

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

© 2015 The College Board. College Board, Advanced Placement Program, AP, AP Central, and the acorn logo are registered trademarks of the College Board.
Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

$K = \frac{1}{2}mv^2$

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

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

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

$\omega = \omega_0 + \alpha t$

$x = A\cos(2\pi ft)$

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

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

$L = I\omega$

$\Delta L = \tau\,\Delta t$

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

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

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

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

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

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

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

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

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

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

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

$U_G = -\frac{Gm_1 m_2}{r}$

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

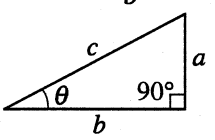
Rectangular solid
$V = \ell wh$

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

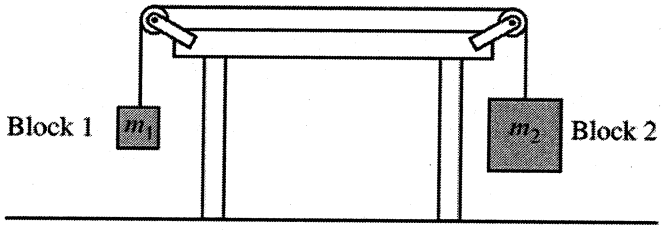
Right triangle
$c^2 = a^2 + b^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

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.



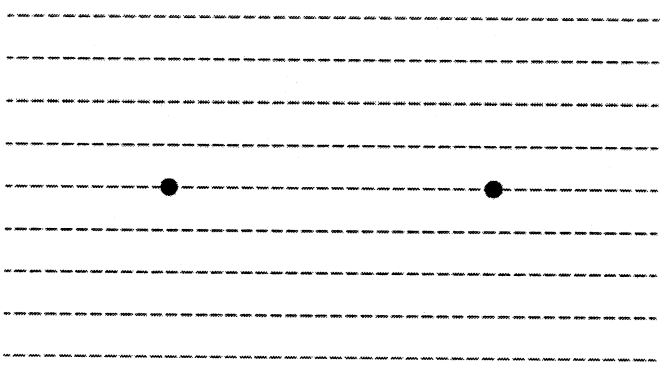
Note: Figure not drawn to scale.

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

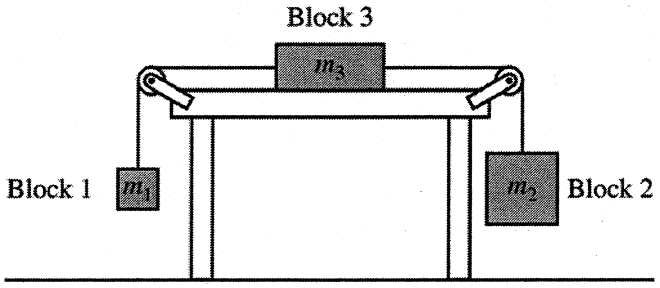
   

   (b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

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.

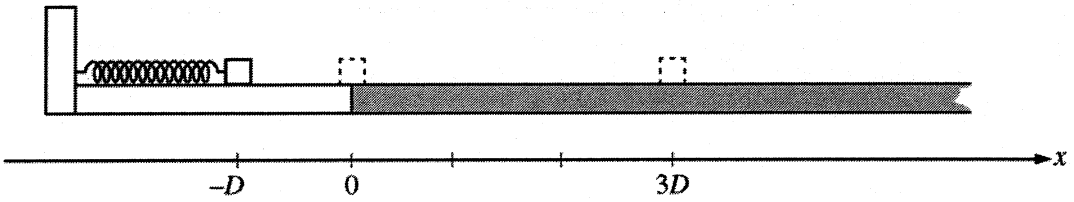
A lightbulb is nonohmic if its resistance changes as a function of current. Your setup from part (a) is to be used or modified to determine whether the lightbulb is nonohmic.

(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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS



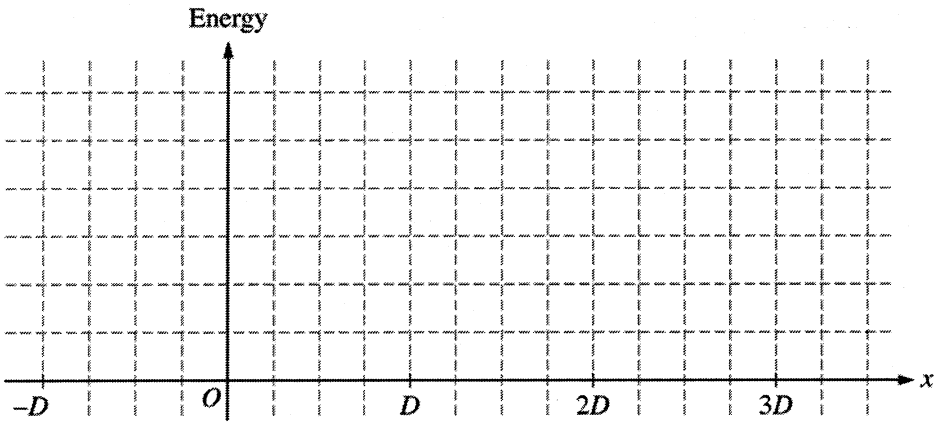
3. (12 points, suggested time 25 minutes)

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



© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

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)

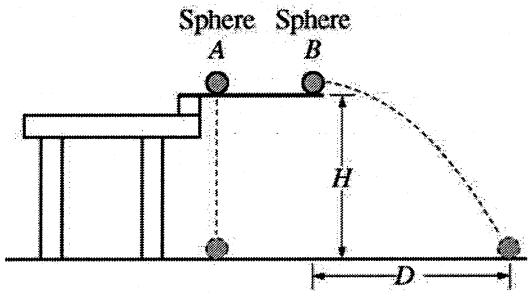
i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.
ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS



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.

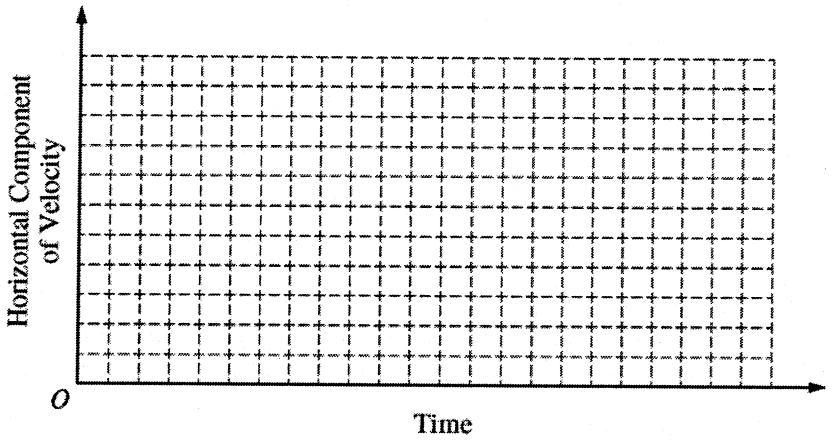
(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.

Sphere A Sphere B

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

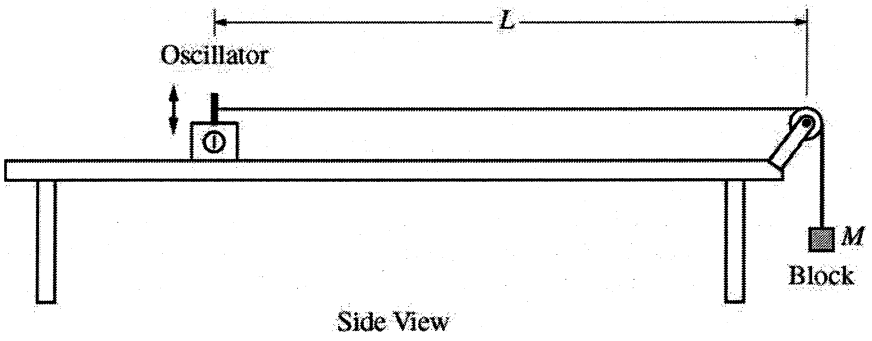
(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.



(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).

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

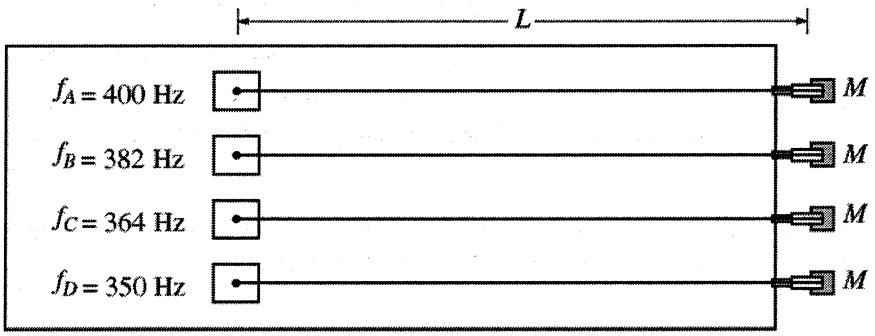
2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS



Side View

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.



Top View

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.

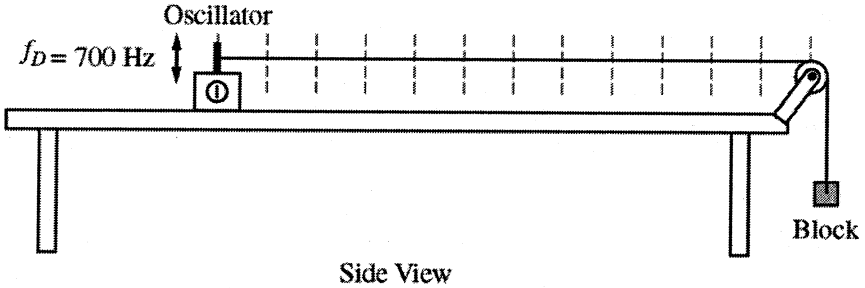
(a) What is different about the four strings shown above that would result in their having different fundamental frequencies? Explain how you arrived at your answer.

(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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2015 AP® PHYSICS 1 FREE-RESPONSE QUESTIONS

(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.



Side View

STOP

END OF EXAM

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics 1
2015 Scoring Guidelines

© 2015 The College Board. College Board, Advanced Placement Program, AP, AP Central, and the acorn logo are registered trademarks of the College Board.
Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



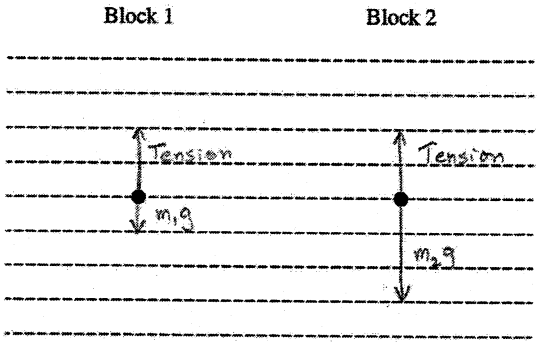
AP® PHYSICS 1
2015 SCORING GUIDELINES

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

$T = m_1a + m_1g$

$m_2a = m_2g - m_1a - m_1g$

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

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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS 1
2015 SCORING GUIDELINES

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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

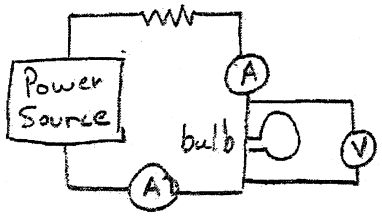
AP® PHYSICS 1
2015 SCORING GUIDELINES

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.

