From the 2018 Administration

AP® CollegeBoard

AP Physics C: Mechanics

Practice Exam

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Note: This publication shows the page numbers that appeared in the ***2017–18 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

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Exam Instructions

The following contains instructions taken from the ***2017–18 AP Exam Instructions*** book.

AP Physics C: Mechanics Exam

Regularly Scheduled Exam Date: Monday afternoon, May 14, 2018

Late-Testing Exam Date: Wednesday afternoon, May 23, 2018

Section I	**Total Time:** 45 minutes Calculator Allowed **Number of Questions:** 35 *(The number of questions may vary slightly depending on the form of the exam.)* **Percent of Total Score:** 50% **Writing Instrument:** Pencil required
Section II	**Total Time:** 45 minutes Calculator Allowed **Number of Questions:** 3 **Percent of Total Score:** 50% **Writing Instrument:** Pen with black or dark blue ink, or pencil

Before Distributing Exams: Check that the title on all exam covers is ***Physics C: Mechanics***. If there are any exam booklets with a different title, contact the AP coordinator immediately.

What Proctors Need to Bring to This Exam

- ☐ Exam packets
- ☐ Answer sheets
- ☐ AP Student Packs
- ☐ *2017-18 AP Coordinator's Manual*
- ☐ This book—*2017-18 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ School Code and Homeschool/Self-Study Codes
- ☐ Extra calculators
- ☐ Extra rulers or straightedges
- ☐ Pencil sharpener
- ☐ Container for students' electronic devices (if needed)
- ☐ Extra No. 2 pencils with erasers
- ☐ Extra pens with black or dark blue ink
- ☐ Extra paper
- ☐ Stapler
- ☐ Watch
- ☐ Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited during the test administration, including breaks"

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for this entire exam (Sections I and II). Before starting the exam administration, make sure each student has an appropriate calculator, and any student with a graphing calculator has a model from the approved list on page 52 of the *2017-18 AP Coordinator's Manual*. See pages 49–52 of the *AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, they must hand copy, date, and sign the release statement on page 51 of the *AP Coordinator's Manual*.

During the administration of Section II, students may have no more than two calculators on their desks. Calculators may not be shared. Calculator memories do not need to be cleared before or after the exam. Students with Hewlett-Packard 48–50 Series and Casio FX-9860 graphing calculators may use cards designed for use with these calculators. Proctors should make sure infrared ports (Hewlett-Packard) are not facing each other. **Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the cancellation of AP Exam scores.**

Tables containing equations commonly used in physics are included in each AP Exam booklet, for use during the entire exam. Students are NOT allowed to bring their own copies of the equation tables to the exam room.

Students may take both Physics C exams, Mechanics only, or Electricity and Magnetism only. The Mechanics exam is administered first, after which students taking both exams are given a break. Then the Electricity and Magnetism exam is administered. Prior to testing day, determine which exams students are taking. Those taking both Physics C exams and those taking Physics C: Mechanics only should report for the 12 noon start time (11 a.m. in Alaska). Those taking Electricity and Magnetism only should report to the testing room after the break (approximately 2 p.m., 1 p.m. in Alaska). If all students are taking Electricity and Magnetism only, you must not begin the exam before 2 p.m.

The two exams are in separate exam packets, and require separate answer sheets. At the beginning of the session, you will distribute **only** the packets and answer sheets for Mechanics. The materials for Electricity and Magnetism will be distributed after the break.

SECTION I: Multiple Choice

› **Do not begin the exam instructions below until you have completed the appropriate General Instructions for your group.**

This exam includes survey questions. The time allowed for the survey questions is in addition to the actual test-taking time.

Make sure that you begin the exam at the designated time. Remember, you must complete a seating chart for this exam. See pages 303–304 for a seating chart template and instructions. See the *2017-18 AP Coordinator's Manual* for exam seating requirements (pages 55–58).

If you are giving the regularly scheduled exam, say:
It is Monday afternoon, May 14, and you will be taking the AP Physics C: Mechanics Exam.

If you are giving the alternate exam for late testing, say:
It is Wednesday afternoon, May 23, and you will be taking the AP Physics C: Mechanics Exam.

Look at your exam packet and confirm that the exam title is "AP Physics C: Mechanics." Raise your hand if your exam packet contains any title other than "AP Physics C: Mechanics," and I will help you.

Once you confirm that all students have the correct exams, say:

In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2017-18 Bulletin for AP Students and Parents*.

You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

Carefully remove the AP Exam label found near the top left of your exam booklet cover. Place it on page 1 of your answer sheet on the light blue box near the top right corner that reads "AP Exam Label.". . .

If students accidentally place the exam label in the space for the number label or vice versa, advise them to leave the labels in place. They should not try to remove the label; their exam can still be processed correctly.

Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.

Give students enough time to complete each step. Don't move on until all students are ready.

Read the statements on the front cover of the Section I booklet. . . .

Sign your name and write today's date. . . .

Now print your full legal name where indicated. . . .

Turn to the back cover of your exam booklet and read it completely. . . .

Are there any questions? . . .

You will now take the multiple-choice portion of the exam. You should have in front of you the multiple-choice booklet and your answer sheet. You may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled.

Open your answer sheet to page 2. You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. Rulers, straightedges, and calculators may be used for the entire exam. You may place these items on your desk. Are there any questions? . . .

You have 45 minutes for this section. Open your Section I booklet and begin.



Note Start Time _____. Note Stop Time _____.

Check that students are marking their answers in pencil on their answer sheets and that they are not looking at their shrinkwrapped Section II booklets. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

After 35 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and turn to the last page in your booklet. . . .

You have 2 minutes to answer Questions 101–106. These are survey questions and will not affect your score. You may not go back to work on any of the exam questions. You may now begin.

To help you and your proctors make sure students are not working on the exam questions, the two pages with the survey questions are identified with a large S on the upper corner of each page. Give students 2 minutes to answer the survey questions.

Then say:

Close your booklet and put your answer sheet on your desk, faceup. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. Sit quietly while I collect your answer sheets.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label.

After all answer sheets have been collected, say:

Now you must seal your exam booklet using the white seals you set aside earlier. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, faceup. I will now collect your Section I booklet. . . .

Collect a Section I booklet from each student. Check that each student has signed the front cover of the sealed Section I booklet.

SECTION II: Free Response

When all Section I materials have been collected and accounted for, say:

May I have everyone's attention? Place your Student Pack on your desk. . . .

You may now remove the shrinkwrap from the Section II packet, but do not open the exam booklet until you are told to do so. . . .

Read the bulleted statements on the front cover of the exam booklet. Look up when you have finished. . . .

Now take an AP number label from your Student Pack and place it on the shaded box. If you don't have any AP number labels, write your AP number in the box. Look up when you have finished. . . .

Read the last statement. . . .

Using your pen, print the first, middle, and last initials of your legal name in the boxes and print today's date where indicated. This constitutes your signature and your agreement to the statements on the front cover. . . .

Turn to the back cover and, using your pen, complete Item 1 under "Important Identification Information." Print the first two letters of your last name and the first letter of your first name in the boxes. Look up when you have finished. . . .

In Item 2, print your date of birth in the boxes. . . .

In Item 3, write the school code you printed on the front of your Student Pack in the boxes. . . .

Read Item 4. . . .

Are there any questions? . . .

I need to collect the Student Pack from anyone who will be taking another AP Exam. Keep it, however, if you will be taking the Physics C: Electricity and Magnetism exam this afternoon. If you have no other AP Exams to take, place your Student Pack under your chair now. . . .

Read the information on the back cover of the exam booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .

Collect the Student Packs.

Then say:

Are there any questions? . . .

Rulers, straightedges, and calculators may be used for Section II. Be sure these items are on your desk. . . .

You have 45 minutes to complete Section II. You are responsible for pacing yourself and may proceed freely from one question to the next. You must write your answers in the exam booklet using a pen with black or dark blue ink or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read. If you need more paper during the exam, raise your hand. At the top of each extra sheet of paper you use, write only your AP number and the question number you are working on. Do not write your name. Are there any questions? . . .

You may begin.

Note Start Time _____ . **Note Stop Time** _____ .

You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

After 35 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and close your exam booklet. Place it on your desk, faceup. . . .

If any students used extra paper for a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report after the exam (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).

Then say:

Remain in your seat, without talking, while the exam materials are collected. . . .

Collect a Section II booklet from each student. Check for the following:

- Exam booklet front cover: The student placed an AP number label on the shaded box and printed their initials and today's date.
- Exam booklet back cover: The student completed the "Important Identification Information" area.

When all exam materials have been collected and accounted for, return to students who are taking Mechanics only any electronic devices you may have collected before the start of the exam.

If you are giving the regularly scheduled exam, say:

You may not discuss or share the free-response exam content with anyone unless it is released on the College Board website in about two days. Your AP Exam score results will be available online in July.

If you are giving the alternate exam for late testing, say:

None of the content in this exam may ever be discussed or shared in any way at any time. Your AP Exam score results will be available online in July.

If any students completed the AP number card at the beginning of this exam and are about to be dismissed say:

Please remember to take your AP number card with you. You will need the information on this card to view your scores and order AP score reporting services online.

If no students are taking Physics C: Electricity and Magnetism, say:

You are now dismissed.

If some students are taking Physics C: Electricity and Magnetism, say:

Those of you taking Mechanics only are now dismissed.

The students taking the Electricity and Magnetism exam now get a 10-minute break. Remember that the Electricity and Magnetism exam cannot begin before 2 p.m., but should start before 3 p.m.

After the students taking Mechanics only have left, say:

If you will also be taking the Physics C: Electricity and Magnetism exam, please listen carefully to these instructions before we take a 10-minute break. Please put all of your calculators under your chair. Your calculators and all items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. You are not allowed to consult teachers, other students, notes, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic or communication device. If you do not follow these rules, your score will be canceled. Are there any questions? . . .

You may begin your break. Testing will resume at _____ .

If you will be administering Physics C: Electricity and Magnetism at 2 p.m., be sure all exam materials are kept secure during the break. When the students return from break, turn to page 231 and begin the exam administration for Physics C: Electricity and Magnetism.

If you have no students taking Physics C: Electricity and Magnetism, return all exam materials to secure storage until they are shipped back to the AP Program. (See page 26 of the *2017-18 AP Coordinator's Manual* for more information about secure storage.)

After-Exam Tasks

Be sure to give the completed seating chart to the AP coordinator. Schools must retain seating charts for at least six months (unless the state or district requires that they be retained for a longer period of time). Schools should not return any seating charts in their exam shipments unless they are required as part of an Incident Report.

NOTE: If you administered exams to students with accommodations, review the *2017-18 AP Coordinator's Manual* and the *2017-18 AP SSD Guidelines* for information about completing the NAR form, and returning these exams.

The exam proctor should complete the following tasks if asked to do so by the AP coordinator. Otherwise, the AP coordinator must complete these tasks:

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration (regular or late testing), as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).
- Before storing materials, check the "School Use Only" section on page 1 of the answer sheet and:
  - Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2017-18 AP Coordinator's Manual*.
  - Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice Section

Use this section to capture student responses. (Note that the following answer sheet is a sample, and may differ from one used in an actual exam.)

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2018 AP Exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4OBP4-S

80

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

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

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

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

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

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

$P = \frac{dE}{dt}$

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

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

$I = \int r^2 dm = \sum m r^2$

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

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
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
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

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

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

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

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\varepsilon = -L\frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

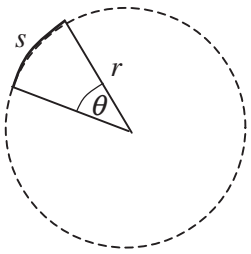
$a^2 + b^2 = c^2$

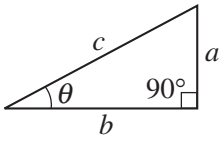
$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

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





CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

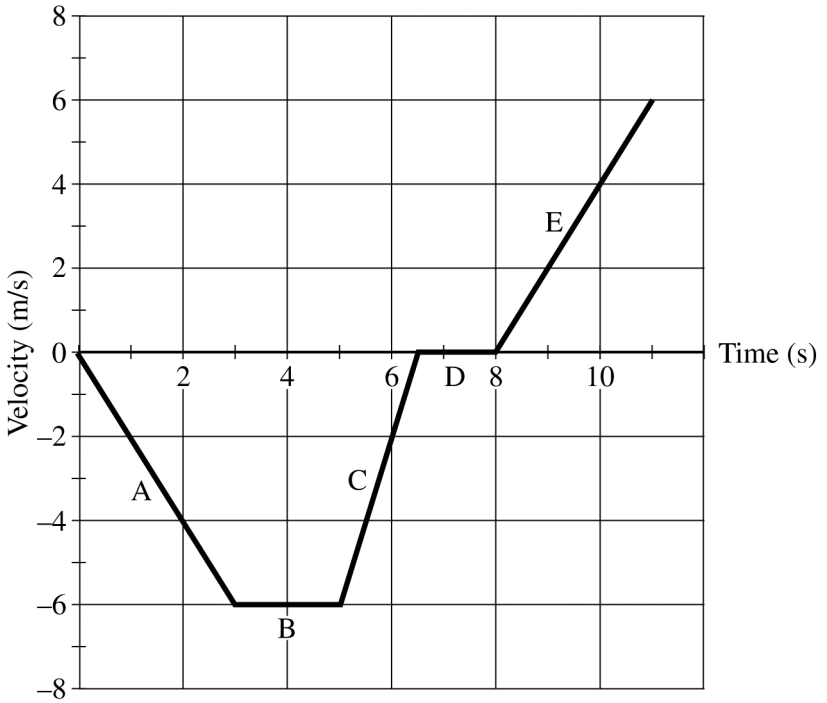
$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

Questions 1-2



An object is moving along a straight line. The object's velocity as a function of time is shown in the graph above.

1. During which of the labeled segments on the graph is the object moving but not accelerating?

   (A) A
   (B) B
   (C) C
   (D) D
   (E) E

2. The object has a speed of $2\ \text{m/s}$ at which of the following times?

   (A) 1 s only
   (B) 6 s only
   (C) 9 s only
   (D) 4 s and 10 s only
   (E) 1 s, 6 s, and 9 s

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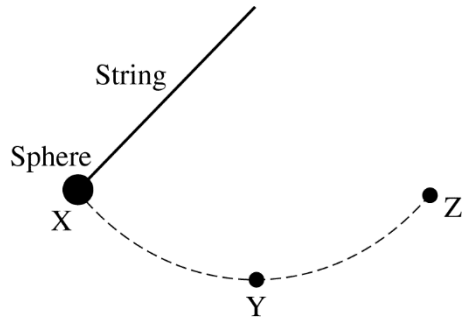
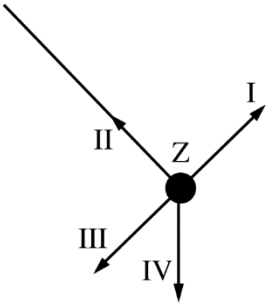
3. An object falls freely from rest under the influence of gravity. If air resistance is negligible, the ratio of the distances traveled during each 1-second time interval by the object during the first, second, and third seconds of its fall is

(A) 1:1:1
(B) 1:2:3
(C) 1:2:4
(D) 1:3:5
(E) 1:4:9

Questions 4-5

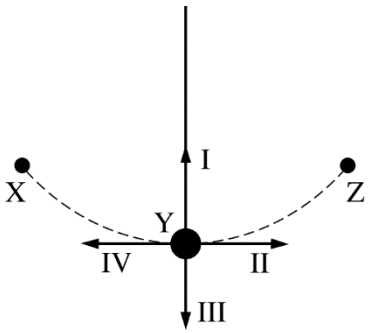


A sphere on the end of a string is released from rest at point X and swings through point Y to point Z, as shown in the figure above. Point Y is the lowest point for the sphere as it swings. Air resistance is negligible.



4. Four directions at point Z are indicated as I, II, III, and IV in the figure above. Which of the arrows best indicates the direction of the acceleration of the sphere at point Z?

(A) I
(B) II
(C) III
(D) IV
(E) The direction of the acceleration is undefined because the acceleration equals zero.



5. Four directions at point Y are indicated as I, II, III, and IV in the figure above. Directions I and III are vertical, II and IV are horizontal, and I is directed along the string. Which of the following best indicates the direction of the acceleration of the sphere at point Y?

(A) I
(B) II
(C) III
(D) IV
(E) The direction of the acceleration is undefined because the acceleration equals zero.

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6. A block of mass m is pulled by a rope along a horizontal surface with negligible friction. For time $t > 0$, the magnitude of the acceleration of the object as a function of time is given by the equation $a = Ae^{-kt}$, where A and k are positive constants. Which of the following expressions determines the impulse exerted on the block by the rope during the time interval $0 < t < t_1$?

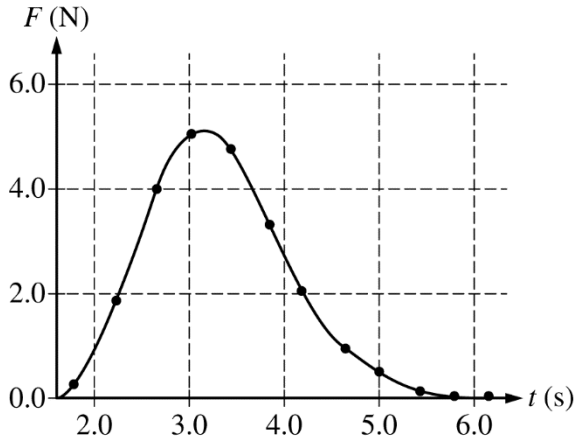
(A) $A\int_0^{t_1} e^{-kt}\,dt$

(B) $mA\dfrac{d}{dt}\left[e^{-kt}\right]_{t_1}$

(C) $A\dfrac{d}{dt}\left[e^{-kt}\right]_{t_1}$

(D) $mAt_1\left[e^{-kt}\right]$

(E) $mA\int_0^{t_1} e^{-kt}\,dt$



7. A 300 g cart with a force sensor attached starts at rest on a track. The force sensor exerts a force on the cart to speed it up. The graph above shows the force F exerted by the sensor on the cart as a function of time t. The change in the cart's momentum during the time interval shown is most nearly

(A) 4.0 N•s
(B) 8.5 N•s
(C) 13 N•s
(D) 25 N•s
(E) 30 N•s

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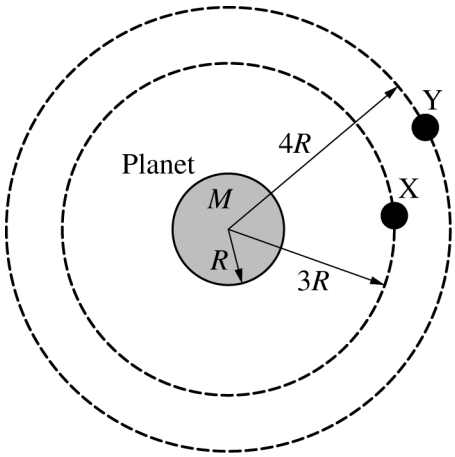
Questions 8-10



Identical satellites X and Y of mass *m* are in circular orbits around a planet of mass *M*. The radius of the planet is *R*. Satellite X has an orbital radius of 3*R*, and satellite Y has an orbital radius of 4*R*. The kinetic energy of satellite X is K_X.

