit

__1__ 40 W bulb in the parallel circuit

__3__ 30 W bulb in the series circuit

__4__ 40 W bulb in the series circuit

For any order showing that both bulbs in parallel are brighter than both in series — 1 point

For any order showing the 40 W bulb in the parallel circuit is brighter than the 30 W bulb in the parallel circuit — 1 point

For any order showing the "30 W" bulb in the series circuit is brighter than the "40 W" bulb in the series circuit — 1 point

(d) i. 1 point

For a correct answer or calculation consistent with values reported in part (a) — 1 point
$P_{tot} = 30\ \text{W} + 40\ \text{W} = 70\text{W}$

OR $P_{tot} = \frac{V^2}{R_{tot}} = \frac{(120\ \text{V})^2}{206\ \Omega} = 70\ \text{W}$

OR $P_{tot} = \sum VI = (120\ \text{V})(0.25\ \text{A}) + (120\ \text{V})(0.33\ \text{A}) = 70\ \text{W}$

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Question 3 (cont'd.)

Distribution of points

(d) ii. 2 points

For using values from part (b) correctly in the equations 1 point
For correct answer or calculation consistent with values reported in part (b) 1 point

$$P_{tot} = \frac{V^2}{R_{tot}} = \frac{(120\ \text{V})^2}{840\ \Omega} = 17\ \text{W}$$

OR $P_{tot} = \sum I^2 R = (0.14\ \text{A})^2 (480\ \Omega) + (0.14\ \text{A})^2 (360\ \Omega) = 17\ \text{W}$

OR $P_{tot} = VI = (120\ \text{V})(0.14\ \text{A}) = 17\ \text{W}$

Note: Both points were awarded for the correct answer, 17 W, as long as it was consistent with the work in part (b). No points were awarded for answers of 70 W unless student's work clearly showed that it was obtained using a combination of values for R, V, and I consistent with part (b).

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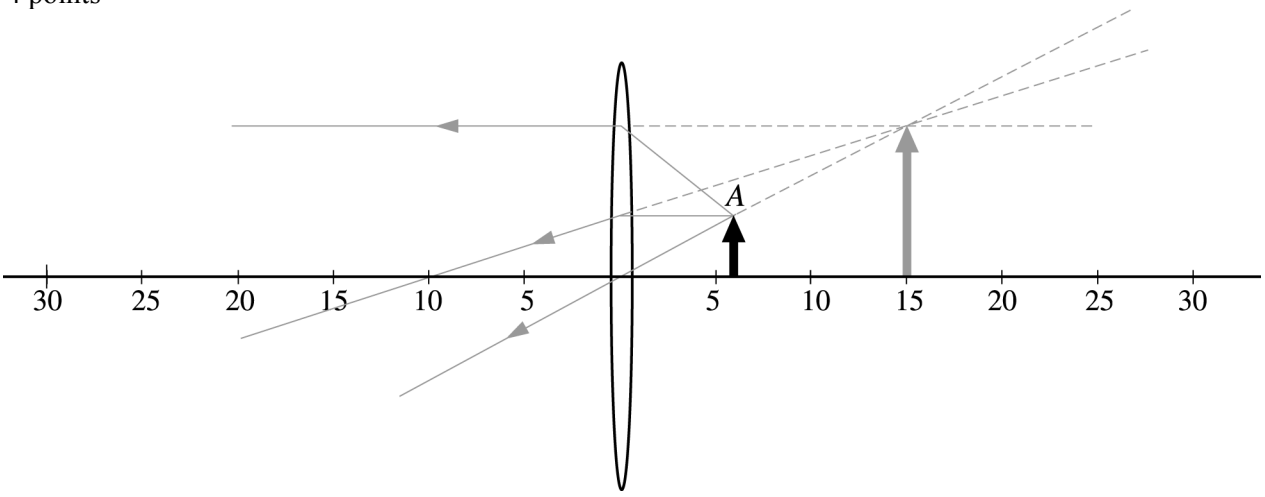
Question 4

15 points total **Distribution of points**

(a) 4 points



For any two correct rays through the lens 2 points
Two of the three principal rays shown on the diagram above were expected.
One point was subtracted for additional incorrect rays. No credit was awarded for reflected rays.
For correct extension of the rays backward 1 point
For showing the image with correct size, position, and orientation 1 point

(b) 2 points

For stating that the image is virtual, or for stating a choice consistent with the ray diagram in part (a) 1 point
If there were no supporting diagrams or calculations, virtual was the only accepted answer.
For a correct explanation consistent with the choice given, such as: 1 point
The light rays diverge on the left side of the lens, but appear to come from a point behind the object. OR The image is on the same side of the lens as the object. OR The object is placed between the converging lens and the focal point.
This point was not awarded if additional wrong statements were part of the response.

(c) 3 points

For the lens equation OR for the lens equation with substituted quantities 1 point

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \quad \text{OR} \quad \frac{1}{s_i} = \frac{1}{10\ \text{cm}} - \frac{1}{6\ \text{cm}}$$

For the correct solution 2 points

$s_i = -15$ cm (Minus sign was not necessary to receive full credit.)

Only 1 of the 2 answer points was awarded for the correct number without units.

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Question 4 (cont'd.)

Distribution of points

(c) continued

Alternate points

Alternate Solution

Let x_o = distance from object to focal point and x_i = distance from image to focal point.

For the correct formula — *1 point*

$$\frac{x_i}{f} = \frac{f}{x_o}$$

For correct substitutions — *1 point*

$$\frac{x_i}{10\ \text{cm}} = \frac{10\ \text{cm}}{10\ \text{cm} - 6\ \text{cm}}$$

$$x_i = \frac{(10\ \text{cm})^2}{4\ \text{cm}} = 25\ \text{cm}$$

$$s_i = 25\ \text{cm} - 10\ \text{cm}$$

For the correct answer — *1 point*

$s_i = 15$ cm

(d) 2 points

For the correct image size to object size ratio with no units, or with units that cancel — 2 points

$$\frac{h_i}{h_o} = \frac{s_i}{s_o} = \frac{15\ \text{cm}}{6\ \text{cm}} = \frac{5}{2}$$

Notes:

Students could use either a calculation or a ray diagram to arrive at the final answer.

1 point only was awarded if the correct ratio was imbedded in extra calculations or if units were provided for the answer (for example, 2.5 cm).

No points were given for giving the object size to image size ratio.

(e) 4 points

Since the question asked for a description, a verbal response was expected, although the image position, size, and orientation could be determined from either a calculation or a ray diagram.

For the correct position:

- Image on the opposite side of the lens from the object — 1 point
- Distance from the image to the lens in the range 20 cm ± 3 cm — 1 point

For the correct size: image size same as object size, or for size consistent with value for position — 1 point

For the correct orientation: image is inverted — 1 point

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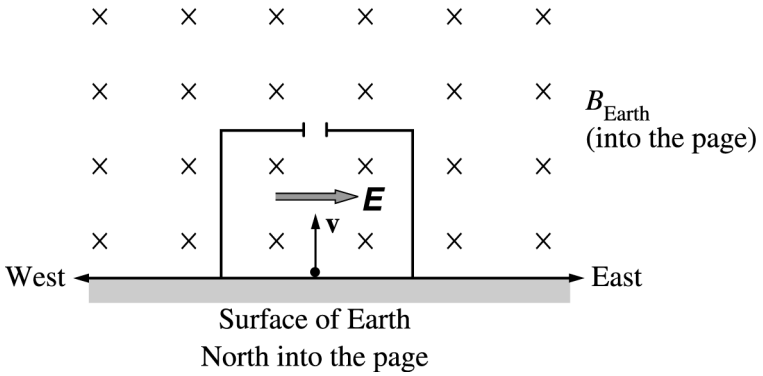
Question 5

10 points total **Distribution of points**

(a) 3 points



For drawing the electric field vector to the right (labeled as E or unlabeled) and parallel to the base of the box — 1 point

For demonstrating an understanding of the physics involved in balancing the magnetic force with an electric force, and for demonstrating an understanding that the electric force and electric field are in the same direction for a proton — 2 points

Note: It was possible to misapply the right-hand rule and obtain an electric field vector to the left, thus not receiving the first point, but still receive 1 or 2 points for the explanation if it was consistent with this direction of the electric field vector.

(b) 2 points

For indicating that the magnetic force and electric force are equal in magnitude, $F_B = F_E$, and thus $ev B_{Earth} \sin\theta = eE$ — 1 point

The velocity and magnetic field are perpendicular to each other, i.e. $\theta = 90°$, so $\sin\theta = 1$

For the correct solution of the above equation for speed in terms of the fields — 1 point

$$v = \frac{E}{B_{Earth}}$$

Note: Since the question asked for the speed "in terms of the fields and the given quantities", and since **v** was unintentionally a given quantity, 2 points were also awarded for realizing that the forces balance and thus the speed remains the same as its initial value, the magnitude of **v.**

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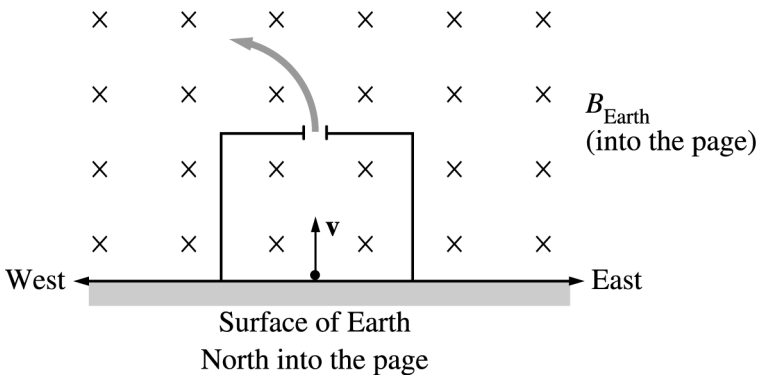
Question 5 (cont'd.)

Distribution of points

(c) 2 points



For sketching a path that moves to the west (i.e. to the left) 1 point
For having the path start out concave downward (either west or east) as soon as the proton leaves the box, and continuing that way for a short distance 1 point

(d) 3 points

For realizing that there is a single force accelerating the proton and that Newton's 2nd law applies 1 point

$F = m_p a$

For knowing that the force is magnetic and substituting its value into Newton's 2nd law 1 point

$evB_{Earth} = m_p a$

For solving for a correctly 1 point

$a = \dfrac{evB_{Earth}}{m_p}$

Note: By substituting $v = \dfrac{E}{B_{Earth}}$ from part (b), the final answer may be expressed as $a = \dfrac{eE}{m_p}$, because those are also given quantities, but full credit was awarded only if it was clearly shown that the force accelerating the proton is the magnetic force.

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Question 5 (cont'd.)

Distribution of points

(d) continued

Alternate points

Alternate Solution

There were several variations of an alternate solution all involving the use of the idea that a particle in a magnetic field with velocity perpendicular to the field will move in a circle of radius *r* at constant speed, and with centripetal acceleration $a = \frac{v^2}{r}$.

The following is one example.

For realizing that the force accelerating the proton is centripetal *1 point*

$$F = m_p a = \frac{m_p v^2}{r}$$

For knowing that the force is magnetic and substituting its value into the equation above *1 point*

$$evB_{Earth} = \frac{m_p v^2}{r}$$

Solving for *r:*

$$r = \frac{m_p v}{eB_{Earth}}$$

Substituting this value of *r* into the equation $a = \frac{v^2}{r}$:

$$a = \frac{v^2}{\left(\frac{m_p v}{eB_{earth}}\right)}$$

For correct answer *1 point*

$$a = \frac{evB_{Earth}}{m_p}$$

Note: Other variations of this general approach could also receive full credit if correct

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AP® PHYSICS B
2002 SCORING GUIDELINES

Question 6

10 points total **Distribution of points**

(a) 3 points

For a correct verbal description of the method used to determine the spring constant 2 points
(One point could be awarded for an incomplete description)
For an appropriate equation for k, or a verbal representation of the equation 1 point

Example 1: Measure the unstretched length of the spring. Hang it with the object at rest and measure the stretched length. Call the difference in these lengths ℓ. Equating the weight of the object and the force exerted by the extended spring gives $mg = k\ell$ from which k can be determined.

Example 2: Set the hanging mass into oscillation. Determine the period T by timing n oscillations and dividing that time by n. The equation $T = 2\pi\sqrt{m/k}$ can then be used to find k.

Example 3: Hold the object at the position where the spring is unstretched and then release it. Measure the maximum distance h it falls. Equating maximum potential and kinetic energies, $mgh = \frac{1}{2}kh^2$, allows determination of k.

(b) 2 points

For a correct observation that includes an indication of whether the change is an increase or decrease 1 point
For a correct explanation of the change 1 point

Example 1: The spring is stretched less when the object is at rest in the fluid. The fluid exerts an upward buoyant force on the object. Since the net force on the object is still zero, the spring does not need to exert as much force as before, and thus stretches less.

Example 2: If the spring oscillates in the fluid, its period will be greater. The fluid exerts a drag force on the object in the direction opposite to its motion, and thus slows it down.

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Question 6 (cont'd.)

15 points total **Distribution of points**

(c & d) 5 points

These parts were scored together. The following describe the criteria for receiving each of the possible scores.

5 points A complete and accurate explanation of a correct experimental method, with correct equations and definitions of symbols

4 points A mostly complete response, with only one or two errors in the explanation or equations
This was the maximum possible score if the student incorrectly used the volume of displaced fluid.

3 points Partially complete response with one or two major errors
OR A complete description of the method (part (c)) with no mathematical treatment (part (d))
OR A complete mathematical treatment with symbol definitions (part (d)) with no description of the method (part (c))

2 points An incomplete explanation and presentation, but one that shows some understanding of the principles involved

1 point An explanation and presentation that shows very little understanding of the principles involved

The following is one example of a correct method.

1) Measure the length of the spring when the object is immersed in the liquid, and subtract the unstretched length to determine the amount the spring is stretched. This will allow calculation of the force exerted by the spring on the object.
2) The volume of fluid displaced is equal to the volume of the object, which can be determined from the given mass and density of the object.
3) The buoyant force on the object is equal to the difference of the object's weight and the force exerted by the spring.
4) The buoyant force also equals the weight of the displaced fluid, which equals the product of the fluid density, displaced volume, and g.

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Question 6 (cont'd.)

15 points total **Distribution of points**

(c & d) continued

Symbol	Physical quantity
m	Mass of object
g	Acceleration due to gravity
k	Spring constant
ℓ	Amount of spring stretch when not immersed
ℓ_w	Amount of spring stretch when immersed
V	Volume (of both object and displaced fluid)
D	Density of object
ρ	Density of fluid
$F_{bouyant}$	Buoyant force on object
F_{spring}	Spring force on object
w_{fluid}	Weight of fluid displaced
m_{fluid}	Mass of fluid displaced

Equation to determine the spring constant

$mg = k\ell$

Equations corresponding to points 1 through 4 in the method described on the previous page:

$F_{spring} = k\ell_w$

$V = m/D$

$F_{bouyant} = mg - F_{spring} = mg - k\ell_w$

$F_{bouyant} = w_{fluid} = m_{fluid}g = \rho Vg$

Solving for ρ (which was not required):

$\rho Vg = mg - k\ell_w$

$$\rho Vg = mg - \frac{mg}{\ell}\ell_w = mg\left(1 - \frac{\ell_w}{\ell}\right)$$

$$\rho = \frac{m}{V}\left(1 - \frac{\ell_w}{\ell}\right) = \frac{m}{m/D}\left(1 - \frac{\ell_w}{\ell}\right)$$

$$\rho = D\left(1 - \frac{\ell_w}{\ell}\right)$$

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Question 7

10 points total **Distribution of points**

(a) 2 points

For a correct equation for the energy of a photon in terms of wavelength (or an equivalent set of equations that will allow such a determination) 1 point

$E = \frac{hc}{\lambda}$

$E_{\gamma i} = \frac{\left(6.63 \times 10^{-34}\ \text{J} \cdot \text{s}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)}{2.0 \times 10^{-11}\ \text{m}}$

For a correct answer 1 point

$E_{\gamma i} = 9.9 \times 10^{-15}\ \text{J}$

(b) 2 points

For a correct equation for the momentum of a photon (or an equivalent set of equations that will allow such a determination) 1 point

$p = \frac{E}{c}$ or $p = \frac{h}{\lambda}$

Using the second equation:

$p_{\gamma i} = \frac{6.63 \times 10^{-34}\ \text{J} \cdot \text{s}}{2.0 \times 10^{-11}\ \text{m}}$

For the correct answer 1 point

$p_{\gamma i} = 3.3 \times 10^{-23}\ \text{kg} \cdot \text{m/s}$ or equivalent in other units (e.g. $6.2 \times 10^{4}\ \text{eV}/c$)

(c) 3 points

For indicating that the photon wavelength increased 1 point

For indicating that the photon energy or momentum is decreased due to the interaction 1 point
This point was not awarded if the student gave an incorrect explanation of the reason for these decreases.

For indicating that there is an inverse relationship between the wavelength and either energy or momentum 1 point

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Question 7 (cont'd.)

(d) 3 points — **Distribution of points**

For indicating that conservation of momentum is applicable — 1 point

For further work applying conservation of momentum that indicates that the momentum of the final photon is in the direction opposite to that of the initial momentum (e.g. correctly including a minus sign in calculations) — 1 point

$p_{ei} + p_{\gamma i} = p_{ef} - p_{\gamma f}$

$p_{ei} = 0$ and $p_{\gamma f}$ can be determined by using the given expression for $\Delta\lambda$ to calculate the wavelength of the final photon

$$\lambda_f = \lambda_i + \Delta\lambda = \lambda_i + \frac{2h}{m_e c}$$

$$\lambda_f = 2.0\times10^{-11}\ \text{m} + \frac{2\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)}{\left(9.11\times10^{-31}\ \text{kg}\right)\left(3.00\times10^{8}\ \text{m/s}\right)} = 2.5\times10^{-11}\ \text{m}$$

$$p_{\gamma f} = \frac{h}{\lambda_f} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{2.5\times10^{-11}\ \text{m}}$$

$$p_{\gamma f} = 2.7\times10^{-23}\ \text{kg}\cdot\text{m/s}$$

$$p_{ef} = p_{\gamma i} + p_{\gamma f} = 3.3\times10^{-23}\ \text{kg}\cdot\text{m/s} + 2.7\times10^{-23}\ \text{kg}\cdot\text{m/s}$$

For a correct final answer, including units — 1 point

$p_{ef} = 6.0\times10^{-23}\ \text{kg}\cdot\text{m/s}$

Alternate solution — *Alternate points*

For indicating that conservation of energy is applicable — *1 point*

For further work applying conservation of energy correctly — *1 point*

$E_{ei} + E_{\gamma i} = E_{ef} + E_{\gamma f}$

$E_{ei} = 0$ and $E_{\gamma f}$ can be determined by using the given expression for $\Delta\lambda$ to calculate the wavelength of the final photon (as shown above)

$$E_{\gamma f} = \frac{hc}{\lambda_f} = \frac{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\right)}{2.5\times10^{-11}\ \text{m}} = 8.0\times10^{-15}\ \text{J}$$

$$E_{ef} = E_{\gamma i} - E_{\gamma f} = 9.9\times10^{-15}\ \text{J} - 8.0\times10^{-15}\ \text{J} = 1.9\times10^{-15}\ \text{J}$$

$$E_{ef} = \frac{1}{2}m_e v_{ef}^2 = \frac{1}{2}\frac{p_{ef}^2}{m_e}$$

$$p_{ef} = \sqrt{2m_e E_{ef}} = \sqrt{2\left(9.11\times10^{-31}\ \text{kg}\right)\left(1.9\times10^{-15}\ \text{J}\right)}$$

For a correct final answer, including units — *1 point*

$p_{ef} = 5.9\times10^{-23}\ \text{kg}\cdot\text{m/s}$

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AP® Physics B
2002 Free-Response Questions
Form B

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TABLE OF INFORMATION FOR 2002

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol} \cdot \text{K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this examination.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

NEWTONIAN MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2} at^2$

$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{\upsilon^2}{r}$

$\tau = rF \sin\theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2} m\upsilon^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \Delta\mathbf{r} = F\Delta r \cos\theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = \mathbf{F} \cdot \mathbf{v} = F\upsilon \cos\theta$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1m_2}{r^2}$

$U_G = -\frac{Gm_1m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = q\upsilon B \sin\theta$

$F_B = BI\ell \sin\theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos\theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell\upsilon$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2002

FLUID MECHANICS AND THERMAL PHYSICS

$p = p_0 + \rho gh$

$F_{buoy} = \rho Vg$

$A_1 v_1 = A_2 v_2$

$p + \rho gy + \frac{1}{2}\rho v^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$Q = mL$

$Q = mc\Delta T$

$p = \frac{F}{A}$

$pV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q + W$

$\Delta U = nc_V \Delta T$

$e = \left| \frac{W}{Q_H} \right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
h = depth
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

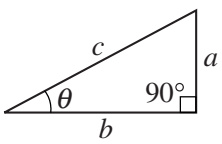
$d \sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

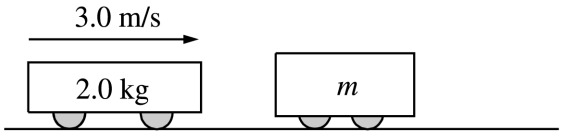
Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

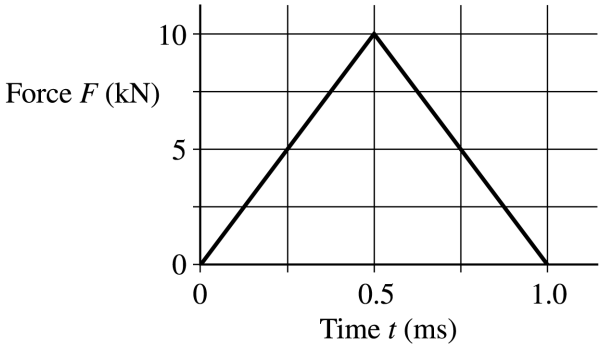
PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the goldenrod booklet in the spaces provided after each part, NOT in this lavender insert.



1. (15 points)

A 2.0 kg frictionless cart is moving at a constant speed of 3.0 m/s to the right on a horizontal surface, as shown above, when it collides with a second cart of undetermined mass m that is initially at rest. The force F of the collision as a function of time t is shown in the graph below, where $t = 0$ is the instant of initial contact. As a result of the collision, the second cart acquires a speed of 1.6 m/s to the right. Assume that friction is negligible before, during, and after the collision.



(a) Calculate the magnitude and direction of the velocity of the 2.0 kg cart after the collision.

(b) Calculate the mass m of the second cart.

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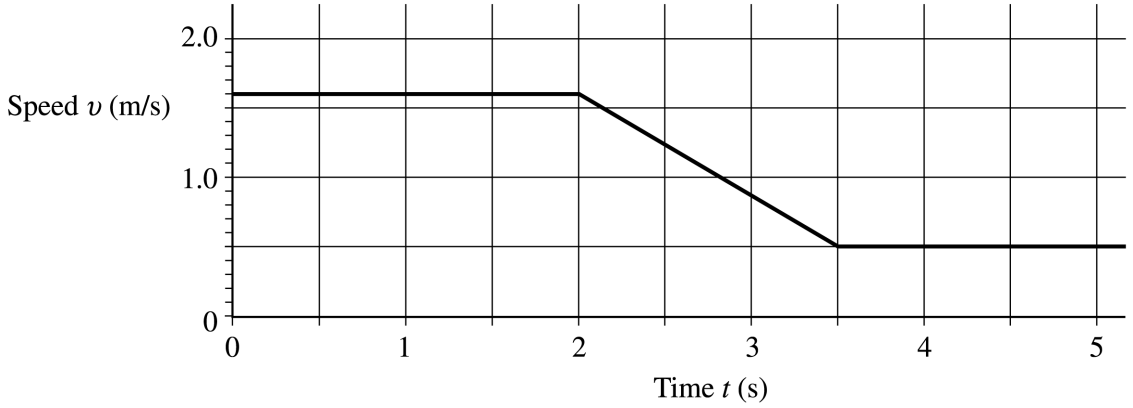
After the collision, the second cart eventually experiences a ramp, which it traverses with no frictional losses. The graph below shows the speed v of the second cart as a function of time t for the next 5.0 s, where $t = 0$ is now the instant at which the carts separate.