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS 1
2015 SCORING GUIDELINES

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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

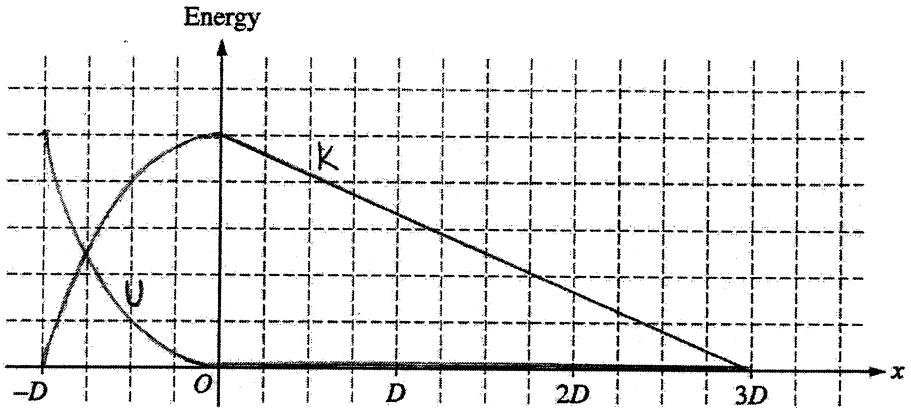
AP® PHYSICS 1
2015 SCORING GUIDELINES

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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS 1
2015 SCORING GUIDELINES

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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

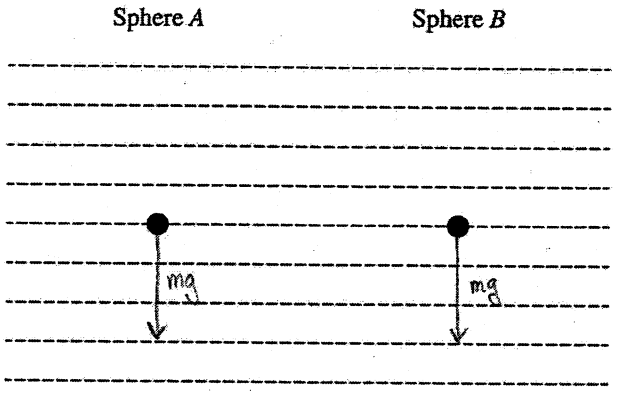
AP® PHYSICS 1
2015 SCORING GUIDELINES

Question 4

7 points total

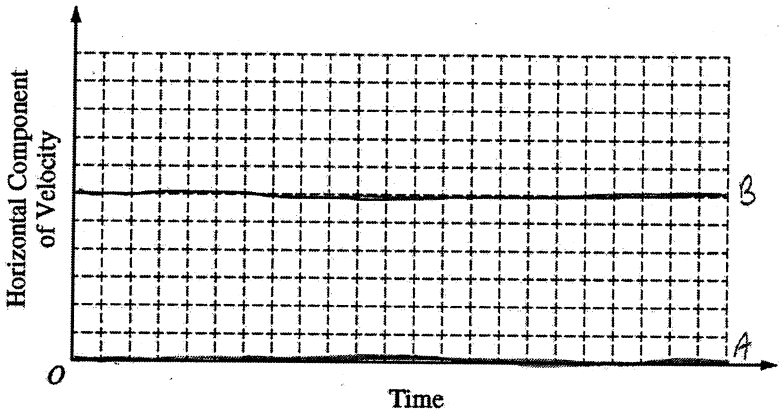
Distribution of points

(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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS 1
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

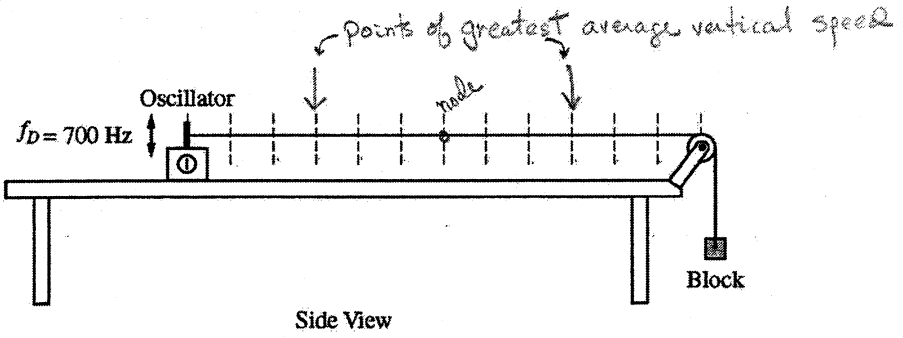
Note: Responses may refer to the physical differences between the strings in a variety of ways, e.g., different linear mass density, different total mass, different thicknesses of the same material

(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

© 2015 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2014 Free-Response Questions

© 2014 The College Board. College Board, Advanced Placement Program, AP, AP Central, and the acorn logo are registered trademarks of the College Board.
Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



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 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 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

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

$K = \frac{1}{2}mv^2$

$\Delta U_g = mgh$

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

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

$P = Fv\cos\theta$

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

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

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

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

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

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

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

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
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

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

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

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

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + \ldots$

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

$R_s = R_1 + R_2 + R_3 + \ldots$

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

$F_B = qvB\sin\theta$

$F_B = BI\ell\sin\theta$

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

$\phi_m = BA\cos\theta$

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

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

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
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS, EFFECTIVE 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

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

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

$PV = nRT = Nk_BT$

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

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

$v = f\lambda$

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

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

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

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

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

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

$d\sin\theta = m\lambda$

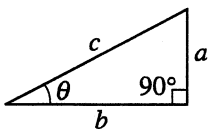
$x_m \approx \frac{m\lambda L}{d}$

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

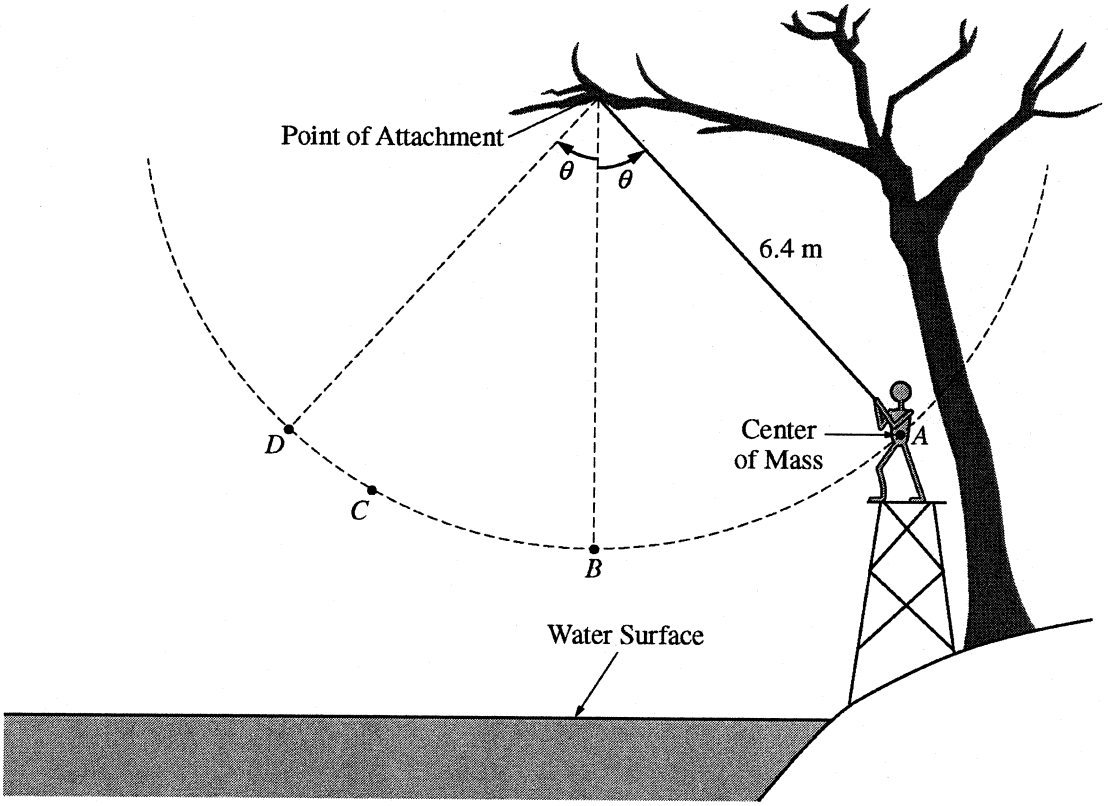


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2014 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 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 solid 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 dashed line to represent the trajectory of the center of mass after the person releases the rope.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS

(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.

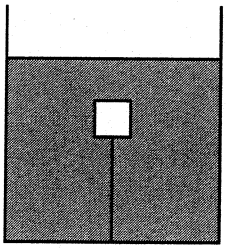
(e) If the person does not let go of the rope, how does the magnitude of the person's momentum p_C at point C compare with the magnitude of the person's momentum p_B at point B ?

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

Provide a physical explanation to justify your answer.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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).

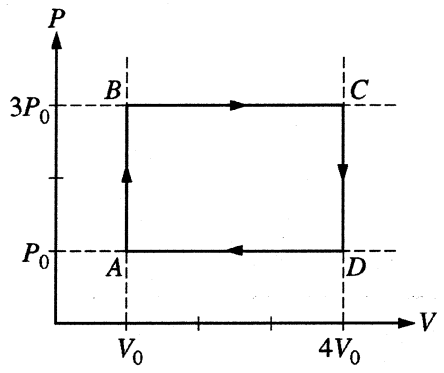
(d) Indicate whether the magnitude of the buoyant force on the cube increases, decreases, or remains the same while the cube is rising, but before it reaches the surface.

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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 by 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?

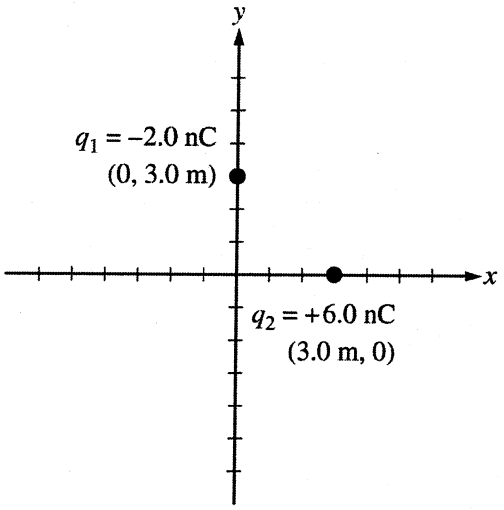
____ Positive ____ Negative ____ Zero

Justify your answer.

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS

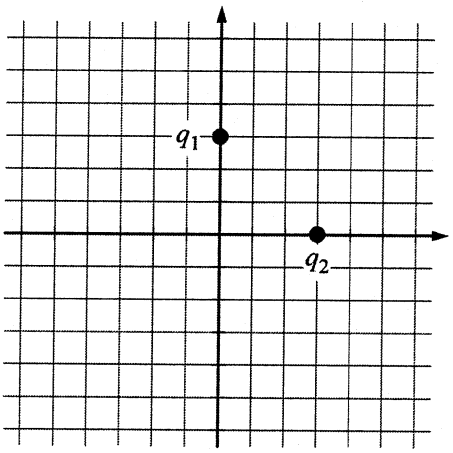


4. (10 points)

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).

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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.

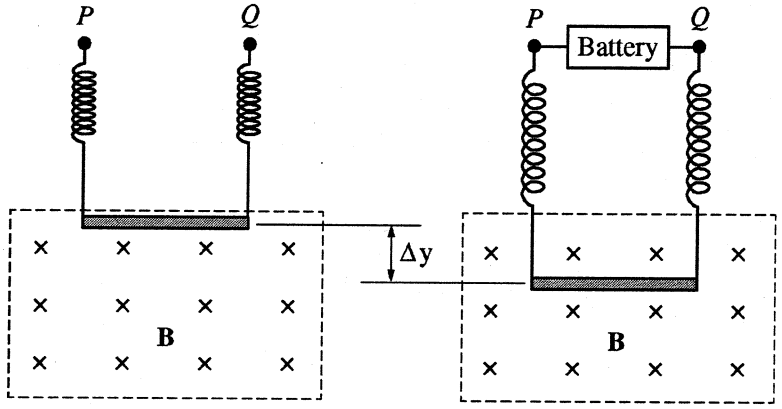
____ Positive ____ Negative ____ Zero

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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



No Battery Battery Connected

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.