8. In terms of K_X, the gravitational potential energy of the planet-satellite X system is

   (A) $-2K_X$
   (B) $-K_X$
   (C) $-K_X/2$
   (D) $K_X/2$
   (E) $2K_X$

9. The kinetic energy of satellite X is K_X. The kinetic energy of satellite Y is K_Y. The ratio K_X/K_Y is

   (A) 1/4
   (B) 3/4
   (C) 1/1
   (D) 4/3
   (E) 4/1

10. Satellite X is moved to the same orbit as satellite Y by a force doing work on the satellite. In terms of K_X, the work done on satellite X by the force is

    (A) $-K_X/2$
    (B) $-K_X/4$
    (C) 0
    (D) $+K_X/4$
    (E) $+K_X/2$

---

11. Car A can travel around a curved section of road without skidding at a maximum constant speed of 10 m/s. When car B travels around the same curve without skidding at its maximum speed, it has twice the centripetal acceleration as car A. The maximum speed at which car B can safely travel around the curve is most nearly

    (A) 5.0 m/s
    (B) 10 m/s
    (C) 14 m/s
    (D) 20 m/s
    (E) 28 m/s

12. A car is traveling down the highway at speed *v* when the driver slams on the brakes and skids to a stop in a distance *d*. Assuming the same frictional force, how far would the car slide if its speed was 2*v* ?

    (A) $d/4$
    (B) $d/2$
    (C) d
    (D) $2d$
    (E) $4d$

13. A 3.0 kg block accelerates at 2.0 m/s^2 because of a constant net force. A block of unknown mass accelerates at 6.0 m/s^2 because of the same net force. What is the mass of the second block?

    (A) 9.0 kg
    (B) 4.0 kg
    (C) 3.0 kg
    (D) 1.5 kg
    (E) 1.0 kg

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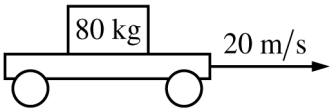

14. A cart is moving to the right with a constant speed of $20\ \text{m/s}$. A box of mass 80 kg moves with the cart without slipping. The coefficient of static friction between the box and cart is 0.30, and the coefficient of kinetic friction between the box and cart is 0.15. What are the magnitude and direction of the frictional force acting on the box as it moves with the cart?

(A) Zero
(B) 120 N to the right
(C) 120 N to the left
(D) 240 N to the right
(E) 240 N to the left

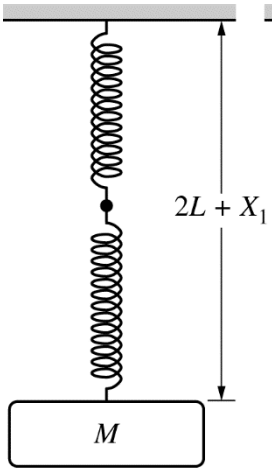

Figure 1

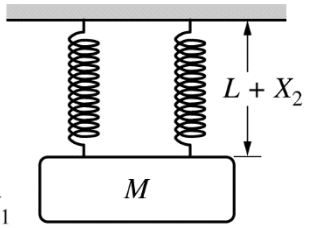

Figure 2

Note: Figure not drawn to scale.

15. A block of mass *M* is suspended from two identical springs of negligible mass, spring constant *k*and unstretched length *L*. First, one spring is attached to the end of the other spring. The block is then attached to the end of the second spring and slowly lowered to its equilibrium position. The two springs stretch a total distance of X_1, as shown in Figure 1 above. Next, the springs are hung side by side. The block is attached to the end of the springs and again slowly lowered to its equilibrium position. The springs each stretch a distance of X_2, as shown in Figure 2 above. Which of the following equations correctly shows the relationship between X_1 and X_2?

(A) $X_1 = X_2$
(B) $X_1 = \sqrt{2}X_2$
(C) $X_1 = 2X_2$
(D) $X_1 = 4X_2$
(E) $X_1 = 8X_2$

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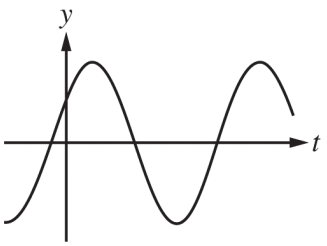
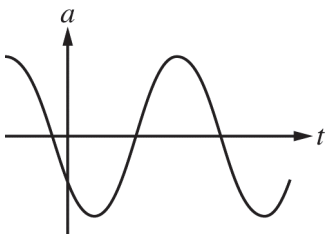
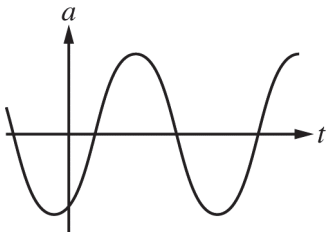
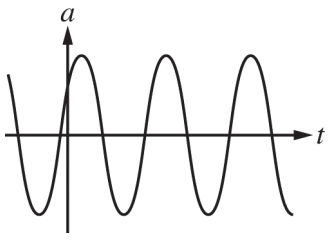
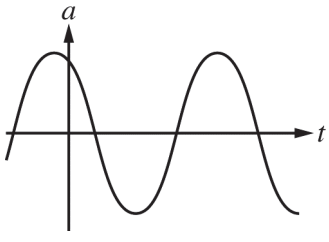


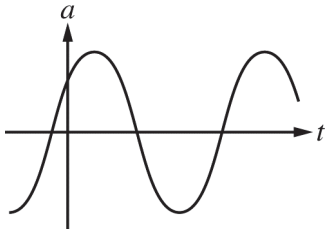
16. A block is hung vertically from an ideal spring. The block is pulled down and allowed to oscillate. The position y as a function for time t is shown in the graph above. Which of the following graphs best represents the acceleration a of the block as a function of time?

(A)


(B)


(C)


(D)


(E)


17. Two moons of equal mass are in circular orbits around a planet. Moon 1 orbits with a radius of r and moon 2 orbits with a radius of $3r$. What is the ratio of the magnitude of the planet's gravitational force on moon 2 to that on moon 1, $F_{G(\text{on } 2)} / F_{G(\text{on } 1)}$?

(A) $9/1$
(B) $3/1$
(C) $1/1$
(D) $1/3$
(E) $1/9$

18. A comet moves in an elliptical orbit around the Sun. Which of the following is at a maximum when the comet is at its farthest distance from the Sun?

(A) Kinetic energy of the comet
(B) Speed of the comet
(C) Acceleration of the comet
(D) Gravitational potential energy of the Sun-comet system
(E) Total energy of the Sun-comet system

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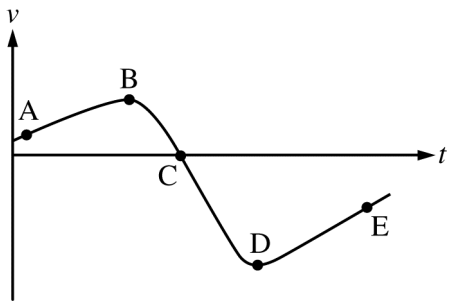
Questions 19-20



The graph above shows velocity as a function of time for a cart moving on a straight, horizontal track.

19. At which labeled point does the cart have the greatest speed?

(A) A
(B) B
(C) C
(D) D
(E) E

20. At which labeled point does the velocity of the cart change direction?

(A) A
(B) B
(C) C
(D) D
(E) E

Questions 21-22 are based on the following information.

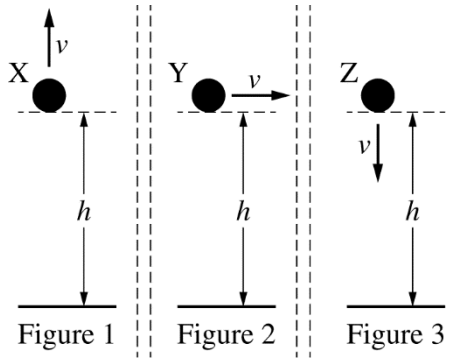


Figure 1 Figure 2 Figure 3

Three identical spheres are thrown from the same height above the ground. Sphere X is thrown vertically up, sphere Y is thrown horizontally, and sphere Z is thrown vertically down, as shown in figures 1, 2, and 3 above, respectively. All three spheres are thrown with the same speed. Air resistance is negligible.

21. Which sphere or spheres initially collide with the ground with the greatest speed?

(A) Sphere X only
(B) Sphere Y only
(C) Sphere Z only
(D) Spheres X and Z only
(E) All three spheres collide with the same speed.

22. Assume the spheres collide elastically with the ground. Which of the following ranks the spheres based on the rebound height after they collide with the ground?

(A) $X > Y > Z$
(B) $Y > (X = Z)$
(C) $Z > Y > X$
(D) $(X = Y) > Z$
(E) $(X = Z) > Y$

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Questions 23-24

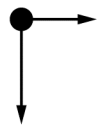
A block on a level horizontal surface of negligible friction is initially traveling at $20\ \text{m/s}$ to the left. A horizontal force $\vec{F}$ is exerted to the right on the block for the time interval $0 < t < 0.10\ \text{s}$. The magnitude of the force is given as a function of time t by the equation $F = \alpha t$, where $\alpha = 240\ \text{N/s}$ and t is in seconds.

23. Which of the following free-body diagrams best shows the forces acting on the block at time $t = 0.05\ \text{s}$?

(A)



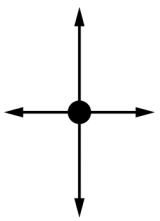
(B)



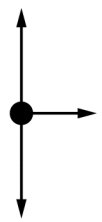
(C)



(D)



(E)



24. What is the magnitude of the change in momentum of the block due to the horizontal force?

(A) $1.2\ \text{kg•m/s}$

(B) $12\ \text{kg•m/s}$

(C) $24\ \text{kg•m/s}$

(D) $240\ \text{kg•m/s}$

(E) The change in momentum of the block cannot be determined without knowing the block's mass.

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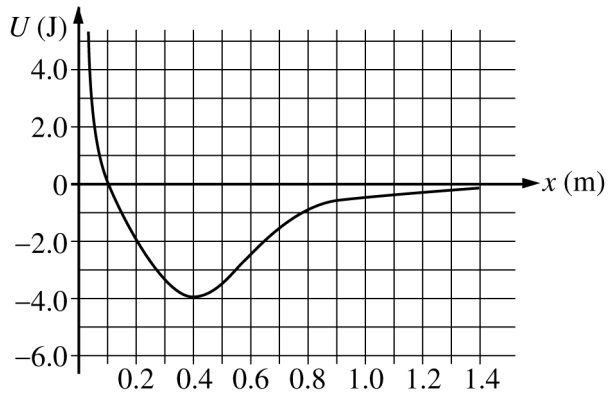
Questions 25-26



The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The graph above shows potential energy U of the system as a function of x.

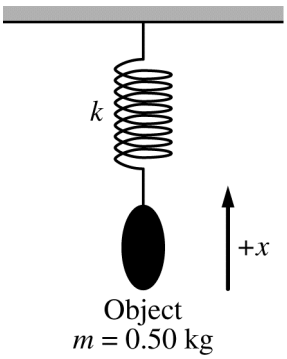
25. If the total energy of the system is -2.0 J, which of the following statements is true?

(A) The system has zero potential energy.
(B) Particle A has 2.0 J of kinetic energy.
(C) The system has 2.0 J of total mechanical energy.
(D) Particle A is always at $x = 0.40$ m.
(E) Particle A oscillates between $x = 0.20$ m and 0.65 m.

26. The x-component of the force on particle A when it is at $x = 0.15$ m is most nearly

(A) –20 N
(B) –2.0 N
(C) –1.0 N
(D) 2.0 N
(E) 20 N

Questions 27-28



A 0.50 kg object is attached to a vertical spring of constant k, as shown above. The object is pulled down and released. The object oscillates vertically. If up is the positive direction, the position x of the object as a function of time t is given by the formula $x = \beta \sin(\omega t + \varphi)$, where $\beta = 0.20$ m, $\omega = 4.0$ rad/s, and $\varphi = \pi/3$ rad.

27. The period of the oscillation for the object is most nearly

(A) 4.0 s
(B) 3.1 s
(C) 2.0 s
(D) 1.6 s
(E) 1.1 s

28. The magnitude of the maximum acceleration of the object as it oscillates is most nearly

(A) 8.0 m/s^2
(B) 6.4 m/s^2
(C) 3.2 m/s^2
(D) 0.80 m/s^2
(E) 0.013 m/s^2

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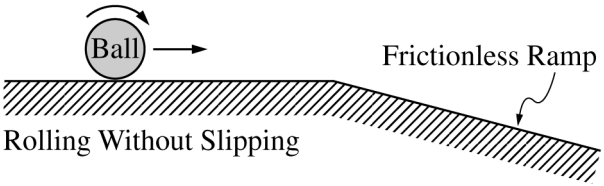
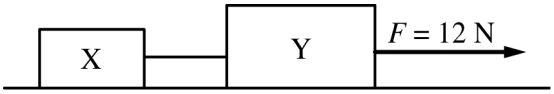


29. A ball, rolling without slipping on a horizontal surface, encounters a frictionless, downward-sloping ramp, as shown above. Which of the following correctly describes the motion of the ball on the ramp?

(A) Constant translational speed with no angular speed
(B) Increasing translational speed with no angular speed
(C) Increasing translational speed with constant nonzero angular speed
(D) Increasing translational speed with decreasing angular speed
(E) Increasing translational speed with increasing angular speed



30. Blocks X and Y of masses 3.0 kg and 5.0 kg, respectively, are connected by a light string and are both on a level horizontal surface of negligible friction. A force F = 12 N is exerted on block Y, as shown in the figure above. What is the tension in the string connecting the two blocks?

(A) 1.5 N
(B) 4.0 N
(C) 4.5 N
(D) 7.5 N
(E) 12 N

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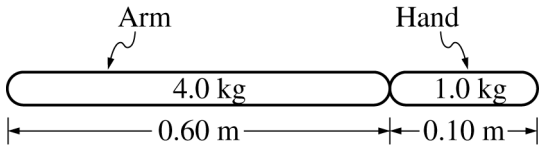
Questions 31-32

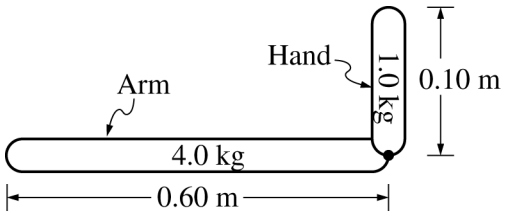


Note: Figure not drawn to scale.

In order to model the motion of an extinct ape, scientists measure its hand and arm bones. From shoulder to wrist, the arm bones are 0.60 m long and their mass is 4.0 kg. From wrist to the tip of the fingers, the hand bones are 0.10 m long and their mass is 1.0 kg. In the model above, each bone is assumed to have a uniform density.

31. When the arm and hand hang straight down, the distance from the shoulder to the center of mass of the arm-hand system is most nearly

(A) 0.25 m
(B) 0.35 m
(C) 0.37 m
(D) 0.50 m
(E) 0.93 m



Note: Figure not drawn to scale.

32. The arm is held in the horizontal position and the hand is bent at the wrist so the fingers point up, as shown in the figure above. The torque exerted by the weight of the hand with respect to the shoulder is most nearly

(A) 6 N•m
(B) 10 N•m
(C) 30 N•m
(D) 60 N•m
(E) 70 N•m

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Questions 33-34

An object moves along a straight line with a velocity v given as a function of time t by the equation $v(t) = \alpha t^2 + \beta t + \gamma$.

33. Which of the following expressions represents $\Delta x(t)$, the displacement of the object as a function of time t starting at time $t = 0$?

(A) 2α

(B) $\alpha t + \beta$

(C) $2\alpha t + \beta$

(D) $\alpha t^3/3 + \beta t^2/2 + \gamma t$

(E) $3\alpha t^3 + 2\beta t^2 + \gamma t$

34. Which of the following expressions represents $a(t)$, the acceleration of the object as a function of time t ?

(A) 2α

(B) $\alpha t + \beta$

(C) $2\alpha t + \beta$

(D) $\alpha t^3/3 + \beta t^2/2 + \gamma t$

(E) $3\alpha t^3 + 2\beta t^2 + \gamma t$

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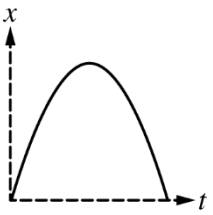
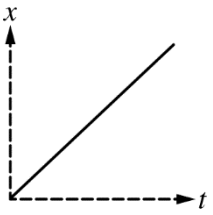
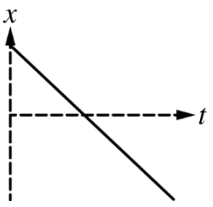
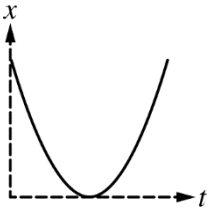
GO ON TO THE NEXT PAGE.

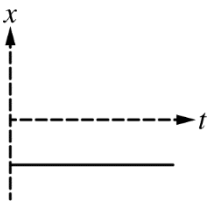
35. A cart is moving in the +x-direction and passes the origin when time t= 0. The cart then moves with decreasing speed, stops, and moves in the –x-direction with increasing speed. Which of the following graphs best represents the cart's position x as a function of time?

(A) 

(B) 

(C) 

(D) 

(E) 

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S T O P

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

Section II: Free-Response Questions

This is the free-response section of the 2018 AP Exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4OBP4-S

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

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

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

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

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

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

$P = \frac{dE}{dt}$

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

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

$I = \int r^2 dm = \sum m r^2$

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

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
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
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

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

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

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

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\varepsilon = -L\frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

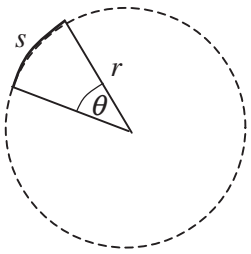
$a^2 + b^2 = c^2$

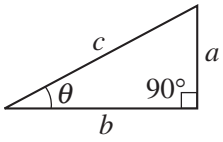
$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

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





CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

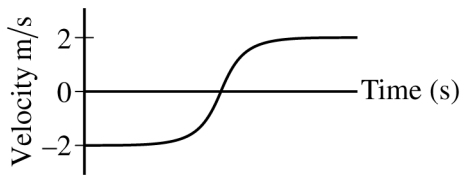
$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

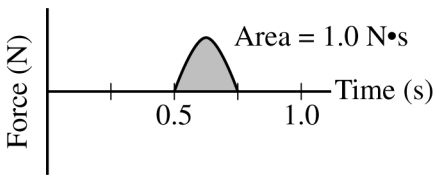
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. 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. A student sets up an experiment with a cart on a level horizontal track. The cart is attached with an elastic cord to a force sensor that is fixed in place on the left end of the track. A motion sensor is at the right end of the track, as shown in the figure above. The cart is given an initial speed of $v_0 = 2.0$ m/s and moves with this constant speed until the elastic cord exerts a force on the cart. The motion of the cart is measured with the motion detector, and the force the elastic cord exerts on the cart is measured with the force sensor. Both sensors are set up so that the positive direction is to the left. The data recorded by both sensors are shown in the graphs of velocity as a function of time and force as a function of time below.





(a) Calculate the mass m of the cart.

For time period from 0.50 s to 0.75 s, the force F the elastic cord exerts on the cart is given as a function of time t by the equation $F = A\sin(\omega t)$, where $A = 6.3$ N and $\omega = 12.6$ rad/s.

(b) Using the given equation, show that the area under the graph above is 1.0 N•s .

Question 1 continues on the next page.

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GO ON TO THE NEXT PAGE.

(c) The experiment is repeated using a different cord that exerts a larger average force on the cart. The cart starts and ends with the same speeds as those in the original experiment. Will the area for the graph of force as a function of time for the new cord be greater than, less than, or equal to the area for that of the original cord?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

The elastic cord from the original experiment can be modeled as an ideal spring with force constant k.

(d) Derive an expression for the maximum change in length x_{MAX} for the cord. Express your answer in terms of m, k, v_0, and physical constants, as appropriate.