(c) Calculate the acceleration of the cart at $t = 3.0$ s.

(d) Calculate the distance traveled by the second cart during the 5.0 s interval after the collision ($0 \text{ s} < t < 5.0 \text{ s}$).

(e) State whether the ramp goes up or down and calculate the maximum elevation (above or below the initial height) reached by the second cart on the ramp during the 5.0 s interval after the collision ($0 \text{ s} < t < 5.0 \text{ s}$).

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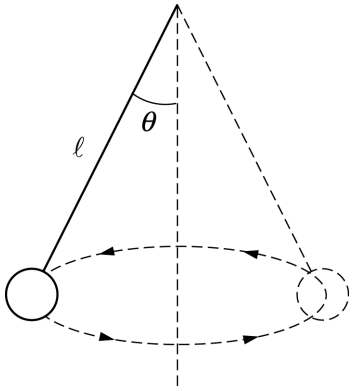
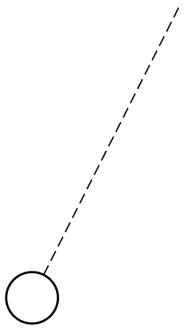


2. (15 points)

A ball attached to a string of length ℓ swings in a horizontal circle, as shown above, with a constant speed. The string makes an angle θ with the vertical, and T is the magnitude of the tension in the string. Express your answers to the following in terms of the given quantities and fundamental constants.

(a) On the figure below, draw and label vectors to represent all the forces acting on the ball when it is at the position shown in the diagram. The lengths of the vectors should be consistent with the relative magnitudes of the forces.



(b) Determine the mass of the ball.

(c) Determine the speed of the ball.

(d) Determine the frequency of revolution of the ball.

(e) Suppose that the string breaks as the ball swings in its circular path. Qualitatively describe the trajectory of the ball after the string breaks but before it hits the ground.

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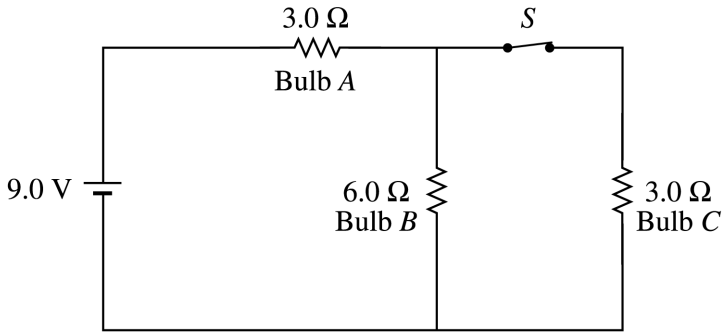

3. (15 points)

Lightbulbs of fixed resistance 3.0 Ω and 6.0 Ω, a 9.0 V battery, and a switch S are connected as shown in the schematic diagram above. The switch S is closed.

(a) Calculate the current in bulb A.

(b) Which lightbulb is brightest? Justify your answer.

(c) Switch S is then opened. By checking the appropriate spaces below, indicate whether the brightness of each lightbulb increases, decreases, or remains the same. Explain your reasoning for each lightbulb.

i. Bulb A: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

ii. Bulb B: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

iii. Bulb C: The brightness ___ increases ___ decreases ___ remains the same

Explanation:

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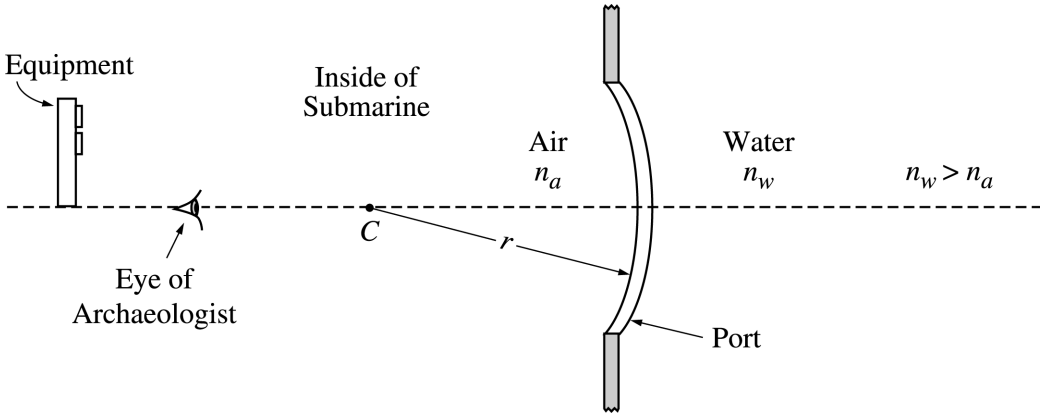
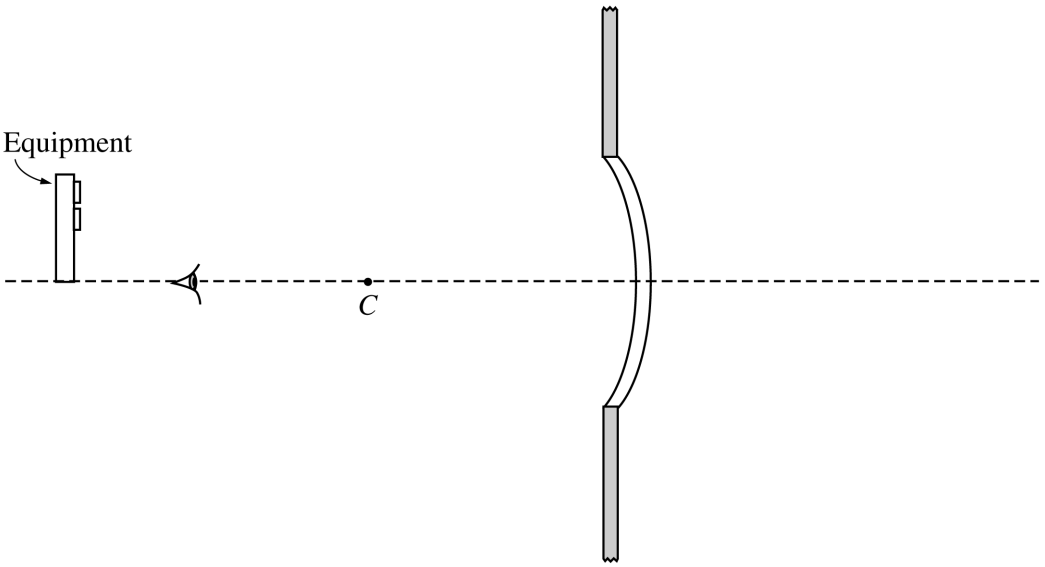


4. (15 points)

A marine archaeologist looks out the port of a research submarine, as shown above. The port is spherically shaped with center of curvature at point C and radius of curvature r. It is made of a material that has an index of refraction of n_w, the same as the index of refraction of seawater, which is greater than n_a, the index of refraction of air. The archaeologist is located to the left of point C and some equipment in the submarine is located behind the archaeologist. The archaeologist can see through the port, but the port also acts as a mirror so the archaeologist can see the reflection of the equipment.

(a) What is the focal length of the mirror?

(b) On the following figure, sketch a ray diagram to locate the position of the image of the equipment formed as a result of the mirror effect.



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(c) Based on your ray diagram, check the appropriate spaces below to describe the image of the equipment formed as a result of the mirror effect.

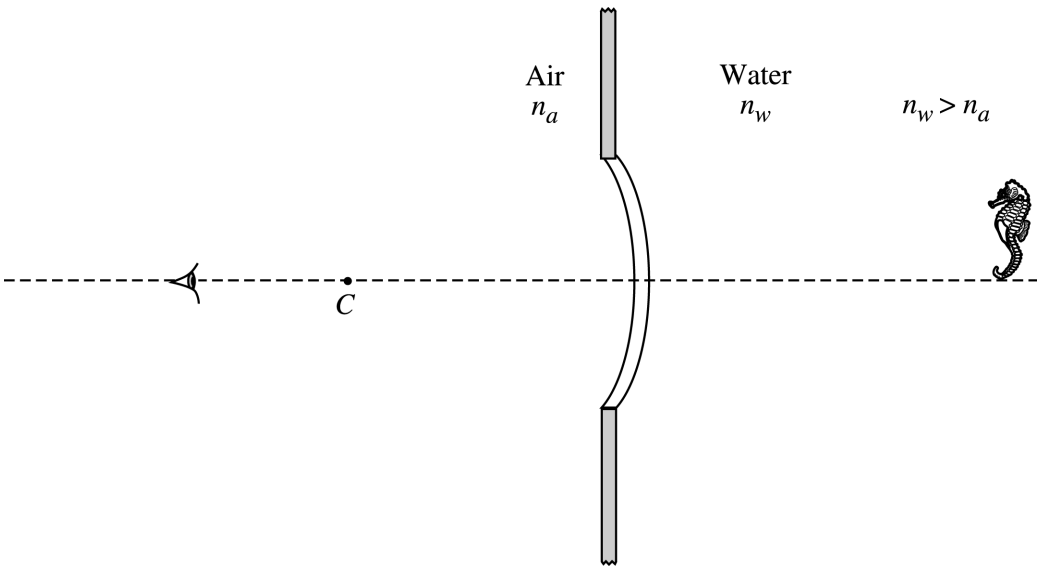
i. Image is: ___ upright ___ inverted

ii. Image is: ___ real ___ virtual

iii. Image is: ___ larger than the equipment ___ smaller than the equipment

The archaeologist also observes a seahorse located outside the port directly in front of the archeologist. Due to refraction of light at the inner surface of the port, the seahorse does not appear to the archaeologist to be at its actual location.

(d) On the following figure, sketch a ray diagram to locate the position of the image of the seahorse formed by the refraction of light at the port.



(e) Based on your ray diagram, check the appropriate spaces below to describe the image of the seahorse, as seen by the archaeologist, formed by the refraction of light at the port.

i. Image is: ___ upright ___ inverted

ii. Image is: ___ real ___ virtual

iii. Image is: ___ larger than the seahorse ___ smaller than the seahorse

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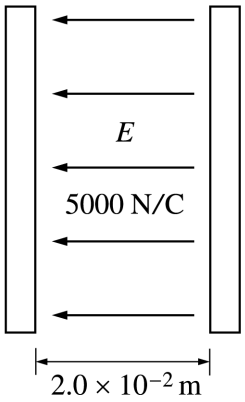

Note: Figure not drawn to scale.

5. (10 points)

Two parallel conducting plates, each of area $0.30\ \text{m}^2$, are separated by a distance of $2.0 \times 10^{-2}\ \text{m}$ of air. One plate has charge $+Q$; the other has charge $-Q$. An electric field of 5000 N/C is directed to the left in the space between the plates, as shown in the diagram above.

(a) Indicate on the diagram which plate is positive (+) and which is negative (-).

(b) Determine the potential difference between the plates.

(c) Determine the capacitance of this arrangement of plates.

An electron is initially located at a point midway between the plates.

(d) Determine the magnitude of the electrostatic force on the electron at this location and state its direction.

(e) If the electron is released from rest at this location midway between the plates, determine its speed just before striking one of the plates. Assume that gravitational effects are negligible.

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6. (10 points)

A sealed steel canister is being used to store neon gas (atomic mass = 20.2 u). The mass of the steel canister alone is 12.0 kg, and it has an interior volume of 8.00 liters $= 8.00 \times 10^{-3}\ \text{m}^3$. There are 4.50 moles of neon gas in the canister, and the temperature of the entire system is 300 K.

Reference information:

Specific heat of steel $= 448\ \text{J kg}^{-1}\text{K}^{-1}$

Specific heat of neon $= 12.5\ \text{J mole}^{-1}\text{K}^{-1}$

Specific heat of water $= 4186\ \text{J kg}^{-1}\text{K}^{-1}$

Heat of fusion of water $= 3.33 \times 10^{5}\ \text{J kg}^{-1}$

Density of water $= 1.00 \times 10^{3}\ \text{kg m}^{-3}$

Density of ice $= 0.917 \times 10^{3}\ \text{kg m}^{-3}$

(a) Determine the pressure within the cylinder.

The sealed cylinder is now placed in a large tank containing a mixture of ice and water at 273 K. You may neglect any change in the volume of the cylinder.

(b) Determine the pressure of the neon gas after the cylinder and its contents have reached thermal equilibrium with the ice-water mixture.

(c) Determine the mass of the ice that melts during the equilibration of the cylinder.

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7. (10 points)

An experimenter determines that when a beam of monoenergetic electrons bombards a sample of a pure gas, atoms of the gas are excited if the kinetic energy of each electron in the beam is 3.70 eV or greater.

(a) Determine the deBroglie wavelength of 3.70 eV electrons.

(b) Once the gas is excited by 3.70 eV electrons, it emits monochromatic light. Determine the wavelength of this light.

Experiments reveal that two additional wavelengths are emitted if the beam energy is raised to at least 4.90 eV.

(c) In the space below construct an energy-level diagram consistent with this information and determine the energies of the photons associated with those two additional wavelengths.

END OF EXAMINATION

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AP® Physics B
2002 Scoring Guidelines
Form B

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General Notes About
2002 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded.
   One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the approximate value $g = 10 \text{ m/s}^2$ for ease of calculation, but use of 9.8 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, in calculations of mass differences in a nuclear reaction, rounding to too few digits can lose the accuracy required to determine a mass difference.

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AP® PHYSICS B
2002 FORM B SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 4 points

For any statement indicating that impulse equals change in momentum — 1 point

For any statement indicating that impulse can be determined from the area under the graph — 1 point

$\Delta p = F\Delta t =$ area under the curve

$$\Delta p = 2\left(\frac{1}{2}\right)\left(0.5\times10^{-3}\ \text{s}\right)\left(10\times10^{3}\ \text{N}\right) = 5\ \text{N}\cdot\text{s}$$

For recognizing that the impulse on the 2 kg cart is negative, and subtracting it from the initial momentum of the cart — 1 point

$$p_{2\ \text{kg after}} = (2.0\ \text{kg})(3.0\ \text{m/s}) - 5\ \text{N}\cdot\text{s} = 1\ \text{N}\cdot\text{s}$$

$$p_{2\ \text{kg after}} = (2\ \text{kg})v_{2\ \text{kg after}} = 1\ \text{N}\cdot\text{s}$$

For the correct answer — 1 point

$v_{2\ \text{kg after}} = 0.5\ \text{m/s}$ to the right

(b) 3 points

For any statement of conservation of momentum — 1 point

$p_{2\ \text{kg before}} = p_{2\ \text{kg after}} + p_{m\ \text{after}}$

For correct substitutions — 1 point

$6\ \text{N}\cdot\text{s} = 1\ \text{N}\cdot\text{s} + m(1.6\ \text{m/s})$

For the correct answer — 1 point

$m = 3.1$ kg

Alternate solution — *Alternate points*

The average acceleration is the average force divided by the mass

$\bar{a} = \bar{F}/m$

For calculating the average acceleration — *1 point*

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{1.6\ \text{m/s}}{1\times10^{-3}\ \text{s}} = 1600\ \text{m/s}^2$$

For calculating the average force — *1 point*

$$\bar{F} = \frac{1}{2}(0 + 10{,}000)\ \text{N} = 5000\ \text{N}$$

$$m = (5000\ \text{N})/(1600\ \text{m/s}^2)$$

For the correct answer — *1 point*

$m = 3.1$ kg

Note: An alternate solution is to do part (b) first using impulse, in which case the first two points noted above for part (a) could be earned. Then conservation of momentum can be used to solve part (a), so the first point noted above for part (b) could be earned.

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Question 1 (cont'd.)

Distribution of points

(c) 2 points

For using the slope of the graph to determine the acceleration — 1 point

$a = \text{ slope } = \dfrac{(0.5 - 1.6)\ \text{m/s}}{(3.5 - 2)\ \text{s}}$

For the correct answer — 1 point

$a = -0.73\ \text{m/s}^2$

(d) 3 points

For using the area under the curve or one of the equations $d = vt$ or $d = \bar{v}t$ — 1 point

For calculating a distance for each segment of the graph — 1 point

$d_1 = (1.6\,\text{m/s})(2\ \text{s}) = 3.2\ \text{m}$

$d_2 = \dfrac{(1.6 + 0.5)\ \text{m/s}}{2}(1.5\ \text{s})$ or $(1.6\ \text{m/s})(1.5\ \text{s}) + \dfrac{1}{2}(-0.73\ \text{m/s}^2)(1.5\ \text{s})^2$

$d_2 = 1.6\ \text{m}$

$d_3 = (0.5\ \text{m/s})(1.5\ \text{s}) = 0.8\ \text{m}$

$d_{\text{tot}} = d_1 + d_2 + d_s$

For the correct answer — 1 point

$d_{\text{tot}} = 5.5\ \text{m}$

(e) 3 points

The acceleration is negative, so the cart must be moving opposite to the force of gravity, which is the only force acting on it.

For indicating that the ramp goes up — 1 point

For using conservation of energy — 1 point

$mgh = \dfrac{1}{2}m\left(v_i^2 - v_f^2\right)$

$h = \dfrac{1}{2(10\ \text{m/s}^2)}\left((1.6\ \text{m/s})^2 - (0.5\ \text{m/s})^2\right)$

For the correct answer — 1 point

$h = 0.12\ \text{m}$

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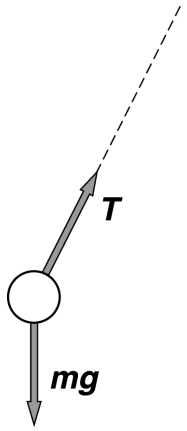
Question 2

15 points total **Distribution of points**

(a) 3 points



1 point for each correctly drawn and appropriately labeled force — 2 points
For no incorrect forces — 1 point

The horizontal and vertical components of the tension were acceptable if properly labeled

(b) 3 points

For indicating that the sum of the vertical forces is zero — 1 point
$\sum F_y = 0$

For correctly substituting the applicable forces — 1 point
$T\cos\theta - mg = 0$

For the correct answer — 1 point
$m = \dfrac{T\cos\theta}{g}$

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Question 2 (cont'd.)

Distribution of points

(c) 4 points

The centripetal force is supplied by the horizontal component of the tension
$F_c = T\sin\theta$

For using a correct expression for the centripetal force F_c — 1 point

$\frac{mv^2}{r} = T\sin\theta$

For eliminating the tension or the mass using the answer to part (b) — 1 point

$\frac{mv^2}{r} = mg\frac{\sin\theta}{\cos\theta} = mg\tan\theta$ OR $\frac{T\cos\theta\ v^2}{gr} = T\sin\theta$

For using the substitution $r = \ell\sin\theta$ — 1 point

$\frac{mv^2}{\ell\sin\theta} = mg\tan\theta$ OR $\frac{T\cos\theta\ v^2}{g\ell\sin\theta} = T\sin\theta$

For the correct answer — 1 point

$v = \sqrt{g\ell\sin\theta\tan\theta}$ or $\sqrt{\frac{g\ell\sin^2\theta}{\cos\theta}}$

(d) 3 points

For using a correct expression for period or frequency — 1 point

$T = \frac{2\pi r}{v}$ or $f = \frac{v}{2\pi r}$

For substituting the velocity from part (c) — 1 point

For the correct answer (unsimplified acceptable) — 1 point

$f = \frac{\sqrt{g\ell\sin\theta\tan\theta}}{2\pi\ell\sin\theta}$ or $\frac{1}{2\pi}\sqrt{\frac{g\tan\theta}{\ell\sin\theta}}$ or $\frac{1}{2\pi}\sqrt{\frac{g}{\ell\cos\theta}}$

(e) 2 points

For any indication that the initial velocity of the ball is horizontal — 1 point

For any indication that the subsequent trajectory is parabolic — 1 point

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Question 3

15 points total **Distribution of points**

(a) 6 points

For the correct expression for the total resistance in the parallel branch — 1 point

$\frac{1}{R_p} = \frac{1}{6\ \Omega} + \frac{1}{3\ \Omega}$

For the correct value for the parallel branch — 1 point

$R_p = 2\ \Omega$

For correctly combining R_p in series with the remaining resistance — 1 point

$R_t = 2\ \Omega + 3\ \Omega$

For the correct total resistance — 1 point

$R_t = 5\ \Omega$

For using Ohm's law — 1 point

$I = V/R = 9\ \text{V}/5\ \Omega$

For the correct answer — 1 point

$I = 1.8\ \text{A}$

(b) 3 points

For indicating that bulb *A* is brightest — 1 point

For a correct justification based on the power expended by each bulb (either quantitative reasoning or direct calculations) — 2 points

For example:

$P = I^2 R$

$P_A = (1.8\ \text{A})^2 (3\ \Omega) = 9.7\ \text{W}$

One third of the current flows through bulb *B* and two-thirds through bulb *C*

$P_B = \left(\frac{1.8\ \text{A}}{3}\right)^2 (6\ \Omega) = 2.2\ \text{W}$ and $P_C = \left(\frac{2(1.8\ \text{A})}{3}\right)^2 (3\ \Omega) = 4.3\ \text{W}$

One justification point was awarded for only discussing the relative currents in the bulbs or the relative voltages across them.

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Question 3 (cont'd.)

Distribution of points

(c)

i. 2 points

For indicating that the brightness of bulb *A* decreases — 1 point
For a correct justification — 1 point
For example: The total resistance increases so the current through bulb *A* decreases, thus decreasing its power output

ii. 2 points

For indicating that the brightness of bulb *B* increases — 1 point
For a correct justification — 1 point
For example: The current through bulb *B* increases, thus increasing its power output

iii. 2 points

For indicating that the brightness of bulb *C* decreases — 1 point
For a correct justification — 1 point
For example: The current through bulb *C* is now zero, so the bulb goes out

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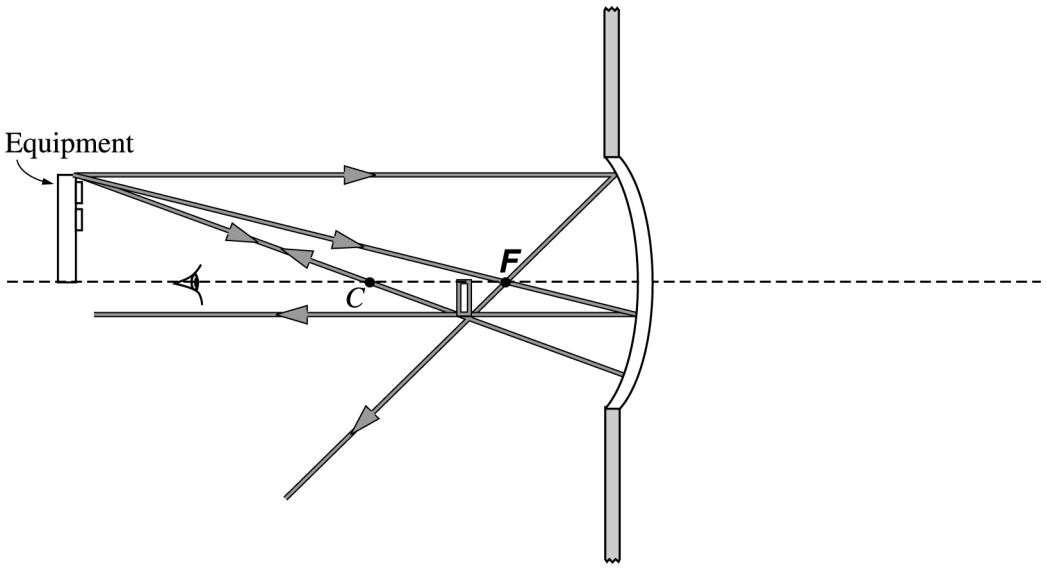
Question 4

15 points total **Distribution of points**

(a) 3 points

For indicating that the focal length is half the radius of curvature 3 points

(b) 3 points



1 point each for any two correct principal rays (the three principal rays are shown above) 2 points
For a correctly drawn image 1 point

(c)

i. 1 point

For indicating the image is inverted 1 point

ii. 1 point

For indicating the image is real 1 point

iii. 1 point

For indicating the image is smaller than the object 1 point

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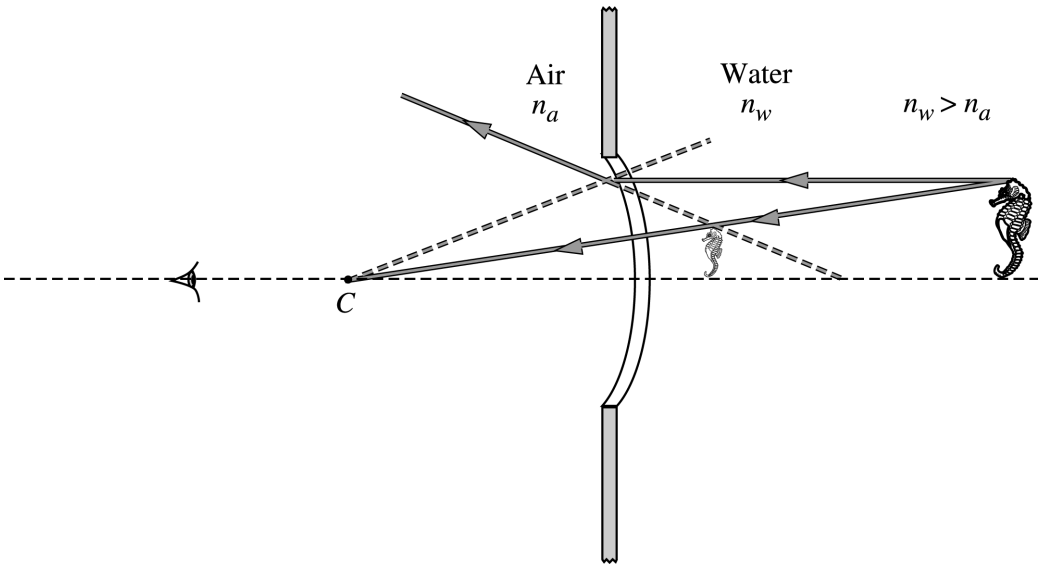
Question 4 (cont'd.)