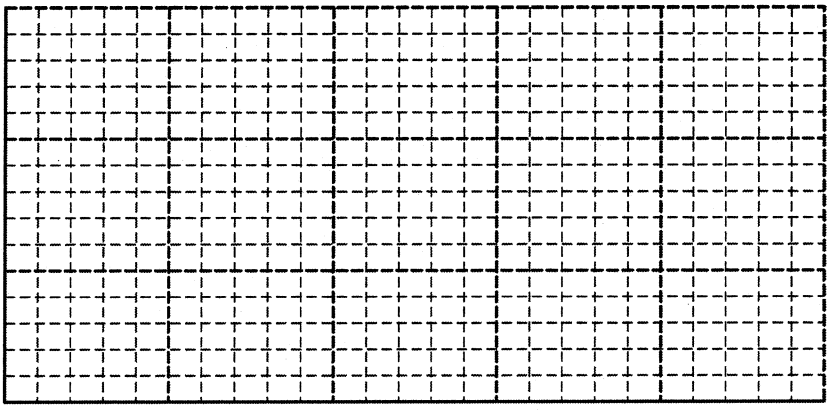
© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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

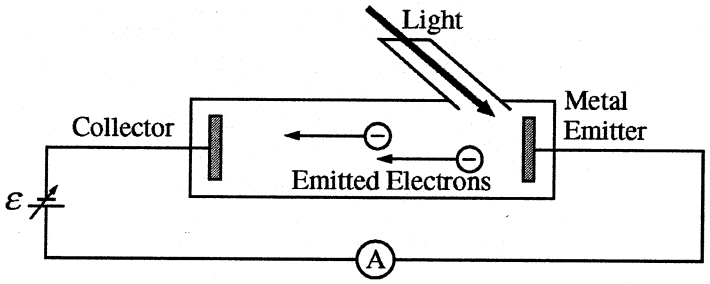
(d) On the grid below, plot the data points for Δy as a function of I. Be sure to label your axes with variables, units, and scale. Draw a straight line that best represents the data.



(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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

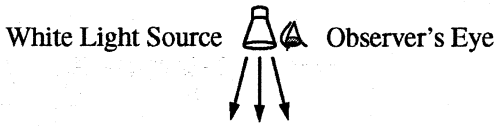
(e) If the wavelength of light is decreased while the power per unit area (intensity) of the incident light stays the same, does the number of electrons emitted from the metal surface per unit time increase, decrease, or remain the same? (Assume that the light is initially above the threshold frequency.)

____ Increases ____ Decreases ____ Remains the same

Justify your answer.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

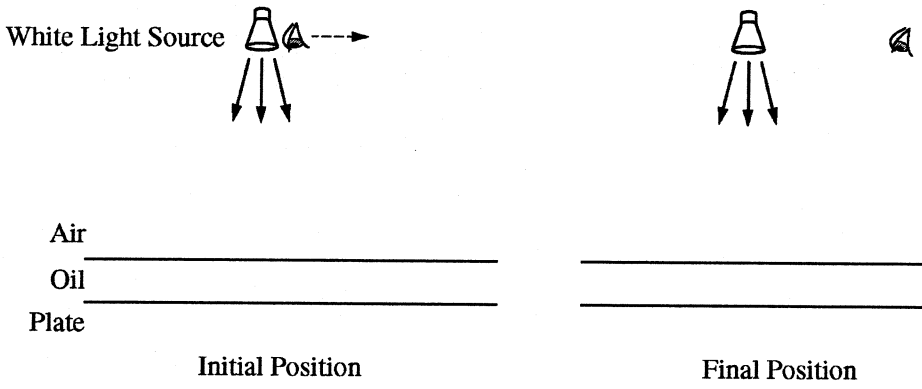
(d) The oil film thickness is half of the wavelength you found in part (c). Is the index of refraction of the plate greater than, less than, or equal to that of the oil?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2014 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2014 Scoring Guidelines

© 2014 The College Board. College Board, Advanced Placement Program, AP, AP Central, and the acorn logo are registered trademarks of the College Board.
Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



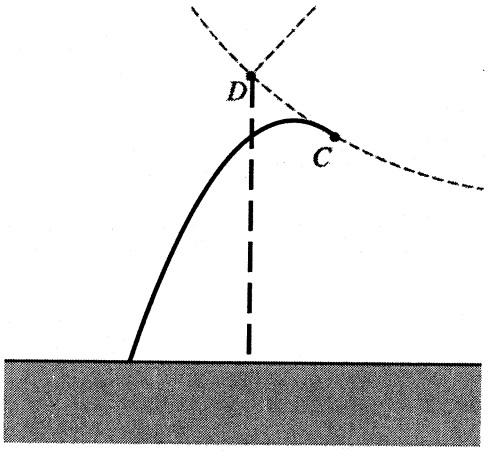
AP® PHYSICS B
2014 SCORING GUIDELINES

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

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(d) 3 points

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

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

For correctly solving for the time of fall — 1 point

$\Delta y = \frac{1}{2}at^2$

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

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

$t = 0.70$ 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

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

$R = 4.1$ 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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

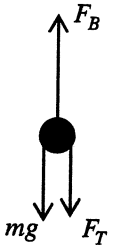
AP® PHYSICS B
2014 SCORING GUIDELINES

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

$F_B = F_g + 0.25F_g = 1.25F_g$

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

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

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

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

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

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*

$\rho_W Vg = mg + 0.25mg$

$\rho_W V = 1.25m$

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

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*

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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
$PV = nRT$
$T = \frac{PV}{nR}$
$T_D = \frac{P_0(4V_0)}{3R} = \frac{4P_0V_0}{3R}$ or $\frac{4P_0V_0}{(3\text{ mol})\cdot R}$
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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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 — 1 point

$W_{net} = -(P\Delta V)_{BC} - (P\Delta V)_{DA}$

For correctly substituting the values of P and ΔV into the above equation — 1 point

$W_{net} = -(3P_0)(3V_0) - (P_0)(-3V_0) = -9P_0V_0 + 3P_0V_0 = -6P_0V_0$

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 — *1 point*

$W_{net} = -(\Delta P \bullet \Delta V)$

For correctly substituting the values of P and ΔV into the above equation — *1 point*

$W_{net} = -(3P_0 - P_0)\bullet(4V_0 - V_0) = -2P_0 \bullet 3V_0 = -6P_0V_0$

For having a negative answer — *1 point*

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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

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

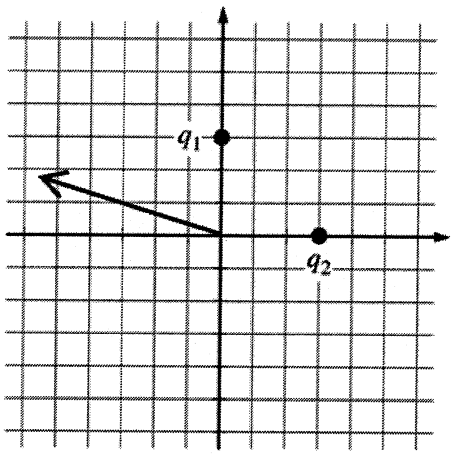
For correctly calculating the x and y component values with units — 1 point

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

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

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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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

$V = 12$ 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

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

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

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

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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*

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

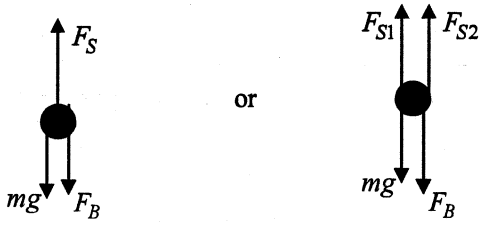
Question 5

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
$\Delta y = BIL/2k$

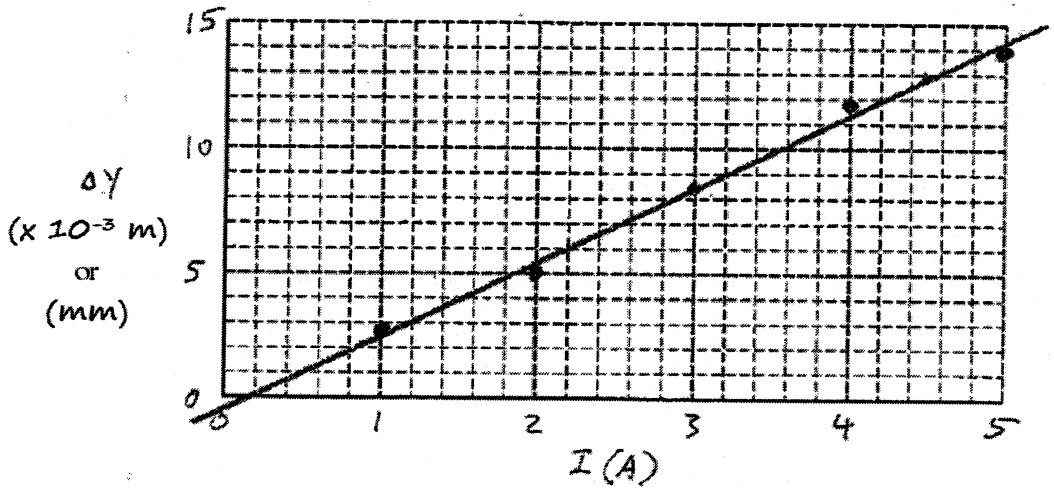
© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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): $\Delta y = \frac{BIL}{2k} = \frac{BL}{2k} I$

$\text{slope} = \frac{BL}{2k}$ so $B = \frac{2k \cdot \text{slope}}{L}$

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.

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

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

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

Question 6

10 points total | **Distribution of points**

(a) 1 point

For correctly calculating the wavelength, with units — 1 point

$c = \lambda f$

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

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

(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

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

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

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))

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

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

(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

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

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

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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 $n_{\text{plate}} > n_{\text{oil}}$.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2014 SCORING GUIDELINES

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.

© 2014 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2013 Free-Response Questions

About the College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of more than 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

© 2013 The College Board. College Board, Advanced Placement Program, AP, AP Central, SAT, and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service and inspiring minds are trademarks owned by the College Board. All other products and services may be trademarks of their respective owners. Visit the College Board on the Web: www.collegeboard.org. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.org/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



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,	$1\text{ u} = 1.66 \times 10^{-27}$ 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 DEVELOPED FOR 2012

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
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

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

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

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

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + \ldots$

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

$R_s = R_1 + R_2 + R_3 + \ldots$

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

$F_B = qvB\sin\theta$

$F_B = BI\ell\sin\theta$

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

$\phi_m = BA\cos\theta$

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

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

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
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

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

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

$PV = nRT = Nk_BT$

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

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

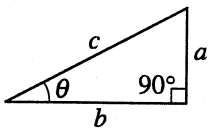
Circle
$A = \pi r^2$
$C = 2\pi r$

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

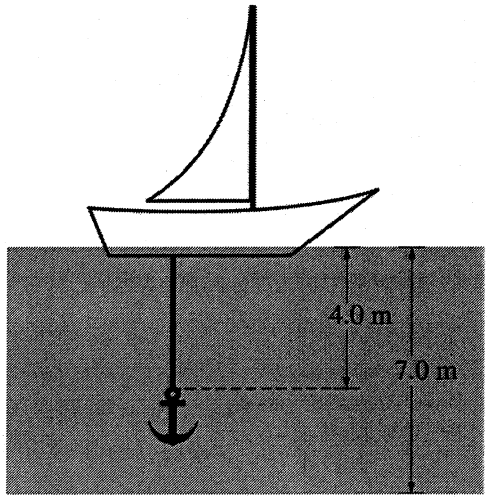


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2013 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 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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

(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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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.