The student performs several trials of the experiment. For the first trial, the cart is empty. In each succeeding trial, a block is added to the cart. In all trials, the cart has an initial speed of $2.0\ \text{m/s}$ to the right, the cart rebounds to the left with a speed of $2.0\ \text{m/s}$, and the maximum change in length of the elastic cord is measured. The total mass M of the cart and the maximum change in length of the cord in each trial are recorded in the table below.

Total Mass of Cart M (kg)	x_{MAX} (m)		
0.25	0.142		
0.75	0.253		
1.25	0.349		
1.75	0.431		
2.25	0.465		

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GO ON TO THE NEXT PAGE.

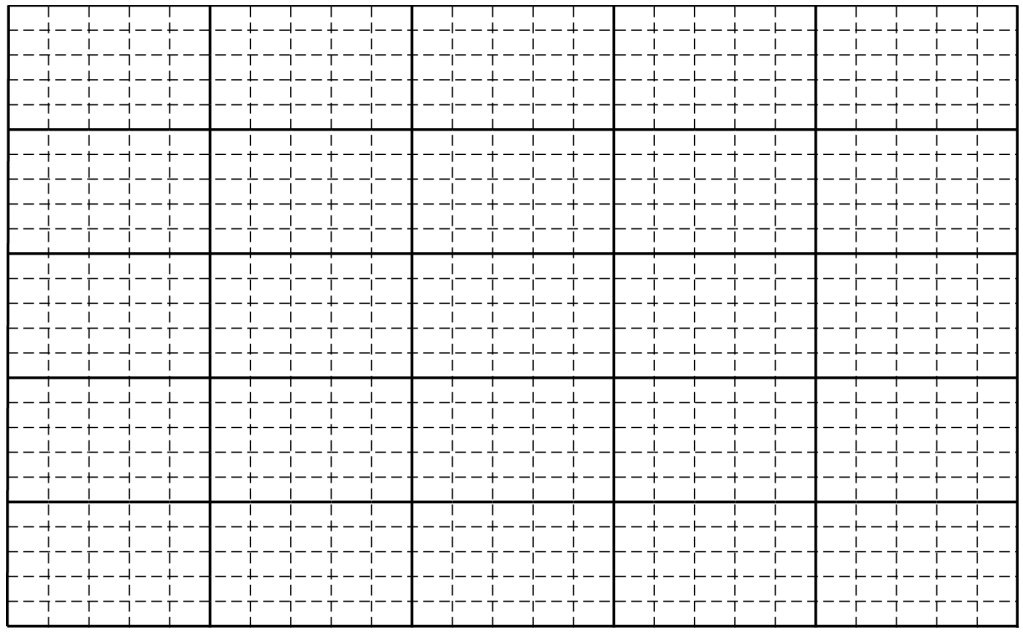
(e) Indicate below which quantities should be graphed to yield a straight line with a slope that could be used to calculate a numerical value for the force constant of the elastic cord k.

Vertical axis: _____

Horizontal axis: _____

Use the remaining columns in the table on the previous page, as needed, to record any quantities that you indicated that are not given.

(f) Plot the data points for the quantities indicated in part (e) on the graph below. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



(g) Use the best-fit line to calculate the force constant k of the elastic cord.

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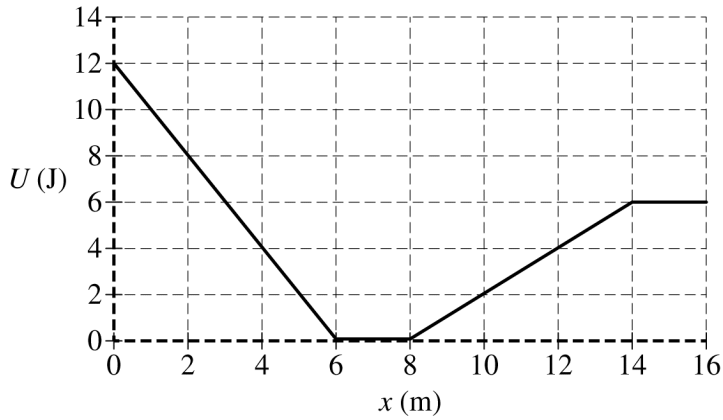

2. The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The above graph shows the potential energy $U(x)$ of the system as a function of position x of particle A, which has a mass of 0.40 kg. Particle A is released from rest at the position x = 2.0 m. Assume positive to be toward the right.

(a) Calculate the speed of particle A when it reaches position x = 14.0 m.

(b)

i. Calculate the magnitude of the acceleration of particle A when it reaches position x= 3.0 m.

ii. What is the direction of the acceleration of particle A when it reaches position x= 3.0 m?

____ Left ____ Right

(c) Determine the magnitude of the acceleration of particle A when it reaches position x = 7.0 m.

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(d) Particle A is again released from rest at the position $x = 2.0$ m.

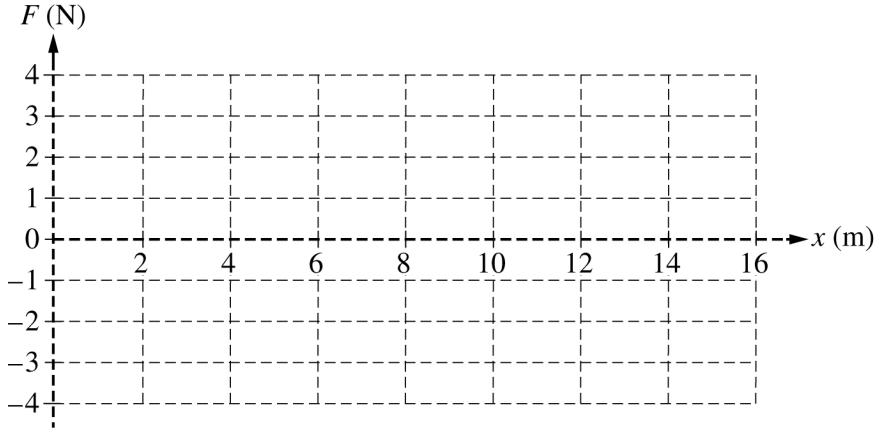
i. Calculate the elapsed time for particle A to travel from position $x = 2.0$ m to position $x = 6.0$ m.

ii. Calculate the elapsed time for particle A to travel from position $x = 6.0$ m to position $x = 8.0$ m.

iii. Calculate the elapsed time for particle A to travel from position $x = 8.0$ m to position $x = 14$ m.

(e) Particle A is now placed at position $x = 7.0$ m. In order for particle A to reach the position $x = 16.0$ m and to be moving at a speed of $1.0\ \text{m/s}$, what initial speed should particle A be given at its new initial position of $x = 7.0$ m?

(f) On the grid below, carefully draw a graph of the force F acting on particle A as a function of x for the range $0 < x < 16$ m.



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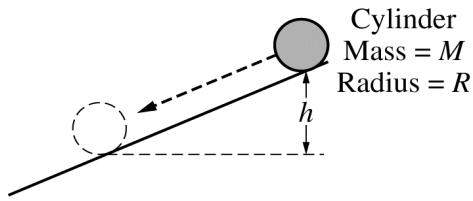


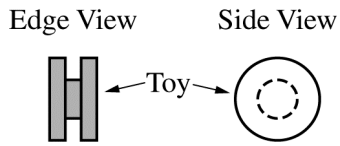
3. A cylinder of mass M and radius R is released from rest at the top of an inclined plane, as shown above. The cylinder rolls without slipping down the incline. The rotational inertia of the cylinder is $MR^2/2$.

   (a) Derive an expression for the angular momentum of the cylinder about its center of mass when it has rolled a vertical distance h. Express your answer in terms of M, R, h, and physical constants, as appropriate.

   (b) Is the angular momentum of the cylinder conserved as the cylinder rolls down the vertical distance h ?

   ____ Yes ____ No

   Justify your answer.



A child's toy is composed of 3 narrow cylinders attached around a common axis through their centers, as shown above. The central cylinder has a mass M and radius R. Each of the two outer cylinders has a mass M and radius $2R$.

   (c) Derive an expression for the rotational inertia of the toy around its center. Express your answer in terms of M, R, and physical constants, as appropriate.

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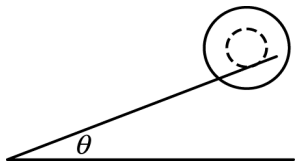


The toy is placed on a narrow track that is inclined at an angle of θ above the horizontal. Only the central cylinder is in contact with the track, as shown above. The toy rolls without slipping down the track.

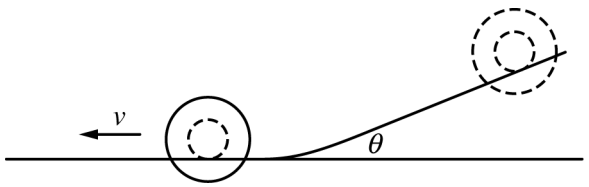
(d)

i. On the dot below, which represents the toy, draw and label the forces (not components) that act on the toy. The dashed line is parallel to the narrow track. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



ii. Derive an expression for the linear acceleration of the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

iii. Determine the force of friction exerted on the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.



(e) The toy reaches the bottom of the incline and rolls at constant speed v along a horizontal section of the track, as shown above. Derive an expression for the total kinetic energy of the toy while it is rolling. Express your answer in terms of M, R, v, and physical constants, as appropriate.

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2018年ap物理C力学真题答案

Multiple-Choice Answer Key

The following contains the answers to
the multiple-choice questions in this exam.

Answer Key for AP Physics C: Mechanics

Practice Exam, Section I

Question 1: B
Question 2: E
Question 3: D
Question 4: C
Question 5: A
Question 6: E
Question 7: B
Question 8: A
Question 9: D
Question 10: D
Question 11: C
Question 12: E
Question 13: E
Question 14: A
Question 15: D
Question 16: A
Question 17: E
Question 18: D
Question 19: D
Question 20: C
Question 21: E
Question 22: E
Question 23: E
Question 24: A
Question 25: E
Question 26: E
Question 27: D
Question 28: C
Question 29: C
Question 30: C
Question 31: C
Question 32: A
Question 33: D
Question 34: C
Question 35: A

Free-Response Scoring Guidelines

The following contains the scoring guidelines
for the free-response questions in this exam.

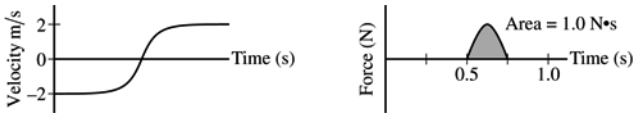
AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**



A student sets up an experiment with a cart on a level horizontal track. The cart is attached with an elastic cord to a force sensor that is fixed in place on the left end of the track. A motion sensor is at the right end of the track, as shown in the figure above. The cart is given an initial speed of $v_0 = 2.0\ \text{m/s}$ and moves with this constant speed until the elastic cord exerts a force on the cart. The motion of the cart is measured with the motion detector, and the force the elastic cord exerts on the cart is measured with the force sensor. Both sensors are set up so that the positive direction is to the left. The data recorded by both sensors are shown in the graphs of velocity as a function of time and force as a function of time below.



(a) 2 points

Calculate the mass m of the cart.

For correctly using the area under the graph to calculate the mass of the cart		1 point
$J = Area = \Delta p = m(v_2 - v_1)$		
For a correct answer with units		1 point
$m = \dfrac{Area}{(v_2 - v_1)} = \dfrac{(1.0\ \text{N•s})}{(2.0\ \text{m/s} - (-2.0\ \text{m/s}))}$		
$m = 0.25\ \text{kg}$		

For time period from 0.50 s to 0.75 s, the force F the elastic cord exerts on the cart is given as a function of time t by the equation $F = A\sin(\omega t)$, where $A = 6.3\ \text{N}$ and $\omega = 12.6\ \text{rad/s}$.

(b) 2 points

Using the given equation, show that the area under the graph above is $1.0\ \text{N•s}$.

For relating the time integral of given equation to the area under the curve		1 point
For applying the correct limits of integration		1 point
$J = Area = \int_{0.50}^{0.75} A\sin(\omega t)dt$		
$J = -\dfrac{A}{\omega}[\cos(\omega t)]_{0.50}^{0.75} = -\dfrac{(6.3\ \text{N})}{(12.6\ \text{rad/s})}[\cos(12.6t)]_{0.50}^{0.75}$		
$J = -(0.50)(\cos[(12.6)(0.75)] - \cos[(12.6)(0.50)])$		
$J = 1.0\ \text{N•s}$		

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Question 1 (continued)

Distribution of points

(c) 2 points

The experiment is repeated using a different cord that exerts a larger average force on the cart. The cart starts and ends with the same speeds as those in the original experiment. Will the area for the graph of force as a function of time for the new cord be greater than, less than, or equal to the area for that of the original cord?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Equal to" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Since the cart starts and ends at the same velocity, the impulse on the cart will be the same so the area under the graph will be the same. Note: If the wrong selection is made, the justification is ignored.		

The elastic cord from the original experiment can be modeled as an ideal spring with force constant k.

(d) 2 points

Derive an expression for the maximum change in length x_{MAX} for the cord. Express your answer in terms of m, k, v_0, and physical constants, as appropriate.

For correctly using conservation of energy		1 point
$U_{MAX} = K_{MAX}$		
$\frac{1}{2}kx_{MAX}^2 = \frac{1}{2}mv_0^2$		
For a correct answer		1 point
$x_{MAX} = v_0\sqrt{\frac{m}{k}}$		

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Question 1 (continued)

Distribution of points

The student performs several trials of the experiment. For the first trial, the cart is empty. In each succeeding trial, a block is added to the cart. In all trials, the cart has an initial speed of $2.0\ \text{m/s}$ to the right, the cart rebounds to the left with a speed of $2.0\ \text{m/s}$, and the maximum change in length of the elastic cord is measured. The total mass M of the cart and the maximum change in length of the cord in each trial are recorded in the table below.

Total Mass of Cart M (kg)	x_{MAX} (m)		
0.25	0.142		
0.75	0.253		
1.25	0.349		
1.75	0.431		
2.25	0.465		

(e) 1 point

Indicate below which quantities should be graphed to yield a straight line with a slope that could be used to calculate a numerical value for the force constant of the elastic cord k.

Vertical axis: _____

Horizontal axis: _____

Use the remaining columns in the table on the previous page, as needed, to record any quantities that you indicated that are not given.

For correctly indicating two variables that will yield a straight line that could be used to determine a value for k		1 point
Example: Vertical Axis: x_{MAX} *Horizontal Axis:* $\sqrt{m}$		
Note: Student earns full credit if axes are reversed or if they use another acceptable combination		

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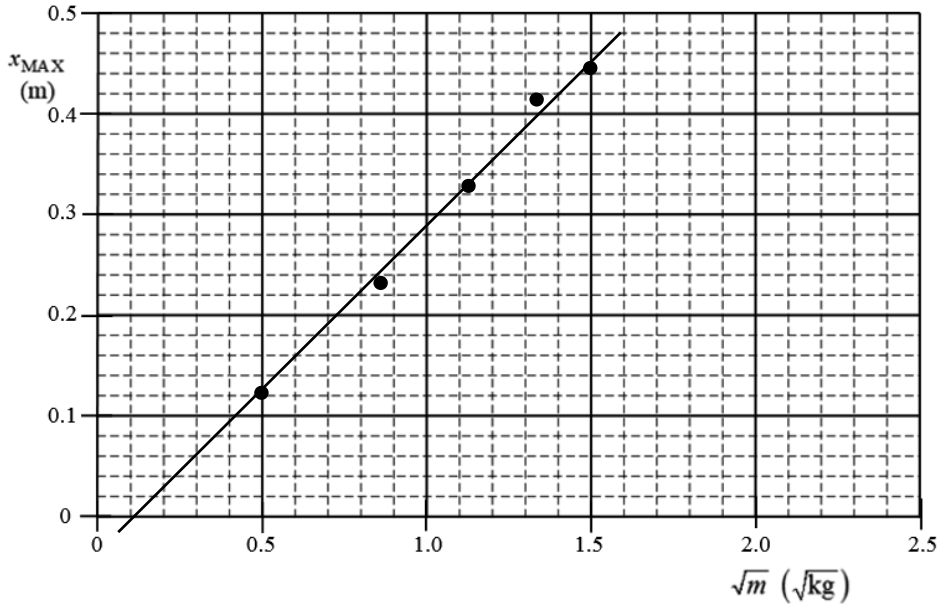
Question 1 (continued)

Distribution of points

(f) 4 points

Plot the data points for the quantities indicated in part (e) on the graph below. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axis with variables and units consistent with part (e) Note: Student earns full credit if axes are reversed		1 point
For correctly plotting data		1 point
For drawing a straight line consistent with the plotted data		1 point

(g) 2 points

Use the best-fit line to calculate the force constant k of the elastic cord.

For correctly calculating the slope from the best-fit line and not the data points		1 point
Example: slope $= \frac{\Delta x_{max}}{\Delta\sqrt{m}} = \frac{(0.40 - 0.20)\ \text{m}}{(1.32 - 0.70)\ \sqrt{kg}} = 0.34\ \text{m}/\sqrt{kg}$		
(linear regression slope $= 0.33\ \text{m}/\sqrt{kg}$)		
For correctly relating the slope to the force constant k		1 point
Example: slope $= \frac{v_0}{\sqrt{k}}\ \therefore\ k = \frac{v_0^2}{(\text{slope})^2} = \frac{(2.0\ \text{m/s})^2}{\left(0.34\ \text{m}/\sqrt{kg}\right)^2}$		
$k = 34.6\ \text{N/m}$		
(linear regression $k = 36.7\ \text{N/m}$ **)**		

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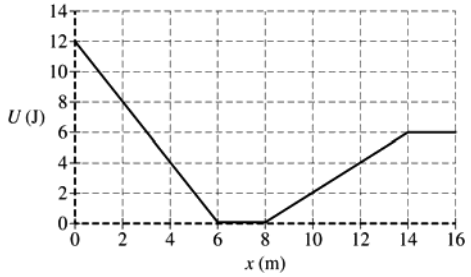
AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**



The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The above graph shows the potential energy $U(x)$ of the system as a function of position x of particle A, which has a mass of 0.40 kg. Particle A is released from rest at the position $x = 2.0$ m. Assume positive to be toward the right.

(a) 2 points

Calculate the speed of particle A when it reaches position $x = 14.0$ m.

For correctly using conservation of energy		1 point
$U_1 + K_1 = U_2 + K_2$		
$U_1 + 0 = U_2 + \frac{1}{2}mv^2$		
For correctly substituting values from the graph into the equation above		1 point
$(8\text{ J}) = (6\text{ J}) + \left(\frac{1}{2}\right)(0.40\text{ kg})v^2$		
$v = 3.16\text{ m/s}$		

(b)

i) 2 points

Calculate the magnitude of the acceleration of particle A when it reaches position $x = 3.0$ m.

For correctly relating the slope of the line to the force exerted on the particle		1 point
$F = -\text{slope} = -\frac{(U_2 - U_1)}{(x_2 - x_1)} = -\frac{(12 - 0)\text{J}}{(0 - 6)\text{m}} = 2.0\text{ N}$		
For using Newton's second law to calculate the acceleration of the particle		1 point
$a = \frac{F}{m} = \frac{(2.0\text{ N})}{(0.40\text{ kg})} = 5.0\text{ m/s}^2$		
Note: point is awarded for -5.0 m/s^2		

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Question 2 (continued)

Distribution of points

(b) con't

i) con't

Alternate Solution		*Alternate Points*
Solving for two velocities between 2.0 m and 6.0 m		*1 point*
$v_1 = 0$		
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For using a correct kinematic equation to find acceleration		*1 point*
$v_2^2 = v_1^2 + 2ad \therefore a = \frac{v_2^2}{2d} = \frac{(6.32\text{ m/s})^2}{(2)(4.0\text{ m})} = 5.0\text{ m/s}^2$		
Note: point is awarded for -5.0 m/s^2		

ii) 1 point

What is the direction of the acceleration of particle A when it reaches position $x = 3.0$ m?