Distribution of points

(d) 3 points



1 point each for any two correct rays (i.e. showing no refraction for normal incidence and refraction away form the normal for non-normal incidence) — 2 points

For a correctly drawn image — 1 point

(e)

i. 1 point

For indicating the image is upright — 1 point

ii. 1 point

For indicating the image is virtual — 1 point

iii. 1 point

For indicating the image is smaller than the object — 1 point

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Question 5

10 points total **Distribution of points**

(a) 2 points

For indicating the correct polarity, negative on the left and positive on the right 2 points

(b) 2 points

Using the expression for the magnitude of the electric field between two parallel plates:
$E = V/d$

For correct substitutions 1 point
$V = (5000\ \text{N/C})(0.02\ \text{m})$

For the correct answer 1 point
$V = 100\ \text{V}$

(c) 2 points

Using the expression for the capacitance of a parallel-plate capacitor:
$C = \frac{\epsilon_0 A}{d}$

For correct substitutions 1 point
$C = \frac{\left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}\right)\left(0.3\ \text{m}^2\right)}{0.02\ \text{m}}$

For the correct answer 1 point
$C = 1.3 \times 10^{-10}\ \text{F}$

(d) 2 points

Using the expression for the force and substituting:
$F = qE = \left(1.6 \times 10^{-19}\ \text{C}\right)(5000\ \text{N/C})$

For the correct magnitude of the force 1 point
For the correct direction 1 point
$F = 8.0 \times 10^{-16}\ \text{N}$ to the right

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Question 5 (cont'd.)

Distribution of points

(e) 2 points

The potential difference between the center and one of the plates is 50 V

For correctly equating the work to the kinetic energy, and using 50 V for the potential difference — 1 point

$$W = qV = \frac{1}{2}mv^2$$

Solving for v:

$$v = \sqrt{2qV/m} = \sqrt{2\left(1.6\times10^{-19}\text{ C}\right)(50\text{ V})\Big/\left(9.11\times10^{-31}\text{ kg}\right)}$$

For the correct answer — 1 point

$$v = 4.2\times10^{6}\text{ m/s}$$

Alternate solution — *Alternate points*

For determining the acceleration — *1 point*

$$a = F/m = \left(8\times10^{-16}\text{ N}\right)\Big/\left(9.11\times10^{-31}\text{ kg}\right) = 8.8\times10^{14}\text{ m/s}^2$$

Using an applicable kinematic equation

$$v_f^2 = v_0^2 + 2ad$$

$$v_f^2 = 0 + 2\left(8.8\times10^{14}\text{ m/s}^2\right)(0.01\text{ m})$$

For the correct answer — *1 point*

$$v = 4.2\times10^{6}\text{ m/s}$$

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Question 6

10 points total | **Distribution of points**

(a) 3 points

For using the equation for an ideal gas — 1 point

$pV = nRT$

$p = nRT/V$

For correct substitutions — 1 point

$p = (4.5 \text{ mol})(8.31 \text{J/mol} \cdot \text{K})(300 \text{ K}) \big/ \left(8 \times 10^{-3} \text{ m}^3\right)$

For the correct answer — 1 point

$p = 1.40 \times 10^6 \text{ Pa}$

(b) 3 points

For the correct relationship between pressures and temperatures at constant volume — 1 point

$\frac{p_1}{T_1} = \frac{p_2}{T_2}$

Solving for p_2:

$p_2 = \frac{p_1 T_2}{T_1}$

For substituting the value of p_1 from part (a) — 1 point

$p_2 = \frac{\left(1.40 \times 10^6 \text{ Pa}\right)(273 \text{ K})}{300 \text{ K}}$

For the correct answer — 1 point

$p_2 = 1.28 \times 10^6 \text{ Pa}$

Alternate solution | *Alternate points*

For using the equation for an ideal gas — *1 point*

$pV = nRT$

$p = nRT/V$

For correct substitutions — *1 point*

$p = (4.5 \text{ mol})(8.31 \text{J/mol} \cdot \text{K})(273 \text{ K}) \big/ \left(8 \times 10^{-3} \text{ m}^3\right)$

For the correct answer — *1 point*

$p = 1.28 \times 10^6 \text{ Pa}$

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Question 6 (cont'd.)

Distribution of points

(c) 4 points

For using the mass of the water times its heat of fusion as the total heat used in melting ice — 1 point

For using the correct expressions for the heat lost by the canister and neon — 1 point

$m_w L_w = nc_n \Delta T + m_s c_s \Delta T$

$m_w = \dfrac{\left(nc_n \Delta T + m_s c_s \Delta T\right)}{L_w}$

For using the correct ΔT — 1 point

$m_w = \dfrac{(4.5 \text{ mol})(12.5 \text{ J/mol} \cdot \text{K})(300 \text{ K} - 273 \text{ K}) + (12.0 \text{ kg})(448 \text{ J/kg} \cdot \text{K})(300 \text{ K} - 273 \text{ K})}{3.33 \times 10^5 \text{ J/kg}}$

For the correct answer — 1 point

$m_w = 0.440 \text{ kg}$

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Question 7

10 points total | **Distribution of points**

(a) 5 points

For using the expression for deBroglie wavelength — 1 point
$\lambda = h/p$ or h/mv

Determining the speed from the kinetic energy K:

$K = \frac{1}{2}mv^2$

$v = \sqrt{2K/m}$

For including the conversion of K from eV to joules — 1 point

For correctly determining the velocity — 1 point

$v = \sqrt{2(3.70\text{ eV})\left(1.6\times10^{-19}\text{ J/eV}\right)\Big/\left(9.11\times10^{-31}\text{ kg}\right)} = 1.14\times10^{6}\text{ m/s}$

For correctly substituting this velocity into the equation for the wavelength — 1 point

$\lambda = \left(6.63\times10^{-34}\text{ J}\cdot\text{s}\right)\Big/\left(9.11\times10^{-31}\text{ kg}\right)\left(1.14\times10^{6}\text{ m/s}\right)$

For the correct answer — 1 point

$\lambda = 6.38\times10^{-10}\text{ m}$

(b) 2 points

For using the correct equation relating wavelength to energy, or an equivalent combination of equations — 1 point

$\lambda = hc/E$ (or a combination such as $E = hf$ and $f = c/\lambda$)

The energy E is equal to the kinetic energy of the electrons. Substituting for hc and E:

$\lambda = \left(1.24\times10^{3}\text{ eV}\cdot\text{nm}\right)\Big/(3.70\text{ eV})$ or equivalent calculation using joules

For the correct answer

$\lambda = 335\text{ nm}$

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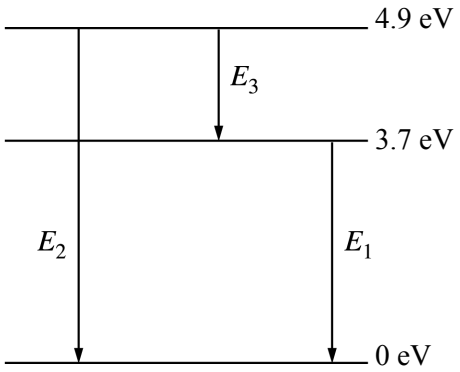
Question 7 (cont'd.)

Distribution of points

(c) 3 points



$E_1 = 3.7$ eV
$E_2 = 4.9$ eV
$E_3 = 1.2$ eV

For a diagram with correctly labeled levels or some identification of the relative energies 1 point
For an indication of the additional transition of 1.2 eV 2 points

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AP Physics B
2001 Free-Response Questions

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AP® PHYSICS B EQUATIONS FOR 2001

NEWTONIAN MECHANICS

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = {v_0}^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$F_{fric} \leq \mu N$

$a_c = \frac{v^2}{r}$

$\tau = rF \sin \theta$

$\mathbf{p} = m\mathbf{v}$

$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$

$K = \frac{1}{2} mv^2$

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \mathbf{s} = Fs \cos \theta$

$P_{avg} = \frac{W}{\Delta t}$

$P = Fv$

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2} kx^2$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$T = \frac{1}{f}$

$F_G = -\frac{Gm_1 m_2}{r^2}$

$U_G = -\frac{Gm_1 m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
s = displacement
T = period
t = time
U = potential energy
v = velocity or speed
W = work
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$

$E_{avg} = -\frac{V}{d}$

$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$

$C = \frac{Q}{V}$

$C = \frac{\epsilon_0 A}{d}$

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$I_{avg} = \frac{\Delta Q}{\Delta t}$

$R = \frac{\rho\ell}{A}$

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

$B = \frac{\mu_0}{2\pi} \frac{I}{r}$

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$

$\mathcal{E} = B\ell v$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux

AP® PHYSICS B EQUATIONS FOR 2001

THERMAL PHYSICS

$\Delta \ell = \alpha \ell_0 \Delta T$

$Q = mL$

$Q = mc\Delta T$

$p = \frac{F}{A}$

$pV = nRT$

$K_{avg} = \frac{3}{2} k_B T$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q - W$

$\Delta U = nc_V \Delta T$

$e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
c = specific heat or molar specific heat
e = efficiency
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molecular mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred
T = temperature
U = internal energy
V = volume
v_{rms} = root-mean-square velocity
W = work done by system
α = coefficient of linear expansion
μ = mass of molecule

WAVES AND OPTICS

$v = f\lambda$

$n = \frac{c}{v}$

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$\sin \theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d \sin \theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
v = speed
x = position
λ = wavelength
θ = angle

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

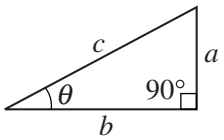
$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2} bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Parallelepiped
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$
Right Triangle
$a^2 + b^2 = c^2$
$\sin \theta = \frac{a}{c}$
$\cos \theta = \frac{b}{c}$
$\tan \theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

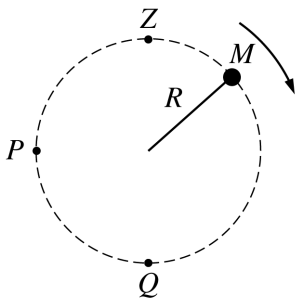
PHYSICS B

SECTION II

Time—90 minutes

7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.

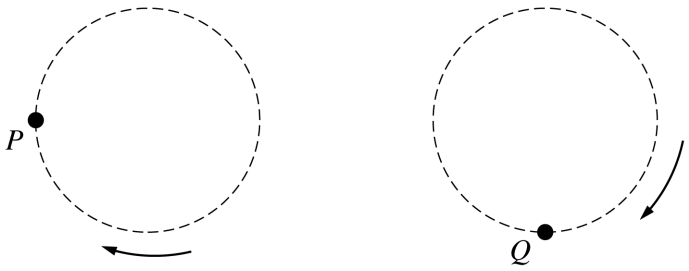


Side View

1. (15 points)

A ball of mass M is attached to a string of length R and negligible mass. The ball moves clockwise in a vertical circle, as shown above. When the ball is at point P, the string is horizontal. Point Q is at the bottom of the circle and point Z is at the top of the circle. Air resistance is negligible. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) On the figures below, draw and label all the forces exerted on the ball when it is at points P and Q, respectively.



(b) Derive an expression for v_{min}, the minimum speed the ball can have at point Z without leaving the circular path.

(c) The maximum tension the string can have without breaking is T_{max}. Derive an expression for v_{max}, the maximum speed the ball can have at point Q without breaking the string.

(d) Suppose that the string breaks at the instant the ball is at point P. Describe the motion of the ball immediately after the string breaks.

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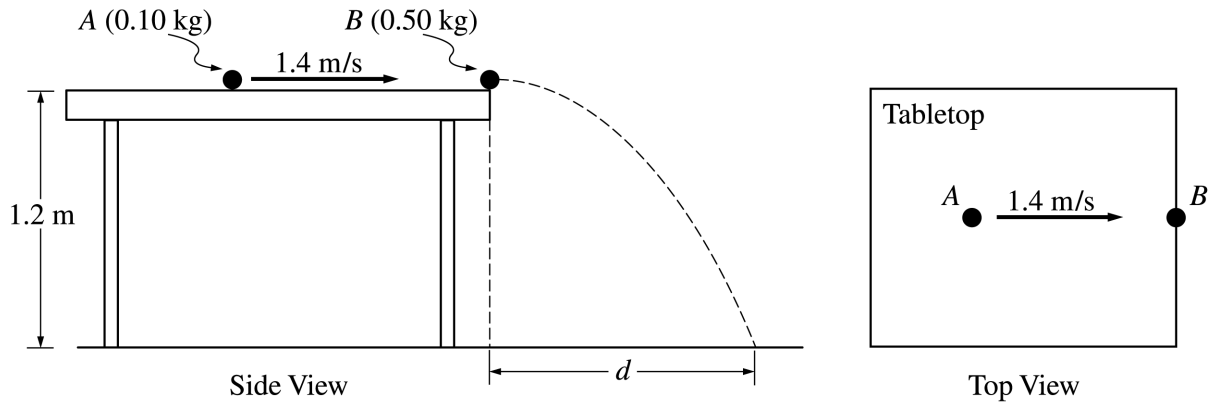


Note: Figures not drawn to scale.

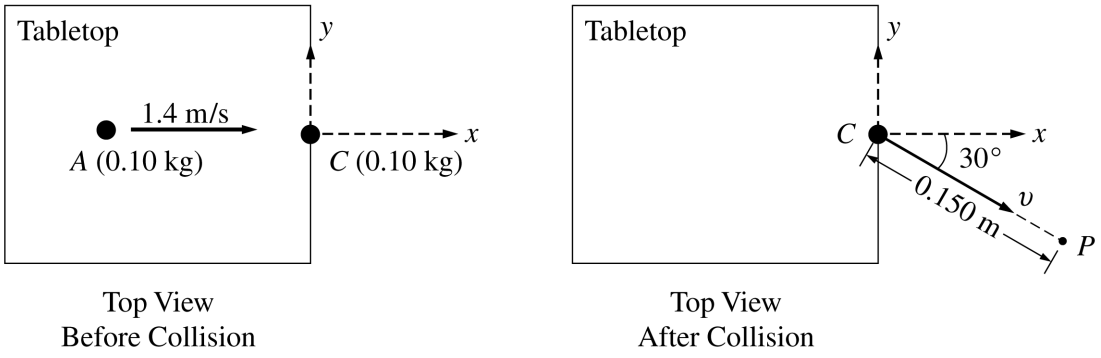
2. (15 points)

An incident ball A of mass 0.10 kg is sliding at 1.4 m/s on the horizontal tabletop of negligible friction shown above. It makes a head-on collision with a target ball B of mass 0.50 kg at rest at the edge of the table. As a result of the collision, the incident ball rebounds, sliding backwards at 0.70 m/s immediately after the collision.

(a) Calculate the speed of the 0.50 kg target ball immediately after the collision.

The tabletop is 1.20 m above a level, horizontal floor. The target ball is projected horizontally and initially strikes the floor at a horizontal displacement d from the point of collision.

(b) Calculate the horizontal displacement d.



In another experiment on the same table, the target ball B is replaced by target ball C of mass 0.10 kg. The incident ball A again slides at 1.4 m/s, as shown above left, but this time makes a glancing collision with the target ball C that is at rest at the edge of the table. The target ball C strikes the floor at point P, which is at a horizontal displacement of 0.15 m from the point of the collision, and at a horizontal angle of 30° from the $+x$-axis, as shown above right.

(c) Calculate the speed v of the target ball C immediately after the collision.

(d) Calculate the y-component of incident ball A's momentum immediately after the collision.

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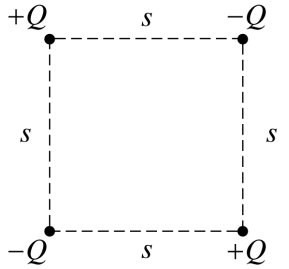


Arrangement 1

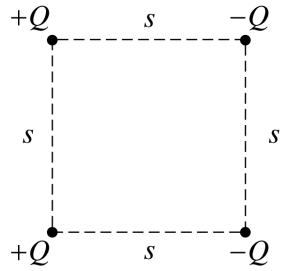
3. (15 points)

Four charged particles are held fixed at the corners of a square of side s. All the charges have the same magnitude Q, but two are positive and two are negative. In Arrangement 1, shown above, charges of the same sign are at opposite corners. Express your answers to parts (a) and (b) in terms of the given quantities and fundamental constants.

(a) For Arrangement 1, determine the following.

i. The electrostatic potential at the center of the square

ii. The magnitude of the electric field at the center of the square



Arrangement 2

The bottom two charged particles are now switched to form Arrangement 2, shown above, in which the positively charged particles are on the left and the negatively charged particles are on the right.

(b) For Arrangement 2, determine the following.

i. The electrostatic potential at the center of the square

ii. The magnitude of the electric field at the center of the square

(c) In which of the two arrangements would more work be required to remove the particle at the upper right corner from its present position to a distance a long way away from the arrangement?

___ Arrangement 1 ___ Arrangement 2

Justify your answer.

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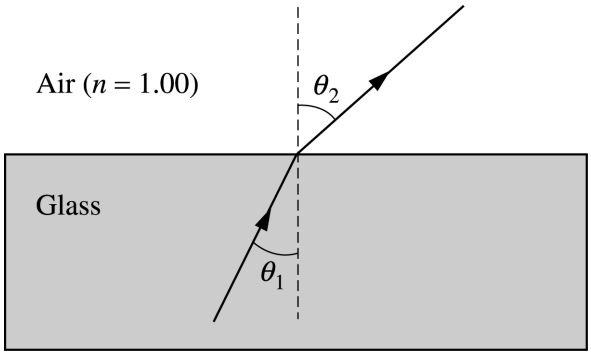
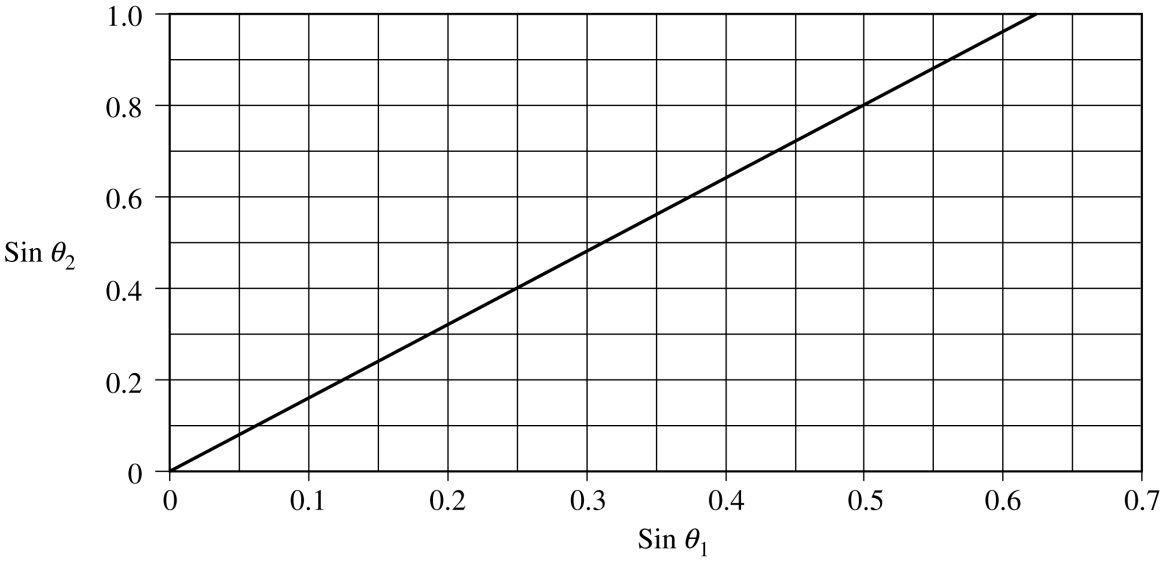


4. (15 points)

In an experiment a beam of red light of wavelength 675 nm in air passes from glass into air, as shown above. The incident and refracted angles are θ_1 and θ_2, respectively. In the experiment, angle θ_2 is measured for various angles of incidence θ_1, and the sines of the angles are used to obtain the line shown in the following graph.



(a) Assuming an index of refraction of 1.00 for air, use the graph to determine a value for the index of refraction of the glass for the red light. Explain how you obtained this value.

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(b) For this red light, determine the following.

i. The frequency in air

ii. The speed in glass

iii. The wavelength in glass

(c) The index of refraction of this glass is 1.66 for violet light, which has wavelength 425 nm in air.

i. Given the same incident angle θ_1, show on the ray diagram on the previous page how the refracted ray for the violet light would vary from the refracted ray already drawn for the red light.

ii. Sketch the graph of sin θ_2 *versus* sin θ_1 for the violet light on the figure on the previous page that shows the same graph already drawn for the red light.

(d) Determine the critical angle of incidence θ_c for the violet light in the glass in order for total internal reflection to occur.

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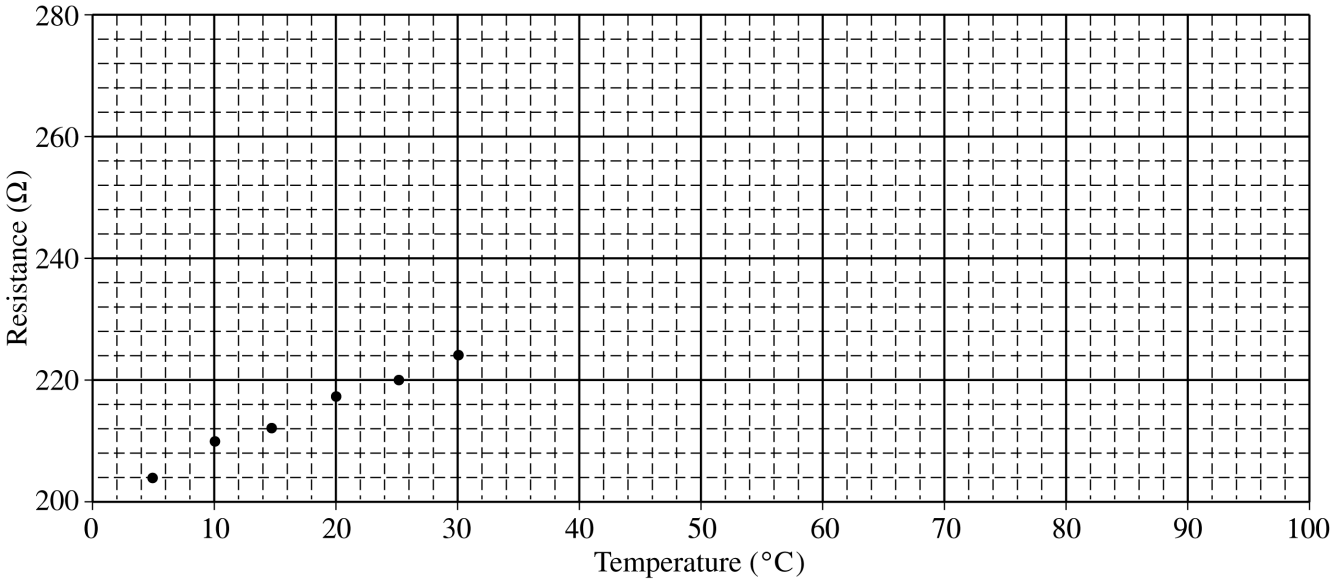

5. (10 points)

A platinum resistor has a resistance that changes with temperature. Values of the resistance were obtained experimentally for several temperatures from 5°C to 30°C only and plotted on the graph above. Design a procedure in which this resistor can be used as a thermometer to measure the temperature of a liquid that is in the 50°C to 75°C range. The resistor can be safely immersed in liquids. Along with the resistor and the container of the liquid of unknown temperature, the following equipment and materials may be used.