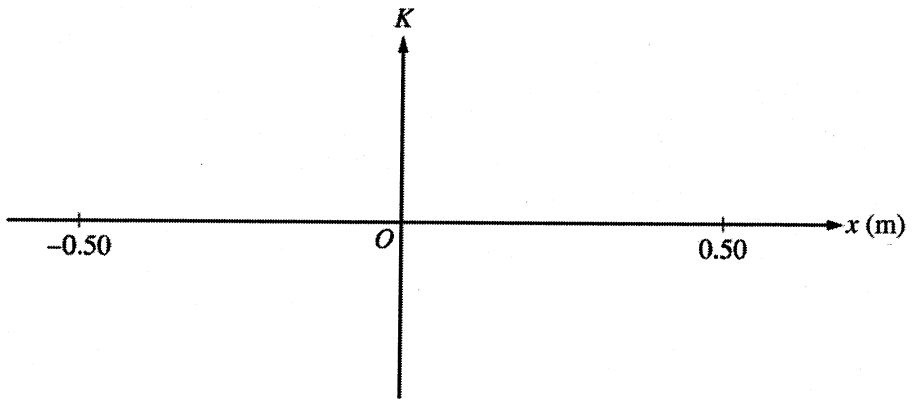
(d) Calculate the frequency of the oscillation of the box.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

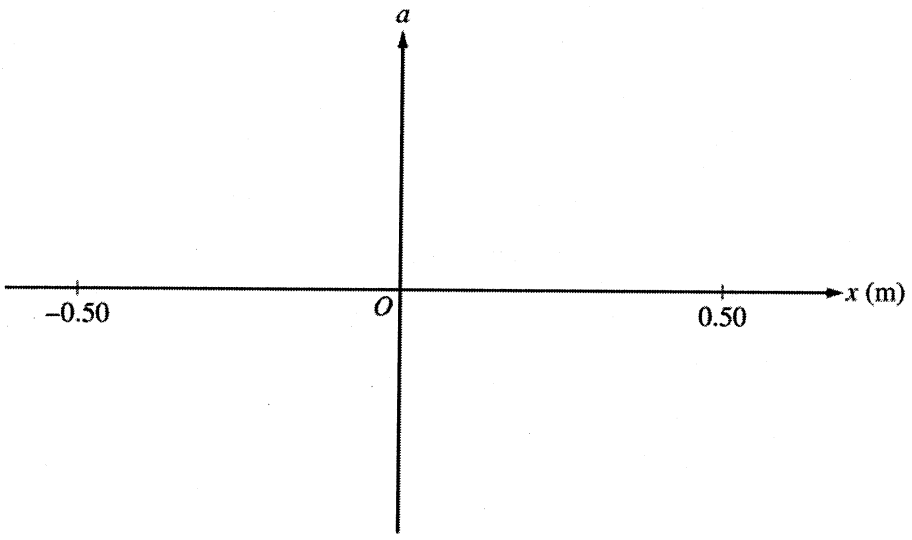
2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS

(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.

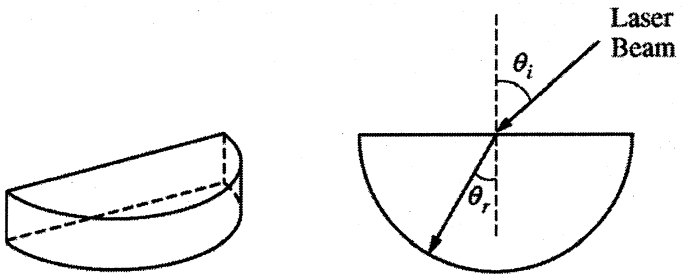


ii. On the axes below, sketch the acceleration a of the oscillating box as a function of position x for the range $x = -0.50$ m to $x = +0.50$ m.



© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS

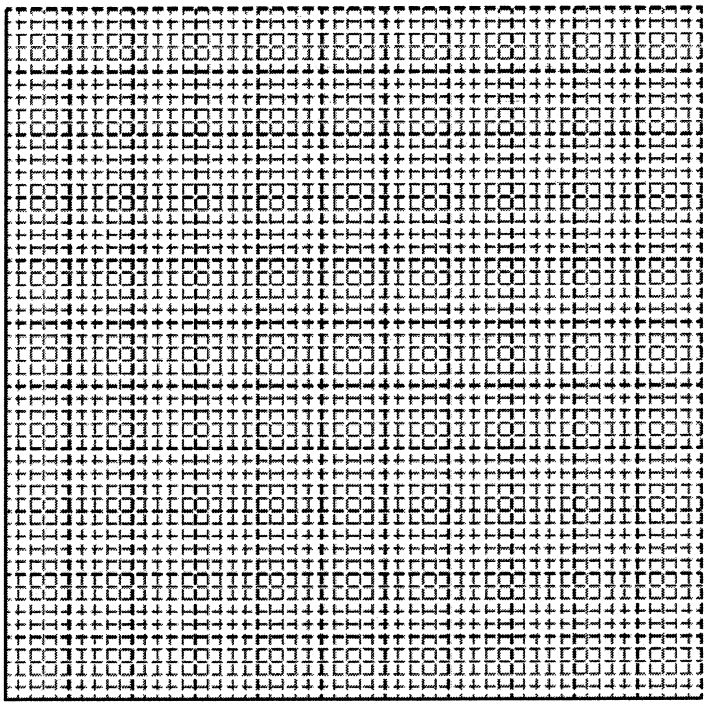


3. (10 points)

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.



© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

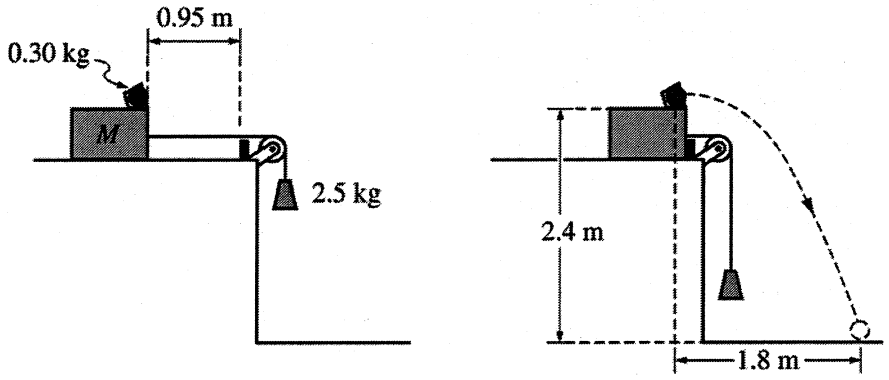
GO ON TO THE NEXT PAGE.

(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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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?

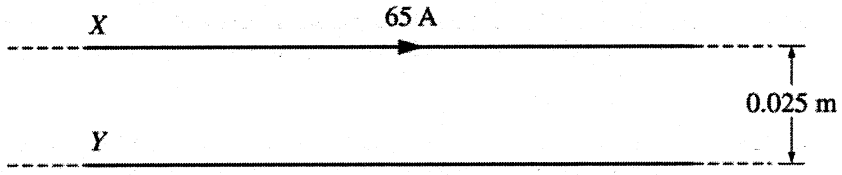
____ Energy is transferred into the gas. ____ Energy is transferred out of the gas.

____ There is no energy transfer by heating.

Justify your answer.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

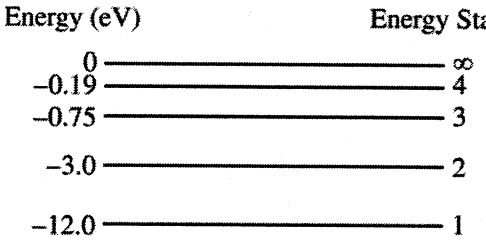
____ The left end ____ The right end

____ Neither end, since they are at the same electric potential

Justify your answer.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2013 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® Physics B
2013 Scoring Guidelines

The College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

© 2013 The College Board. College Board, Advanced Placement Program, AP, SAT and the acorn logo are registered trademarks of the College Board. All other products and services may be trademarks of their respective owners.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.

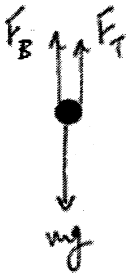
AP® PHYSICS B
2013 SCORING GUIDELINES

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 $g = 10 \text{ m/s}^2$)

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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

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

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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 2 (continued)

Distribution of points

(d) 2 points

For a correct expression of the frequency 1 point

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

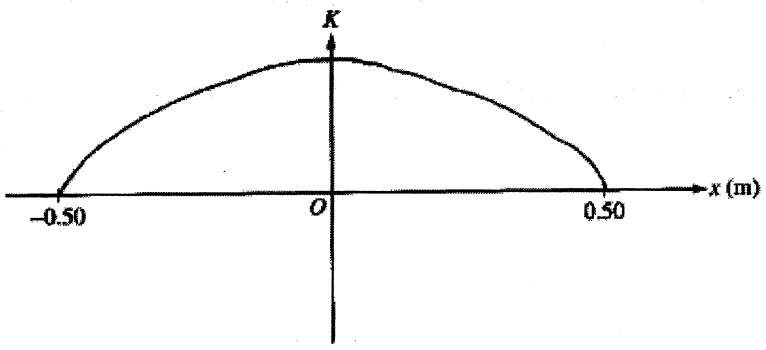
For correct substitution consistent with the answer from part (b) 1 point

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

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

(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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

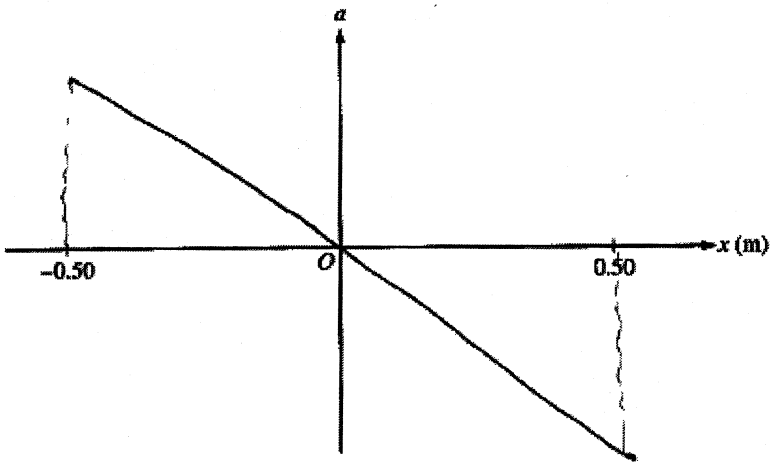
AP® PHYSICS B
2013 SCORING GUIDELINES

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

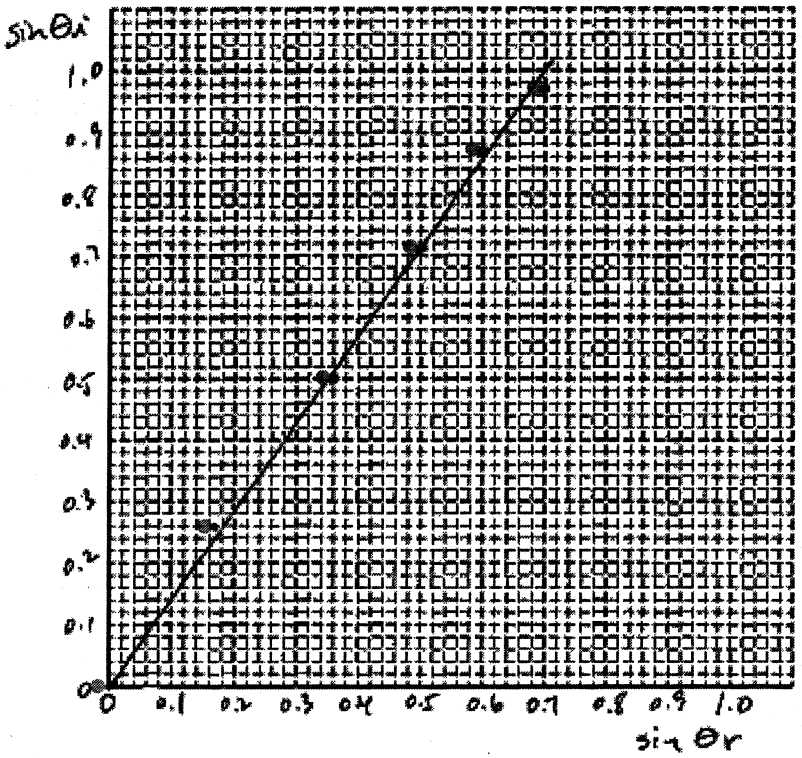
© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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
$n = 1.43$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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 $n = 1/\sin\theta_c$.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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

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

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

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

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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) 3 points

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

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

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

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

(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 $(v_{launch} \times t_{fall})$ will be less.