____ Left ____ Right

For selecting answer consistent with part (b)(i)		1 point

(c) 1 point

Determine the magnitude of the acceleration of particle A when it reaches position $x = 7.0$ m.

For a correct answer		1 point
$F = -\text{slope} = 0 \therefore a = 0$		
Note: credit is given even if no work is shown		

(d) Particle A is again released from rest at the position $x = 2.0$ m.

i) 2 points

Calculate the elapsed time for particle A to travel from position $x = 2.0$ m to position $x = 6.0$ m.

For using a correct kinematic equation to calculate the time		1 point
$d = v_1 t + \frac{1}{2}at^2 = 0 + \frac{1}{2}at^2$		
For correctly substituting acceleration from part (b)(i) into equation above		1 point
$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{(2)(6.0 - 2.0)\text{m}}{(5.0\text{ m/s}^2)}} = 1.26\text{ s}$		

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Question 2 (continued)

Distribution of points

(d) con't

i) con't

Alternate Solution		*Alternate Points*
For correctly using the energy equation to solve for the speed at 6.0 m (or using the value from alternate solution part (b)(i)		*1 point*
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For correctly substituting velocity above and acceleration from part (b)(i) into an appropriate kinematic equation		*1 point*
$v_2 = v_1 + at \therefore t = \frac{v_2 - v_1}{a} = \frac{(6.32\text{ m/s} - 0)}{\left(5.0\text{ m/s}^2\right)} = 1.26\text{ s}$		

ii) 2 points

Calculate the elapsed time for particle A to travel from position $x = 6.0$ m to position $x = 8.0$ m.

For using a correct kinematic equation to determine the speed at $x = 6.0$ m or using the velocity at 6.0 m from alternate solutions part (b)(i) or (d)(i)		1 point
$v_2^2 = v_1^2 + 2ad = 0 + 2ad$		
$v_2 = \sqrt{2ad} = \sqrt{(2)\left(5.0\text{ m/s}^2\right)(6.0 - 2.0)\text{m}}$		
$v_2 = 6.32\text{ m/s}$		
For using a kinematic equation for zero acceleration to calculate the time		1 point
$d = vt$		
$t = \frac{d}{v} = \frac{(8.0 - 6.0)\text{m}}{(6.32\text{ m/s})}$		
$t = 0.32\text{ s}$		
Alternate Solution		*Alternate Points*
For correctly using the energy equation to solve for the speed at 6.0 m (or using the value from alternate solution part (b)(i)		*1 point*
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For using a kinematic equation with zero acceleration to calculate the time		*1 point*
$d = vt$		
$t = d/v = (8.0 - 6.0)\text{m}/(6.32\text{ m/s})$		
$t = 0.32\text{ s}$		

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Question 2 (continued)

Distribution of points

(d) con't

iii) 1 point

Calculate the elapsed time for particle A to travel from position $x = 8.0$ m to position $x = 14$ m.

For using a correct kinematic equation to calculate the time		1 point
$d = \frac{1}{2}(v_1 + v_2)t$		
$t = \frac{2d}{(v_1 + v_2)} = \frac{(2)(14 - 8.0)\text{m}}{(6.32\ \text{m/s} + 3.16\ \text{m/s})}$		
$t = 1.26$ s		

(e) 1 points

Particle A is now placed at position $x = 7.0$ m. In order for particle A to reach the position $x = 16.0$ m and to be moving at a speed of $1.0\ \text{m/s}$, what initial speed should particle A be given at its new initial position of $x = 7.0$ m?

For correctly using conservation of energy to calculate the speed		1 point
$U_1 + K_1 = U_2 + K_2$		
$0 + \frac{1}{2}m_1v_1^2 = U_2 + \frac{1}{2}m_2v_2^2$		
$\left(\frac{1}{2}\right)(0.40\ \text{kg})v_1^2 = (6\ \text{J}) + \left(\frac{1}{2}\right)(0.40\ \text{kg})(1.0\ \text{m/s})^2$		
$v = 5.57\ \text{m/s}$		

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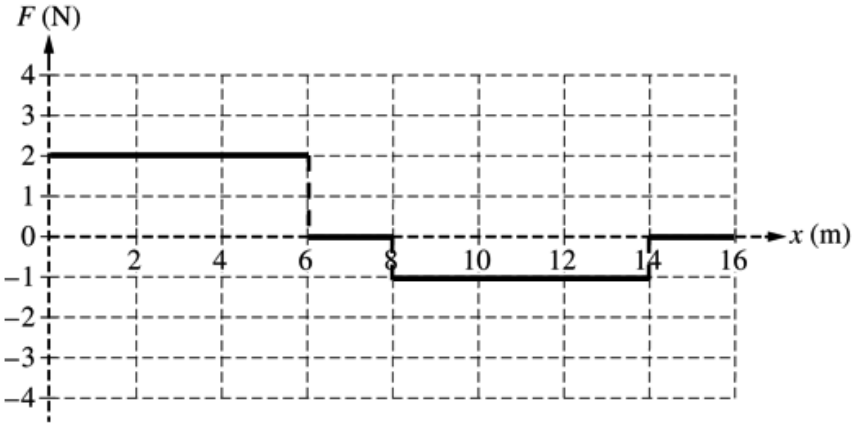
Question 2 (continued)

Distribution of points

(f) 3 points

On the grid below, carefully draw a graph of the force F acting on particle A as a function of x for the range $0 < x < 16$ m.



For a horizontal line at $F = 2$ N from $x = 0$ m to $x = 6$ m		1 point
For a horizontal line at $F = 0$ from $x = 6$ m to $x = 8$ m and from $x = 14$ m to $x = 16$ m		1 point
For a horizontal line at $F = –1$ N from $x = 8$ m to $x = 14$ m		1 point
Note: Two points earned if shape and magnitudes are correct but graph is inverted		

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AP® PHYSICS C: MECHANICS
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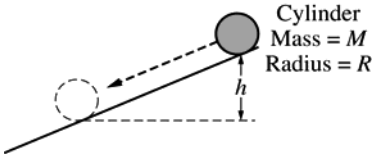
Question 3

15 points total **Distribution of points**



A cylinder of mass M and radius R is released from rest at the top of an inclined plane, as shown above. The cylinder rolls without slipping down the incline. The rotational inertia of the cylinder is $MR^2/2$.

(a) 3 points

Derive an expression for the angular momentum of the cylinder about its center of mass when it has rolled a vertical distance h. Express your answer in terms of M, R, h, and physical constants, as appropriate.

For correctly using conservation of energy		1 point
$U_{g1} + K_1 = U_{g2} + K_2$		
$U_{g1} + 0 = 0 + K_2$		
$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$		
For correctly substituting into equation above for both linear and rotational kinetic energy		1 point
$Mgh = \frac{1}{2}M(R\omega)^2 + \frac{1}{2}\left(\frac{MR^2}{2}\right)\omega^2$		
$gh = \frac{3}{4}R^2\omega^2$		
$\omega = \sqrt{\frac{4gh}{3R^2}}$		
For correctly substituting into the equation for angular momentum		1 point
$L = I\omega = \left(\frac{MR^2}{2}\right)\left(\sqrt{\frac{4gh}{3R^2}}\right)$		
$L = MR\sqrt{\frac{gh}{3}}$		

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Question 3 (continued)

Distribution of points

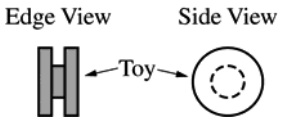
(b) 1 point

Is the angular momentum of the cylinder conserved as the cylinder rolls down the vertical distance h ?

____ Yes ____ No

Justify your answer.

Selecting "No"		
For a correct justification		1 point
Example: The frictional force exerts an external torque on the cylinder therefore the angular momentum of the cylinder is not conserevd.		
Example: The angular velocity is changing with h; therefore, L is changing.		



A child's toy is composed of 3 narrow cylinders attached around a common axis through their centers, as shown above. The central cylinder has a mass M and radius R. Each of the two outer cylinders has a mass M and radius $2R$.

(c) 2 points

Derive an expression for the rotational inertia of the toy around its center. Express your answer in terms of M, R, and physical constants, as appropriate.

For setting the total rotational inertia for the toy equal to the sum of the rotaional inertias of the three cylinders		1 point
$I_{tot} = 2I_{OUTER} + I_{INNER} = 2\left(\frac{MR^2}{2}\right)_{OUTER} + \left(\frac{MR^2}{2}\right)_{INNER}$		
$I_{tot} = 2\left(\frac{M(2R)^2}{2}\right) + \left(\frac{MR^2}{2}\right) = 4MR^2 + \frac{MR^2}{2}$		
For a correct answer:		1 point
$I_{tot} = \frac{9}{2}MR^2$		

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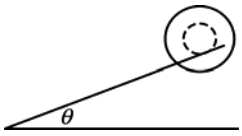
Question 3 (continued)

Distribution of points

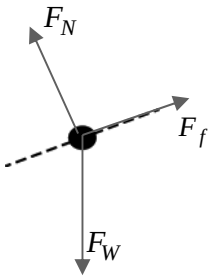


The toy is placed on a narrow track that is inclined at an angle of θ above the horizontal. Only the central cylinder is in contact with the track, as shown above. The toy rolls without slipping down the track.

(d)

i) 3 points

On the dot below, which represents the toy, draw and label the forces (not components) that act on the toy. The dashed line is parallel to the narrow track. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



For correctly drawing a vector representing the normal force perpendicular to the dashed line		1 point
For correctly drawing a vector representing the weight of the toy directed straight down		1 point
For correctly drawing a vector representing the frictional force directed up the incline		1 point
Note: A maximum of two points can be earned if there are any extraneous vectors		

ii) 3 points

Derive an expression for the linear acceleration of the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

For correctly using Newton's second law in linear form for the toy on the incline		1 point
$F = ma \therefore (3M)g(\sin\theta) - F_f = (3M)a$		
For correctly using Newton's second law in rotational form for the toy on the incline		1 point
$\tau = I\alpha \therefore F_f R = I\alpha \therefore F_f R = \left(\frac{9}{2}MR^2\right)\left(\frac{a}{R}\right) \therefore F_f = \frac{9}{2}Ma$		
For combining the two equation above to calculate the acceleration		1 point
$3Mg(\sin\theta) - \frac{9}{2}Ma = 3Ma \therefore 3g(\sin\theta) = \frac{15}{2}a$		
$a = \frac{2}{5}g(\sin\theta)$		

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Question 3 (continued)

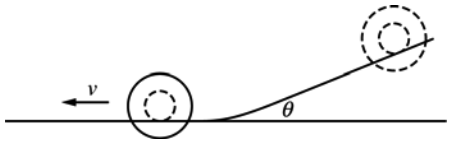
Distribution of points

(d) Con't

iii) 1 point

Determine the force of friction exerted on the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

For an answer consistent with part (d)(ii)		1 point
$F_f = \frac{9}{2}M\left(\frac{2}{5}g(\sin\theta)\right) = \frac{9}{5}Mg(\sin\theta)$		



(e) 2 points

The toy reaches the bottom of the incline and rolls at constant speed v along a horizontal section of the track, as shown above. Derive an expression for the total kinetic energy of the toy while it is rolling. Express your answer in terms of M, R, v, and physical constants, as appropriate.

For using both rotational and linear kinetic energy for the total kinetic energy of the toy		1 point
$K = K_L + K_R = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$		
For correctly substituting for both the rotational inertia, the mass, and $\omega = v / R$ into the equation above		1 point
$K = \frac{1}{2}(3M)v^2 + \frac{1}{2}\left(\frac{9}{2}MR^2\right)\omega^2 = \frac{3}{2}Mv^2 + \frac{9}{4}MR^2\left(\frac{v}{R}\right)^2 = \frac{15}{4}Mv^2$		

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Scoring Worksheet

The following provides a scoring worksheet and conversion table used for calculating a composite score of the exam.

2018 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	×	1.2857	=	_____
Number Correct (out of 35)				Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)
Question 2	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)
Question 3	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
55-90	5
42-54	4
33-41	3
24-32	2
0-24	1

Question Descriptors and Performance Data

The following contains tables showing the content assessed,
the correct answer, and how AP students performed on each question.

2018 AP Physics C: Mechanics
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Topic	Key	% Correct
1	Kinematics	B	93
2	Kinematics	E	82
3	Kinematics	D	22
4	Newton's laws	C	43
5	Newton's laws	A	41
6	Sys of particles & lin mom	E	81
7	Sys of particles & lin mom	B	49
8	Gravity	A	27
9	Gravity	D	58
10	Gravity	D	37
11	Rotation & Circular Motion	C	74
12	Newton's laws	E	65
13	Newton's laws	E	96
14	Newton's laws	A	30
15	Oscillations	D	33
16	Oscillations	A	63
17	Gravity	E	68
18	Gravity	D	64
19	Kinematics	D	90
20	Kinematics	C	97
21	Kinematics	E	16
22	Sys of particles & lin mom	E	82
23	Newton's laws	E	84
24	Sys of particles & lin mom	A	57
25	Work/energy/power	E	42
26	Work/energy/power	E	16
27	Oscillations	D	72
28	Oscillations	C	66
29	Rotation & Circular Motion	C	39
30	Newton's laws	C	59
31	Sys of particles & lin mom	C	47
32	Rotation & Circular Motion	A	60
33	Kinematics	D	89
34	Kinematics	C	89
35	Kinematics	A	78

From the 2017 Administration

AP CollegeBoard

Physics C: Mechanics

Practice Exam

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2017

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4NBP4-S

80

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\text{m/s}^2$ in all problems.

1. A plane starts at rest on a straight runway. For the first 30 s, the plane's acceleration a is given as a function of time t by the equation $a = \beta t^2$, where $\beta = 1/90\ \text{m/s}^4$ and t is in seconds.

   What is the plane's speed at $t = 30$ s ?

   (A) 10 m/s
   (B) 30 m/s
   (C) 100 m/s
   (D) 150 m/s
   (E) 300 m/s

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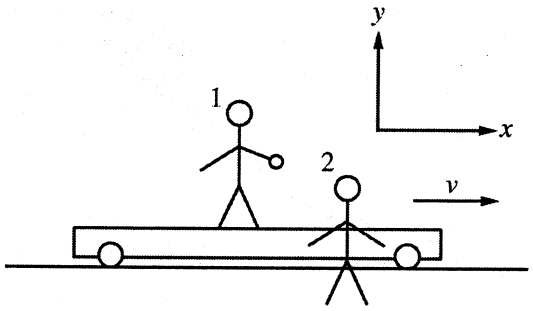
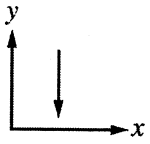
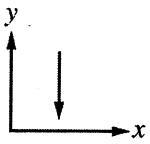
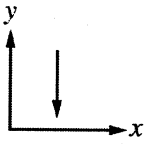
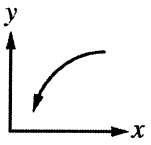
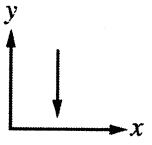
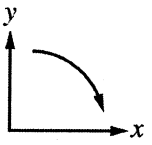
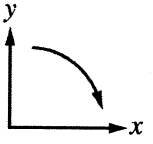
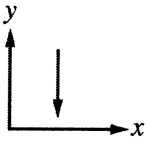
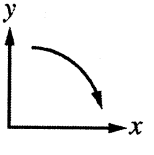
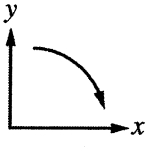


2. Student 1 is standing on a cart holding a small stone, while student 2 is standing at rest on the ground, as shown in the figure above. The cart is moving at a constant speed v in the $+x$-direction, as indicated by the coordinate system shown. Student 1 drops the stone precisely when passing student 2. Which of the following best represents the path of the falling stone relative to student 1 and the path of the falling stone relative to student 2 ?

	Student 1	Student 2
(A)		
(B)		
(C)		
(D)		
(E)		

3. A particle of mass 2.0 kg is moving in the xy-plane at a constant speed of 0.80 m/s in the $+x$-direction along the line $y = 4$ m. As the particle travels from $x = -3$ m to $x = +3$ m, the magnitude of its angular momentum with respect to the origin is

(A) not constant

(B) 0

(C) 4.8 $kg \cdot m^2/s$

(D) 6.4 $kg \cdot m^2/s$

(E) 8.0 $kg \cdot m^2/s$

4. Suppose that a spherical star spinning at an initial angular velocity ω suddenly collapses to half of its original radius without any loss of mass. Assume the star has uniform density before and after the collapse. What will the angular velocity of the star be after the collapse?

(A) $\omega/4$

(B) $\omega/2$

(C) ω

(D) 2ω

(E) 4ω

5. Two identical, unlabeled boxes are transported to an orbiting space station. The astronauts know that one box is filled with a light sample of ants for an experiment, and the other is filled with heavy tools for repairs. How can the astronauts tell, without opening the boxes, which box has the tools?

(A) Weigh each box on a spring scale. The box with the tools will have a higher reading.

(B) Shake each box. The box with the tools will be harder to move back and forth.

(C) Push each box. The box with the tools will travel farther before it stops.

(D) Place each box on opposite sides of a balance. The box on the side that goes down lower will be the box with the tools.

(E) Toss each box straight up. The box with the tools will go higher before coming back down.

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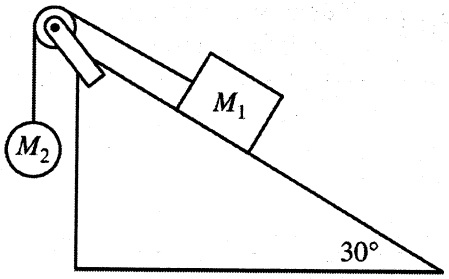

6. A block of mass M_1 is connected by a string to a sphere of mass M_2. The block is on a frictionless plane inclined at an angle of $30°$, as shown in the figure above. The string passes over a pulley of negligible mass and friction, and the sphere hangs freely. Which of the following is always true if the block is accelerating down the incline?

(A) $M_1 < M_2$
(B) $M_1 = M_2$
(C) $M_1 < M_2(\sin 30°)$
(D) $M_1(\sin 30°) < M_2$
(E) $M_1(\sin 30°) > M_2$

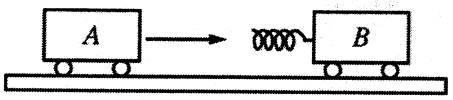

Figure 1

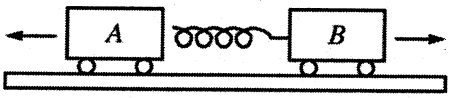

Figure 2

7. Two carts of equal mass are on a horizontal surface with negligible friction. Cart *A* is approaching cart *B*, which is at rest, as shown in Figure 1 above. Attached to cart *B* is a spring that is initially compressed. At the moment cart *A* collides with cart *B*, the spring is released and pushes on cart *A*, as shown in Figure 2 above. Which of the following correctly states what happens to the kinetic energy and the momentum of the two-cart system as a result of the collision compared to those quantities before the collision?

	Kinetic energy	Magnitude of Momentum
(A)	Increases	Decreases
(B)	Increases	Stays the same
(C)	Increases	Increases
(D)	Stays the same	Increases
(E)	Stays the same	Stays the same

8. A ball of mass m is dropped from rest from a height h and collides elastically with the floor, rebounding to its original height. What is the magnitude of the average force applied by the floor on the ball during the time the ball is in contact with the floor?

(A) Zero
(B) mg
(C) $2mg$
(D) $4mg$
(E) It cannot be determined without knowing the length of time that the ball is in contact with the floor.