Power supply
Ammeter (Note: The ammeter and the voltmeter cannot
Voltmeter be used directly as an ohmmeter.)
Connecting wires
Ice-water bath
Boiling-water bath

(a) Sketch a diagram (with labels) to show how equipment is to be connected to make the necessary measurements, and briefly outline the steps to be followed.

(b) Discuss what measurements will be taken to determine the temperature of the unknown liquid.

(c) Discuss one assumption that must be made regarding equipment or procedure in order to use the method you have described.

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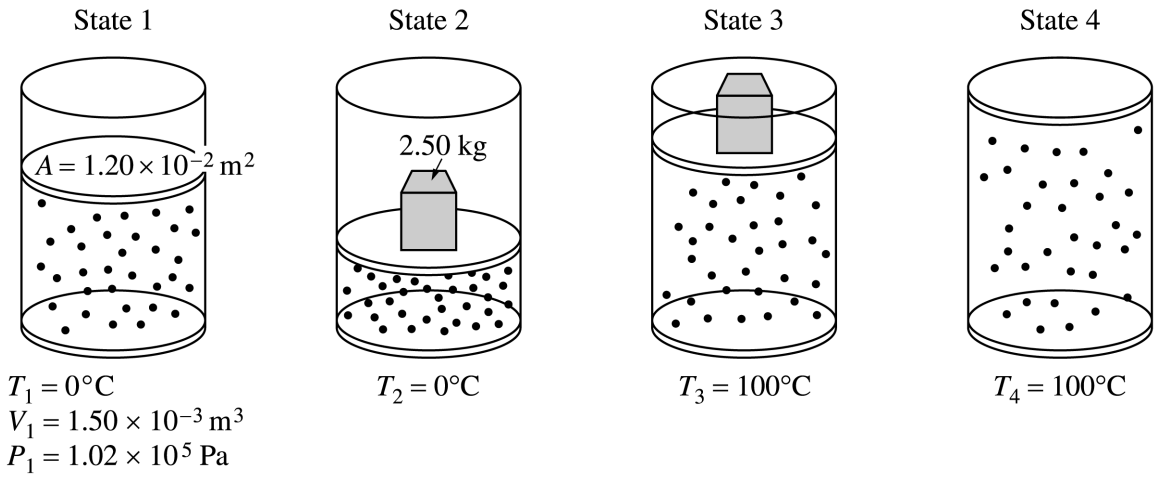

Note: Figures not drawn to scale.

6. (10 points)

A cylinder is fitted with a freely moveable piston of area $1.20 \times 10^{-2}\ \text{m}^2$ and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume $1.50 \times 10^{-3}\ \text{m}^3$, pressure $1.02 \times 10^5\ \text{Pa}$, and the cylinder is in contact with a water bath at a temperature of 0°C. The gas is then taken through the following four-step process.

- A 2.50 kg metal block is placed on top of the piston, compressing the gas to state 2, with the gas still at 0°C.
- The cylinder is then brought in contact with a boiling water bath, raising the gas temperature to 100°C at state 3.
- The metal block is removed and the gas expands to state 4 still at 100°C.
- Finally, the cylinder is again placed in contact with the water bath at 0°C, returning the system to state 1.

(a) Determine the pressure of the gas in state 2.

(b) Determine the volume of the gas in state 2.

(c) Indicate below whether the process from state 2 to state 3 is isothermal, isobaric, or adiabatic.

___ Isothermal ___ Isobaric ___ Adiabatic

Explain your reasoning.

(d) Is the process from state 4 to state 1 isobaric? ____ Yes ____ No

Explain your reasoning.

(e) Determine the volume of the gas in state 4.

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7. (10 points)

Consider the following nuclear fusion reaction that uses deuterium as fuel.

$$3\left({}^{2}_{1}\mathrm{H}\right) \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{1}\mathrm{H} + {}^{1}_{0}\mathrm{n}$$

(a) Determine the mass defect of a single reaction, given the following information.

$${}^{2}_{1}\mathrm{H} = 2.0141\ \mathrm{u} \qquad {}^{4}_{2}\mathrm{He} = 4.0026\ \mathrm{u} \qquad {}^{1}_{1}\mathrm{H} = 1.0078\ \mathrm{u} \qquad {}^{1}_{0}\mathrm{n} = 1.0087\ \mathrm{u}$$

(b) Determine the energy in joules released during a single fusion reaction.

(c) The United States requires about $10^{20}\ \mathrm{J}$ per year to meet its energy needs. How many deuterium atoms would be necessary to provide this magnitude of energy?

(d) Assume that 0.015% of the hydrogen atoms in seawater $(\mathrm{H_2O})$ are deuterium. The atomic mass number of oxygen is 16. About how many kilograms of seawater would be needed per year to provide the hydrogen fuel for fusion reactors to meet the energy needs of the United States?

END OF EXAMINATION

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AP Physics B
2001 Scoring Guidelines

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General Notes about 2001 AP Physics Solutions

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.
2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded.
3. An exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a solution contains the application of the equation to the problem but does not separately list the basic equation, the point is still awarded.

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AP® PHYSICS B
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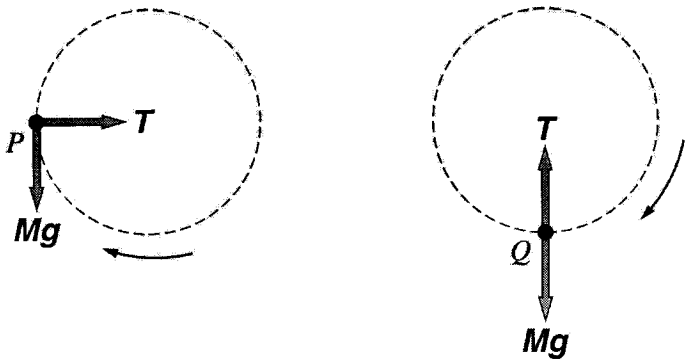
Question 1

15 points total

1. (a) **4 points**



Distribution of Points

For each correctly drawn and appropriately labeled force — **1 point each (total 4 points)**

One point was deducted for each incorrect force, to a maximum of the number of points earned for correct forces (i.e., lowest score awarded is zero).

The upward force in the figure on the right did not receive credit if it was labeled as the centripetal force, since in this case the net centripetal force is the sum of two physical forces (tension and weight).

1. (b) **4 points**

For setting the net force equal to some physical force, such as gravity or a tension — **1 point**

For correctly identifying that the only force is that due to gravity — **1 point**

$F_{net} = Ma = Mg$

For substituting the expression for centripetal acceleration — **1 point**

$\frac{Mv_{min}^2}{R} = Mg$

For the correct answer — **1 point**

$v_{min} = \sqrt{Rg}$

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Question 1 (cont.)

1. (b) (continued)

Distribution of Points

Alternate Solution

Alternate points

For using the expression for centripetal acceleration — *1 point*

$$a = \frac{v^2}{R}$$

For recognizing that the condition for minimum speed at point Z is that the centripetal acceleration equals the acceleration due to gravity — *2 points*

$$g = \frac{v^2}{R}$$

For the correct answer — *1 point*

$$v_{min} = \sqrt{Rg}$$

1. (c) **5 points**

For setting the net force equal to some physical force, such as gravity or a tension — **1 point**
For indicating that the net force is the difference between the tension and gravity — **1 point**
For indicating that the tension is larger than gravity — **1 point**

$$Ma = T - Mg$$

For substituting the expression for centripetal acceleration — **1 point**

$$M\frac{v_{max}^2}{R} = T_{max} - Mg$$

For the correct answer — **1 point**

$$v_{max} = \sqrt{\frac{R}{M}(T_{max} - Mg)}$$

1. (d) **2 points**

For any indication that the velocity of the ball is straight up — **1 point**
For any indication that the ball would be slowing down — **1 point**

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Question 2

15 points total

2. (a) **4 points**

Distribution of Points

For any indication that conservation of momentum is applicable **1 point**

$p_{before} = p_{after}$

$m_A v_{Ai} = m_B v_{Bf} + m_A v_{Af}$

Solving for v_{Bf}

$$v_{Bf} = \frac{m_A (v_{Ai} - v_{Af})}{m_B}$$

For correct substitution of values before the collision **1 point**

For correct substitution of values after the collision, including $v_{Af} = -0.70 \text{ m/s}$ **1 point**

$$v_{Bf} = \frac{(0.10 \text{ kg})(1.4 \text{ m/s} + 0.70 \text{ m/s})}{0.50 \text{ kg}}$$

For the correct answer **1 point**

$v_{Bf} = 0.42 \text{ m/s}$

2. (b) **5 points**

For any statement of an equation that can be used to find the time t for the ball to fall **1 point**

For example:

$$h = h_0 + v_0 t + \frac{1}{2} a t^2$$

For correct substitution **1 point**

$$0 = 1.2 \text{ m} + 0(t) + \frac{1}{2}(-9.8 \text{ m/s}^2) t^2$$

For the correct value for t **1 point**

$t = 0.49 \text{ s}$ (same value obtained using $g = 10 \text{ m/s}^2$)

For substituting the value of v from part (a) into a correct equation for the horizontal distance (i.e., having initial position and acceleration both zero) **1 point**

$d = vt = (0.42 \text{ m/s})(0.49 \text{ s})$

For the correct answer **1 point**

$d = 0.21 \text{ m}$

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Question 2 (cont.)

2. (c) **3 points**

Distribution of Points

For any statement of the equation for speed **1 point**

$v_C = d/t$

For substituting the time from part (b) or correctly recalculating it **1 point**

$v_C = 0.15 \text{ m}/0.49 \text{ s}$

For the correct answer **1 point**

$v_C = 0.31 \text{ m/s}$

2. (d) **3 points**

For an indication that the momentum in the y-direction is conserved **1 point**

$\mathbf{p}_{Ay} = -\mathbf{p}_{Cy}$

For an indication that the y-component of ball C's momentum was calculated **1 point**

$p_{Ay} = m_C v_C \sin 30°$

$p_{Ay} = (0.10 \text{ kg})(0.31 \text{ m/s}) \sin 30°$

For the correct answer **1 point**

$p_{Ay} = 0.015 \text{ kg} \cdot \text{m/s}$

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Question 3

15 points total

3. (a) i. **3 points**

Distribution of Points

For using a scalar sum of potentials due to each charge **1 point**

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

For correctly substituting charges and distance (either as $s/\sqrt{2}$ or a generic distance notation, such as r) **1 point**

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{-Q}{r} + \left(\frac{-Q}{r}\right) + \frac{Q}{r} + \frac{Q}{r}\right)$$

For the correct answer **1 point**

$V = 0$

3. (a) ii. **3 points**

For taking the vector sum of fields due to each charge **1 point**

For using an appropriate expression for calculating the field **1 point**

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\hat{\mathbf{r}} \quad \text{OR} \quad \mathbf{E} = \frac{\mathbf{F}}{q}$$

Defining diagonal axes, arbitrarily labeled t and u, with the t-axis along the line connecting the positive charges, and the u-axis along the line connecting the negative charges:

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r^2}\hat{\mathbf{t}} - \frac{Q}{r^2}\hat{\mathbf{t}} + \left(\frac{-Q}{r^2}\hat{\mathbf{u}}\right) - \left(\frac{-Q}{r^2}\hat{\mathbf{u}}\right)\right)$$

For the correct answer **1 point**

$E = 0$

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Question 3 (cont.)

3. (b) i. **2 points**

Distribution of Points

Using a scalar sum of potentials due to each charge:

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

For correctly substituting charges and distance (either as $s/\sqrt{2}$ or a generic distance notation, such as r) **1 point**

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{-Q}{r} + \left(\frac{-Q}{r}\right) + \frac{Q}{r} + \frac{Q}{r}\right)$$

For the correct answer **1 point**

$V = 0$

An incorrect answer equal to that in part (a) received **one point**, for realizing that swapping the charges does not affect the scalar sum

Note: The three answers above can easily be determined from symmetry considerations without calculation, so **full credit** was awarded for writing just the correct answer. Incorrect work or ambiguous statements with a correct answer could only receive the answer point.

3. (b) ii. **4 points**

The field from each individual charge points along a diagonal, with an x-component to the right. The vertical components cancel in pairs, and the x-components are equal in magnitude.

For taking the vector sum of fields due to each charge **1 point**

For correctly using the x-components (i.e. writing cos 45° or $\sqrt{2}/2$) **1 point**

$$E = 4\frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\frac{\sqrt{2}}{2}$$

For substituting $r^2 = s^2/2$ **1 point**

$$E = 4\frac{1}{4\pi\epsilon_0}\frac{2Q}{s^2}\frac{\sqrt{2}}{2}$$

For the correct answer **1 point**

$E = \dfrac{\sqrt{2}Q}{\pi\epsilon_0 s^2}$ or equivalent

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Question 3 (cont.)

3. (c) **2 points**	**Distribution of Points**
For choosing arrangement 1	**1 point**
For an appropriate justification	**2 points**
For example: The force of attraction on the upper right charge is greater in arrangement 1 because the two closest charges are both positive, whereas in arrangement 2 one is positive and one is negative.	

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Question 4

15 points total

4. (a) **3 points**

Distribution of Points

For using Snell's law OR indicating that the index of refraction is the slope of the graph **1 point**

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

For substituting or otherwise indicating use of data from the given graph **1 point**

$(1)(0.5) = n_2(0.8)$ OR $\text{slope} = \dfrac{0.8}{0.5}$

For the correct answer **1 point**

$n_2 = 1.60$

Alternate Solution

Alternate points

For using the expression for the critical angle *1 point*

$\sin\theta_c = \dfrac{n_2}{n_1}$

For using data from the graph *1 point*

The critical angle occurs when $\sin\theta_2 = 1$. From the graph, $\sin\theta_2 = \sin\theta_c = 0.625$

$0.625 = \dfrac{1}{n_1}$

For the correct answer *1 point*

$n_2 = 1.60$

Two points were awarded for inverting the values from the graph to obtain $n_2 = 0.625$

4. (b) i. **2 points**

For using the correct equation with the correct substitutions **1 point**

$f = v/\lambda$

$f = \left(3\times10^8 \text{ m/s}\right)/\left(675\times10^{-9} \text{ m}\right)$

For the correct answer **1 point**

$f = 4.44\times10^{14} \text{ Hz}$

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Question 4 (cont.)

4. (b) ii. **2 points**

Distribution of Points

For using the correct equation with the correct substitutions **1 point**

$v = c/n$

$v = (3\times10^8 \text{ m/s})/1.60$

For the correct answer **1 point**

$v = 1.88\times10^8 \text{ m/s}$

If an incorrect answer was carried through to obtain a speed greater than 3×10^8 m/s, only **one point** was awarded for the solution. The **second point** could be earned if there was some indication that the student realized that the value must be incorrect, because it could not be greater than the speed of light.

4. (b) iii. **2 points**

For using the correct equation with correct substitutions (consistent with previous answers) **1 point**

$\lambda = v/f$

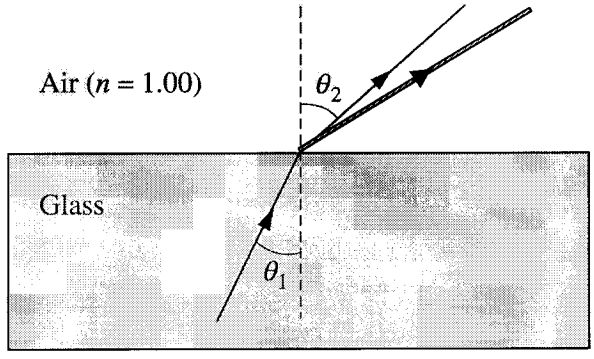
$\lambda = (1.88\times10^8 \text{ m/s})/(4.44\times10^{14} \text{ Hz})$

For the correct answer **1 point**

$\lambda = 423\times10^{-9} \text{ m} = 423 \text{ nm}$

Units point: For correct units on two of the three answers in part (b) **1 point**

4. (c) i. **1 point**



For correctly indicating on the figure that θ_2 increases **1 point**

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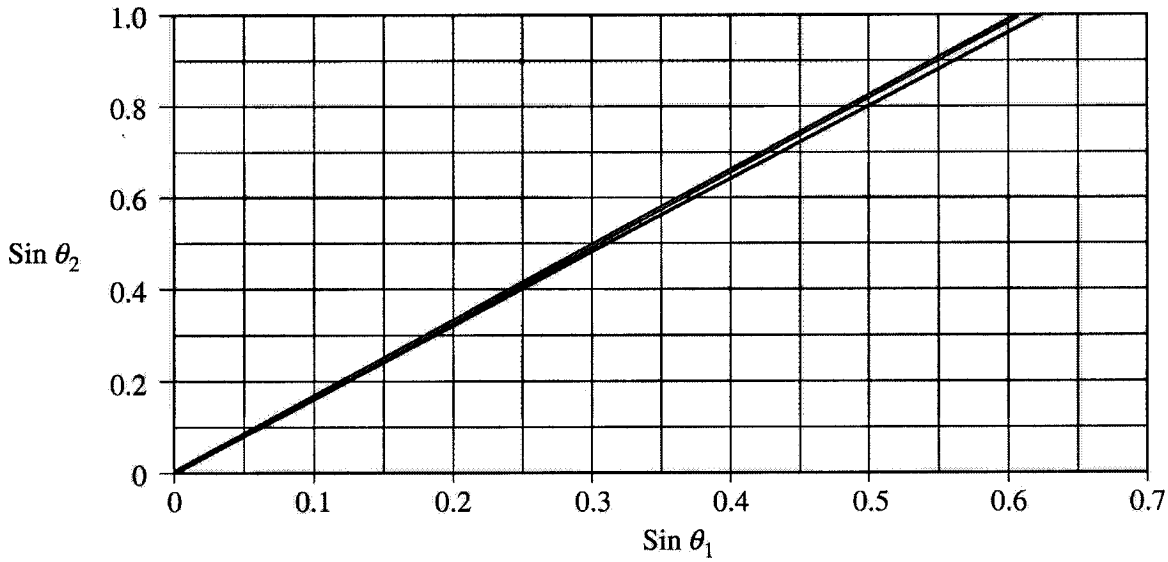
Question 4 (cont.)

4. (c) ii. **2 points**



Distribution of Points

For a straight line that goes through the origin **1 point**
For a steeper slope than the given line **1 point**

Full credit was awarded for a line with less steep slope if it was consistent with the answer to part (a)

4. (d) **2 points**

For the correct equation for the critical angle **1 point**

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\sin\theta_c = \frac{1}{1.66} = 0.602$$

For the correct answer **1 point**

$\theta_c = 37°$ or 0.624 radians

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Question 5

10 points total

The resistor needs to be connected in a circuit with the power supply, with the ammeter and voltmeter used to take the necessary measurements. Either the given data needs to be extrapolated to the range of interest, or a point at 100°C is measured by immersing the resistor in the hot water bath so that interpolation can be used. In either case a best-fit line should be drawn. Measurements of voltage and current are then taken with the resistor immersed in the liquid of unknown temperature, and are used to calculate a value for resistance. The line on the graph is then used to determine the temperature corresponding to that value of resistance.

5. (a) **3 points**

Distribution of Points

For including all four circuit elements in a circuit diagram (power supply, resistor, voltmeter, and ammeter) **1 point**

For connecting the power supply, ammeter, and resistor in a complete series circuit **1 point**

For connecting the voltmeter in parallel with the power supply or resistor **1 point**

Clear labels must be included to receive credit.
One earned point was deducted if the circuit that was drawn would not work.

The brief outline of the steps to be followed was scored along with part (b), since it is natural to combine these into one discussion.

5. (b) **5 points**

For using the boiling water bath to obtain another data point and then interpolating the data **2 points**
One of these points was awarded for simply extrapolating the data, since this is a less precise method.

For indicating that measurements of the voltage and the current must be taken when the resistor is immersed in the liquid of unknown temperature **1 point**

For indicating that the resistance must be calculated from the measurements (if an equation is included it must be correct) **1 point**

For using the graph to obtain a temperature corresponding to the calculated resistance **1 point**

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Question 5 (cont.)

5. (c) **2 points**

Distribution of Points

For any reasonable answer clearly stated as an assumption **2 points**

One point was awarded for a less complete but still reasonable answer, or a true statement that is not a relevant assumption.

Examples of full-credit answers:

Resistance versus temperature must be linear throughout the range of interest.

The temperature of the boiling water is 100°C (only awarded if hot water bath was used in part (b) to allow interpolation).

Heat from the resistor does not significantly affect the temperature of the liquid it is immersed in.

Resistance of the connecting wires is negligible, with an explanation of how this would affect the measurements.

Examples of partial-credit answers:

Resistance is proportional to temperature.

Resistance of the connecting wires is negligible, with no explanation.

Reference to impact of voltmeter or ammeter on the measurement

No heat transferred to or from the environment

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Question 6

10 points total

6. (a) **3 points** — **Distribution of Points**

For using the definition of pressure — **1 point**

$$P = \frac{F}{A}$$

Calculating the additional pressure due to the weight of the block:

$$\Delta P_2 = \frac{(2.50\text{ kg})(9.8\text{ m/s}^2)}{1.20\times10^{-2}\text{ m}^2} = 2.04\times10^3\text{ Pa} \quad (\text{or } 2.08\times10^3\text{ Pa using } g = 10\,\text{m/s}^2)$$

For adding the additional pressure to the pressure in state 1 — **1 point**

$$P_2 = P_1 + \Delta P_2$$

$$P_2 = 1.02\times10^5\text{ Pa} + 2.04\times10^3\text{ Pa}$$

For the correct answer — **1 point**

$$P_2 = 1.04\times10^5\text{ Pa}$$

Alternate Solution — *Alternate points*

For determining the force on the piston in state 1 — *1 point*

$$F_1 = P_1 A$$

$$F_1 = (1.02\times10^5\text{ Pa})(1.20\times10^{-2}\text{ m}^2) = 1224\text{ N}$$

Calculating the force due to the block:

$$\Delta F_2 = (2.50\text{ kg})(9.8\,\text{m/s}^2) = 24.5\text{ N}$$

For adding these two forces — *1 point*

$$F_2 = F_1 + \Delta F_2$$

$$F_2 = 1224\text{ N} + 24.5\text{ N} = 1250\text{ N}$$

Calculating the pressure in state 2:

$$P_2 = \frac{F_2}{A} = \frac{1250\text{ N}}{1.20\times10^{-2}\text{ m}^2}$$

For the correct answer — *1 point*

$$P_2 = 1.04\times10^5\text{ Pa}$$

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Question 6 (cont.)

6. (b) **1 point**

Distribution of Points

At constant temperature, pressure times volume is a constant:

$P_1V_1 = P_2V_2$

Solving for V_2:

$$V_2 = \frac{P_1V_1}{P_2}$$

For correct substitutions **1 point**

$$V_2 = \frac{(1.02\times10^5\ \text{Pa})(1.50\times10^{-3}\ \text{m}^3)}{1.04\times10^5\ \text{Pa}}$$

$$V_2 = 1.47\times10^{-3}\ \text{m}^3$$

Alternate Solution

Alternate points

Applying the ideal gas law to state 1:

$P_1V_1 = nRT_1$

Solving for n:

$$n = \frac{P_1V_1}{RT_1}$$

$$n = \frac{(1.02\times10^5\ \text{Pa})(1.50\times10^{-3}\ \text{m}^3)}{(8.31\ \text{J/mol}\cdot\text{K})(273\ \text{K})} = 6.74\times10^{-2}\ \text{mol}$$

Applying the ideal gas law to state 2:

$P_2V_2 = nRT_2$

Solving for V_2:

$$V_2 = \frac{nRT_2}{P_2}$$

For correct substitutions *1 point*

$$V_2 = \frac{(6.74\times10^{-2}\ \text{mol})(8.31\ \text{J/mol}\cdot\text{K})(273\ \text{K})}{1.04\times10^5\ \text{Pa}}$$

$$V_2 = 1.47\times10^{-3}\ \text{m}^3$$

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Question 6 (cont.)