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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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

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

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

$I = 106$ 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

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

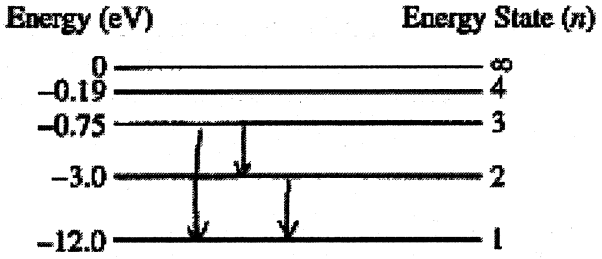
© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

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.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2012 Free-Response Questions

About the College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of more than 5,900 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

© 2012 The College Board. College Board, Advanced Placement Program, AP, AP Central, SAT, and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service and inspiring minds are trademarks owned by the College Board. All other products and services may be trademarks of their respective owners. Visit the College Board on the Web: www.collegeboard.org. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.org/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



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,	$1\text{ u} = 1.66 \times 10^{-27}$ 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 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

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

$K = \frac{1}{2}mv^2$

$\Delta U_g = mgh$

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

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

$P = Fv\cos\theta$

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

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

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

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

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

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

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

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
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

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

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

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

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

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

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = C_1 + C_2 + C_3 + \ldots$

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

$R_s = R_1 + R_2 + R_3 + \ldots$

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

$F_B = qvB\sin\theta$

$F_B = BI\ell\sin\theta$

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

$\phi_m = BA\cos\theta$

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

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

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
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

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

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

$PV = nRT = Nk_BT$

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

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

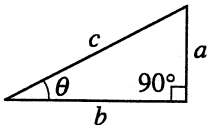
Circle
$A = \pi r^2$
$C = 2\pi r$

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

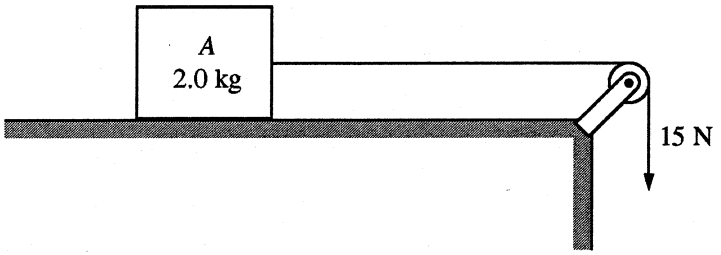


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2012 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 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.

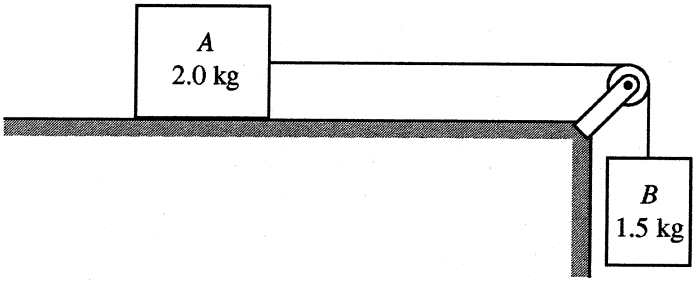
(a) On the dot below, which represents the block, draw and label the forces (not components) that act on the block as it is pulled across the table.

●

(b) Calculate the magnitude of the acceleration of the block.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

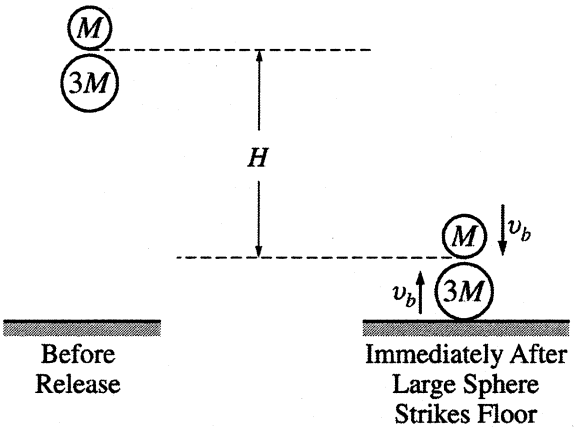
(d) Calculate the tension in the string connecting the two blocks.

(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.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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 $v_L = 0$.

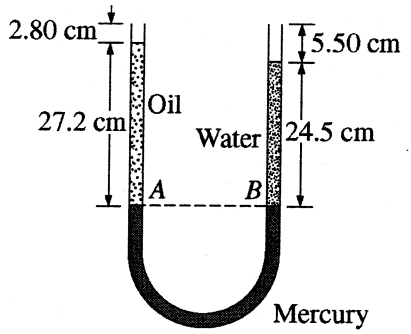
(c) Use your relationship from part (b) to determine the speed of the small sphere in terms of v_b.

(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.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS

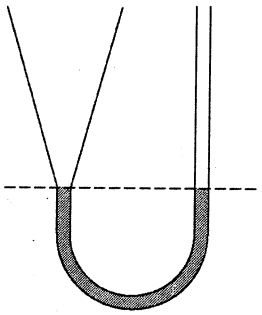


3. (10 points)

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 1.00×10^3 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

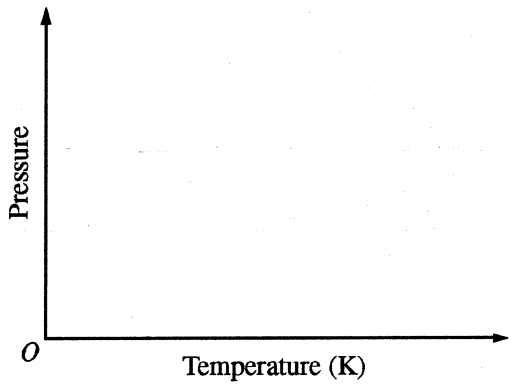
© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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.

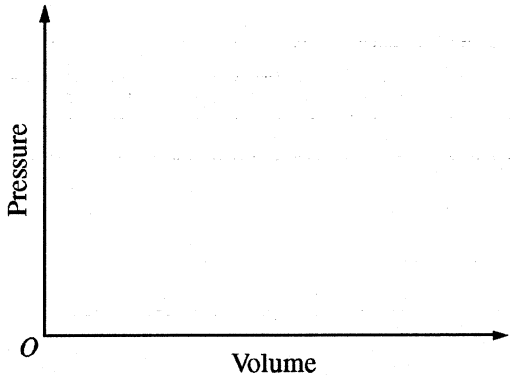


(b) The cylinder is removed from the hot-water bath. After equilibrium is reached, the lock is removed so the piston is free to move. Indicate whether the piston moves up, moves down, or remains stationary.

____ Moves up ____ Moves down ____ Remains stationary

Justify your answer.

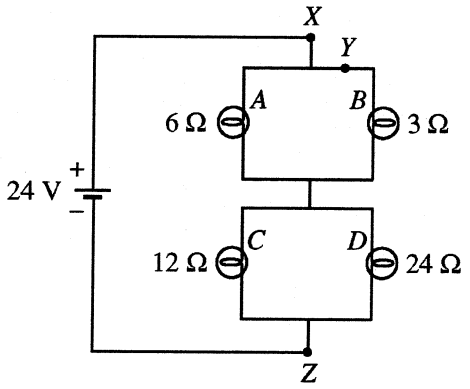
(c) When the system is again at equilibrium, the piston is pushed down very slowly. On the axes below, sketch a graph of pressure versus volume for the process the gas undergoes as a result, and indicate the direction of the process on the graph. Label this process "C."



(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."

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

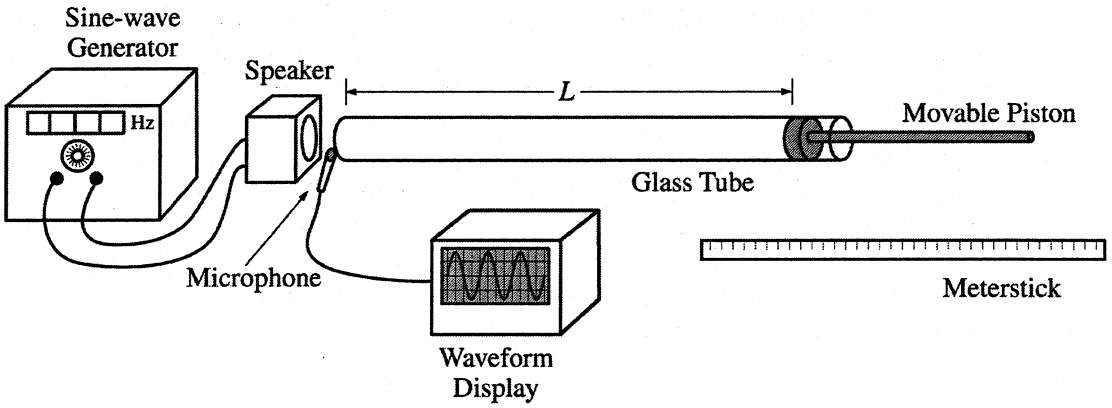
(d) Calculate the energy dissipated in the 12 Ω bulb in 5 s.

(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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2012 AP® PHYSICS B FREE-RESPONSE QUESTIONS

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2012 Scoring Guidelines

The College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of more than 5,900 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

© 2012 The College Board. College Board, Advanced Placement Program, AP, SAT and the acorn logo are registered trademarks of the College Board. All other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.com/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.org.



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.

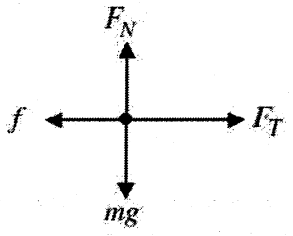
© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

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 $g = 10\text{ m/s}^2$)

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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*

$$a = \frac{m_B g - \mu m_A g}{(m_A + m_B)} = \frac{(1.5\text{ kg})(9.8\text{ m/s}^2) - (0.25)(2.0\text{ kg})(9.8\text{ m/s}^2)}{(2.0\text{ kg} + 1.5\text{ kg})}$$

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

$F_T = m_A(a + \mu g)$
$= (2.0\text{ kg})(2.8\text{ m/s}^2 + (0.25)(9.8\text{ m/s}^2))$

or

$F_T = m_B(g - a)$
$= (1.5\text{ kg})(9.8\text{ m/s}^2 - 2.8\text{ m/s}^2)$

$F_T = 10.5\text{ N}$

(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

$\Delta y = \frac{1}{2}(2.8\text{ m/s}^2)(0.40\text{ s})^2$

$\Delta y = 0.22\text{ m}$

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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*.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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

$v_S = 2v_b$

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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
$P_{atm} + \rho_o g h_o = P_{atm} + \rho_w g h_w$ — 1 point

For a substitution of the correct density and the correct heights
$\rho_o = \rho_w h_w / h_o = (1000 \text{ kg/m}^3)(24.5 \text{ cm})/(27.2 \text{ cm})$ — 1 point

For the correct answer
$\rho_o = 901 \text{ kg/m}^3$ — 1 point

(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
$P = P_0 + \rho g h = (1.0 \times 10^5 \text{ Pa}) + (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(0.245 \text{ m})$
$P = 1.02 \times 10^5 \text{ Pa}$

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

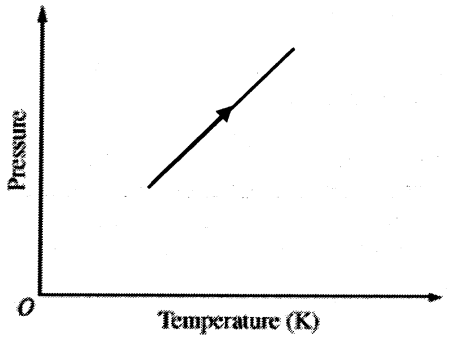
AP® PHYSICS B
2012 SCORING GUIDELINES

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

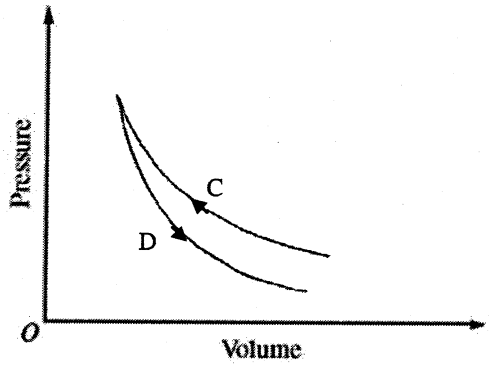
AP® PHYSICS B
2012 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(c) and (d) 5 points

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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

$R_T = R_{AB} + R_{CD} = 2\ \Omega + 8\ \Omega$

$R_T = 10\ \Omega$

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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 $D = 2$

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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 $v = \lambda f$.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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.

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2012 SCORING GUIDELINES

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

© 2012 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

CollegeBoard
Advanced Placement
Program

AP® Physics B
2011 Free-Response Questions

About the College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of more than 5,900 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators and schools.