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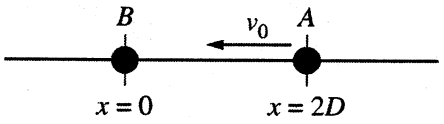
Questions 9-10



Particle A and particle B, each of mass M, move along the x-axis exerting a force on each other. The potential energy of the system of two particles associated with the force is given by the equation $U = \beta/r^2$, where r is the distance between the two particles and β is a positive constant. At time $t = 0$, particle A is located at $x = 2D$ with an initial speed of v_0 to the left, and particle B is at rest at the origin, as shown in the figure above.

9. At time $t = T_1$, particle A is observed to be traveling with speed $2v_0/3$ to the left. The speed and direction of motion of particle B is

(A) $2v_0/3$ to the left
(B) $v_0/3$ to the left
(C) $v_0/3$ to the right
(D) $2v_0/3$ to the right
(E) $5v_0/3$ to the right

10. Which of the following equations could be used to find r_{MIN}, the minimum distance between the masses as particle A approaches particle B?

(A) $\frac{\beta}{4D^2} + Mv_0^2 = \frac{\beta}{r_{MIN}^2} + M\left(\frac{v_0}{2}\right)^2$

(B) $\frac{\beta}{4D^2} + \frac{1}{2}Mv_0^2 = \frac{\beta}{r_{MIN}^2} + M\left(\frac{v_0}{2}\right)^2$

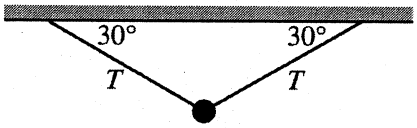
(C) $\frac{\beta}{4D^2} + \frac{1}{2}Mv_0^2 = \frac{\beta}{r_{MIN}^2} + \frac{1}{2}Mv_0^2$

(D) $\frac{\beta}{4D^2} + \frac{1}{2}Mv_0^2 = \frac{\beta}{r_{MIN}^2}$

(E) $\frac{\beta}{4D^2} + Mv_0^2 = \frac{\beta}{r_{MIN}^2}$

11. A 2 kg object is released from rest from a height of 3 m above Earth's surface. How much kinetic energy does the object have when it reaches a height of 1 m?

(A) 2.5 J
(B) 10 J
(C) 20 J
(D) 30 J
(E) 40 J



12. A sphere of mass m hangs from two strings that each make an angle of 30° with the horizontal, as shown in the figure above. What is the tension T in one of the strings?

(A) $mg/6$
(B) $mg/4$
(C) $mg/2$
(D) mg
(E) $3mg/2$

13. A skier is traveling down a slope that is inclined 30° above the horizontal. The coefficient of kinetic friction between the skier and the slope is 0.10. Which of the following best describes the acceleration of the skier?

(A) It is zero.
(B) It is about 4.0 m/s^2.
(C) It is about 9.0 m/s^2.
(D) It is about 10 m/s^2.
(E) It cannot be determined without knowing the mass of the skier.

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Questions 14-16

A ball of mass 2.0 kg is thrown vertically upward from the top of a building. The ball's velocity v is given as a function of time t by the equation $v(t) = R - St$, where $R = 5$ m/s and $S = 10$ m/s^2. The positive direction is upward.

14. What is the ball's acceleration at time $t = 1$ s?

(A) -10 m/s^2
(B) -5 m/s^2
(C) 0
(D) 5 m/s^2
(E) 10 m/s^2

15. At what time does the ball reach its maximum height above the building?

(A) 0.2 s
(B) 0.4 s
(C) 0.5 s
(D) 1.0 s
(E) 2.0 s

16. If the ball reaches the ground at $t = 2.0$ s, what is the height of the building?

(A) 5 m
(B) 10 m
(C) 15 m
(D) 20 m
(E) 30 m

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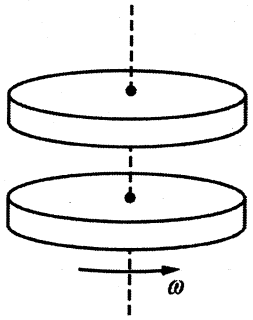
Questions 17-19



A solid disk of mass M and radius R is freely rotating horizontally in a counterclockwise direction with angular speed ω about a vertical axis through its center with negligible friction. The rotational inertia of the disk is $MR^2/2$. A second identical disk is at rest and suspended above the first disk with the centers of the two disks aligned, as shown in the figure above. There is no contact between the disks. The second disk is dropped onto the first disk, and after a short time they rotate counterclockwise with the same angular speed ω_f.

17. Which of the following properties of the two-disk system must be conserved between the time the second disk is dropped on the first disk and the time that the two disks begin rotating with the same speed?

(A) Kinetic energy only
(B) Angular momentum only
(C) Both kinetic energy and angular momentum
(D) Neither kinetic energy nor angular momentum
(E) It cannot be determined without knowing the nature of the forces between the two disks.

18. The interval of time Δt is the elapsed time from the moment of first contact between the two disks until they are both spinning at the same angular velocity. Which of the following expressions gives the magnitude of the average torque that the first disk exerts on the second disk?

(A) $MR^2\omega_f$
(B) $\dfrac{MR^2\omega_f}{\Delta t}$
(C) $\dfrac{MR^2\omega_f}{2\Delta t}$
(D) $\dfrac{2MR^2\omega_f}{\Delta t}$
(E) It cannot be determined without knowing the nature of the forces between the two disks.

19. The two disks are now shifted so that the axis of rotation goes through a point on the edge of the disks. The rotational inertia of the two-disk system is now

(A) $2MR^2$
(B) $3MR^2$
(C) $4MR^2$
(D) $5MR^2$
(E) $10MR^2$

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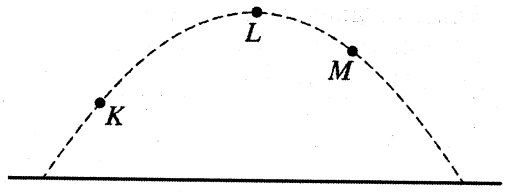


20. A student throws a metal sphere, which follows the path shown above. If air resistance is negligible, which of the following is a correct relationship between the magnitudes of the accelerations a_K, a_L, and a_M at the three points shown?

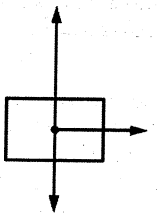
(A) $a_K = a_L = a_M$
(B) $a_K = a_L > a_M$
(C) $a_K = a_M > a_L$
(D) $a_K > a_L = a_M$
(E) $a_K > a_M > a_L$

21. A cannonball is shot from the top of a 30 m high hill at a velocity of 25 m/s and at an angle of 40° above the horizontal and lands on the ground below. The speed of the cannonball at the top of its path is most nearly

(A) 0
(B) 16 m/s
(C) 19 m/s
(D) 25 m/s
(E) 29 m/s

22. A 1500 kg car is pushing a 4000 kg truck. The car and truck are accelerating at 2.0 m/s^2. Assuming that the frictional force on the truck is negligible, what force is the truck exerting on the car?

(A) 0 N
(B) 3000 N
(C) 5000 N
(D) 8000 N
(E) 11,000 N



23. The figure above shows the directions and relative magnitudes of all three forces that are acting on an object. Which of the following best shows the direction of the object's acceleration?

(A)


(B)


(C)


(D)

(E)

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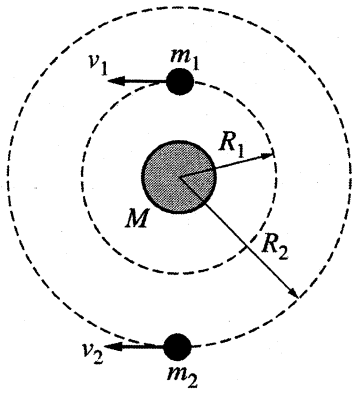
Questions 24-26



Note: Figure not drawn to scale.

Two satellites of masses m_1 and m_2 orbit a planet of mass M in circular orbits. The satellites travel in opposite directions with speeds v_1 and v_2, as shown in the figure above. Their orbital radii are R_1 and R_2, respectively. Assume that $M >> m_2 > m_1$.

24. The ratio of the speeds v_1/v_2 is

(A) $\sqrt{R_2/R_1}$
(B) $\sqrt{R_1/R_2}$
(C) $\sqrt{m_2/m_1}$
(D) $\sqrt{m_1/m_2}$
(E) 1

25. The magnitude of the angular momentum of the two-satellite system is best represented by

(A) $|m_1v_1 + m_2v_2|$
(B) $|m_1v_1 - m_2v_2|$
(C) $|m_1v_1R_1 + m_2v_2R_2|$
(D) $|m_1v_1R_1 - m_2v_2R_2|$
(E) $|m_1v_1/R_1 + m_2v_2/R_2|$

26. If U_1 is the potential energy of the planet-satellite system containing the satellite of mass m_1 and U_2 is the potential energy of the planet-satellite system containing the satellite of mass m_2, which of the following expressions best represents the ratio U_1/U_2 ?

(A) $\frac{m_1R_1}{m_2R_2}$
(B) $\frac{m_2R_2}{m_1R_1}$
(C) $\frac{m_1R_2}{m_2R_1}$
(D) $\frac{m_2R_1}{m_1R_2}$
(E) $\frac{m_1R_2^2}{m_2R_1^2}$

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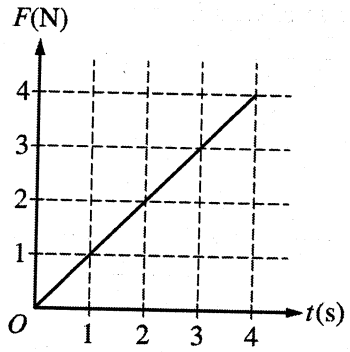
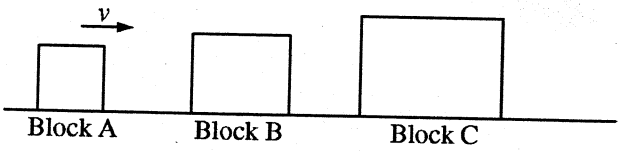


27. The graph above shows a variable force F that acts on an object as it moves along a straight line as a function of time t. What is the change in momentum of the object from $t = 2$ s to $t = 4$ s ?

(A) 1 kg•m/s
(B) 2 kg•m/s
(C) 4 kg•m/s
(D) 6 kg•m/s
(E) 8 kg•m/s



28. Blocks A, B, and C are aligned along a straight line on a horizontal frictionless surface. The masses of the blocks are M, $2M$, and $3M$, respectively. Block A is initially moving to the right along the same line at a speed v, as shown in the figure above. Blocks B and C are initially at rest. Block A collides with and sticks to block B. The two blocks then collide with and stick to block C. What is the speed of block C after the collisions?

(A) 0
(B) $v/6$
(C) $v/3$
(D) $v/2$
(E) $6v$

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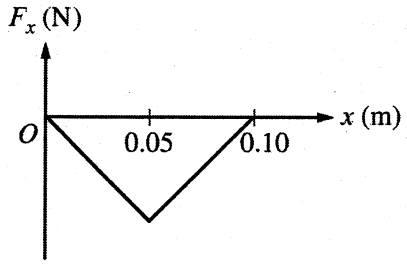


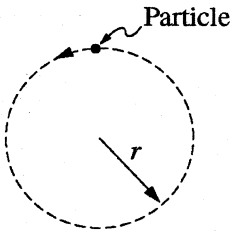
29. The graph above shows a conservative force F_x as a function of position x acting on an object in a closed system. If this is the only force acting on the object, what happens to the potential energy of the system as the object moves from 0 m to 0.10 m?

(A) It increases only.
(B) It decreases only.
(C) It increases and then decreases.
(D) It decreases and then increases.
(E) It does not change.

30. How does the work required to accelerate a particle from 10 m/s to 20 m/s compare to that required to accelerate it from 20 m/s to 30 m/s?

(A) It is less.
(B) It is the same.
(C) It is greater.
(D) It cannot be determined without knowing the magnitude of the force exerted on the particle.
(E) It cannot be determined without knowing the mass of the particle.

Questions 31-32



Top View

A particle of mass m moves counterclockwise around a horizontal circle of radius r, as shown above. The angular speed of the particle is given as a function of time t by $\omega(t) = bt$, where b is a positive constant and $t \geq 0$.

31. Which of the following best describes the acceleration vector for the particle at the moment shown in the diagram?

(A) It is directed toward the left.
(B) It is directed toward the bottom of the page.
(C) It is directed toward the top of the page.
(D) It has components directed toward the right and toward the bottom of the page.
(E) It has components directed toward the left and toward the bottom of the page.

32. What is the magnitude of the angular momentum of the particle about the center of the circle as a function of time?

(A) mbt/r
(B) $mbrt$
(C) mbr^2t
(D) mb^2rt^2
(E) $mb^2r^2t^2$

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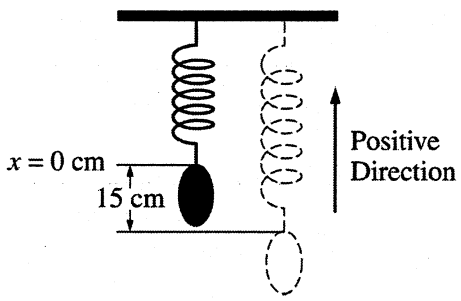
Questions 33-35



An object is initially hanging in equilibrium from a vertical spring. The object is pulled down 15 cm from its equilibrium position, as illustrated above, and released at time $t = 0$. The object then oscillates with a period of 2.0 s. Let $x = 0$ be the equilibrium position and let the positive direction be upward.

33. What is the position of the object at $t = 3.0$ s?

(A) 15 cm
(B) 7.5 cm
(C) 0 cm
(D) −7.5 cm
(E) −15 cm

34. What is the total distance traveled by the object during the first 2.0 s of its motion?

(A) 90 cm
(B) 75 cm
(C) 60 cm
(D) 45 cm
(E) 30 cm

35. Which of the following statements is true of the magnitude of the acceleration of the object at time $t = 1.0$ s?

(A) It is equal to zero.
(B) It is equal to g.
(C) It has its minimum value that is not zero.
(D) It has its maximum value.
(E) It has a value between zero and its maximum value.

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S T O P

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2017

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ ☐☐ ☐☐☐☐
   Month Day Year
3. Six-digit school code
   ☐☐☐☐☐☐
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   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

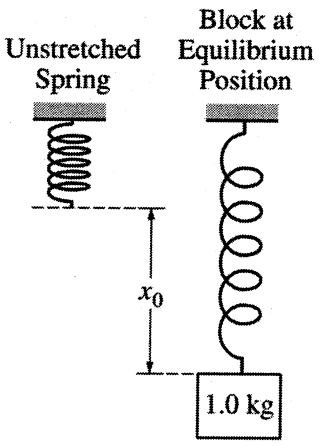
Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4NBP4-S

80

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. 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. A spring of negligible mass and with a spring constant of 50 N/m is hung vertically, as shown above in the figure on the left. A block of mass 1.0 kg is attached to the spring and slowly lowered a distance x_0 until it hangs at rest at the equilibrium position, as shown above in the figure on the right.

   (a) On the dot below that represents the block, draw and label the forces (not components) that act on the block when it is at the equilibrium position shown. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

   (b) Calculate the distance x_0 that the spring is stretched from its original length to the equilibrium position.

Question 1 continues on the next 2 pages.

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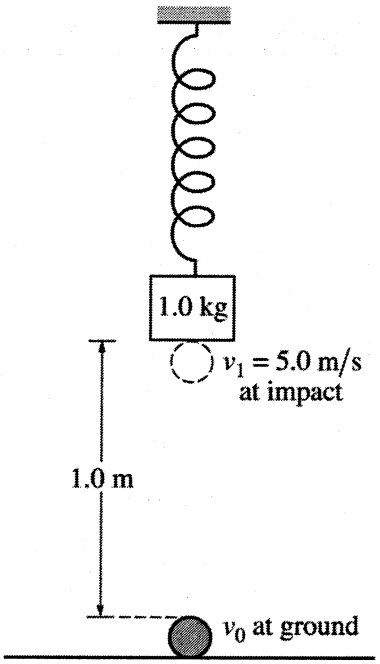
GO ON TO THE NEXT PAGE.



While the 1.0 kg block is in equilibrium, a 0.20 kg ball of clay is launched with speed v_0 vertically from the ground 1.0 meter below the hanging block. The clay has speed $v_1 = 5.0$ m/s when it collides with the block.

(c) Calculate the speed v_0.

Upon impact, the clay sticks to the 1.0 kg block.

(d)

i. Calculate the speed of the block immediately after the collision.

ii. Calculate the kinetic energy lost in the collision.

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GO ON TO THE NEXT PAGE.

iii. Determine the period of oscillation for the block-clay-spring system.

(e) When the oscillating block-clay-spring system reaches its maximum speed after the collision, will the spring be stretched from its original length by a distance greater than, less than, or equal to x_0 ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

(f) The collision is repeated using a rubber ball with the same mass as the ball of clay. The rubber ball is launched vertically with the same speed v_0. The collision between the rubber ball and the block is elastic. Will the speed of the block immediately after colliding with the rubber ball be greater than, less than, or equal to the speed of the block you calculated in part (d)i ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

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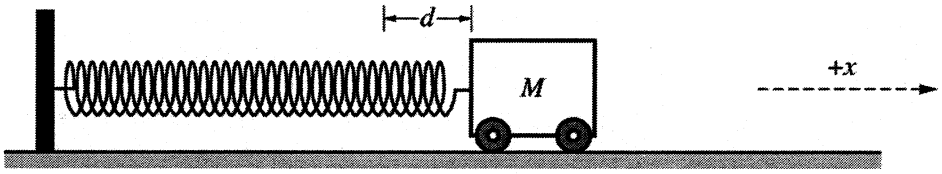
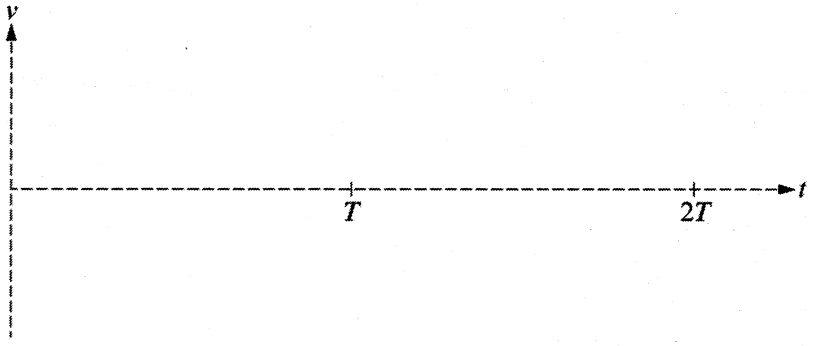


2. A cart of mass M is on a level, horizontal track. The cart is attached to one end of an ideal spring, and the other end of the spring is attached to a vertical support. The spring has a spring constant k. The cart is pulled to the right, stretching the spring a distance d, as shown above, and released from rest at time $t = 0$. The cart-spring system begins to oscillate, and the position x of the cart as a function of time t is given by the equation $x(t) = d\cos(\omega t)$, where x is in meters, ω is in rad/s, and t is in seconds. Assume the mass of the cart's wheels to be negligible.

(a) Derive an equation for the velocity of the cart v as a function of time t.

(b) On the axes below, sketch a graph of the velocity v of the cart as a function of time t for two complete oscillations. On the graph, T represents the time for one complete oscillation. Explicitly label asymptotes, maxima, or minima with algebraic expressions, as appropriate.



(c) Express all answers in part (c) in terms of ω, t, M, d, k, and physical constants, as appropriate.

i. Determine an expression for the kinetic energy K of the system as a function of time t.

ii. Determine an expression for the potential energy U of the system as a function of time t.

iii. Using the equations from parts (c)i and (c)ii, show that the rate of change of the total energy of the system dE/dt is zero.