6. (c) **2 points**

Distribution of Points

For indicating the process is isobaric — **1 point**
For any explanation indicating that the pressure does not change from state 1 to state 2 — **1 point**

6. (d) **2 point**

For indicating "yes" (the process is isobaric) — **1 point**
For any explanation indicating that the pressure does not change from state 4 to state 1 — **1 point**

6. (e) **2 points**

At constant pressure, volume divided by temperature is constant

$$\frac{V_1}{T_1} = \frac{V_4}{T_4}$$

Solving for V_4:

$$V_4 = \frac{V_1 T_4}{T_1}$$

For correctly converting the temperatures to Kelvin — **1 point**
For correct substitutions — **1 point**

$$V_4 = \frac{(1.50\times10^{-3}\ \text{m}^3)(373\ \text{K})}{273\ \text{K}}$$

$$V_4 = 2.05\times10^{-3}\ \text{m}^3$$

Alternate Solution

Alternate points

Applying the ideal gas law to state 4:

$$P_4 V_4 = nRT_4$$

Solving for V_4:

$$V_4 = \frac{nRT_4}{P_4}$$

For correctly converting the temperature to Kelvin — *1 point*
For correct substitutions (using n from part (b) and $P_4 = P_1$) — *1 point*

$$V_4 = \frac{(6.74\times10^{-2}\ \text{mol})(8.31\ \text{J/mol}\cdot\text{K})(373\ \text{K})}{1.02\times10^{5}\ \text{Pa}}$$

$$V_4 = 2.05\times10^{-3}\ \text{m}^3$$

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Question 7

10 points total

7. (a) **2 points**

Distribution of Points

For any statement of conservation of mass **1 point**
3 × (deuterium mass) = helium mass + hydrogen mass + neutron mass + mass defect
Substituting:
$3(2.0141\ \text{u}) = 4.0026\ \text{u} + 1.0078\ \text{u} + 1.0087\ \text{u} + \Delta m$

For the correct answer **1 point**
$\Delta m = 0.0232\ \text{u}$

7. (b) **3 points**

For indicating that mass-energy equivalence is applicable **1 point**
For correctly converting the mass in order to get an answer in joules **1 point**
For correct substitution and answer **1 point**

$$E = (\Delta m)c^2 = (0.0232\ \text{u})\left(\frac{1.66\times10^{-27}\ \text{kg}}{1\ \text{u}}\right)(3\times10^{8}\ \text{m/s})^2 = 3.47\times10^{-12}\ \text{J}$$

or

$$E = (\Delta m)c^2 = (0.0232\ \text{u})\left(\frac{931\ \text{Mev}/c^2}{1\ \text{u}}\right)(3\times10^{8}\ \text{m/s})^2\left(\frac{1.6\times10^{-13}\ \text{J}}{1\ \text{MeV}}\right) = 3.46\times10^{-12}\ \text{J}$$

7. (c) **2 points**

The number of reactions required is the total energy divided by the energy per reaction
For correctly using the energy from part (b) **1 point**
$10^{20}\ \text{J}/(3.47\times10^{-12}\ \text{J/reaction}) = 2.89\times10^{31}\ \text{reactions}$

$$\text{Number of deuterium atoms} = (2.89\times10^{31}\ \text{reactions})\left(\frac{3\ \text{deuterium}}{\text{reaction}}\right)$$

For the correct answer, including the factor of 3 **1 point**
Number of deuterium atoms $= 8.66\times10^{31}$

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Question 7 (cont.)

7. (d) **3 points**

Distribution of Points

There are a number of different logical paths that can lead to a correct solution, all of which could earn full credit. The following is just one example of a correct method.

Deriving an expression for the number of deuterium atoms that a given mass of seawater would yield:

$$\text{Number of deuterium atoms} = 0.015\%(\text{number of H atoms in needed amount of } H_2O)$$

$$= 0.015\%\frac{(\text{total mass of H needed})}{(\text{mass of one H})}$$

$$= 0.015\%\frac{(\text{total mass of } H_2O \text{ needed})(\text{fraction of mass that is H})}{(\text{mass of one H})}$$

$$= 0.015\%\frac{(\text{total mass of } H_2O \text{ needed})}{(\text{mass of one H})}\ \frac{(\text{mass of H atoms in one } H_2O \text{ molecule})}{(\text{mass of } H_2O \text{ molecule})}$$

Solving for the total mass of water needed:

$$\text{Total mass of } H_2O \text{ needed} = \frac{(\text{number of deuterium atoms})(\text{mass of one H})(\text{mass of } H_2O \text{ molecule})}{0.015\%(\text{mass of H atoms in one } H_2O \text{ molecule})}$$

For correctly using 0.015% **1 point**

For the correct ratio of masses (2 hydrogen atoms to one water molecule) **1 point**

Substituting and adding the conversion to kilograms:

$$\text{Total mass of } H_2O = \frac{(8.66\times10^{31}\text{ atoms})(1.008\text{ u})(18\text{ u})}{(0.00015)(2\text{ u})}\left(\frac{1.66\times10^{-27}\text{ kg}}{1\text{ u}}\right)$$

For the correct answer **1 point**

$$\text{Total mass of } H_2O = 8.69\times10^{9}\text{ kg}$$

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Free-Response Questions

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The College Board

PHYSICS B

SECTION II

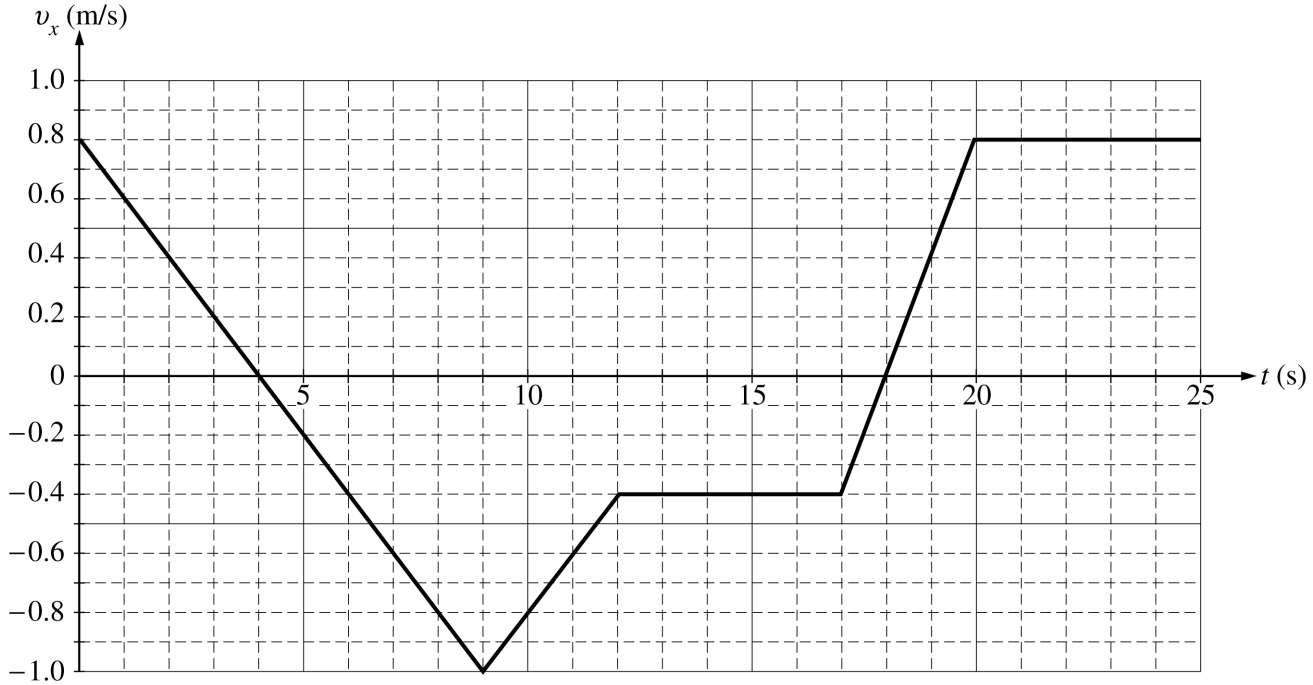
Time—90 minutes

7 **Questions**

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in this green insert.

1. (15 points)

A 0.50 kg cart moves on a straight horizontal track. The graph of velocity v_x versus time t for the cart is given below.



(a) Indicate every time t for which the cart is at rest.

(b) Indicate every time interval for which the speed (magnitude of velocity) of the cart is increasing.

(c) Determine the horizontal position x of the cart at $t = 9.0$ s if the cart is located at $x = 2.0$ m at $t = 0$.

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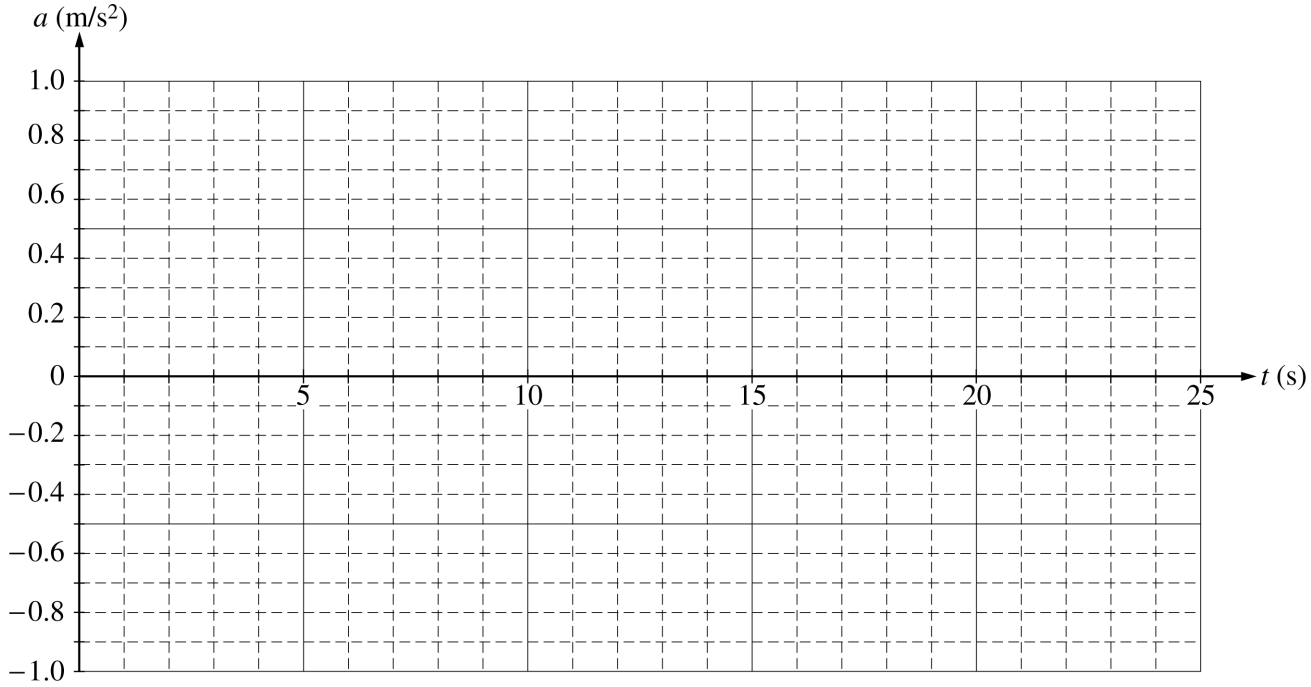
(d) On the axes below, sketch the acceleration a *versus* time t graph for the motion of the cart from $t = 0$ to $t = 25$ s.



(e) From $t = 25$ s until the cart reaches the end of the track, the cart continues with constant horizontal velocity. The cart leaves the end of the track and hits the floor, which is 0.40 m below the track. Neglecting air resistance, determine each of the following.

i. The time from when the cart leaves the track until it first hits the floor

ii. The horizontal distance from the end of the track to the point at which the cart first hits the floor

iii. The kinetic energy of the cart immediately before it hits the floor

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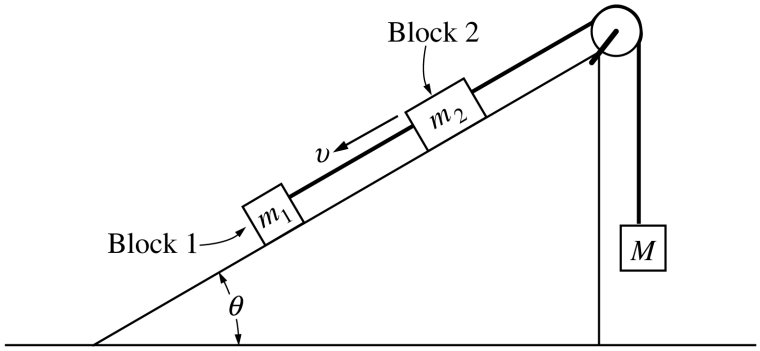
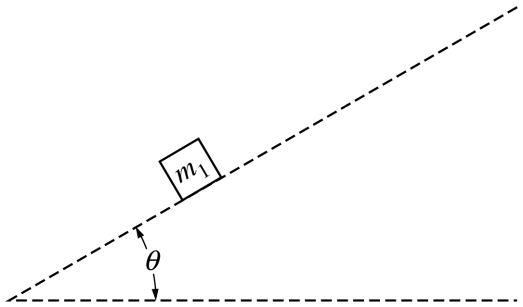


2. (15 points)

Blocks 1 and 2 of masses m_1 and m_2, respectively, are connected by a light string, as shown above. These blocks are further connected to a block of mass M by another light string that passes over a pulley of negligible mass and friction. Blocks 1 and 2 move with a constant velocity v down the inclined plane, which makes an angle θ with the horizontal. The kinetic frictional force on block 1 is f and that on block 2 is $2f$.

(a) On the figure below, draw and label all the forces on block m_1.



Express your answers to each of the following in terms of m_1, m_2, g, θ, and f.

(b) Determine the coefficient of kinetic friction between the inclined plane and block 1.

(c) Determine the value of the suspended mass M that allows blocks 1 and 2 to move with constant velocity down the plane.

(d) The string between blocks 1 and 2 is now cut. Determine the acceleration of block 1 while it is on the inclined plane.

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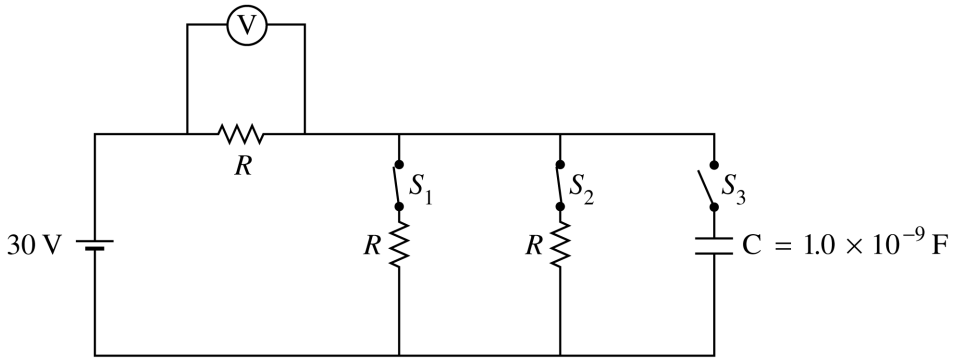


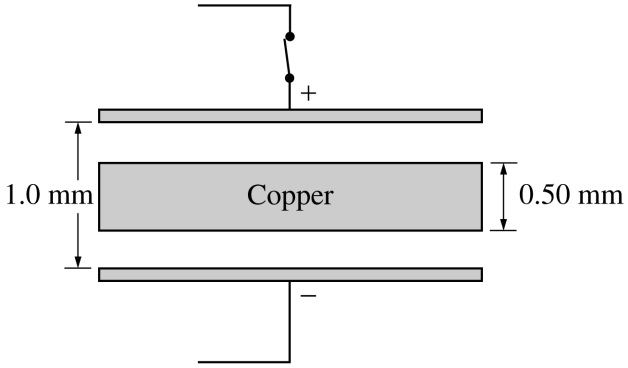
3. (15 points)

Three identical resistors, each with resistance R, and a capacitor of 1.0×10^{-9} F are connected to a 30 V battery with negligible internal resistance, as shown in the circuit diagram above. Switches S_1 and S_2 are initially closed, and switch S_3 is initially open. A voltmeter is connected as shown.

(a) Determine the reading on the voltmeter.

(b) Switches S_1 and S_2 are now opened, and then switch S_3 is closed. Determine the charge Q on the capacitor after S_3 has been closed for a very long time.

After the capacitor is fully charged, switches S_1 and S_2 remain open, switch S_3 remains closed, the plates are held fixed, and a conducting copper block is inserted midway between the plates, as shown below. The plates of the capacitor are separated by a distance of 1.0 mm, and the copper block has a thickness of 0.5 mm.



(c) i. What is the potential difference between the plates?

ii. What is the electric field inside the copper block?

iii. On the diagram above, draw arrows to clearly indicate the direction of the electric field between the plates.

iv. Determine the magnitude of the electric field in each of the spaces between the plates and the copper block.

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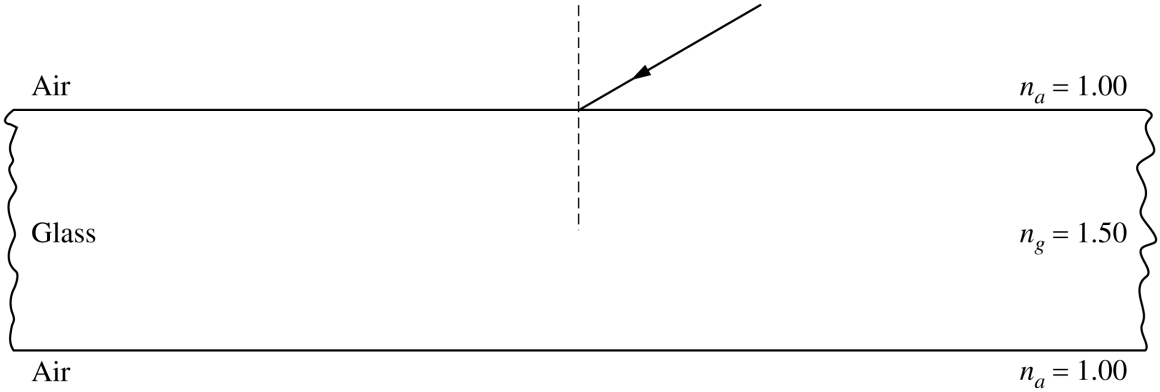
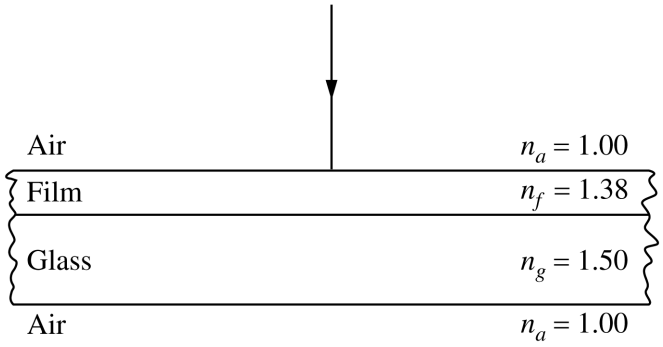
4. (15 points)

A sheet of glass has an index of refraction $n_g = 1.50$. Assume that the index of refraction for air is $n_a = 1.00$.

(a) Monochromatic light is incident on the glass sheet, as shown in the figure below, at an angle of incidence of 60°. On the figure, sketch the path the light takes the first time it strikes each of the two parallel surfaces. Calculate and label the size of each angle (in degrees) on the figure, including angles of incidence, reflection, and refraction at each of the two parallel surfaces shown.



(b) Next a thin film of material is to be tested on the glass sheet for use in making reflective coatings. The film has an index of refraction $n_f = 1.38$. White light is incident normal to the surface of the film as shown below. It is observed that at a point where the light is incident on the film, light reflected from the surface appears green ($\lambda = 525$ nm).



i. What is the frequency of the green light in air?

ii. What is the frequency of the green light in the film?

iii. What is the wavelength of the green light in the film?

iv. Calculate the minimum thickness of film that would produce this green reflection.

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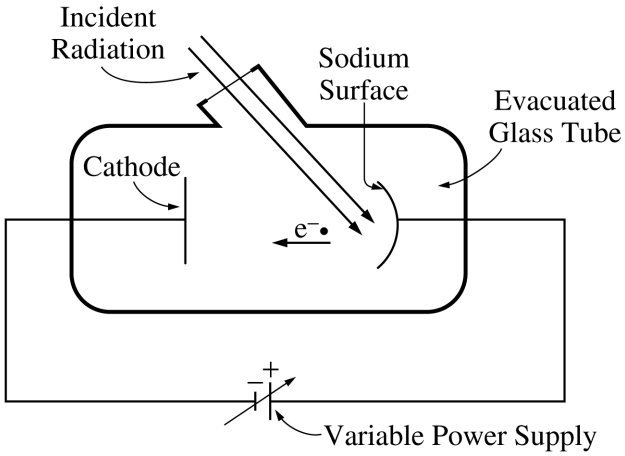

5. (10 points)

A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

(a) For the electrons emitted from the sodium surface, calculate the following.

i. The maximum kinetic energy

ii. The speed at this maximum kinetic energy

(b) Calculate the wavelength of the radiation that is incident on the sodium surface.

(c) Calculate the minimum frequency of light that will cause photoemission from this sodium surface.

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6. (10 points)

You are to design a procedure to determine experimentally the specific heat of an unknown liquid. You may not damage or destroy any equipment you use, and your method must be feasible and practical.

(a) List the equipment you would need. Include a labeled diagram.

(b) Describe the measurements you would make. Assign each measurement a symbol (such as time = t).

(c) Show explicitly using equations how the measured quantities would be used to determine the specific heat of the unknown liquid.

(d) Indicate one possible source of experimental error and discuss how it would affect your value for the specific heat. Justify your answer.

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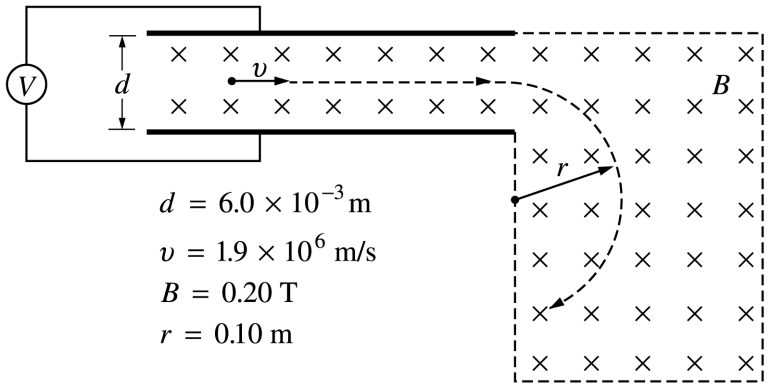

7. (10 points)

A particle with unknown mass and charge moves with constant speed $v = 1.9 \times 10^6$ m/s as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance $d = 6.0 \times 10^{-3}$ m, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude $B = 0.20$ T directed into the page exists both between the plates and in a region to the right of them as shown. After the particle passes into the region to the right of the plates where only the magnetic field exists, its trajectory is circular with radius $r = 0.10$ m.

(a) What is the sign of the charge of the particle? Check the appropriate space below.

__ Positive __ Negative __ Neutral __ It cannot be determined from this information.

Justify your answer.

(b) On the diagram above, clearly indicate the direction of the electric field between the plates.

(c) Determine the magnitude of the potential difference V between the plates.

(d) Determine the ratio of the charge to the mass (q/m) of the particle.