© 2011 The College Board. College Board, Advanced Placement Program, AP, AP Central, SAT and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service and inspiring minds are trademarks owned by the College Board. All other products and services may be trademarks of their respective owners. Visit the College Board on the Web: www.collegeboard.org. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.org/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

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

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(x - x_0)$

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

$K = \frac{1}{2}mv^2$

$\Delta U_g = mgh$

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

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

$P = Fv\cos\theta$

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

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

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

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

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

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

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

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
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
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

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

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

$PV = nRT = Nk_BT$

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

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

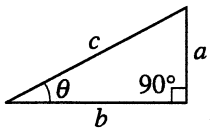
Circle
$A = \pi r^2$
$C = 2\pi r$

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

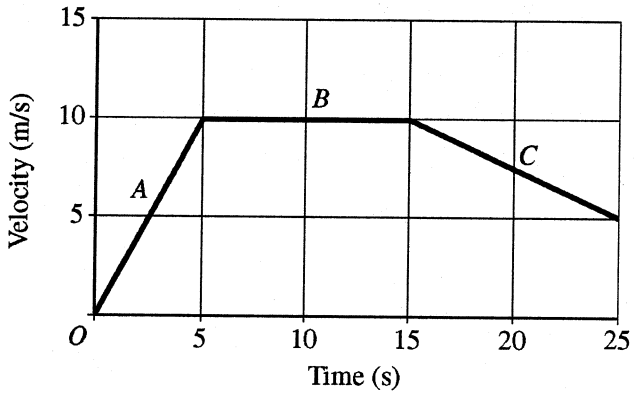


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS

PHYSICS B
SECTION II
Time—90 minutes
6 Questions

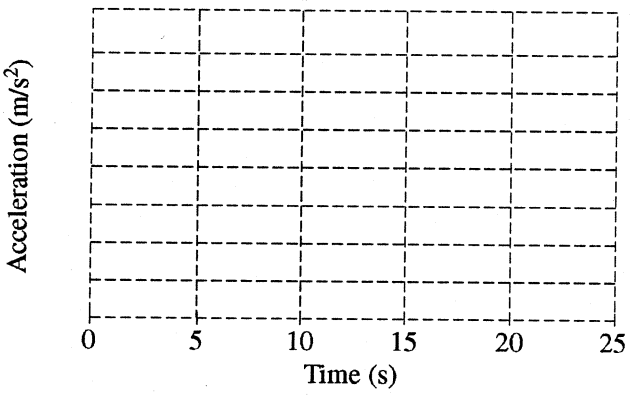
Directions: Answer all six questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-3 and 5 and about 11 minutes for answering each of Questions 4 and 6. The parts within a question may not have equal weight. Show all 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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

GO ON TO THE NEXT PAGE.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS

(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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS

2. (15 points)

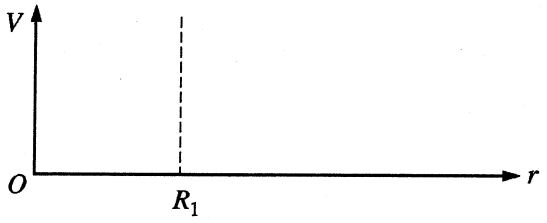
An isolated, solid copper sphere of radius $R_1 = 0.12$ m has a positive charge of 6.4×10^{-9} C.

(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.

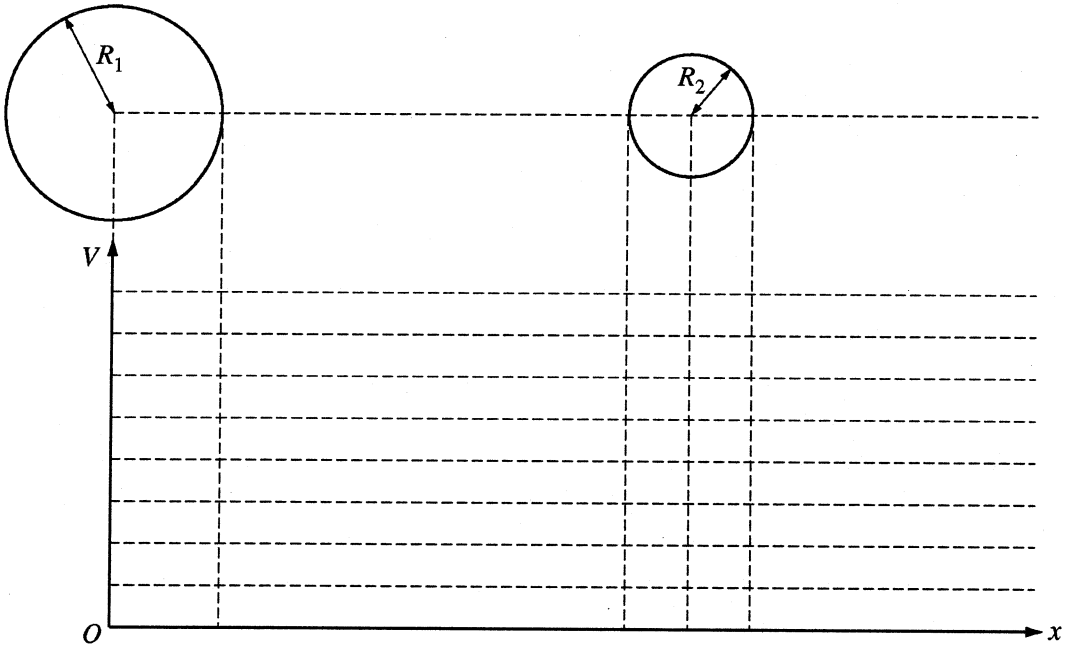


(c)

i. Determine the magnitude of the electric field at a point 0.10 m from the center of the sphere.

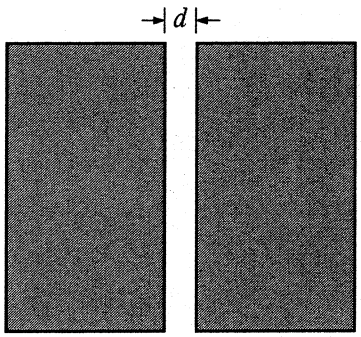
ii. Determine the magnitude of the electric field at a point 0.24 m from the center of the sphere.

(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 $x = 0$.

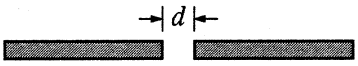


© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

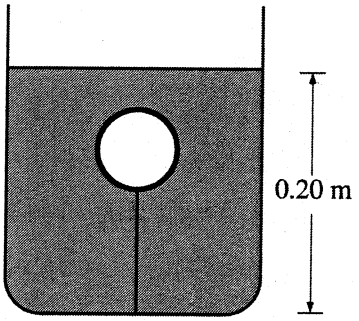
(c) Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.

(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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

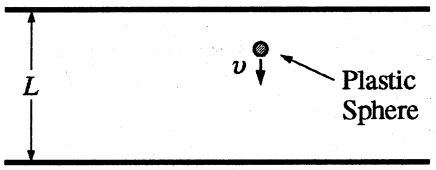
(e) The string is cut, and the ball rises to the surface and floats. Indicate whether the water level is higher, lower, or the same after equilibrium is reached.

____ Higher ____ Lower ____ The same

Justify your answer.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS



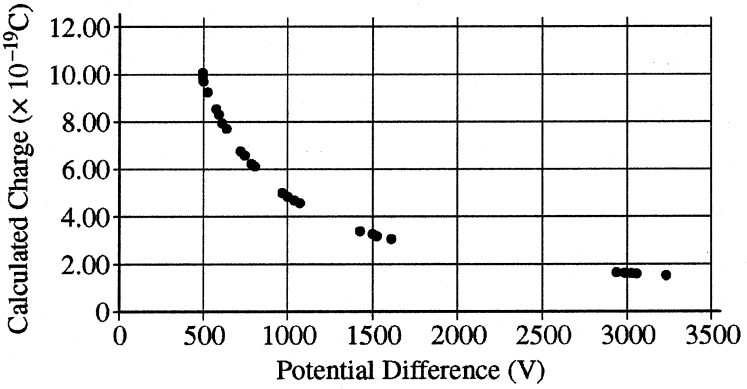
Note: Figure not drawn to scale.

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.



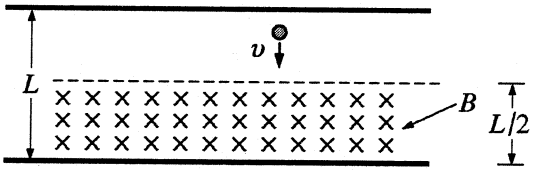
(b) Provide a physical explanation for the gap observed in the data between potential differences of 1700 V and 2800 V.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

2011 AP® PHYSICS B FREE-RESPONSE QUESTIONS

(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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.



AP® Physics B
2011 Scoring Guidelines

The College Board

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the College Board is composed of more than 5,700 schools, colleges, universities and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,800 colleges through major programs and services in college readiness, college admission, guidance, assessment, financial aid and enrollment. Among its widely recognized programs are the SAT®, the PSAT/NMSQT®, the Advanced Placement Program® (AP®), SpringBoard® and ACCUPLACER®. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities and concerns.

© 2011 The College Board. College Board, ACCUPLACER, Advanced Placement Program, AP, AP Central, SAT, SpringBoard and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service is a trademark owned by the College Board. PSAT/NMSQT is a registered trademark of the College Board and National Merit Scholarship Corporation. All other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.com/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.org.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com

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 $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ 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.

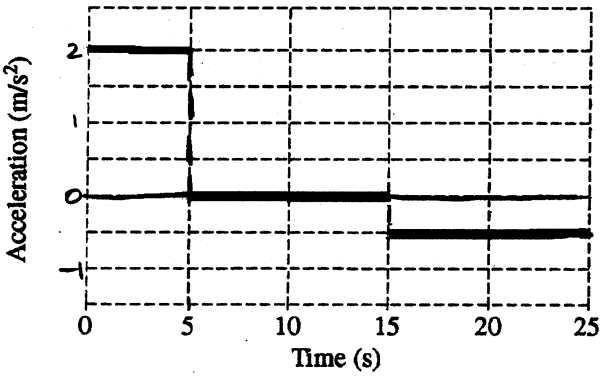
© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

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 2m/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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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
$F_{net} = ma$
$F_{net} = (0.40 \text{ kg})(2 \text{ m/s}^2)$
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*
$W = 20 \text{ J}$

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

Question 1 (continued)

		Distribution of points
(f)	3 points	
	For selecting "Negative"	1 point
	For an appropriate explanation using kinematic or dynamic principles 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.	1 point
	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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

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

$V = \frac{(9.0 \times 10^9 \text{ N•m}^2/\text{C}^2)(6.4 \times 10^{-9} \text{ C})}{0.12 \text{ m}}$

For the correct answer — 1 point

$V = 480 \text{ V}$

ii. 2 points

For writing the appropriate expression for the electric potential — 1 point

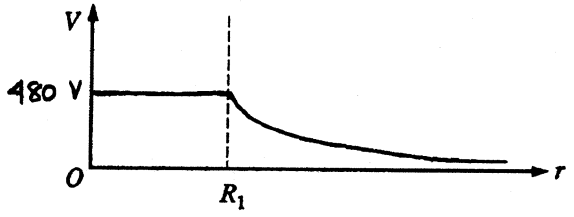
$V = \frac{kq}{r}$

$V = \frac{(9.0 \times 10^9 \text{ N•m}^2/\text{C}^2)(6.4 \times 10^{-9} \text{ C})}{0.24 \text{ m}}$

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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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

$$E = \frac{kq}{r^2}$$

$$E = \frac{\left(9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9} \text{ C}\right)}{(0.24 \text{ m})^2}$$