Question 2 continues on the next 2 pages.

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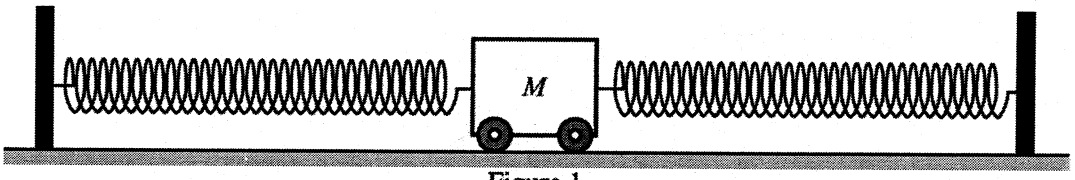


Figure 1

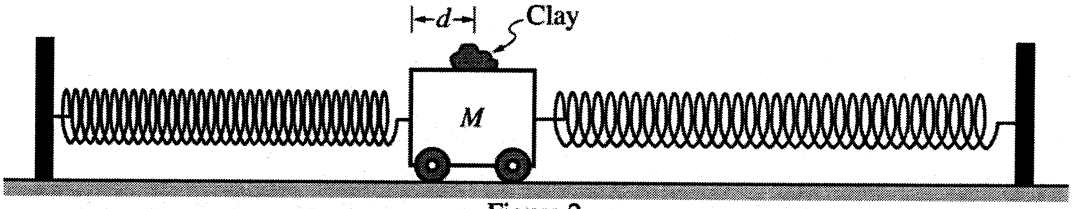
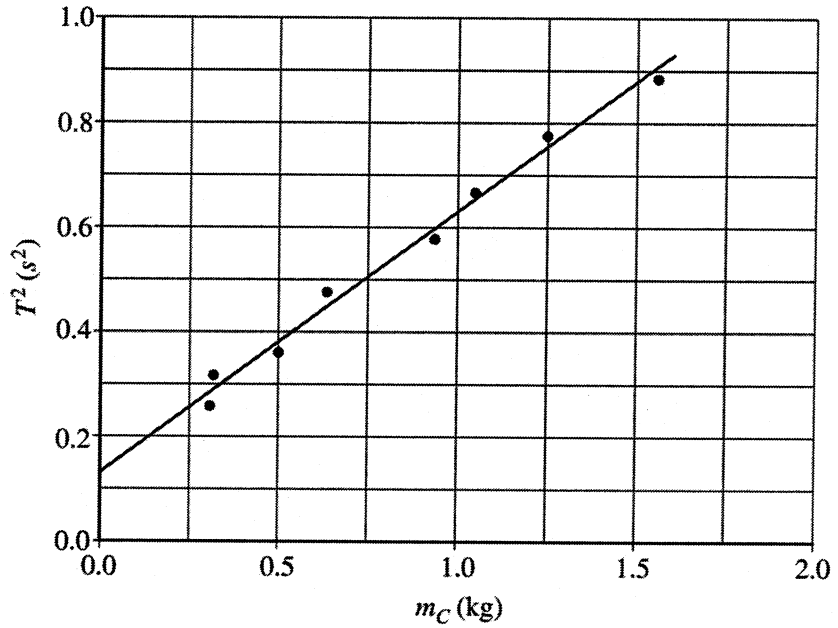


Figure 2

Two springs identical to the spring above are attached to each side of the cart of unknown mass M, as shown in Figure 1 above. The cart is on a level, horizontal track of negligible friction. A piece of clay is added to the top of the cart so that it will stick to the cart. The cart is displaced to the left a distance d and released from rest, as shown in Figure 2 above. The period of oscillation is recorded. This procedure is repeated for several different pieces of clay of different masses. In each trial, the cart is displaced the same distance d. The data are shown below on the linear graph of T^2 as a function of m_C, where T is the period of oscillation and m_C represents the mass of the clay.



(d) From the graph, determine the following.

i. k, the spring constant of each spring

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GO ON TO THE NEXT PAGE.

ii. M, the mass of the cart

(e) The experiment is repeated, but in a second set of trials, the cart is pulled back a distance D, where $D > d$. Describe any changes that will occur for the straight line on the graph in part (d).

Justify your answer.

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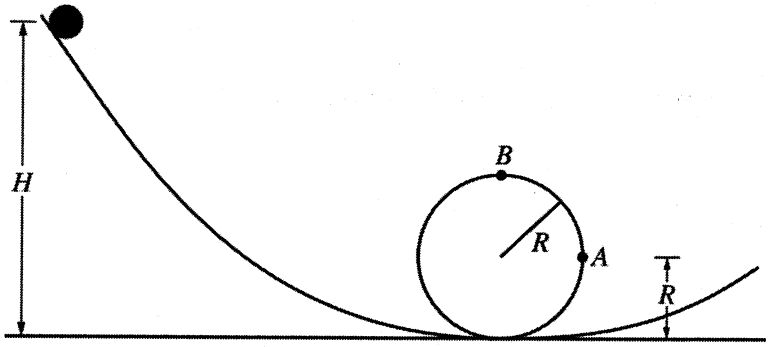
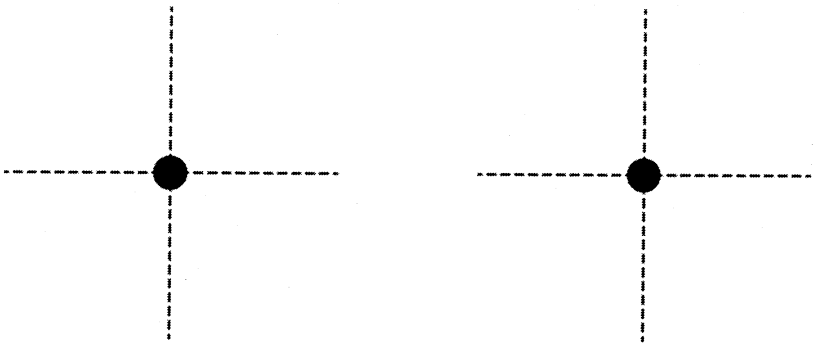


3. A sphere of mass m and radius r is released from rest at the top of a curved track of height H. The sphere travels down the curved track and around a loop of radius R. The sphere rolls without slipping during the entire motion. Point A on the loop is at height R, and point B is at the top of the loop. The rotational inertia of the sphere is $2mr^2/5$. Express all of your answers in parts (a) through (d) in terms of m, r, H, R, and physical constants, as appropriate. Assume $r << R$.

(a) On the dots below, which represent the sphere, draw and label the forces (not components) that are exerted on the sphere at point A and at point B, respectively. Each force must be represented by a distinct arrow starting on and pointing away from the dot.

Sphere at Point A Sphere at Point B



(b)

i. Derive an expression for the speed of the sphere at point A.

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ii. Derive an expression for the normal force the track exerts on the sphere at point A.

(c) Calculate the ratio of the rotational kinetic energy to the translational kinetic energy of the sphere at point A.

(d) The minimum release height necessary for the sphere to travel around the loop and not lose contact with the loop at point B is H_{MIN}. The sphere is replaced with a hoop of the same mass and radius. Will the value of H_{MIN} increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

Question 3 continues on the next page.

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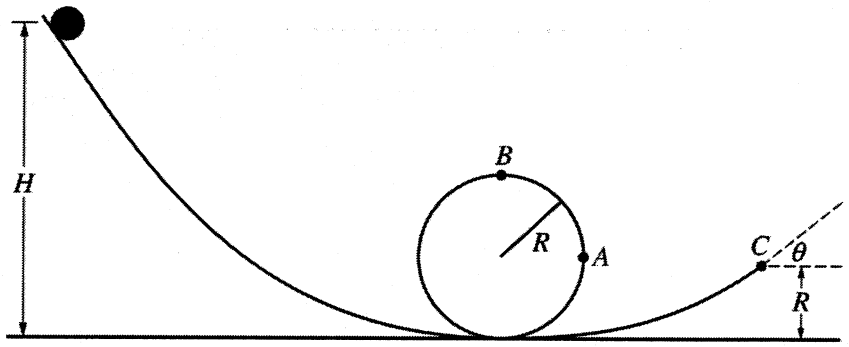

The sphere is again released from a known height H and eventually leaves the track at point C, which is a height R above the bottom of the loop, as shown in the figure above. The track makes an angle of θ above the horizontal at point C. Express your answer in part (e) in terms of m, r, H, R, θ, and physical constants, as appropriate.

(e) Calculate the maximum height above the bottom of the loop that the sphere will reach.

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GO ON TO THE NEXT PAGE.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Question 1: C

Question 2: C

Question 3: D

Question 4: E

Question 5: B

Question 6: E

Question 7: B

Question 8: E

Question 9: B

Question 10: B

Question 11: E

Question 12: D

Question 13: B

Question 14: A

Question 15: C

Question 16: B

Question 17: B

Question 18: C

Question 19: B

Question 20: A

Question 21: C

Question 22: D

Question 23: A

Question 24: A

Question 25: D

Question 26: C

Question 27: D

Question 28: B

Question 29: A

Question 30: A

Question 31: E

Question 32: C

Question 33: A

Question 34: C

Question 35: D

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Question 1

15 points total | **Distribution of points**

(a) 2 points



For correctly drawing and labeling the weight of the block — 1 point
For correctly drawing and labeling the force of the spring — 1 point
Note: A maximum of one point can be earned if there are any extraneous vectors.

(b) 2 points

For correctly substituting an expression for the spring force and the gravitational force into Newton's second law — 1 point

$F_S = mg$

$kx = mg$

$x_0 = mg/k = (1.0\text{ kg})\left(9.8\text{ m/s}^2\right)/(50\text{ N/m})$

For a correct answer — 1 point

$x_0 = 0.20\text{ m}$

(c) 2 points

For using an appropriate kinematics equation to determine the initial speed of the clay — 1 point

$v_1^2 = v_0^2 + 2a\Delta y$

$v_0 = \sqrt{v_1^2 - 2a\Delta y} = \sqrt{(5.0\text{ m/s})^2 - (2)\left(-9.8\text{ m/s}^2\right)(1.0\text{ m})}$

For a correct answer with units — 1 point

$v_0 = 6.68\text{ m/s}$

Alternate Solution — *Alternate points*

For using an equation for the conservation of energy to determine the initial speed of the clay — *1 point*

$K_1 = K_2 + U_{g2} \therefore (1/2)mv_1^2 = (1/2)mv_2^2 + mgh_2$

$v_1 = \sqrt{v_2^2 + 2gh} = \sqrt{(5.0\text{ m/s})^2 + (2)\left(9.8\text{ m/s}^2\right)(1.0\text{ m})}$

For a correct answer with units — *1 point*

$v_1 = 6.68\text{ m/s}$

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Question 1 (continued)

Distribution of points

(d)

i) 2 points

For using conservation of momentum to determine the speed of the block after the collision — 1 point

$p_1 = p_2 \therefore m_1 v_1 = (m_1 + m_2) v_2$

$v_2 = m_1 v_1 / (m_1 + m_2) = (0.20 \text{ kg})(5.0 \text{ m/s})/(0.20 \text{ kg} + 1.0 \text{ kg})$

For a correct answer with units — 1 point

$v_f = 0.83 \text{ m/s}$

ii) 2 points

For substituting the correct mass and initial speed OR the same mass and initial speed as part (d)(i) into the kinetic energy equation — 1 point

$K_1 = (1/2) m_1 v_1^2 = (1/2)(0.20 \text{ kg})(5.0 \text{ m/s})^2 = 2.5 \text{ J}$

For calculating the total kinetic energy after the collision using the combined mass and using the speed from part (d)(i) — 1 point

$K_2 = (1/2)(m_1 + m_2) v_2^2 = (1/2)(0.20 \text{ kg} + 1.0 \text{ kg})(0.83 \text{ m/s})^2 = 0.41 \text{ J}$

Subtract the two kinetic energies

$\Delta K = K_1 - K_2 = 2.5 \text{ J} - 0.41 \text{ J} = 2.1 \text{ J}$

Note: A maximum of one point can be earned if any other energy is included in the calculations above.

iii) 1 point

For using the combined mass in the equation for the period of oscillation of a spring — 1 point

$$T = 2\pi\sqrt{\frac{(m_1 + m_2)}{k}} = 2\pi\sqrt{\frac{(1.0 \text{ kg} + 0.20 \text{ kg})}{(50 \text{ N/m})}} = 0.97 \text{ s}$$

(e) 2 points

Select "Greater than"

For any correct equilibrium statement even if the wrong selection is made — 1 point

For indicating that the greater mass will stretch the spring more at equilibrium and the corresponding checkbox is selected — 1 point

Example: Since maximum velocity occurs when the block is at equilibrium and there is now more mass attached to the spring, the spring will be longer when the block-spring system is at maximum velocity.

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Question 1 (continued)

		Distribution of points
(f)	2 points	
	For correctly selecting "Greater than" and attempting to justify the selection	1 point
	For a correct justification	1 point
	Example: Since kinetic energy is conserved in an elastic collision, the speed of the target object (block) will be greater after the collision with the rubber ball than it was with the piece of clay.	
	Note: If incorrect selection is made, the justification cannot earn credit.	

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Question 2

15 points total

Distribution of points

(a) 2 points

For indicating that the velocity is the derivative of the position — 1 point

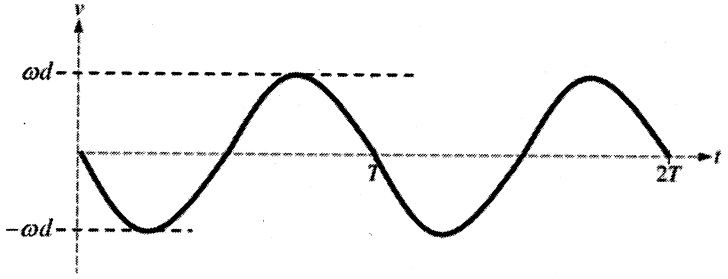
$v(t) = \frac{dx}{dt}$

$v(t) = \left(\frac{d(d\cos(\omega t))}{dt}\right)$

For correctly taking the derivative of the position — 1 point

$v(t) = -\omega d \sin(\omega t)$

(b) 3 points



For labeling maximum and/or minimum velocity as ωd and/or $-\omega d$ respectively OR labels consistent with the expression in part (a) — 1 point

For beginning the graph at zero and in the negative direction — 1 point

For drawing two sinusoidal curves with the first ending at T and the second ending at $2T$ — 1 point

(c)

i) 1 point

For an answer consistent with part (a) — 1 point

$K(t) = \frac{1}{2}mv(t)^2 = \left(\frac{1}{2}\right)(M)(-\omega d \sin(\omega t))^2 = \frac{M\omega^2 d^2}{2}\sin^2(\omega t)$

ii) 1 point

For an answer consistent with the position function used in part (a) — 1 point

$U(t) = \frac{1}{2}kx(t)^2 = \left(\frac{1}{2}\right)(k)(d\cos(\omega t))^2 = \frac{kd^2}{2}\cos^2(\omega t)$

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Question 2 (continued)

Distribution of points

(c) (continued)

iii) 2 points

For indicating that the total energy is the sum of the equations for parts (c)(i) and (c)(ii) — 1 point

$$E(t) = K(t) + U(t) = \frac{M\omega^2 d^2}{2}\sin^2(\omega t) + \frac{kd^2}{2}\cos^2(\omega t)$$

For correctly indicating that the derivative of the above equation is zero — 1 point

$$\omega = \sqrt{\frac{k}{m}} \therefore E(t) = \frac{M\left(\sqrt{\frac{k}{M}}\right)^2 d^2}{2}\sin^2(\omega t) + \frac{kd^2}{2}\cos^2(\omega t)$$

$$E(t) = \frac{kd^2}{2}\sin^2(\omega t) + \frac{kd^2}{2}\cos^2(\omega t) = \frac{kd^2}{2}\left(\sin^2(\omega t) + \cos^2(\omega t)\right) = \frac{kd^2}{2}$$

$$\frac{dE}{dt} = \frac{d}{dt}\left(\frac{kd^2}{2}\right) = 0$$

(d)

i) 2 points

For correctly calculating the slope using the best-fit line and not the data points — 1 point

Example:

$$\text{slope} = \frac{\Delta T^2}{\Delta m_{clay}} = \frac{(0.88 - 0.38)(\text{s}^2)}{(1.5 - 0.5)(\text{kg})} = 0.50\ \text{s}^2/\text{kg}$$

Acceptable range of answers: $0.48 - 0.60\ \text{s}^2/\text{kg}$

For correctly relating the slope to the equivalent spring constant for the two-spring system — 1 point

Example:

$$T = 2\pi\sqrt{\frac{m}{k_{eq}}} \therefore T^2 = \left(4\pi^2\right)\frac{m}{2k} \therefore \text{slope} = \frac{4\pi^2}{2k} \therefore k = \frac{4\pi^2}{2(\text{slope})} = \frac{\left(4\pi^2\right)}{(2)\left(0.50\ \text{s}^2/\text{kg}\right)}$$

$k = 39.5\ \text{N/m}$

Acceptable range of answers: $32.5 - 41.5\ \text{N/m}$

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Question 2 (continued)

Distribution of points

(d) (continued)

ii) 2 points

For relating the mass of the cart to the period and substituting values of a point from the graph — 1 point

For substituting the value for the spring constant from part (d)(i) — 1 point

Example:

$$T^2 = \left(4\pi^2\right)\frac{m_c + M}{2k} \therefore M = \frac{2kT^2}{4\pi^2} - m_c = \frac{(2)(39.5\ \text{N/m})\left(0.50\ \text{s}^2\right)}{\left(4\pi^2\right)} - 0.75kg$$

$m = 0.25$ kg

(e) 2 points

For indicating that the line would not change — 1 point

For a correct justification — 1 point

Example: Since the period does not depend on the amplitude of oscillation, the graph would not change.

Note: If student does not indicate the line would not change, the justification cannot earn credit.

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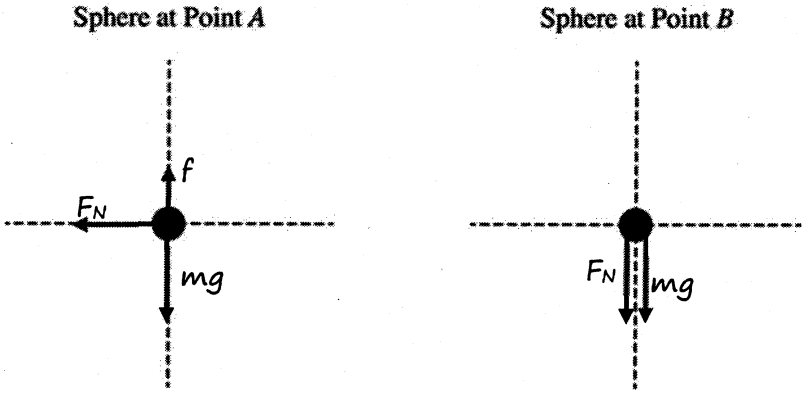
AP® PHYSICS C: MECHANICS
2017 SCORING GUIDELINES

Question 3

15 points total

Distribution of points

(a) 3 points



For correctly drawing and labeling the weight and normal force at point A — 1 point
For correctly drawing and labeling the weight and normal force at point B — 1 point
For correctly drawing and labeling the frictional force at point A — 1 point
Note: A maximum of 2 points can be earned if there are any extraneous vectors.