END OF EXAMINATION

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AP Physics B
2000 Scoring Guidelines

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2000 Physics B Solutions **Distribution of points**

Question 1 (15 points)

(a) 1 point

The cart is at rest at $t = 4$ s and 18 s.
For indicating both times that the car is at rest and not including any incorrect times — 1 point

(b) 2 points

The speed of the cart is increasing during the intervals $t =$ 4 to 9 s and 18 to 20 s.
For each correct time interval one point was awarded. — 2 points

One point was deducted for each incorrect interval, for a maximum two-point deduction.

(c) 3 points

For indicating that the change in position is equal to the area under the graph, or for using an appropriate kinematic equation with non-zero initial velocity — 1 point

$\Delta x =$ area OR, for example, $\Delta x = v_i t + \frac{1}{2} a t^2$

For correct substitution of values — 1 point

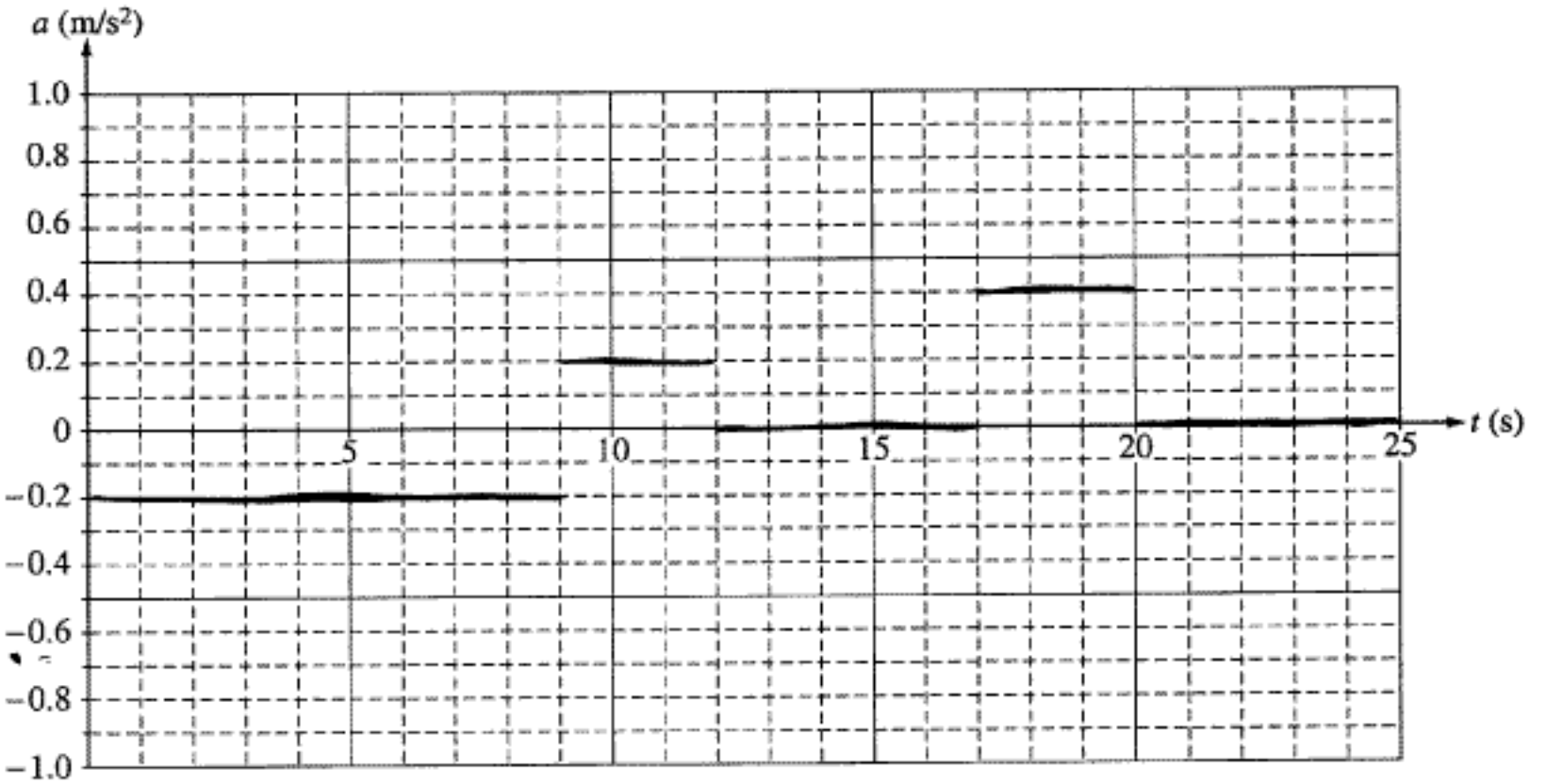
$\Delta x = \frac{1}{2}(4\text{ s})(0.8\text{ m/s}) + \frac{1}{2}(5\text{ s})(-1\text{ m/s})$

OR $\Delta x = (0.8\text{ m/s})(9\text{ s}) + \frac{1}{2}\left(-0.2\text{ m/s}^2\right)(9\text{ s})^2$

$\Delta x = -0.9$ m
For adding the initial position to Δx — 1 point
$x = x_0 + \Delta x = 2\text{ m} + (-0.9\text{ m})$
$x = 1.1$ m

Question 1 (continued)

(d) 3 points



For indicating that the acceleration is zero during the intervals of constant velocity, 12 to 17 s and 20 to 25 s — 1 point

For indicating that the acceleration is negative and constant from zero to 9 s, and positive and constant from 9 to 11 s and 17 to 20 s — 1 point

For having the correct values for two of the three intervals of non-zero acceleration: $-0.20\ \text{m/s}^2$, $+0.20\ \text{m/s}^2$, and $+0.40\ \text{m/s}^2$ — 1 point

(e)

i. 1 point

For using the correct kinematic equation, with the initial vertical velocity equal to zero — 1 point

$$y = \frac{1}{2} gt^2$$

Solving for t:

$$t = \sqrt{2y/g}$$

$$t = \sqrt{2(0.40\ \text{m})/10\ \text{m/s}^2}$$

$t = 0.28$ s (or 0.29 s using $g = 9.8\ \text{m/s}^2$)

Question 1 (continued)

(e) (continued)

ii. 2 points

Using the kinematic equation for the horizontal motion:

$x = v_x t$

For using the correct value for the horizontal speed — 1 point

$v_x = 0.8$ m/s

$x = (0.8 \text{ m/s})(0.28 \text{ s})$

For the correct answer — 1 point

$x = 0.22$ m (or 0.23 m using $g = 9.8 \text{ m/s}^2$)

iii. 3 points

For correctly applying conservation of energy — 2 points

$K_{bottom} = K_{top} + U_{top}$

$K_{bottom} = \frac{1}{2} m v_x^2 + mgy$

$K_{bottom} = \frac{1}{2}(0.50 \text{ kg})(0.8 \text{ m/s})^2 + (0.50 \text{ kg})(10 \text{ m/s}^2)(0.40 \text{ m})$

For the correct answer — 1 point

$K_{bottom} = 2.2$ J (or 2.1 J using $g = 9.8 \text{ m/s}^2$)

In the absence of any of the above credit, one point was awarded for any recognition that the vertical velocity changes.

(Alternate solution) — *(Alternate points)*

For any recognition that the vertical velocity changes. — *1 point*

Calculating the y-component of velocity at the bottom:

$v_y = v_{yi} - gt$

$v_y = 0 + (10 \text{ m/s}^2)(0.28 \text{ s}) = 2.8 \text{ m/s}$

For correctly calculating the total speed from the components — *1 point*

$v^2 = v_x^2 + v_y^2$

$v = \sqrt{(0.8 \text{ m/s})^2 + (2.8 \text{ m/s})^2}$

$v = 2.9$ m/s

For correctly calculating the final kinetic energy — *1 point*

$K = \frac{1}{2} m v^2$

$K = \frac{1}{2}(0.50 \text{ kg})(2.9 \text{ m/s})^2$

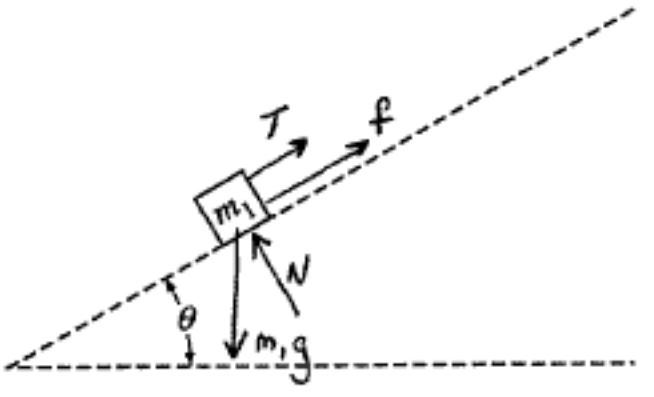
$K = 2.2$ J (or 2.1 J depending on the value of g used and amount of rounding in intermediate calculations)

2000 Physics B Solutions

Distribution of points

Question 2 (15 points)

(a) 4 points



For each correctly drawn and labeled force one point was awarded (Credit was awarded for any reasonable placement of forces) — 4 points

In the absence of the total weight, showing both components $m_1 g \sin\theta$ and $m_1 g \cos\theta$ received credit

One point was deducted from earned credit for one or more obvious incorrect forces (no penalty for showing both weight and its components)

(b) 3 points

Using the expression for frictional force:
$f = \mu N$

For a correct substitution for the normal force — 1 point
$N = m_1 g \cos\theta$

For correctly solving for the coefficient of friction — 1 point

$$\mu = \frac{f}{m_1 g \cos\theta}$$

For an answer correctly expressed in terms of the given quantities — 1 point

For example, beginning with the equation $f + T_1 - m_1 g \sin\theta = 0$ for block 1, substituting for f and solving for μ yields $\mu = \dfrac{m_1 g \sin\theta - T_1}{m_1 g \cos\theta}$, which receives credit for the first two points.

Since only one block is involved in this part, no penalty was assessed for omitting the subscript on the mass variable.

Question 2 (continued)

(c) 5 points

For an indication that the acceleration or the net force is zero — 1 point

Using Newton's second law:

$\Sigma \mathbf{F} = 0$

Applying this to the three-block system, with the tensions treated as internal forces (so they do not appear in the equation):

$-m_1 g \sin\theta + f - m_2 g \sin\theta + 2f + Mg = 0$

For the correct weight components, with correct signs, in the above equation — 1 point

For the correct friction terms, with correct signs — 1 point

Solving for Mg:

$Mg = m_1 g \sin\theta - f + m_2 g \sin\theta - 2f$

For the correct answer in terms of the given quantities — 2 points

$$M = (m_1 + m_2)\sin\theta - \frac{3f}{g}$$

Only one point was awarded for a correct answer in terms of quantities other than the given ones

Alternate solutions containing a set of equations from which tensions should be eliminated were awarded similar credit. For example, credit for the second and third points above could be earned for correctly written equations even if no attempt was made to solve them. Two possible sets of equations:

Set 1 -- $-f + T_1 - m_1 g \sin\theta + 2f + T_2 - m_2 g \sin\theta - T_1 = (m_1 + m_2)a$ and $Mg - T_2 = Ma$

Set 2 -- $m_1 g \sin\theta = f + T_1$ and $T_1 + m_2 g \sin\theta = 2f + T_2$ and $Mg = T_2$

(This set also earns credit for the first point.)

(d) 3 points

Applying Newton's second law:

$m_1 g \sin\theta - f = m_1 a$

For correctly including friction in the equation — 1 point

For correctly including the weight component in the equation — 1 point

For the correct answer in terms of the given quantities — 1 point

$$a = g \sin\theta - \frac{f}{m_1}$$

Since only one block is involved in this part, no penalty was assessed for omitting the subscript on the mass variable.

2000 Physics B Solutions **Distribution of points**

Question 3 (15 points)

(a) 5 points

For determining the net resistance of the two parallel resistors — 1 point

$$\frac{1}{R_{\parallel}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

$$R_{\parallel} = \frac{R}{2}$$

For determining the total resistance of the circuit — 1 point

$$R_T = R + \frac{R}{2}$$

$$R_T = \frac{3R}{2}$$

Using Ohm's law:
$I = V/R$

For correctly substituting values that apply to the entire circuit to determine the total current — 1 point

$$I = \frac{30\text{V}}{(3R/2)}$$

$$I = \frac{20\text{ V}}{R}$$

For correctly substituting values applying to the resistor across which the voltmeter is connected — 1 point

$$V = \frac{20}{R} R$$

For the correct answer — 1 point

$V = 20$ V

Since all three resistors have equal values, it is possible to compare the resistance of the parallel combination to the total resistance and then split the voltage correctly with a minimum of written calculation. Full credit could be earned for this approach.

(b) 2 points

For using the equation relating capacitance, voltage, and charge — 1 point

$Q = CV$

For correct substitution — 1 point

$$Q = \left(1 \times 10^{-9}\text{ F}\right)(30\text{ V})$$

$$Q = 3 \times 10^{-8}\text{ C}$$

2000 Physics B Solutions **Distribution of points**

Question 3 (continued)

(c)

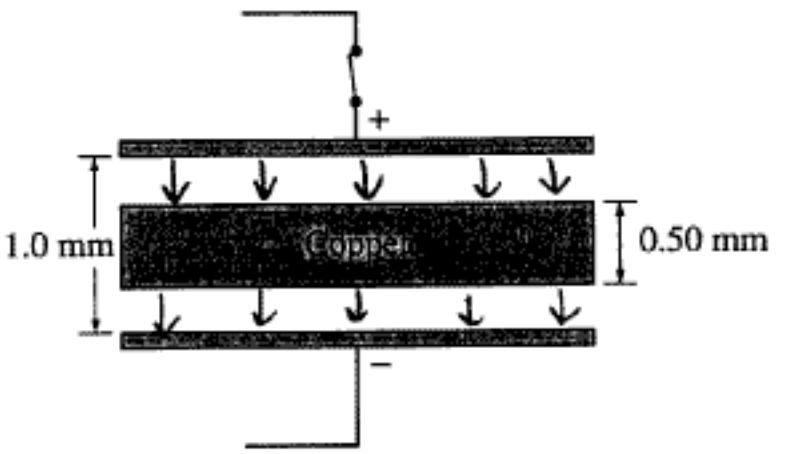
i. 1 point

The 30 V battery is still connected across the capacitor and there is no current, so the potential difference remains the same.
For indicating that the potential between the plates is 30 V — 1 point

ii. 1 point

At equilibrium, the field inside any conductor is zero.
For indicating that the electric field inside the copper block is zero — 1 point

iii. 3 points



For arrows directed down between the top plate and the copper block — 1 point
For having no arrows inside the copper block — 1 point
For arrows directed down between the copper block and the lower plate — 1 point

No credit was awarded if there was nothing drawn between the plates

iv. 3 points

For using the equation relating voltage, electric field, and plate separation for a parallel plate capacitor — 1 point

$$E = \frac{V}{d}$$

For correct substitution of consistent values — 1 point

$$E = \frac{30\ \text{V}}{0.5\ \text{mm}} \quad \text{OR} \quad E = \frac{15\ \text{V}}{0.25\ \text{mm}}$$

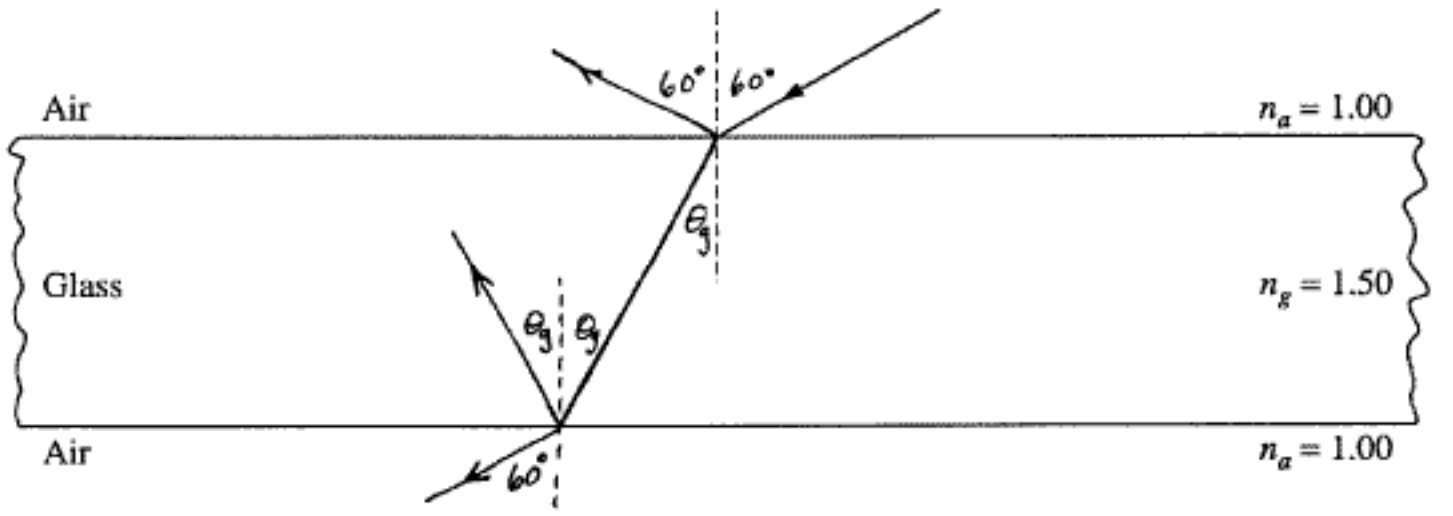
For the correct answer with proper units — 1 point

$E = 60$ V/mm OR 60,000 V/m

2000 Physics B Solutions **Distribution of points**

Question 4 (15 points)

(a) 8 points



For correctly labeling the initial 60° angle of incidence — 1 point

For each correctly drawn ray with angle of reflection or refraction labeled one point was awarded — 4 points

For correctly labeling the angle of incidence at the lower interface — 1 point

Using Snell's law:

$n_a \sin \theta_a = n_g \sin \theta_g$

For correct substitution — 1 point

$1.0 \sin 60° = 1.5 \sin \theta_g$

For the correct value of θ_g — 1 point

$\theta_g = 35.3°$ OR 0.61 rad

At each interface, only one point was awarded for a correct sketch of rays with incorrect or missing angle labels.

At each interface, one point was deducted for an incorrect sketch with correct angle labels.

(b)

i. 2 points

Using the relationship between frequency and wavelength:

$c = f\lambda$

For substituting the correct values in air — 1 point

$$f_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8 \text{ m/s}}{5.25 \times 10^{-7} \text{ m}}$$

For the correct answer — 1 point

$f_a = 5.71 \times 10^{14}$ Hz

Question 4 (continued)

ii. 1 point

For a correct answer — 1 point
$f_f = 5.71 \times 10^{14}$ Hz OR indicating it's the same value as part i

iii. 2 points

For correctly applying one or more equations, including substitution — 1 point

$\lambda_f = \frac{\lambda_a}{n_f}$ OR $v_f = \frac{c}{n_f}$ and $\lambda_f = \frac{v_f}{f_f}$

$\lambda_f = \frac{5.25 \times 10^{-7} \text{ m}}{1.38}$ OR $\lambda_f = \frac{(3 \times 10^8 \text{ m/s})/1.38}{5.71 \times 10^{14} \text{ Hz}}$

For the correct answer, with proper units — 1 point
$\lambda_f = 3.8 \times 10^{-7}$ m OR 380 nm

iv. 2 points

For indicating the correct condition for constructive interference — 1 point
$2L = \lambda_f$

$2L = 3.8 \times 10^{-7}$ m

For the correct answer, with proper units — 1 point
$L = 1.9 \times 10^{-7}$ m OR 190 nm

2000 Physics B Solutions **Distribution of points**

Question 5 (10 points)

(a)

i. 2 points

The maximum kinetic energy of the electrons is equal to the work done as they are decelerated by the potential difference that is required to stop the photoelectric current.

$K_{max} = qV$

$K_{max} = e(4.5\text{ V})$, where e is the charge of an electron OR $(1.6 \times 10^{-19}\text{ C})(4.5\text{ V})$

$K_{max} = 4.5\text{ eV}$ OR $7.2 \times 10^{-19}\text{ J}$

For a correct numerical answer — 1 point

For correct units — 1 point

ii. 3 points

Using the definition of kinetic energy:

$K_{max} = \frac{1}{2} m v_{max}^2$

$v_{max} = \sqrt{2K_{max}/m}$

For substituting the value of K_{max} from part i — 1 point

For converting eV to joules — 1 point

(If part i was calculated in joules, this point was awarded for making the conversion there)

$v_{max} = \sqrt{2(4.5\text{ eV})(1.6 \times 10^{-19}\text{ J/eV})/9.11 \times 10^{-31}\text{ kg}}$

OR $\sqrt{2(7.2 \times 10^{-19}\text{ J})/9.11 \times 10^{-31}\text{ kg}}$

For the correct answer — 1 point

$v_{max} = 1.26 \times 10^{6}\text{ m/s}$

(b) 3 points

For a correct equation for energy in terms of wavelength — 1 point

$E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E}$

For substituting the correct total energy into the equation above — 1 point

$\lambda = \frac{1.24 \times 10^{3}\text{ eV nm}}{(4.5 + 2.3)\text{ eV}}$

For the correct answer — 1 point

$\lambda = 1.83 \times 10^{-7}\text{ m}$

Question 5 (continued)

(c) 2 points

Using the photoelectric equation:

$K_{max} = hf - \phi$

For the correct expression for the minimum frequency (i.e. with $K_{max} = 0$) — 1 point

$$f_0 = \frac{\phi}{h}$$

$$f_0 = \frac{2.3 \text{ eV}}{4.14 \times 10^{-15} \text{ eV s}}$$

For the correct answer — 1 point

$f_0 = 5.56 \times 10^{14}$ Hz

2000 Physics B Solutions

Question 6 (10 points)

The most common approach used by students was calorimetry. They typically used water or a block of metal as the material of known specific heat that was to be heated to a known temperature, and used to transfer energy to the unknown liquid. Another method was immersion of an electrical heater, where measurement of current, voltage, and the time of immersion could be used to calculate the energy transfer.

(a) 2 points

2 points awarded	1 point awarded	No credit awarded
Diagram is provided and labeled where necessary for clarity and Equipment list is complete (i.e., equipment necessary to do the experiment is described)	Equipment list is provided and is complete but there is no diagram	Only a partial equipment list is provided
	OR Equipment list and diagram are provided but some equipment is missing	OR Only an unlabeled diagram is provided (In this case credit can still be earned for later parts.)
OR Diagram is provided with all equipment clearly labeled	OR Drawings of individual, labeled pieces of equipment is provided but the setup is not shown	

(b) 2 points

2 points awarded	1 point awarded	No credit awarded
Complete list of measurements is provided (i.e., all measurements necessary to do the proper calculations) and A symbol is assigned to each quantity	An incomplete listing of measurements and symbols is provided	The list of measurements provided does not lead to a productive experiment
	OR A list of measurements with no symbols is provided	

Continued on next page

Question 6 (continued)

(c) 3 points

3 points awarded	2 points awarded	1 point awarded	No credit awarded
Statement of conservation of energy is included and All relevant variables are substituted correctly to form an equation and Sign conventions are used correctly throughout	Response correct at 3-point level, but heat exchange with container is not considered (unless the container is specifically stated as made of styrofoam, etc.) OR Response correct at 3-point level except signs of terms are incorrect Note: If $Q = mc\Delta T$ appears, with Q defined in (b) or (c) as the heat transferred to the liquid, and ΔT defined as a measured quantity, two points are awarded (one point for energy conservation and one pt for the correct sign)	Only conservation of energy is stated	$Q = mc\Delta T$ stated with no definition of Q

(d) 2 points

2 points awarded	1 point awarded	No credit awarded
Statement of at least one reasonable source of experimental error, with no incorrect sources of error and Correct justification of the effect on the value of specific heat obtained	Statement of at least one reasonable source of error, with no justification or an inappropriate justification OR Reasonable source(s) of error listed, along with an appropriate justification, but incorrect source(s) or justification(s) also given	Neither source of error nor justification relates reasonably to the method used

Feasibility 1 point

One additional point was awarded if a practical and feasible experimental method is described overall (i.e., enough information is given throughout the problem that the reader judges it to be feasible --- even if it is not described explicitly).