For the correct answer — 1 point

$E = 1000 \text{ N/C}$

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

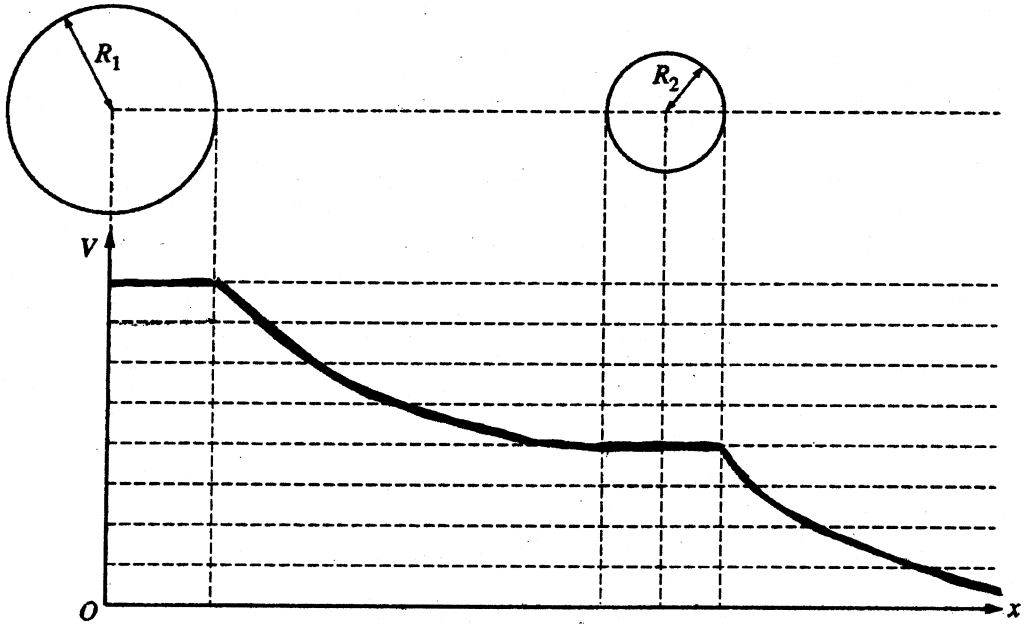
AP® PHYSICS B
2011 SCORING GUIDELINES

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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

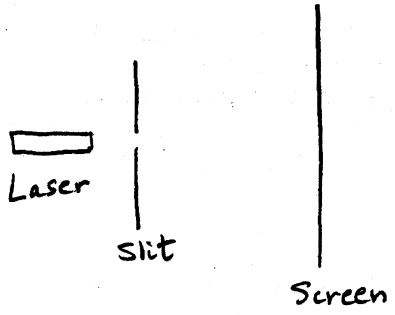
Question 3

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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

$W_{tot} = W_{beaker} + W_{ball} + W_{water}$

For calculating W_{water} — 1 point

$\rho = m/V$, so $m = \rho V$

$W_{water} = m_{water}g = \rho_{water}V_{water}g$

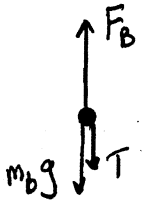
$W_{water} = \left(1000\ \text{kg/m}^3\right)\left(5.0 \times 10^{-3}\ \text{m}^3\right)\left(9.8\ \text{m/s}^2\right) = 49\ \text{N}$

$W_{water} = 49\ \text{N}$

$W_{tot} = 2.0\ \text{N} + 3.0\ \text{N} + 49\ \text{N}$

$W_{tot} = 54\ \text{N}$ (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

$F_B = 7.0\ \text{N}$

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

Question 4 (continued)

Distribution of points

(d) 2 points

$P = \rho g h$

For correct substitutions — 1 point

$P = (1000\ \text{kg/m}^3)(9.8\ \text{m/s}^2)(0.20\ \text{m})$

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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 $F_B = qvB$ — 1 point

For a correct substitution for the centripetal force $ma_c = mv^2/r$ — 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.

$qvB = m\frac{v^2}{r}$

Note: If a response starts with the equation above, 3 points are earned.

$B = \frac{mv}{qr}$

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.

$B_{min} = \frac{2mv}{qL}$

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

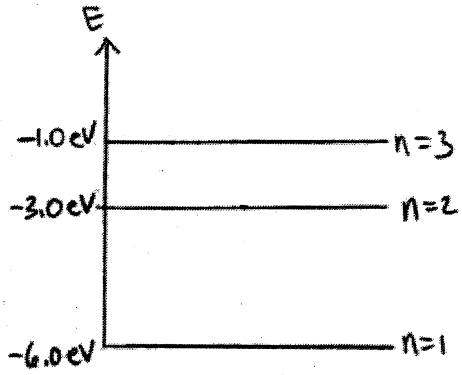
AP® PHYSICS B
2011 SCORING GUIDELINES

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

$n = 3 \rightarrow n = 1$

$\Delta E = -1 \text{ eV} - (-6 \text{ eV}) = 5 \text{ eV}$

$$\lambda_{n=3\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV·nm}}{5.0 \text{ eV}} = 248 \text{ nm}$$

$n = 3 \rightarrow n = 2$

$\Delta E = -1 \text{ eV} - (-3 \text{ eV}) = 2 \text{ eV}$

$$\lambda_{n=3\rightarrow n=2} = \frac{1.24 \times 10^3 \text{ eV·nm}}{2.0 \text{ eV}} = 620 \text{ nm}$$

$n = 2 \rightarrow n = 1$

$\Delta E = -3 \text{ eV} - (-6 \text{ eV}) = 3 \text{ eV}$

$$\lambda_{n=2\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV·nm}}{3.0 \text{ eV}} = 413 \text{ nm}$$

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2011 SCORING GUIDELINES

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.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

CollegeBoard
Advanced Placement Program

AP® Physics B
2010 Free-Response Questions

The College Board

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the College Board is composed of more than 5,700 schools, colleges, universities and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,800 colleges through major programs and services in college readiness, college admission, guidance, assessment, financial aid and enrollment. Among its widely recognized programs are the SAT®, the PSAT/NMSQT®, the Advanced Placement Program® (AP®), SpringBoard® and ACCUPLACER®. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities and concerns.

© 2010 The College Board. College Board, ACCUPLACER, Advanced Placement Program, AP, AP Central, SAT, SpringBoard and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service is a trademark owned by the College Board. PSAT/NMSQT is a registered trademark of the College Board and National Merit Scholarship Corporation. All other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.com/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.com.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

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

$v = v_0 + at$

$x = x_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0{}^2 + 2a(x - x_0)$

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

$F_{fric} \le \mu N$

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

$\tau = rF \sin\theta$

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

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

$K = \frac{1}{2}mv^2$

$\Delta U_g = mgh$

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

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

$P = Fv\cos\theta$

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

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

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

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

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

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

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

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
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
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2010 and 2011

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

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

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

$PV = nRT = Nk_B T$

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

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

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

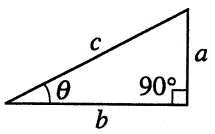
Circle
$A = \pi r^2$
$C = 2\pi r$

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

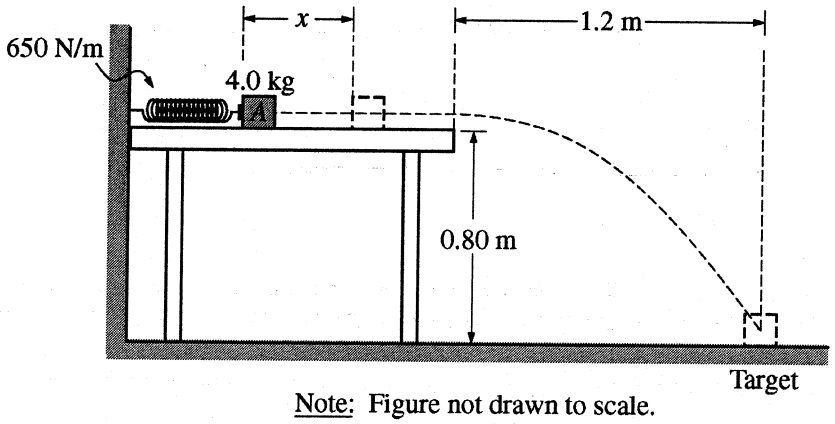


A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

2010 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 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 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.

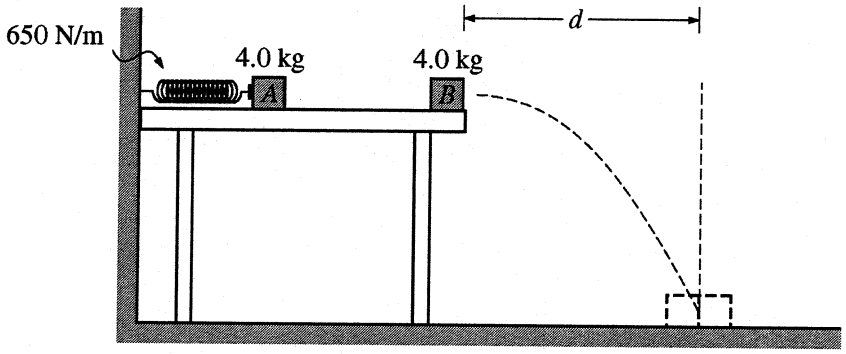
(c) Calculate the distance x the spring was compressed.

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.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

GO ON TO THE NEXT PAGE.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



Note: Figure not drawn to scale.

(d) Calculate d if x is equal to the value determined in part (c).

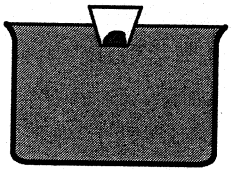
(e) Consider the system consisting of the spring, the blocks, and the table. How does the total mechanical energy E_2 of the system just before the blocks leave the table compare to the total mechanical energy E_1 of the system just before block A is released?

____ $E_2 < E_1$ ____ $E_2 = E_1$ ____ $E_2 > E_1$

Justify your answer.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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).

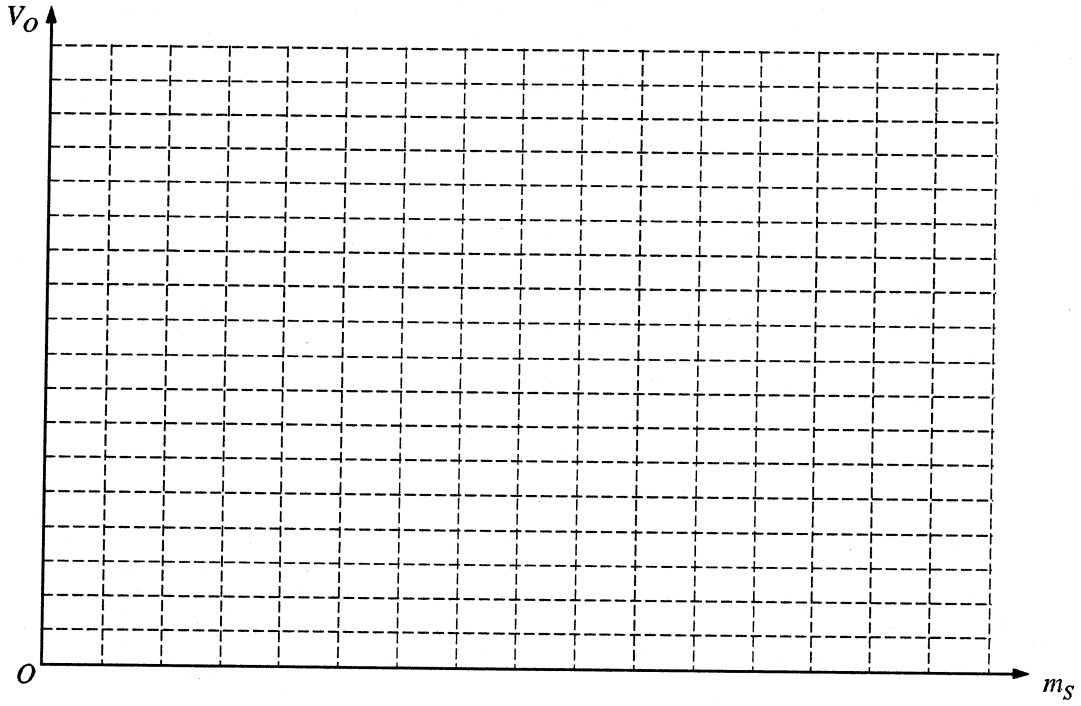
Assume that the following data are obtained for the overflow volume V_O for several sample masses m_S.

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}

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS

(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.

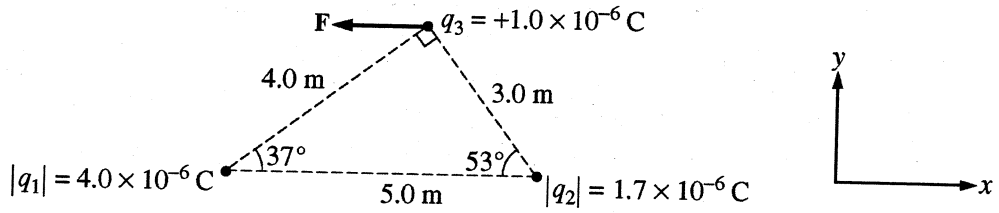


(d) Use the slope of the best-fit line to calculate the density of the oil.