(b)

i) 2 points

For using the equation for conservation of energy for the sphere — 1 point

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

$$mgH = mgR + \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

$$mg(H - R) = \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{2}{5}mr^2\right)\left(\frac{v}{r}\right)^2 = \frac{7}{10}mv^2$$

For a correct answer — 1 point

$$v = \sqrt{\frac{10}{7}g(H - R)}$$

ii) 2 points

For correctly setting the normal force equal to the centripetal force — 1 point

$$F_N = F_C = \frac{mv^2}{r}$$

For an answer consistent with part (b)(i) above — 1 point

$$F_N = \frac{10mg(H - R)}{7R}$$

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Question 3 (continued)

Distribution of points

(c) 2 points

For using the equation for the ratio of the rotational and translational kinetic energies — 1 point

$$\frac{K_R}{K_T} = \frac{(1/2)I\omega^2}{(1/2)mv^2} = \frac{\left(\frac{2}{5}mr^2\right)\left(\frac{v}{r}\right)^2}{mv^2}$$

For a correct answer: — 1 point

$$\frac{K_R}{K_T} = \frac{2}{5}$$

Note: Credit is given if units are included.

(d) 2 points

Correct answer: "Increase"

For a statement indicating the rotational inertia of the hoop is greater — 1 point
For a statement indicating the effect of the greater rotational inertia on the linear speed of the hoop — 1 point

Example: Since the rotational inertia of the hoop is higher than that of the sphere, if the hoop and sphere start at the same height, the hoop will rotate at a slower speed and thus have a lower linear speed. Therefore, you need to start it at a higher initial height so that it travels fast enough to make it through the loop.

(e) 4 points

For using an appropriate kinematics equation to determine the maximum height of the sphere — 1 point

$$v_2^2 = v_1^2 + 2a\Delta y$$

For using only the vertical component of the velocity at point C to calculate the maximum height of the sphere — 1 point

$$0 = (v_C \sin\theta)^2 + 2(-g)\Delta y$$

For indicating that the speed at point C is the same as the speed at point A — 1 point

$$\Delta y = \frac{(v_A \sin\theta)^2}{2g}$$

$$y_{MAX} - R = \frac{\frac{10}{7}g(H-R)\sin^2\theta}{2g}$$

For a correct answer — 1 point

$$y_{MAX} = R + \frac{5}{7}(H-R)\sin^2\theta$$

Alternate solution on next page

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Question 3 (continued)

Distribution of points

(e) (continued)

Alternate solution — *Alternate points*

For using conservation of energy to determine the maximum height of the sphere and indicating the rotational kinetic energy does not change — *1 point*

$K_1 + U_1 = K_2 + U_2$

$\frac{1}{2}mv_1^2 + \frac{1}{2}I\omega_1^2 + mgh_1 = \frac{1}{2}mv_2^2 + \frac{1}{2}I\omega_2^2 + mgh_2$

$\frac{1}{2}mv_1^2 + mgh_1 = \frac{1}{2}mv_2^2 + mgh_2$

For using only the horizontal component of the velocity at point C to determine the kinetic energy when the sphere is at its maximum height — *1 point*

$\frac{1}{2}v_C^2 + gh_1 = \frac{1}{2}(v_C\cos\theta)^2 + gh_2$

For indicating that the speed at point C is the same as the speed at point A — *1 point*

$\frac{1}{2}\left(\frac{10}{7}g(H-R)\right) + gR = \frac{1}{2}\left(\frac{10}{7}g(H-R)\right)\cos^2\theta + gh_{MAX}$

$\frac{5}{7}(H-R) + R = \frac{5}{7}(H-R)\cos^2\theta + h_{MAX}$

$h_{MAX} = R + \frac{5}{7}(H-R)\left(1-\cos^2\theta\right)$

For a correct answer — *1 point*

$h_{MAX} = R + \frac{5}{7}(H-R)\sin^2\theta$

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2017 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	× 1.2857 =	_____
Number Correct (out of 35)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 2	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 3	_____ (out of 15)	× 1.0000 =	_____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
53-90	5
42-52	4
33-41	3
24-32	2
0-24	1

2017 AP Physics C: Mechanics
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Topic	Key	% Correct
1	Kinematics	C	68
2	Kinematics	C	70
3	Rotation & Circular Motion	D	30
4	Rotation & Circular Motion	E	39
5	Newton's laws	B	58
6	Newton's laws	E	90
7	Sys of particles & lin mom	B	40
8	Sys of particles & lin mom	E	28
9	Sys of particles & lin mom	B	57
10	Work/energy/power	B	23
11	Work/energy/power	E	82
12	Newton's laws	D	56
13	Newton's laws	B	65
14	Kinematics	A	89
15	Kinematics	C	90
16	Kinematics	B	66
17	Rotation & Circular Motion	B	63
18	Rotation & Circular Motion	C	55
19	Rotation & Circular Motion	B	34
20	Kinematics	A	85
21	Kinematics	C	69
22	Newton's laws	D	48
23	Newton's laws	A	92
24	Gravity	A	45
25	Gravity	D	52
26	Gravity	C	61
27	Sys of particles & lin mom	D	71
28	Sys of particles & lin mom	B	89
29	Work/energy/power	A	28
30	Work/energy/power	A	38
31	Rotation & Circular Motion	E	37
32	Rotation & Circular Motion	C	69
33	Oscillations	A	41
34	Oscillations	C	59
35	Oscillations	D	41

2017 AP Physics C: Mechanics
Question Descriptors and Performance Data

Free-Response Questions

Question	Topic	Mean Score
1	Sys of particles & lin mom	10.71
2	Oscillations	6.74
3	Rotation & Circular Motion	4.81

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AP® Physics C: Mechanics Practice Exam

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2016

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

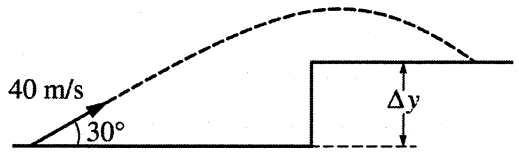
Form I
Form Code 4MBP4-S

80

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

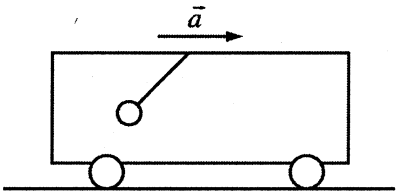
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\text{m/s}^2$ in all problems.



1. A projectile is launched with a speed of 40 m/s at an angle of 30° above the horizontal, as shown in the figure above. The projectile lands on a plateau 3 s later. The height Δy of the plateau is most nearly

   (A) 15 m
   (B) 30 m
   (C) 45 m
   (D) 60 m
   (E) 75 m



2. A small sphere hangs from a string attached to the ceiling of a uniformly accelerating train car. It is observed that the string makes an angle of 37° with respect to the vertical. The magnitude of the acceleration a of the train car is most nearly

   (A) $6.0\ \text{m/s}^2$
   (B) $7.5\ \text{m/s}^2$
   (C) $8.0\ \text{m/s}^2$
   (D) $10\ \text{m/s}^2$
   (E) $13\ \text{m/s}^2$

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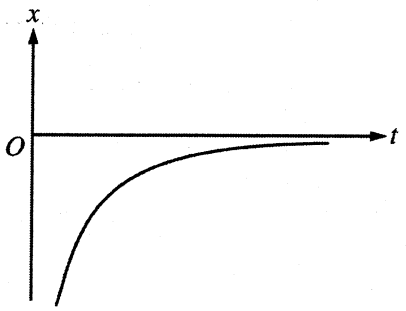
3. Which of the following statements must be true for a falling object that has been dropped from rest near the surface of Earth?

(A) The derivative of the distance the object falls with respect to time equals $9.8\ \text{m/s}^2$.
(B) The object falls a vertical distance of 9.8 m during the first second only.
(C) The object falls a vertical distance of 9.8 m during each second.
(D) The speed of the object as it falls is a constant $9.8\ \text{m/s}$.
(E) The speed of the object increases by $9.8\ \text{m/s}$ during each second.



4. The position x as a function of time t for an object moving in a straight line is shown in the graph above. Which of the following best describes the object's speed and direction of motion during the time interval shown?

	Speed	Direction of Motion
(A)	Decreasing	Positive
(B)	Increasing	Positive
(C)	Constant	Positive
(D)	Decreasing	Negative
(E)	Increasing	Negative

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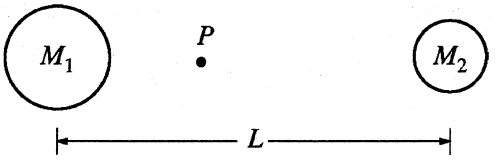
5. The force F exerted on a ball during a collision with a wall is given as a function of time t by the equation $F(t) = \alpha t - \beta t^2$, where $\alpha = 400$ N/s and $\beta = 4000$ N/s^2. The ball first contacts the wall at $t = 0$, and the collision lasts for 0.10 s. What is the magnitude of the change in momentum of the ball?

(A) 0
(B) 0.67 kg•m/s
(C) 3.33 kg•m/s
(D) 3.60 kg•m/s
(E) The change in momentum of the ball cannot be determined without knowing the mass of the ball.



6. Two spheres of uniform density are located a distance L apart, as shown in the figure above. The left sphere has a mass M_1, and the right sphere has a mass M_2. The center of mass of the two spheres is labeled point P. Which of the following is a correct expression for the distance from point P to the center of the left sphere?

(A) $\frac{M_1}{M_2}L$
(B) $\frac{(M_1 + M_2)}{M_1}L$
(C) $\frac{(M_1 + M_2)}{M_2}L$
(D) $\frac{M_2}{(M_1 + M_2)}L$
(E) $\frac{M_1}{(M_1 + M_2)}L$

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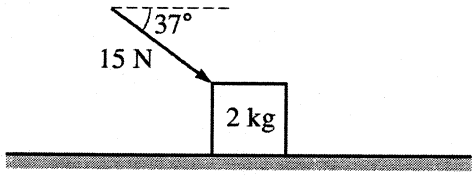
Questions 7-8



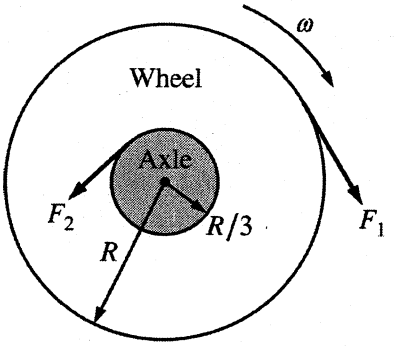
A 2 kg block is initially at rest on a horizontal frictionless table. A force of 15 N is then exerted on the block at an angle of 37° to the horizontal, as shown above.

7. The change in the kinetic energy of the block after moving a distance of 3 m is most nearly

   (A) 60 J
   (B) 45 J
   (C) 36 J
   (D) 27 J
   (E) 24 J

8. The magnitude of the force exerted on the block by the table is most nearly

   (A) 35 N
   (B) 32 N
   (C) 29 N
   (D) 20 N
   (E) 11 N



Note: Vectors not drawn to scale.

9. A wheel of radius R is fixed to an axle of radius $R/3$ and rotates at constant angular speed ω, as shown in the figure above. A force of magnitude F_1 is applied tangent to the outer edge of the wheel. A second force of magnitude F_2 is applied tangent to the edge of the axle to keep the wheel rotating at constant angular speed ω. The magnitude F_2 is equal to

   (A) $F_1/9$
   (B) $F_1/3$
   (C) F_1
   (D) $3F_1$
   (E) $9F_1$

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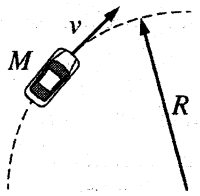
Questions 10-11



On a level horizontal table, a toy race car of mass M moves with constant speed v around a flat circular racetrack of radius R.

10. Which of the following best represents the minimum coefficient of static friction required for the race car to continue to follow the circular path shown?

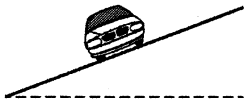
(A) $\frac{Rg}{v^2}$

(B) $\frac{Mv^2}{R}$

(C) $\frac{v^2}{g}$

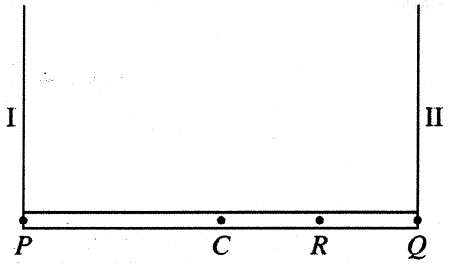
(D) $\frac{v^2}{Rg}$

(E) $\frac{v^2}{2Rg}$



11. The car is now going around a banked curve, as shown in the figure above. The banked curve is higher toward the outside of the circular turn. The car can now travel at a higher speed without sliding because the banked curve

(A) increases the coefficient of friction between the car and the track.
(B) increases the momentum of the car.
(C) allows a component of the normal force to point toward the center of the track.
(D) allows a component of the weight of the car to point toward the center of the track.
(E) allows gravity to do work on the car.



12. A horizontal uniform plank is supported by ropes I and II at points P and Q, respectively, as shown above. The two ropes have negligible mass. The tension in rope I is 150 N. The point at which rope II is attached to the plank is now moved to point R halfway between point Q and point C, the center of the plank. The plank remains horizontal. Which of the following are most nearly the new tensions in the two ropes?

	Tension in I	Tension in II
(A)	75 N	225 N
(B)	100 N	200 N
(C)	112.5 N	112.5 N
(D)	112.5 N	187.5 N
(E)	150 N	300 N

13. The potential energy U as a function of the position x of an object is given by $U(x) = -400/x$, where U is in joules and x is in meters. The object is released from rest at position $x = 30$ m and is free to move along the x-axis. When the object has moved a distance of 10 m from its initial position, the magnitude of the force associated with this potential energy function is

(A) 20 N
(B) 10 N
(C) 4.0 N
(D) 1.0 N
(E) 0.25 N

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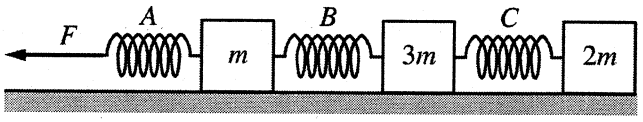
14. A student pushes a box across a rough horizontal floor. If the amount of work done by the student on the box is 100 J and the amount of energy dissipated by friction is 40 J, what is the change in kinetic energy of the box?

(A) 0 J
(B) 40 J
(C) 60 J
(D) 100 J
(E) 140 J



15. Three blocks of masses m, $3m$, and $2m$ resting on a frictionless horizontal surface are connected to identical ideal springs, as shown above. A force of magnitude F directed to the left is then applied to the left end of spring A. Which spring is stretched the most when the blocks are all moving with the same acceleration?

(A) A
(B) B
(C) C
(D) None, because the springs do not stretch.
(E) None, because the springs all stretch the same amount.

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16. At time $t = 0$, a ball is thrown with initial speed v_0 at an angle θ above the horizontal. Air resistance is negligible. Which of the following best represents the speed of the ball as a function of time t while the ball is in flight?

(A) $v_0 \sin\theta - gt$

(B) $v_0 \cos\theta - gt$

(C) $\sqrt{v_0^2 \cos^2\theta + (v_0 \sin\theta - gt)^2}$

(D) $\sqrt{(v_0 \cos\theta - gt)^2 + v_0^2 \sin^2\theta}$

(E) $\sqrt{(v_0 \cos\theta - gt)^2 + (v_0 \sin\theta - gt)^2}$

17. The position x of an object is given as a function of time t by the equation $x = 8 + 4t - 6t^3$, where x is in meters and t is in seconds. What is the maximum positive velocity attained by this object?

(A) 4 m/s
(B) 8 m/s
(C) 18 m/s
(D) 36 m/s
(E) There is no maximum positive velocity because the object never moves in the positive direction.

18. Two balls, A and B, have the same mass and diameter but are made from different types of rubber. The balls are dropped from the same height above the floor. After colliding with the floor, ball A bounces higher than ball B bounces. Which of the following quantities must necessarily be larger for ball A than for ball B ?

(A) The average force exerted by the floor
(B) The amount of time in contact with the floor
(C) The impulse exerted by the floor
(D) The momentum just before colliding with the floor
(E) The kinetic energy just before colliding with the floor

19. Object A of mass M is moving east at speed v. It collides with object B of mass $2M$ that was initially at rest. The motion of the objects before and after the collision is along the same line. After the collision, object A is moving west at a speed of $v/3$. What is the speed of object B immediately after the collision?

(A) $v/3$
(B) $v/2$
(C) $2v/3$
(D) v
(E) $2v$

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Questions 20-21

A wheel of mass m, which has a rotational inertia I and a radius r, rotates with an angular speed ω about an axis through its center. A retarding force F is applied tangentially to the rim of the wheel.

20. Which of the following is equal to the magnitude of the angular acceleration of the wheel?

(A) $\frac{F\omega}{m}$

(B) $\frac{Fr}{I}$

(C) $\frac{\omega^2}{r}$

(D) $I\omega$

(E) ωr

21. The retarding force F finally stops the rotation of the wheel. Which of the following best represents the total reduction in mechanical energy in the process of stopping the wheel?

(A) Fr

(B) $I\omega^2$

(C) $\omega^2 r$

(D) Fr^2

(E) $\frac{1}{2}I\omega^2$

22. An airplane travels horizontally at a constant velocity $\vec{v}$. An object is dropped from the plane, and one second later another object is dropped from the plane. If air resistance is negligible, what happens to the vertical distance between the two objects while they are both falling?

(A) It increases.
(B) It decreases.
(C) It remains the same.
(D) It depends on the mass of the objects.
(E) It depends on the horizontal speed of the plane.

23. A boat moves across a river. The river's velocity relative to the land is $\vec{v}_{RL}$, and the boat's velocity relative to the river is $\vec{v}_{BR}$. Which of the following best represents the velocity of the boat relative to the land?

(A) $\vec{v}_{BR} + \vec{v}_{RL}$

(B) $\vec{v}_{BR} - \vec{v}_{RL}$

(C) $-\vec{v}_{BR} + \vec{v}_{RL}$

(D) $|\vec{v}_{BR}| + |\vec{v}_{RL}|$

(E) $|\vec{v}_{BR}| - |\vec{v}_{RL}|$

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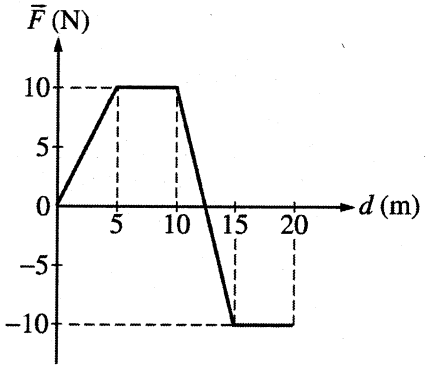
GO ON TO THE NEXT PAGE.

Questions 24-25

The following graph shows the force $\vec{F}$ exerted on a 2 kg object as a function of the distance d that the object travels. The object is at rest at $d = 0$ and travels on a horizontal, frictionless surface along the line of action of the force.



24. The work done on the object by the force $\vec{F}$ during the first 10 m of travel is most nearly

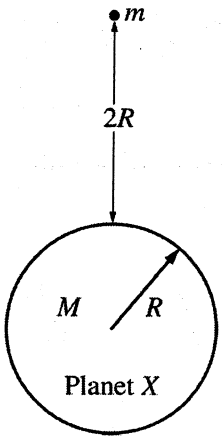
(A) 7.5 J
(B) 10 J
(C) 50 J
(D) 75 J
(E) 100 J

25. The kinetic energy of the 2 kg object when d equals 20 m is the same as when d is most nearly

(A) 0 m
(B) 5 m
(C) 10 m
(D) 12.5 m
(E) 15 m

26. The acceleration due to gravity on the surface of the Moon is about 1/6 of that on the surface of Earth. An astronaut weighs 600 N on Earth. The astronaut's mass on the Moon is most nearly

(A) 600 kg
(B) 360 kg
(C) 100 kg
(D) 60 kg
(E) 10 kg



27. Planet X has a mass M, radius R, and no atmosphere. An object of mass m is located a distance $2R$ above the surface of planet X, as shown in the figure above. The object is released from rest and falls to the surface of the planet. What is the speed of the object just before it reaches the surface of planet X?