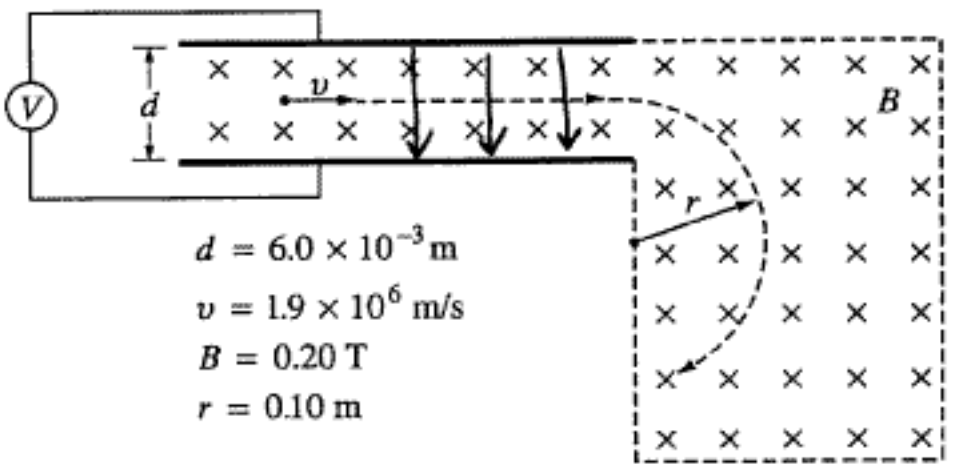
2000 Physics B Solutions **Distribution of points**

Question 7 (10 points)

(a) 2 points

For indicating that the particle has a negative charge — 1 point
For a reasonable justification that considers the particle's behavior in the region of magnetic field outside the space between the plates. — 1 point
For example: By the right-hand rule, the directions of the velocity and the magnetic field indicate that a positive charge would move in a circular path curving above the plates. Since the curve is in the opposite direction the charge must be negative.

(b) 2 points



$d = 6.0 \times 10^{-3}$ m
$v = 1.9 \times 10^{6}$ m/s
$B = 0.20$ T
$r = 0.10$ m

For indicating a vertical field only in the region between the plates, and not extending outside that region — 1 point
For indicating that the field is downward — 1 point

(c) 3 points

For a correct relationship between the potential difference and the electric field — 1 point
$E = V/d$
Between the plates, the electric and magnetic forces must be equal in order for the particle to pass through undeflected
For a correct expression relating the electric and magnetic fields — 1 point
$qE = qvB$
Substituting for the electric field and solving for the potential:
$V = vBd$
$V = (1.9 \times 10^{6}\ \text{m/s})(0.20\ \text{T})(6 \times 10^{-3}\ \text{m})$
For the correct answer — 1 point
$V = 2300$ V

Question 7 (continued)

(d) 3 points

For correctly relating the centripetal and magnetic forces on the particle — 1 point

$$\frac{mv^2}{r} = qvB$$

For the correct expression for $\frac{q}{m}$ — 1 point

$$\frac{q}{m} = \frac{v}{rB}$$

$$\frac{q}{m} = \frac{1.9 \times 10^6 \text{ m/s}}{(0.10 \text{ m})(0.20 \text{ T})}$$

For a correct answer — 1 point

$$\frac{q}{m} = 9.5 \times 10^7 \text{ C/kg}$$

AP Physics B
1999 Free-Response Questions

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1999

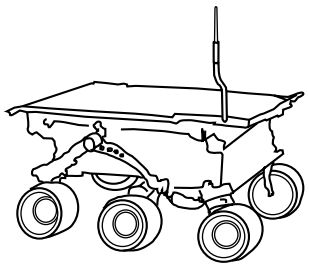
PHYSICS B

SECTION II

Time—90 minutes

7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



1. (15 points)
The Sojourner rover vehicle shown in the sketch above was used to explore the surface of Mars as part of the Pathfinder mission in 1997. Use the data in the tables below to answer the questions that follow.

Mars Data	
Radius:	$0.53 \times$ Earth's radius
Mass:	$0.11 \times$ Earth's mass

Sojourner Data	
Mass of Sojourner vehicle:	11.5 kg
Wheel diameter:	0.13 m
Stored energy available:	5.4×10^5 J
Power required for driving under average conditions:	10 W
Land speed:	6.7×10^{-3} m/s

(a) Determine the acceleration due to gravity at the surface of Mars in terms of g, the acceleration due to gravity at the surface of Earth.

(b) Calculate Sojourner's weight on the surface of Mars.

(c) Assume that when leaving the Pathfinder spacecraft Sojourner rolls down a ramp inclined at $20°$ to the horizontal. The ramp must be lightweight but strong enough to support Sojourner. Calculate the minimum normal force that must be supplied by the ramp.

(d) What is the net force on Sojourner as it travels across the Martian surface at constant velocity? Justify your answer.

(e) Determine the maximum distance that Sojourner can travel on a horizontal Martian surface using its stored energy.

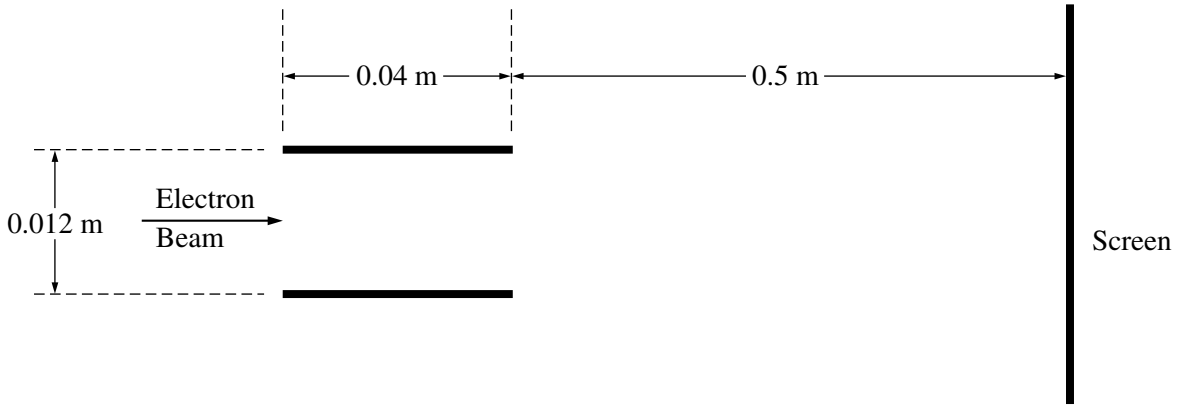
(f) Suppose that 0.010% of the power for driving is expended against atmospheric drag as Sojourner travels on the Martian surface. Calculate the magnitude of the drag force.

GO ON TO THE NEXT PAGE

2. (15 points)
In a television set, electrons are first accelerated from rest through a potential difference in an electron gun. They then pass through deflecting plates before striking the screen.

(a) Determine the potential difference through which the electrons must be accelerated in the electron gun in order to have a speed of 6.0×10^7 m/s when they enter the deflecting plates.

The pair of horizontal plates shown below is used to deflect electrons up or down in the television set by placing a potential difference across them. The plates have length 0.04 m and separation 0.012 m, and the right edge of the plates is 0.50 m from the screen. A potential difference of 200 V is applied across the plates, and the electrons are deflected toward the top of the screen. Assume that the electrons enter horizontally midway between the plates with a speed of 6.0×10^7 m/s and that fringing effects at the edges of the plates and gravity are negligible.



Note: Figure not drawn to scale.

(b) Which plate in the pair must be at the higher potential for the electrons to be deflected upward? Check the appropriate box below.

☐ Upper plate ☐ Lower plate

Justify your answer.

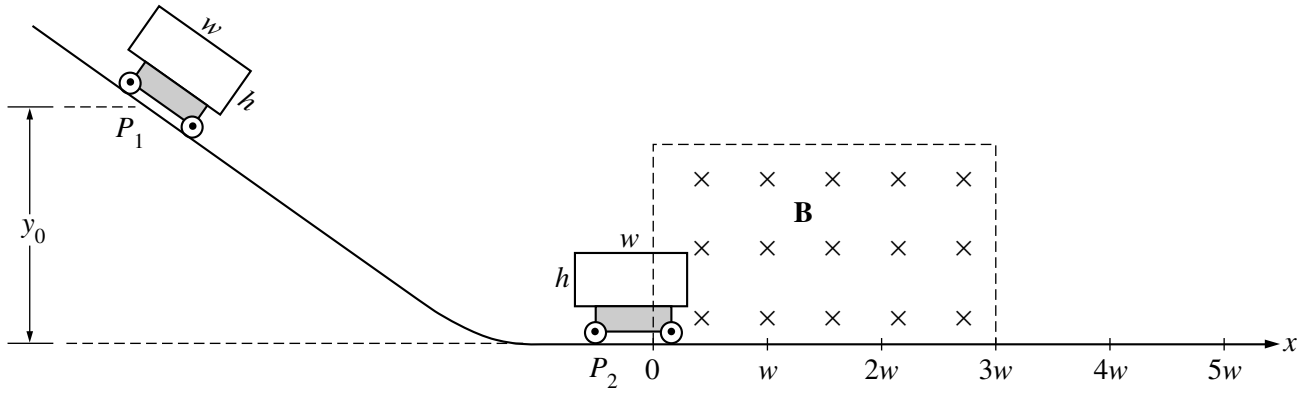
(c) Considering only an electron's motion as it moves through the space between the plates, compute the following.

i. The time required for the electron to move through the plates

ii. The vertical displacement of the electron while it is between the plates

(d) Show why it is a reasonable assumption to neglect gravity in part (c).

(e) Still neglecting gravity, describe the path of the electrons from the time they leave the plates until they strike the screen. State a reason for your answer.



3. (15 points)

A rectangular conducting loop of width w, height h, and resistance R is mounted vertically on a nonconducting cart as shown above. The cart is placed on the inclined portion of a track and released from rest at position P_1 at a height y_0 above the horizontal portion of the track. It rolls with negligible friction down the incline and through a uniform magnetic field **B** in the region above the horizontal portion of the track. The conducting loop is in the plane of the page, and the magnetic field is directed into the page. The loop passes completely through the field with a negligible change in speed. Express your answers in terms of the given quantities and fundamental constants.

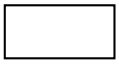
(a) Determine the speed of the cart when it reaches the horizontal portion of the track.

(b) Determine the following for the time at which the cart is at position P_2, with one-third of the loop in the magnetic field.

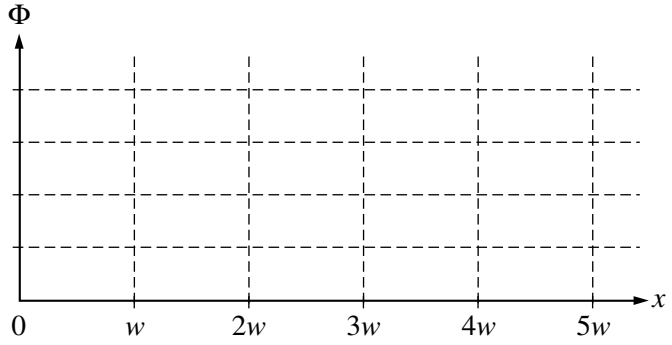
i. The magnitude of the emf induced in the conducting loop

ii. The magnitude of the current induced in the conducting loop

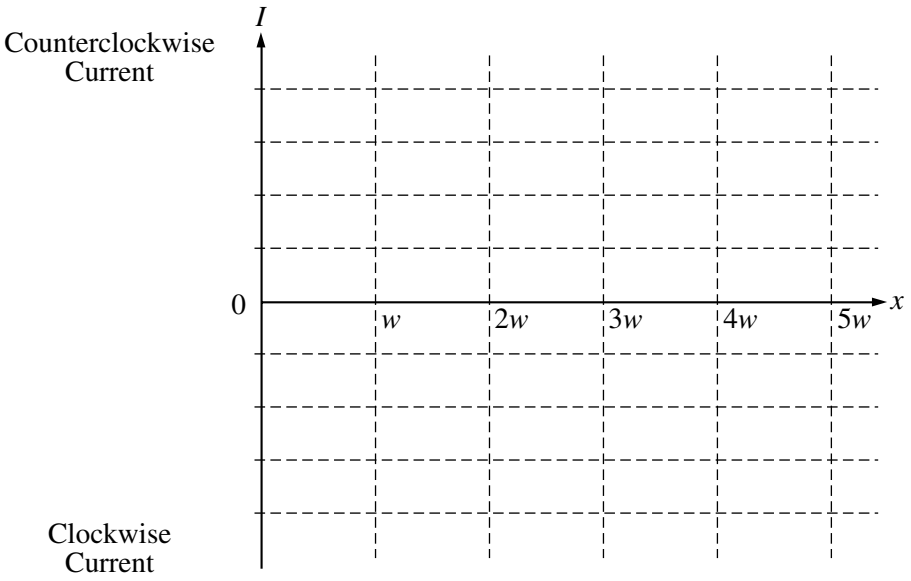
(c) On the following diagram of the conducting loop, indicate the direction of the current when it is at position P_2.



(d) i. Using the axes below, sketch a graph of the magnitude of the magnetic flux Φ through the loop as a function of the horizontal distance x traveled by the cart, letting $x = 0$ be the position at which the front edge of the loop just enters the field. Label appropriate values on the vertical axis.



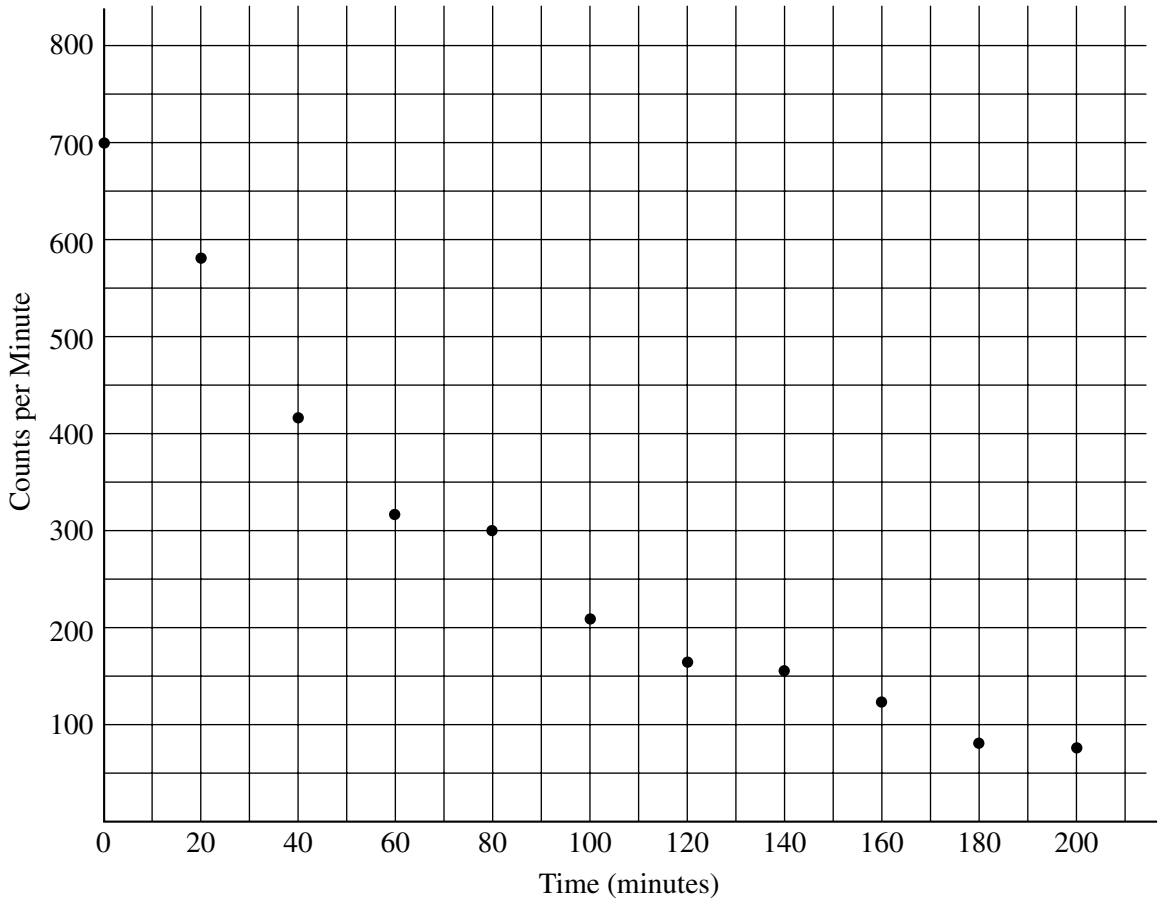
ii. Using the axes below, sketch a graph of the current induced in the loop as a function of the horizontal distance x traveled by the cart, letting $x = 0$ be the position at which the front edge of the loop just enters the field. Let counterclockwise current be positive and label appropriate values on the vertical axis.



4. (15 points)
You use a Geiger counter to measure the decay of a radioactive sample of bismuth 212 over a period of time and obtain the following results.

Time (min)	0	20	40	60	80	100	120	140	160	180	200
Counts/minute	702	582	423	320	298	209	164	154	124	81	79

(a) Your results are plotted on the following graph. On the graph, draw an estimate of a best-fit curve that shows the radioactive counts as a function of time.



(b) From the data or from your graph, determine the half-life of this isotope. Explain how you arrived at your answer.

(c) The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$$^{212}_{83}\text{Bi} \rightarrow \text{Tl} + \alpha$$

Determine the atomic number Z and the mass number A of the thallium nuclei produced and enter your answers in the spaces provided below.

$Z =$ _____ $A =$ _____

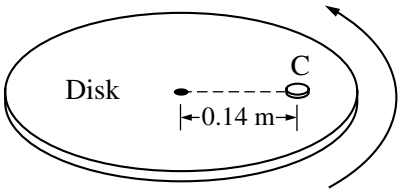
GO ON TO THE NEXT PAGE

(d) The mass of the alpha particle is 6.64×10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.

i. Determine the momentum of the alpha particle.

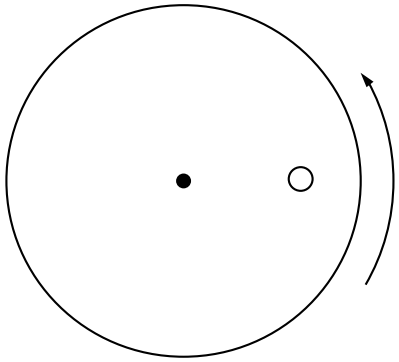
ii. Determine the kinetic energy of the recoiling thallium nucleus.

(e) Determine the total energy released during the decay of 1 mole of bismuth 212.



5. (10 points)
A coin C of mass 0.0050 kg is placed on a horizontal disk at a distance of 0.14 m from the center, as shown above. The disk rotates at a constant rate in a counterclockwise direction as seen from above. The coin does not slip, and the time it takes for the coin to make a complete revolution is 1.5 s.

(a) The figure below shows the disk and coin as viewed from above. Draw and label vectors on the figure below to show the instantaneous acceleration and linear velocity vectors for the coin when it is at the position shown.



(b) Determine the linear speed of the coin.

(c) The rate of rotation of the disk is gradually increased. The coefficient of static friction between the coin and the disk is 0.50. Determine the linear speed of the coin when it just begins to slip.

(d) If the experiment in part (c) were repeated with a second, identical coin glued to the top of the first coin, how would this affect the answer to part (c) ? Explain your reasoning.

6. (10 points)
You are given the following equipment for use in the optics experiments in parts (a) and (b).

A solid rectangular block made of transparent plastic
A laser that produces a narrow, bright, monochromatic ray of light
A protractor
A meterstick
A diffraction grating of known slit spacing
A white opaque screen

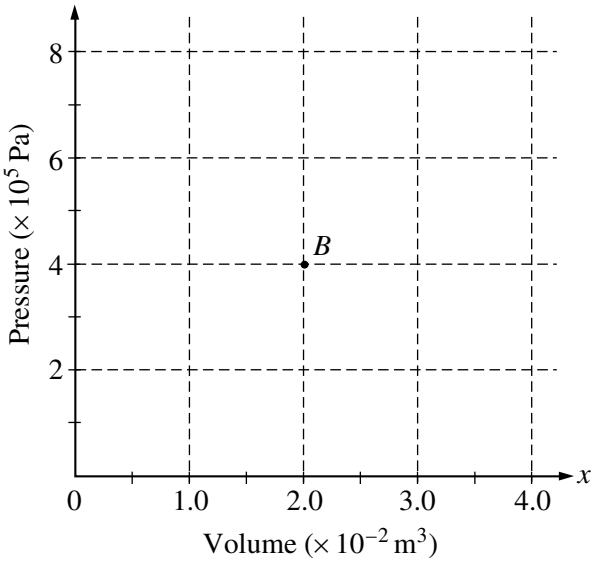
(a) Briefly describe the procedure you would use to determine the index of refraction of the plastic. Include a labeled diagram to show the experimental setup. Write down the corresponding equation you would use in your calculation and make sure all the variables in this equation are labeled on your diagram.

(b) Since the index of refraction depends on wavelength, you decide you also want to determine the wavelength of your light source. Draw and label a diagram showing the experimental setup. Show the equation(s) you would use in your calculation and identify all the variables in the equation(s). State and justify any assumptions you make.

7. (10 points)
A cylinder contains 2 moles of an ideal monatomic gas that is initially at state A with a volume of 1.0×10^{-2} m^3 and a pressure of 4.0×10^5 Pa. The gas is brought isobarically to state B, where the volume is 2.0×10^{-2} m^3. The gas is then brought at constant volume to state C, where its temperature is the same as at state A. The gas is then brought isothermally back to state A.

(a) Determine the pressure of the gas at state C.

(b) On the axes below, state B is represented by the point B. Sketch a graph of the complete cycle. Label points A and C to represent states A and C, respectively.



(c) State whether the net work done by the gas during the complete cycle is positive, negative, or zero. Justify your answer.

(d) State whether this device is a refrigerator or a heat engine. Justify your answer.

END OF EXAMINATION

AP Physics B
1999 Scoring Guidelines

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1999 Physics B Solutions

Distribution of points

Question 1 (15 points)

(a) 3 points

For a correct expression of Newton's Gravitation law — 1 point

$$F = \frac{GM_1M_2}{R^2}$$

For correct substitution/calculation in formula — 1 point

$$g_{Mars} = \frac{GM_M}{R_M^2} = \frac{G(0.11)M_E}{(0.53R_E)^2} = \frac{0.11}{(0.53)^2} g_E$$

For expressing g_M in terms of g_E — 1 point

$$g_M = \frac{0.11}{(0.53)^2} g_E \quad \text{OR} \quad g_M = 0.39 g_E$$

However, the third point for expressing g_M in terms of g_E is not awarded if no points have been awarded up to that part.