(e) What is the physical significance of the intercept of your line with the vertical axis?

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



3. (10 points)

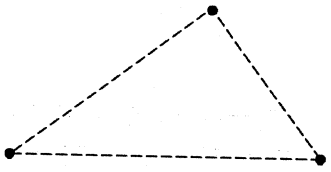
Three particles are fixed in place in a horizontal plane, as shown in the figure above. Particle 3 at the top of the triangle has charge q_3 of $+1.0 \times 10^{-6}$ C, and the electrostatic force **F** on it due to the charge on the two other particles is measured to be entirely in the negative x-direction. 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 ____ Positive

q_2 ____ Negative ____ Positive

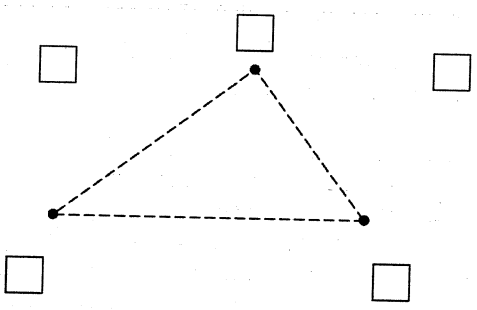
(b) On the diagram below, draw and label arrows to indicate the direction of the force F_1 exerted by particle 1 on particle 3 and the force F_2 exerted by particle 2 on particle 3.



(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.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS

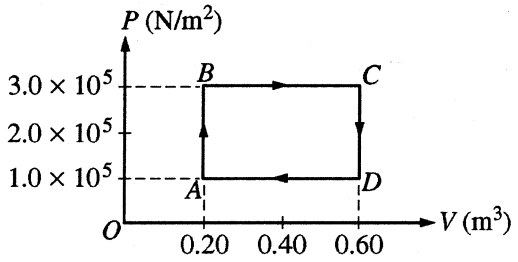
4. (10 points)

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 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?

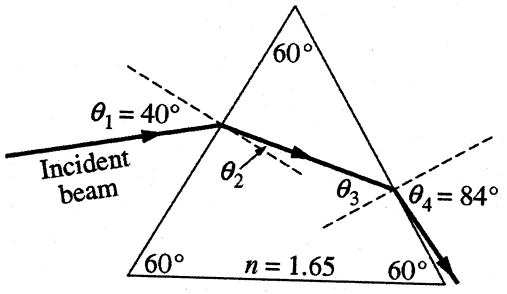
ii. Calculate the power output of the engine.

(d) Indicate below all of the processes during which heat is added to the gas in the heat engine.

____ *AB* ____ *BC* ____ *CD* ____ *DA*

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

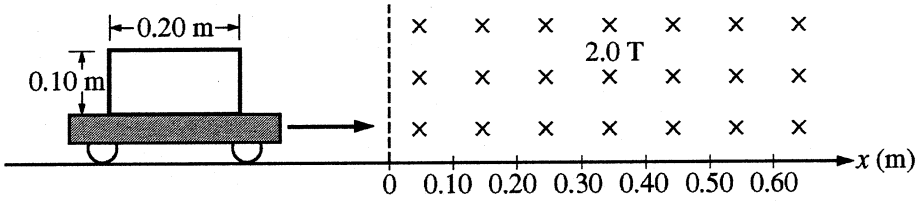
i. Calculate the wavelength of the red light in the film.

ii. Calculate the minimum thickness of the film for which the intensity of the reflected red ray is near zero.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

GO ON TO THE NEXT PAGE.

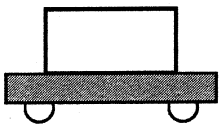
2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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.

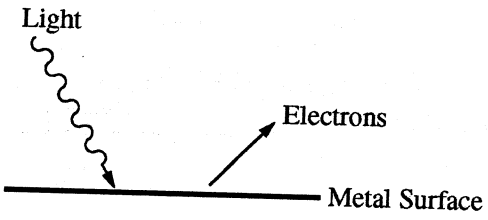
i. The magnitude of the induced current in the rectangular loop of wire

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.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

2010 AP® PHYSICS B FREE-RESPONSE QUESTIONS



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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.



AP® Physics B
2010 Scoring Guidelines

The College Board

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the College Board is composed of more than 5,700 schools, colleges, universities and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,800 colleges through major programs and services in college readiness, college admission, guidance, assessment, financial aid and enrollment. Among its widely recognized programs are the SAT®, the PSAT/NMSQT®, the Advanced Placement Program® (AP®), SpringBoard® and ACCUPLACER®. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities and concerns.

© 2010 The College Board. College Board, ACCUPLACER, Advanced Placement Program, AP, AP Central, SAT, SpringBoard and the acorn logo are registered trademarks of the College Board. Admitted Class Evaluation Service is a trademark owned by the College Board. PSAT/NMSQT is a registered trademark of the College Board and National Merit Scholarship Corporation. All other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.com/inquiry/cbpermit.html.

Visit the College Board on the Web: www.collegeboard.com.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

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.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

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

$v = \frac{x}{t} = \frac{1.2\text{ m}}{0.40\text{ s}}$

$v = 3.0$ 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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(d) 4 points

For any statement of conservation of momentum
$m_A v_i = (m_A + m_B)v_f$ — 1 point

For substitution of both masses into the equation
For substitution of the velocity from part (b) into the equation — 1 point
$v_f = \left(\frac{m_A}{m_A + m_B}\right)v_i = \left(\frac{4\text{ kg}}{4\text{ kg} + 4\text{ kg}}\right)3.0\text{ m/s} = 1.5\text{ m/s}$ — 1 point

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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

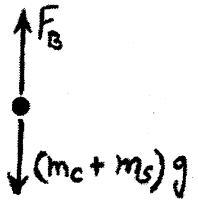
AP® PHYSICS B
2010 SCORING GUIDELINES

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

$F_B = F_g$

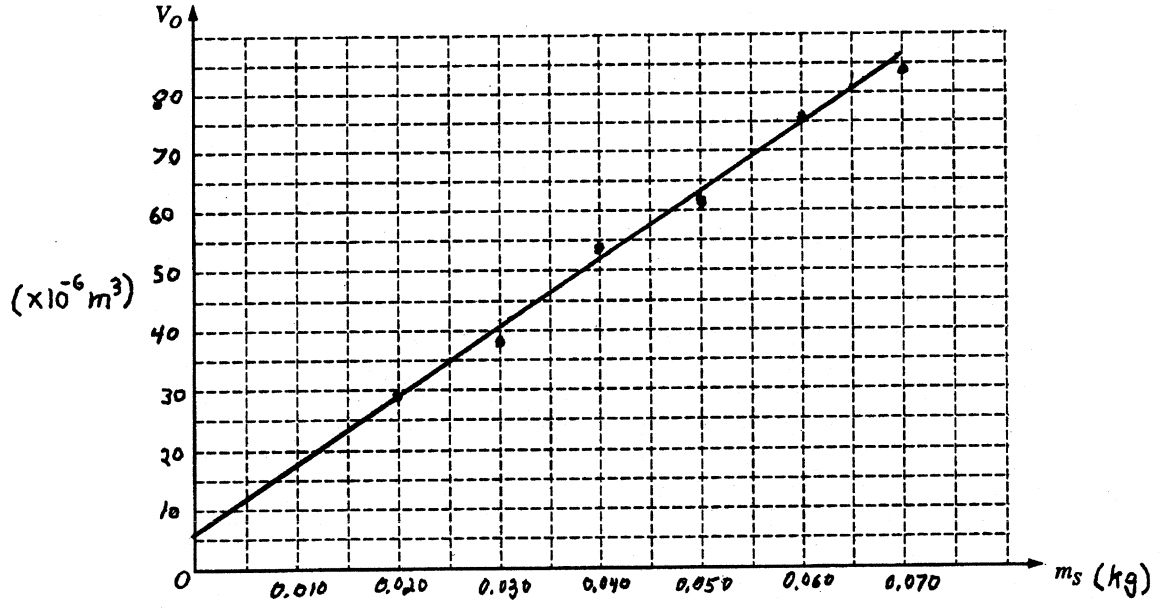
For a correct substitution including both masses m_C and m_S — 1 point

$\rho_O V_O g = (m_C + m_S)g$

For correct statement of the overflow volume, V_O — 1 point

$$V_O = \frac{m_C + m_S}{\rho_O}$$

(c) 4 points



© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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

$\rho_O = 8.8 \times 10^2 \text{ kg/m}^3$

(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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

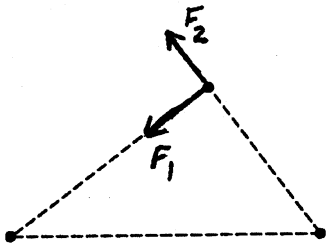
Question 3

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

$$F = 2.8\times10^{-3}\ \text{N}$$

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(d) 2 points

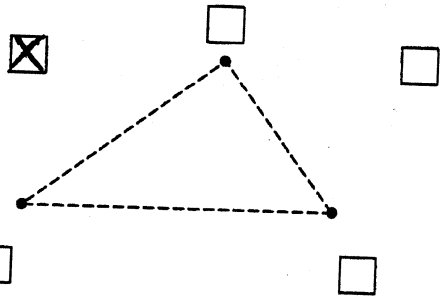
For substituting the value of F from part (c) and using the correct value for q_3 — 1 point

$$E = \frac{F}{q_3} = \frac{2.8 \times 10^{-3}\ \text{N}}{1.0 \times 10^{-6}\ \text{C}}$$

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
$E = 2.8 \times 10^3\ \text{N/C}$ — 1 point

(e) 2 points



For an × 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**.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

Question 4

10 points total

Distribution of points

(a) 3 points

$e = W_{out}/Q_{in}$ or $e = P_{out}/P_{in}$ $\left(\text{i.e. } \dfrac{W_{out}/t}{Q_{in}/t}\right)$

For a correct substitution of the efficiency into a correct equation — 1 point

$0.12 = W_{out}/Q_{in}$ or $0.12 = P_{out}/P_{in}$

For a correct recognition of the relationship between power, energy and time — 1 point

Examples of exhibiting that relationship include: starting with $e = P_{out}/P_{in}$, using $P = W/t$ or Q/t in the efficiency equation or referring to the power as a rate.

$P_{in} = P_{out}/e = 4.5 \times 10^6 \text{ W}/0.12$

For a correct answer with correct units — 1 point

$P_{in} = 3.8 \times 10^7 \text{ W}$

(b) 2 points

$P_{out} = Fv\cos\theta$

$F = P_{out}/(v\cos\theta)$

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.

$P_{out} = W_{out}/\Delta t = 8.0 \times 10^4 \text{ J}/0.25 \text{ s}$

For a consistent calculation of the power output from the work calculated, with units — 1 point

$P_{out} = 3.2 \times 10^5 \text{ W}$

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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.	

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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.

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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

$t = 1.20 \times 10^{-7}\ \text{m}$

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

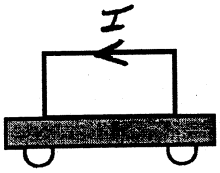
AP® PHYSICS B
2010 SCORING GUIDELINES

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

$I = 0.15\text{ A}$

(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

$F_B = (2.0\text{ T})(0.15\text{ A})(0.10\text{ m})\sin 90°$

$F_B = 0.030\text{ N}$

Units 1 point

For correct units in the answers to both parts (i) and (ii) — 1 point

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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

$f = 7.5 \times 10^{14}$ 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

$$\phi = \left(6.63 \times 10^{-34} \text{ J•s}\right)\left(7.5 \times 10^{14} \text{ Hz}\right) - 1.1 \times 10^{-19} \text{ J}$$

$\phi = 3.9 \times 10^{-19}$ 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

$V = 0.69$ V

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.

AP® PHYSICS B
2010 SCORING GUIDELINES

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

© 2010 The College Board.
Visit the College Board on the Web: www.collegeboard.com.