(b) 2 points

For the correct formula for weight: $W = Mg$ — 1 point

For the correct value of g for Mars, where any value of g signifying Mars is acceptable, such as $0.39g_E$, 3.8 m/s^2, g_{Mars}, $\frac{0.11}{(0.53)^2} g_E$, etc. — 1 point

$$W = (11.5\,\text{kg})(3.8\,\text{m/s}^2) = 44\,\text{N}$$

(Alternate solution) — *(Alternate points)*

For correct calculation using $F = \frac{GM_1M_2}{R^2}$, where the student has calculated the mass of Mars, the radius of Mars and uses the correct mass of Sojourner. (A student needs to have memorized the mass of the Earth and its radius to do this.) — *2 points*

(c) 2 points

For indication that sine or cosine is needed as a necessary factor for computation of N — 1 point

For correct formula and calculation — 1 point

$$N = Mg_M \cos\theta$$

$$N = (11.5\text{ kg})(3.8\text{ m/s}^2)\cos 20° = 41\text{ N}$$

OR $\quad N = (11.5\text{ kg})(3.8\text{ m/s}^2)\sin 70° = 41\text{ N}$

Distribution of points

Question 1 (continued)

(d) 2 points

For correct statement that $F_{net} = 0$ — 1 point
For a correct reason such as $a = 0$, OR υ = constant, OR Newton's First law — 1 point

(e) 3 points

For a correct formula for power — 1 point

$$P = \frac{W}{t}$$

For a correct formula for distance — 1 point

$$d = \upsilon t$$

For a correct calculation of distance — 1 point

$$d = \frac{\upsilon W}{P} = \frac{(6.7 \times 10^{-3}\ \text{m/s})(5.4 \times 10^{5}\ \text{J})}{10\ \text{W}}$$

$$d = 362\ \text{m}$$

(Alternate solution) — *(Alternate points)*

For correct formulas for work and power — *1 point*

$W = Fd$ and $P = F\upsilon$

For combining these to yield a correct formula for the distance — *1 point*

$$d = \frac{\upsilon W}{P}$$

For a correct calculation — *1 point*

$$d = \frac{(6.7\times10^{-3}\ \text{m/s})(5.4\times10^{4}\ \text{J})}{10\ \text{W}} = 362\ \text{m}$$

(f) 3 points

For correct formula $P = F\upsilon$, so $F = \frac{P}{\upsilon}$ — 1 point

For correct substitutions using the correct percentage of 0.01% — 1 point

$$F = \frac{(0.0001)(10\,\text{W})}{6.7\times10^{-3}\ \text{m/s}}$$

For correct calculation of force — 1 point

$F = 0.15$ N (0.149 N and 0.1 N were acceptable)

1999 Physics B Solutions **Distribution of points**

Question 2 (15 points)

(a) 3 points

For the expression $V = W/q$ 1 point

For the expression $W = \Delta K = \frac{1}{2}mv^2$ 1 point

For correct substitutions and answer 1 point

$$V = \frac{mv^2}{2q} = \frac{(9.31\times10^{-31}\text{ kg})(6.0\times10^{7}\text{ m/s})^2}{2(1.6\times10^{-19}\text{ C})}$$

$$V = 1.0\times10^{4}\text{ V}$$

(b) 2 points

For correct answer, i.e., upper plate indicated as the one at the higher potential 1 point

For proper justification for correct answer 1 point

Examples: F_e is up, therefore E is down; E points in the direction of decreasing potential.

Electrons travel toward higher potential.

The justification point was not awarded if the lower plate was indicated as being at the higher potential

(c)

i. 1 point

For $v_x = \frac{x}{t}$ 1 point

$$t = \frac{x}{v_x} = \frac{0.04\text{ m}}{6.0\times10^{7}\text{ m/s}} = 6.7\times10^{-10}\text{ s}$$

ii. 5 points

For each of the following relationships necessary in the solution:

$V = Ed$ 1 point

$E = F/q$ 1 point

$F = ma$ 1 point

$y = \frac{1}{2}at^2,\ v_{0y} = 0$ 1 point

For correct substitutions and answer 1 point

$$y = \frac{qVt^2}{2dm} = \frac{(1.6\times10^{-19}\text{ C})(200\text{ V})(6.7\times10^{-10}\text{ s})^2}{2(0.012\text{ m})(9.1\times10^{-31}\text{ kg})}$$

$$y = 6.5\times10^{-4}\text{ m}$$

Distribution of points

Question 2 (continued)

(d) 2 points

For a correct qualitative comparison of F_g *vs* F_E, or g *vs* a_E, or the distances traveled — 1 point
Examples: F_g is much less than F_E
g is much less than a_E

For additional quantitative comparison of F_g *vs.* F_E or g *vs.* a_E by computing actual numerical values — 1 point
Example: $F_g = mg = (9.1 \times 10^{-31}\ \text{kg})(9.8\ \text{m/s}^2) = 8.9 \times 10^{-30}\ \text{N}$

$$F_E = qE = \frac{qV}{d} = \frac{(1.6 \times 10^{-19}\ \text{C})(200\ \text{V})}{0.012\ \text{m}} = 1.9 \times 10^{-14}\ \text{N}$$

so $F_g \ll F_E$

(e) 2 points

For indicating that the path is a straight line, not horizontal — 1 point
For correct reason, such as an indication that $F = 0$, or $a = 0$. — 1 point

Question 3 (15 points)

(a) 4 points

As the cart rolls down the ramp, potential energy is changed to kinetic energy.
For indicating conservation of energy — 1 point
Initial energy = final energy
For indicating the proper energies — 1 point
This point given for either of the following two equations
P.E. = K.E.

$$mgh = \frac{1}{2}mv^2$$

For making the proper substitution of y_0 for h — 1 point

$$mgy_0 = \frac{1}{2}mv^2$$

For the correct answer — 1 point

$$v = \sqrt{2gy_0}$$

Alternate solution — *(Alternate points)*
Find acceleration using Newton's 2nd law and use kinematic equations
For making the proper substitution for the distance traveled — *1 point*
For the correct answer — *3 points*

(b)
i. 2 points

As the loop enters the field, the magnetic flux changes, resulting in an induced emf, which can be found using Faraday's law or more simply from the given equation $\mathcal{E} = B\ell v$

For correct substitution of one value, h for ℓ, or $\sqrt{2gy_0}$ for v from part (a) — 1 point
For the correct answer, which requires both substitutions into this equation — 1 point

$$\mathcal{E} = Bh\sqrt{2gy_0}$$

(b)
ii. 2 points

The current in the loop is related to the resistance and voltage by the equation $V = IR$, or $I = \frac{V}{R}$

For the correct substitution of $Bh\sqrt{2gy_0}$ for V — 1 point
For the correct answer — 1 point

$$I = \frac{Bh\sqrt{2gy_0}}{R}$$

Question 3 (continued)

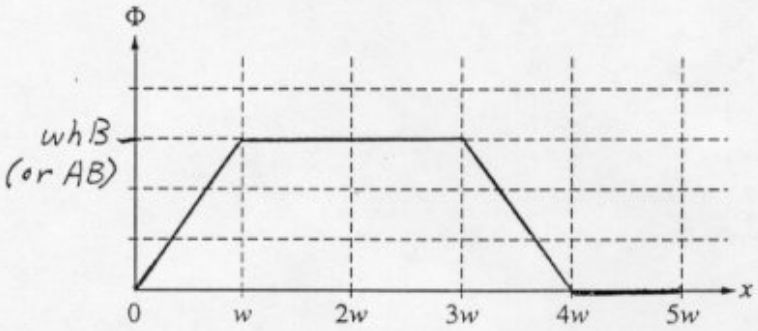
(c) 1 point

As the loop enters the field, a current is induced in the loop so as to oppose the change in flux.

For an indication that the current is counterclockwise, as shown by arrows or words. 1 point

(d)

i. 3 points



For giving the correct label on the vertical axis as *whB* or *BA* 1 point
(The label could be at any point on the vertical axis as long as it was consistent with the graph drawn.)

For drawing a horizontal, non-zero line between w and $3w$ 1 point

For straight lines of constant and proper slope between 0 and w and between $3w$ and $4w$ 1 point
(The first has positive slope; the second has negative slope.)

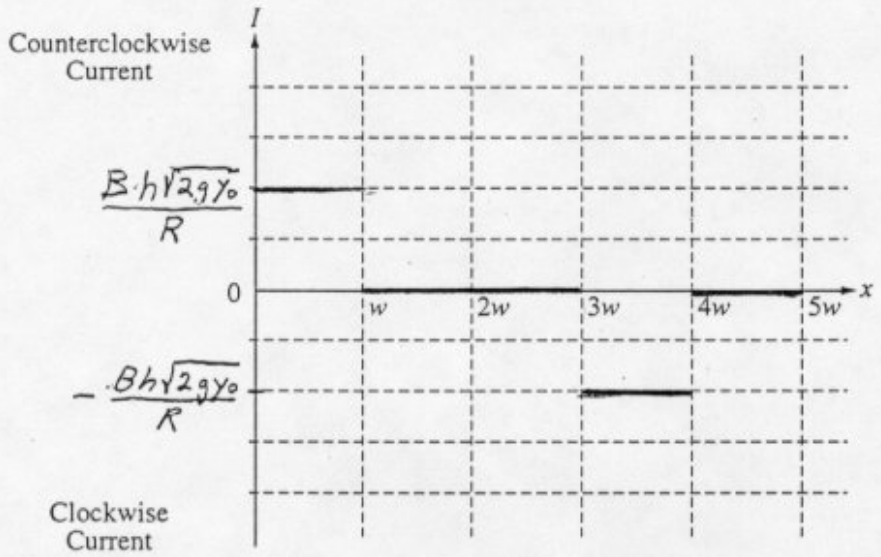
The flux is zero from $4w$ to $5w$, but it was not required to show this on the graph.

(If the last two points above were not awarded, 1 point was given if the shape of the graph was a trapezoid with parallel top and bottom lines. For example, this point would be given if the graph were horizontal between w and $2w$ with straight sloped lines between 0 and w and between $2w$ and $3w$.)

Question 3 (continued)

(d)

ii. 3 points



For proper labeling of the graph with $I = \frac{Bh\sqrt{2gy_0}}{R}$ or the answer found in part (b)ii. 1 point

(The label could be at any point on the vertical axis as long as it was consistent with the graph drawn.)

For recognizing that the current was zero between w and $3w$ and showing it with a horizontal line 1 point

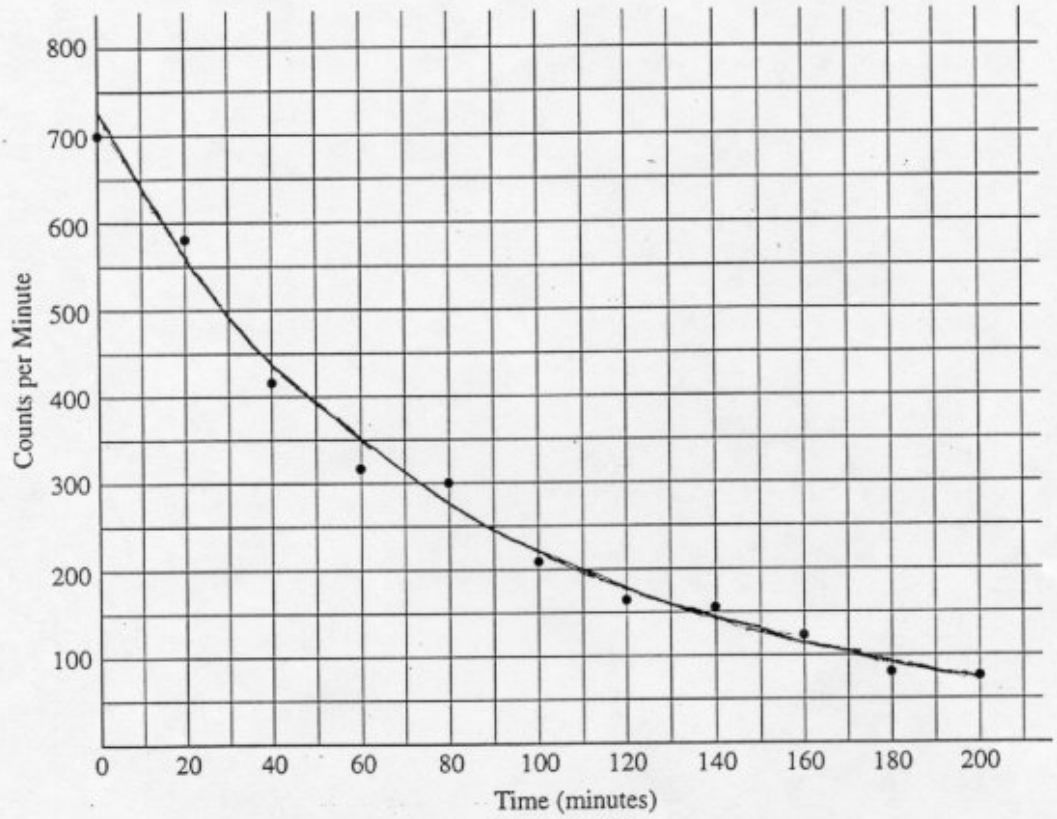
For showing horizontal, non-zero lines of opposite sign between 0 and w and between $3w$ and $4w$ 1 point

The current is zero from $4w$ to $5w$, but it was not required to show this on the graph.

(Because of the labeling of the axis "Counterclockwise Current" as positive, which was confusing to some, starting negative (from 0 to w) and ending positive (from $3w$ to $4w$) was also acceptable for the third point above. Using slopes consistent with (d)i. also received the two graphing points.)

Question 4 (15 points)

(a) 2 points



For a smooth curve 1 point
For reasonable best fit (with dots above and below curve) 1 point

(No points awarded for (a) for a straight line or a "point-to-point" curve)

(b) 2 points

For answer between 50 and 64 minutes, or for answer consistent with incorrect curve, including straight line 1 point
For showing or explaining that one can read from the graph the time at which the count is halved, or by use of the equation $N = N_0 e^{-\lambda t}$ and two points (data points or points on curve) 1 point

Question 4 (continued)

(c) 3 points

For indicating the atomic mass and mass number of the alpha particle: ${}^{4}_{2}\alpha$	1 point
For showing $Z = 81$	1 point
For showing $A = 208$	1 point
(Full credit awarded for $Z = 81$ and $A = 208$ alone)	
(Alternate partial credit answers)	*(Alternate points)*
$Z = 208$ $A = 81$	*2 points*
$Z = 79$ $A = 210$	*2 points*
$Z = 210$ $A = 79$	*1 point*
Show incorrect values for the alpha particle, but consistent Z and A given those values	*2 points*
Show incorrect values for the alpha particle, consistent Z and A given those values, but Z and A reversed	*1 point*

(d)

i. 4 points

For conversion to like units	1 point
$6.09 \text{ MeV} = 9.7 \times 10^{-13} \text{ J}$	
For use of both the kinetic energy and the momentum equation	1 point
$K = \frac{1}{2}mv^2$	
$p = mv$	
Solving for v_α and substituting	
$v_\alpha = \sqrt{2K/m}$	
$p = m\sqrt{2K/m} = \sqrt{2Km}$	
$p_\alpha = \sqrt{2(9.7 \times 10^{-13} \text{ J})(6.64 \times 10^{-27} \text{ kg})}$	
For consistent answer	1 point
For correct units	1 point
$p_\alpha = 1.1 \times 10^{-19} \text{ kg·m/s}$	

Question 4 (continued)

(d)

ii. 2 points

For showing conservation of momentum of Tl and α 1 point

$p_{Tl} = |-p_\alpha|$

$m_{Tl}v_{Tl} = 1.1 \times 10^{-19}$ kg·m/s

For showing the mass of Tl: $(208)(1.67\times10^{-27}$ kg) 1 point

(This point also given for alternate ways of showing Tl mass, such as $v_{Tl} = \frac{4}{208}v_\alpha$)

$v_{Tl} = 3.28\times10^5$ m/s

$K_{Tl} = \frac{1}{2}mv_{Tl}^2 = \frac{1}{2}(208)(1.67\times10^{-27}\text{ kg})(3.28\times10^5\text{ m/s})^2$

$K_{Tl} = 1.9\times10^{-14}$ J

(e) 2 points

$K_{tot} = (K_\alpha + K_{Tl})N_0 = (9.7 \times 10^{-13}\text{ J} + 1.9 \times 10^{-14}\text{ J})(6.02 \times 10^{23}\text{ mol}^{-1})$

$K = 6 \times 10^{11}$ J or 3.7×10^{24} MeV

For summing $K_\alpha + K_{Tl}$ 1 point

For multiplying total energy by Avogadro's number 1 point

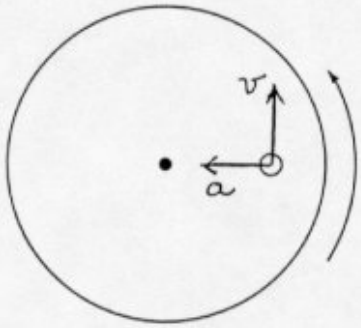
Alternatively, 1 point awarded for using equation $\Delta E = (\Delta m)c^2$ and mentioning binding energy or mass difference

1999 Physics B Solutions

Distribution of points

Question 5 (10 points)

(a) 2 points



For any properly labeled, vertical vector pointing upward — 1 point
For any properly labeled, horizontal vector pointing to the left — 1 point

(b) 2 points

$$v = \frac{\text{circumference}}{\text{period}} = \frac{2\pi R}{T} = \frac{2\pi(0.14\,\text{m})}{1.5\,\text{s}} = 0.60\ \text{m/s}$$

For indicating use of circumference for distance traveled in one revolution, such as $\frac{\text{circumference}}{\text{period}}$ OR $\frac{2\pi R}{T}$ — 1 point

For correct answer — 1 point
Answer ranges accepted: $0.187\pi \rightarrow 0.190\pi$ m/s OR $0.58 \rightarrow 0.60$ m/s

(c) 4 points

$$F_t = F_c$$

$$\mu mg = \frac{mv^2}{r}$$

$$v = \sqrt{\mu r g} = \sqrt{(0.5)(0.14\ \text{m})\left(9.8\ \text{m/s}^2\right)} = 0.83\ \text{m/s}$$

For correct expression of centripetal force — 1 point
For correct expression of frictional force — 1 point
For equating centripetal force to frictional force — 1 point
For correct answer — 1 point
Answer range: 0.80 m/s → 0.84 m/s

Question 5 (continued)

(d) 2 points

For indicating no change to answer in part (c)	1 point
For any reasonable explanation, such as the masses cancel	1 point

(No points awarded for explanation if it is without statement of no change.)

1999 Physics B Solutions **Distribution of points**

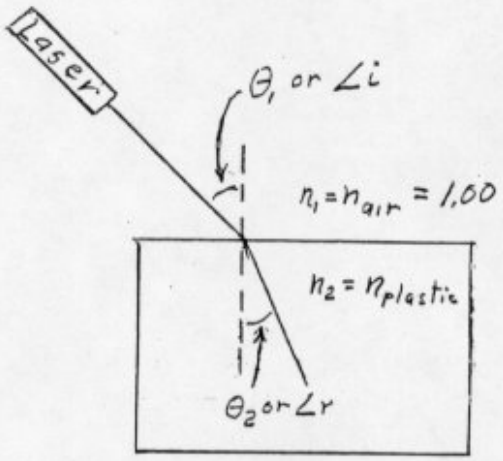
Question 6 (10 points)

(a) 6 points

For a verbal description of the procedure — 1 point

An example of a complete procedure would be: Place the laser on the table so that the beam will travel along the white screen placed on the tabletop. Locate the plastic block so that the light enters it at an angle to the normal to the surface of the plastic. Draw a line representing the surface of the block and the incident ray. Mark where the ray exits the block and remove the block. Draw a ray from the exit point back to the normal and incident ray. Measure the angle of incidence and the angle of refraction. Use Snell's law and the fact that the index of refraction in air is unity to calculate the index of refraction of the plastic.

(Shorter descriptions were also acceptable for this point.)



Points awarded for diagram

For all the correct rays drawn and meeting at the interface — 1 point

For both θ_1 and θ_2 measured from the normal — 1 point

For $\theta_2 < \theta_1$ — 1 point

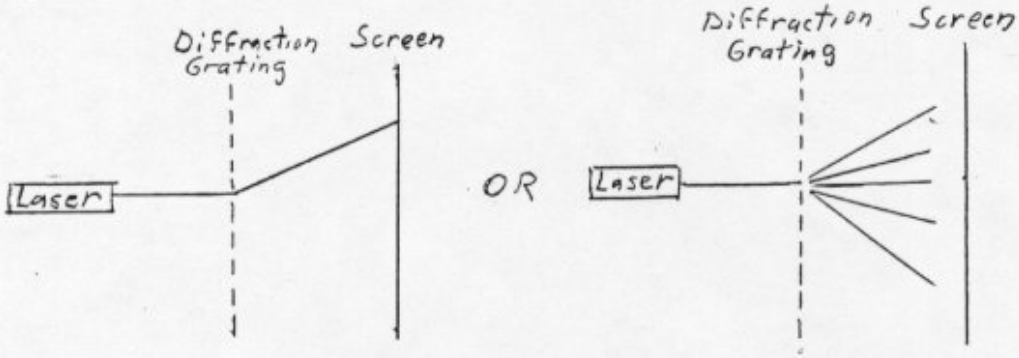
For all quantities being labeled on the diagram, including n_1 and n_2 (n_1 and n_2 could also be described in the text.) — 1 point

For the correct equation — 1 point

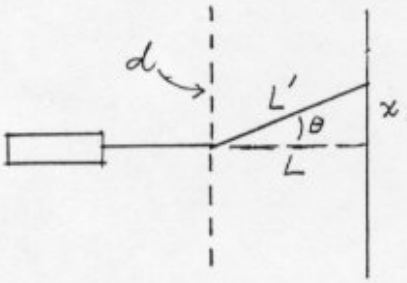
$n_1 \sin\theta_1 = n_2 \sin\theta_2$ OR $\dfrac{\sin\angle i}{\sin\angle r} = n$

Question 6 (continued)

(b) 4 points



For diagram that must include laser, diffraction grating, screen, and some indication of bending or spreading of light at the grating, as shown above — 1 point



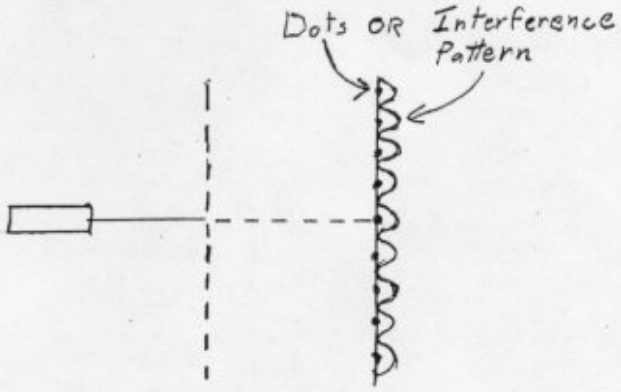
For the labels on the diagram as shown above that correspond to those in the equation used — 1 point
For the equation and any necessary assumptions made — 1 point
The equation could be any one of the following three.

$n\lambda = d\sin\theta$; d and θ must also be shown in the diagram

$n\lambda = xd/L'$; d and L' must be shown in the diagram

$n\lambda = xd/L$; only for small angles using the approximation $\sin\theta \approx \tan\theta$, and d and L must be shown in the diagram

For indicating in some fashion that n is equal to the number of a particular bright line. — 1 point
This could be with a verbal description or by showing successive dots or an interference pattern, as shown in the example below.



Note: Only one diagram was necessary if it included all the features described. For purposes of these standards several diagrams were used to clearly illustrate how the points were awarded.

1999 Physics B Solutions **Distribution of points**

Question 7 (10 points)

(a) 2 points

For relating the thermodynamic states at point A and point C — 1 point

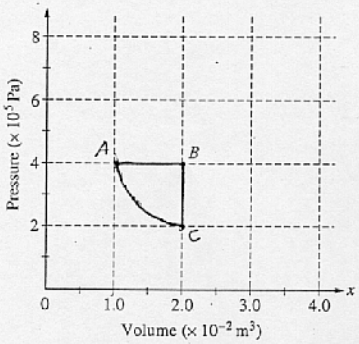
Examples: $\frac{p_A V_A}{T_A} = \frac{p_C V_C}{T_C}$ OR $p_A V_A = p_C V_C$

For finding the pressure at point C — 1 point

$$p_C = p_A \frac{V_A}{V_C} = (4 \times 10^5 \text{ Pa})\left(\frac{1.0 \times 10^{-2} \text{ m}^3}{2.0 \times 10^{-2} \text{ m}^3}\right)$$

$p_C = 2.0 \times 10^5$ Pa OR $p_C = 2.0$ atm

(b) 4 points



For correctly plotting and labeling Point A — 1 point

For correctly plotting and labeling Point C — 1 point

For indicating that path CA is along an isotherm — 1 point

For drawing a complete cycle with path AB shown as an isobaric process and path BC shown as an isochoric process. — 1 point

Distribution of points

Question 7 (continued)

(c) 2 points

For statement that net work done by the gas is positive — 1 point
For correct justification — 1 point

Examples:

1. Work is related to area and the net area is positive.
2. More heat is absorbed in the cycle that is exhausted.
3. Expansion occurs at a higher pressure while compression occurs at a lower pressure.
4. Thermodynamic cycle is clockwise.

(d) 2 points

For statement that the device is a heat engine — 1 point
For correct justification — 1 point

Examples:

1. Work done by the system is positive.
2. Work done by the system is done at a higher temperature.
3. Heat is absorbed at a higher temperature and exhausted at a lower temperature.
4. Thermodynamic cycle is clockwise.