(A) $\sqrt{\frac{2GM}{3R}}$

(B) $\sqrt{\frac{4GM}{3R}}$

(C) $\sqrt{\frac{8GM}{3R}}$

(D) $\sqrt{\frac{3GM}{R}}$

(E) $\sqrt{\frac{6GM}{R}}$

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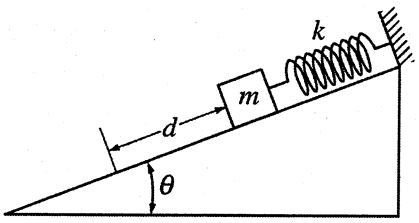
28. A ball is kicked from the ground with an initial speed v_0 at an angle θ above the horizontal. Which of the following best describes the magnitudes of the velocity and acceleration of the ball when it reaches the highest point of its trajectory?

	Velocity	Acceleration
(A)	0	0
(B)	$v_0 \cos\theta$	0
(C)	$v_0 \sin\theta$	0
(D)	$v_0 \cos\theta$	9.8 m/s^2
(E)	$v_0 \sin\theta$	9.8 m/s^2



29. A block of mass m is attached to a spring and placed on an inclined plane. The spring has a spring constant k, and there is negligible friction between the block and inclined plane. The block is released from rest at the position shown in the figure above with the spring initially unstretched. What distance d does the block slide down the plane before coming momentarily to rest?

(A) $\frac{2mg}{k}$

(B) $\frac{mg}{k}$

(C) $\frac{mg\sin\theta}{k}$

(D) $\frac{2mg\sin\theta}{k}$

(E) $\sqrt{\frac{mg\sin\theta}{k}}$

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GO ON TO THE NEXT PAGE.

30. A 5.0 kg object suspended on a spring oscillates such that its position x as a function of time t is given by the equation $x(t) = A\cos(\omega t)$, where $A = 0.80$ m and $\omega = 2.0\ \text{s}^{-1}$. What is the magnitude of the maximum net force on the object during the motion?

(A) 3.2 N
(B) 4.0 N
(C) 8.0 N
(D) 12.8 N
(E) 16.0 N

31. Consider Earth to be stationary, and the Moon as orbiting Earth in a circle of radius R. If the masses of Earth and the Moon are M_E and M_M, respectively, which of the following best represents the total mechanical energy of the Earth-Moon system?

(A) $\frac{GM_EM_M}{2R}$

(B) $\frac{GM_EM_M}{R}$

(C) $-\frac{GM_EM_M}{2R}$

(D) $-\frac{GM_EM_M}{R}$

(E) $-\frac{2GM_EM_M}{R}$

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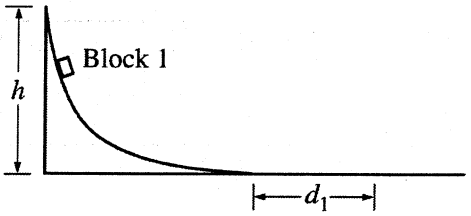
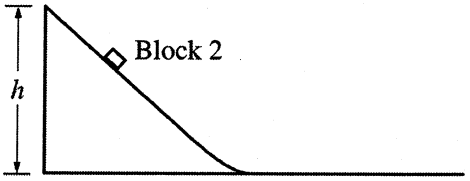
32. A small rock is launched straight upward from the surface of a planet with no atmosphere. The initial speed of the rock is twice the escape speed v_e of the rock from the planet. If gravitational effects from other objects are negligible, the speed of the rock at a very great distance from the planet will approach a value of

(A) zero
(B) $v_e/2$
(C) v_e
(D) $\sqrt{2}v_e$
(E) $\sqrt{3}v_e$





33. Identical blocks 1 and 2 start from rest at height h and travel down two differently shaped tracks onto identical rough horizontal surfaces, as shown in the figures above. Both tracks are frictionless, and both blocks make a smooth transition onto the rough horizontal surfaces. Block 1 comes to rest at a horizontal distance d_1 from the bottom of the track. Which of the following best describes and explains the horizontal distance d_2 that block 2 travels before coming to rest?

(A) $d_2 < d_1$, because block 2 reaches its maximum speed later than block 1
(B) $d_2 < d_1$, because block 2 has a lower maximum speed than block 1
(C) $d_2 = d_1$, because the blocks have the same mass
(D) $d_2 = d_1$, because the blocks start at the same height
(E) $d_2 > d_1$, because the track for block 2 is shorter

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GO ON TO THE NEXT PAGE.

	Mass (kg)	Area (cm^2)	μ_s
Block 1	0.75	75	0.20
Block 2	3.0	100	0.40

34. In an experiment, two blocks of different roughness are placed on the same rough wooden board. The table above shows three values for each block: the mass, the area of the block in contact with the board, and the coefficient of static friction μ_s between the block and the board. The experiment begins with the board horizontal. One end of the board is then slowly raised. Which of the following correctly identifies the block that will start sliding down the board first and why?
(A) Block 1, because it has less mass per unit area
(B) Block 1, because the coefficient of friction is smaller
(C) Block 2, because it has greater mass
(D) Block 2, because it has a smaller surface area
(E) Block 2, because the coefficient of friction is larger

35. An equation for the motion of an object is given as $2vt - 4x = Bt^2$, where B is a constant. The variable v indicates velocity, in meters per second; t indicates time, in seconds; and x indicates displacement, in meters. What is the unit of measure for B ?
(A) s
(B) m/s
(C) m/s^2
(D) m^2/s
(E) m^2/s^2

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GO ON TO THE NEXT PAGE.

S T O P

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2016

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐

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Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

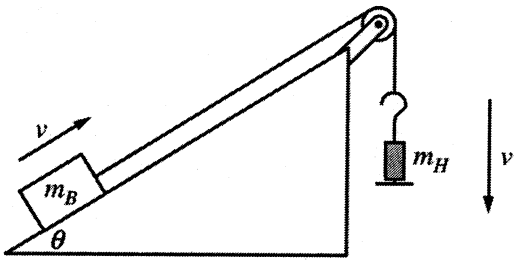
Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4MBP4-S

80

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

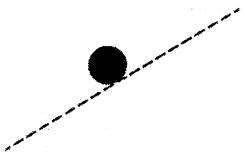


Mech.1.

A block of mass m_B is being pulled up a ramp by a hanging object of mass m_H, as shown in the figure above. The blocks are attached to each other by a light string that passes over a pulley of negligible mass and friction. Both the block and the hanging object are moving at constant speed, and the angle of the ramp with the horizontal is θ. The coefficient of kinetic friction between the block and the ramp is μ_k.

(a) On the dots below, which represent the block and the hanging object, draw and label the forces (not components) that act on the block and the hanging object. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.

Block



Hanging Object



(b) Derive an expression for the mass m_H of the hanging object. Express your answer in terms of m_B, θ, μ_k, and physical constants, as appropriate. 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).

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GO ON TO THE NEXT PAGE.

It is determined that $m_B = 2.0\,\text{kg}$, $\theta = 30^\circ$, and $\mu_k = 0.10$. While the block is moving up the ramp and the hanging object is moving downward, the string is suddenly cut.

(c)

i. Calculate the magnitude of the acceleration of the block immediately after the string is cut.

ii. What is the direction of the acceleration of the block immediately after the string is cut?

____ Up the ramp ____ Down the ramp

____ No direction, because the acceleration is zero

iii. Determine the magnitude of the acceleration of the hanging object immediately after the string is cut.

(d) Assume the block is moving up the ramp at 2.0 m/s when the string is cut. Calculate how far the block travels up the ramp from the time the string is cut until the block stops, assuming there is sufficient distance on the ramp.

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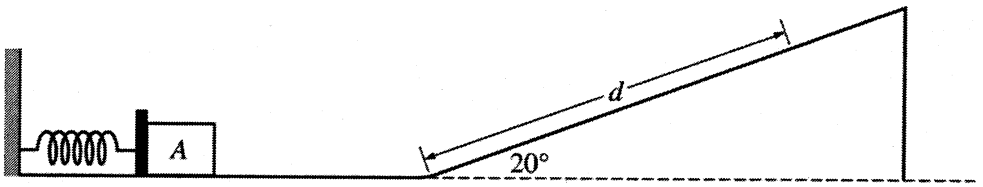


Note: Figure not drawn to scale.

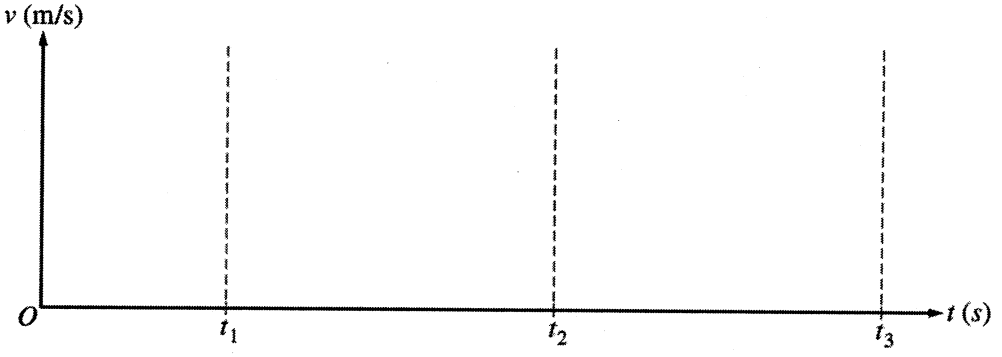
Mech.2.

An experiment is performed on a frictionless surface consisting of a horizontal section and a ramp inclined at a $20°$ angle. Block A of mass 3.0 kg rests on the horizontal section against but not attached to an ideal spring at its equilibrium length, as shown in the figure above. The spring has a spring constant of $k = 700$ N/m. Block A is pushed to the left, compressing the spring 0.15 m, and then released.

(a) Calculate the speed of block A when it leaves the spring.

(b) Calculate the maximum distance d block A travels up the ramp.

(c) On the axis below, sketch a graph of the speed v of block A as a function of time t from $t = 0$ to $t = t_3$. Block A is released at time $t = 0$, loses contact with the spring at time $t = t_1$, transitions to the ramp at time $t = t_2$, and reaches its maximum height at time $t = t_3$.



Note: Time intervals not to scale.

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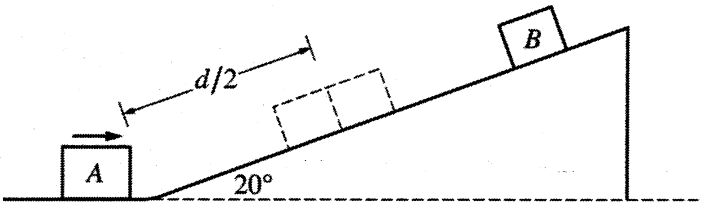

Note: Figure not drawn to scale.

In a second experiment, block B, of mass 0.50 kg, is placed on the ramp a distance of d from the bottom of the ramp and held in place. Block A is released from the spring as in the first experiment. Block B is released from rest so that it collides with block A as block A travels up the ramp. The two blocks collide at a distance of $d/2$ up the ramp. The blocks stick together after the collision.

(d)

i. Calculate the speed of the two blocks immediately after the collision.

ii. In what direction, if any, are the two blocks moving immediately after the collision?

____ Up the ramp ____ Down the ramp

____ Undefined, because the blocks momentarily come to rest after the collision

(e)

i. Calculate the magnitude of the impulse exerted on block A by block B.

ii. In what direction, if any, is the impulse exerted on block A by block B ?

____ Up the ramp ____ Down the ramp

____ Undefined, because the impulse is zero

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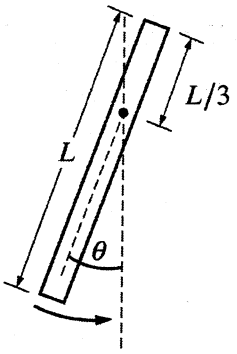

Mech.3.

A uniform rod of mass M and length L is pivoted at a point a distance $L/3$ from the top end, as shown above. The rod is pulled back so that it makes a small angle with the vertical and is then released.

(a) Using integral calculus, show that the rotational inertia for the rod around its pivot is $ML^2/9$.

(b)

i. Using Newton's 2nd law in rotational form, write but do NOT solve a differential equation in terms of M, L, and physical constants, as appropriate, that can be used to determine the angular displacement theta as a function of time t.

ii. Using the differential equation from part (b)i, show that the period of oscillation for the rod is given by the expression $T = 2\pi\sqrt{\frac{2L}{3g}}$.

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GO ON TO THE NEXT PAGE.

An experiment is performed with thin, uniform metal rods of different lengths, each pivoted around a point one third the length of the rod from the top end and used as a physical pendulum, as shown in the figure on the previous page. Each rod is pulled back so that it makes a small angle with the vertical and is then released, and the period of oscillation is measured. The data are recorded in the table below.

Length (m)	0.5	1.0	1.5	2.0	2.5
Period (s)	1.2	1.6	2.0	2.3	2.6

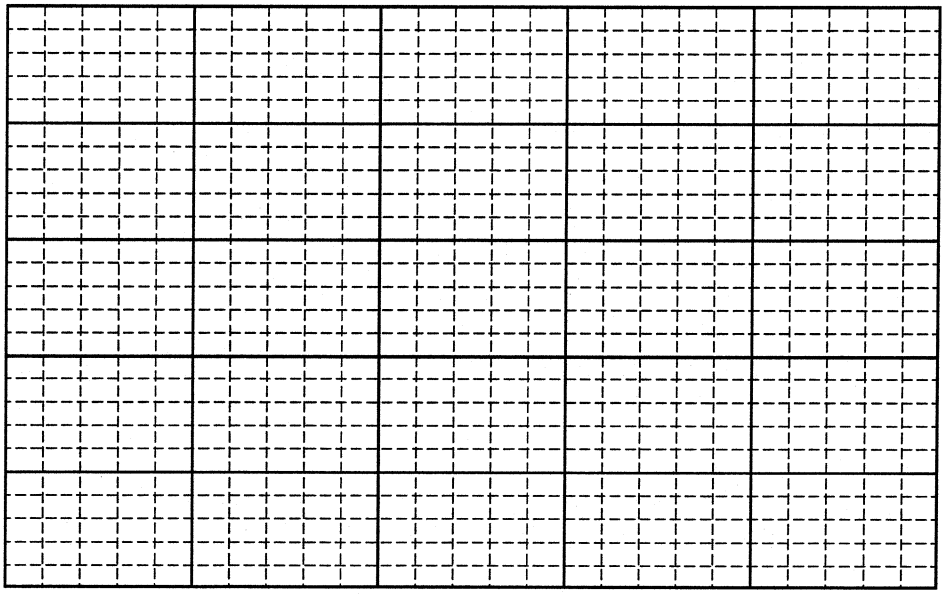
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Horizontal axis:_____

Vertical axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the straight line data points on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(e) Using your straight line, determine an experimental value for g.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Question 1: A
Question 2: B
Question 3: E
Question 4: A
Question 5: B
Question 6: D
Question 7: C
Question 8: C
Question 9: D
Question 10: D
Question 11: C
Question 12: B
Question 13: D
Question 14: C
Question 15: A
Question 16: C
Question 17: A
Question 18: C
Question 19: C
Question 20: B
Question 21: E
Question 22: A
Question 23: A
Question 24: D
Question 25: B
Question 26: D
Question 27: B
Question 28: D
Question 29: D
Question 30: E
Question 31: C
Question 32: E
Question 33: D
Question 34: B
Question 35: C

AP® PHYSICS C: MECHANICS
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Question 1

15 points total

Distribution of points

(a) 4 points



For correctly drawing and labeling the force of tension and the force of friction for the Block — 1 point

For correctly drawing and labeling the normal force vector for the Block — 1 point

For correctly drawing and labeling the weight vector for the Block — 1 point

For correctly drawing and labeling both vertical vectors for the Hanging Object — 1 point

Note: a maximum of three points can only be earned if there are any extraneous vectors

(b) 3 points

For a correct Newton's 2nd law equation of the two-block system — 1 point

$m_Hg - F_T = m_Ha = 0$

$F_T - m_Bg\sin\theta - f = m_Ba = 0$ or $m_Hg - m_Bg\sin\theta - f = (m_H + m_B)a = 0$

For setting the acceleration of the two-block system equal to zero either implicitly or explicitly — 1 point

$m_Hg - m_Bg\sin\theta - \mu_k m_Bg\cos\theta = 0$

For a correct answer — 1 point

$m_H = m_B(\sin\theta + \mu_k\cos\theta)$

(c)

i. 3 points

For correctly applying Newton's second law to the block — 1 point

$-m_Bg\sin\theta - \mu_k m_Bg\cos\theta = m_Ba$

$-g(\sin\theta + \mu_k\cos\theta) = a$

For correctly substituting into the above equation — 1 point

$a = -(9.8\ \text{m/s}^2)((0.10)\cos 30 + \sin 30)$

For a correct answer — 1 point

$a = 5.75\ \text{m/s}^2$ (Note: $a = 5.87\ \text{m/s}^2$ if $g = 10\ \text{m/s}^2$ is used)

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Question 1 (continued)

Distribution of points

ii. 1 point

For selecting "Down the ramp" 1 point

iii. 1 point

For a correct answer 1 point
$a = g = 9.81\ \text{m/s}^2$ (Note: $a = g = 10\ \text{m/s}^2$ is also acceptable)
Note: No work needs to be shown for this part

(d) 3 points

For using a correct kinematics equation for calculating the distance traveled by the block 1 point
$v_2^2 = v_1^2 + 2ad$
For setting the final velocity of the block equal to zero 1 point
$0 = v_1^2 + 2ad$

$$d = \frac{-v_1^2}{2a} = \frac{-(2.0\ \text{m/s})^2}{(2)\left(-5.75\ \text{m/s}^2\right)}$$

For a correct answer 1 point
$d = 0.348$ m (Note: $d = 0.341$ m if $g = 10\ \text{m/s}^2$ is used)

Alternate solution
For using a correct statement of conservation of energy *1 point*
$KE_i + W_f = PE_f$
For converting h to d *1 point*
$h = d\sin\theta$
For a correct answer *1 point*
$d = 0.348$ m *(Note:* $d = 0.341$ m *if* $g = 10\ \text{m/s}^2$ *is used)*

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Question 2

15 points total | **Distribution of points**

(a) 2 points

For correctly using conservation of energy to determine the speed of block A — 1 point

$U_{S1} = K_2$

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

$v = \sqrt{\frac{k}{m}}x = \sqrt{\frac{(700\text{ N/m})}{(3.0\text{ kg})}}(0.15\text{ m})$

For a correct answer — 1 point

$v = 2.29\text{ m/s}$

(b) 2 points

For correctly using conservation of energy to determine the distance block A travels up the ramp — 1 point

$K_1 = U_{g2}$

$\frac{1}{2}mv^2 = mgh = mgd\sin\theta$

$d = \frac{mv^2}{2mg\sin\theta} = \frac{(3.0\text{ kg})(2.29\text{ m/s})^2}{(2)(3.0\text{ kg})(9.8\text{ m/s}^2)(\sin 20)}$

For a correct answer — 1 point

$d = 0.783\text{ m}$ (Note: $d = 0.767\text{ m}$ if $g = 10\text{ m/s}^2$ is used)

Alternate Solution

For correctly using conservation of energy to determine the distance block A travels up the ramp — *1 point*

$U_{S1} = U_{g2}$

$\frac{1}{2}kx^2 = mgh = mgd\sin\theta$

$d = \frac{kx^2}{2mg\sin\theta} = \frac{(700\text{ N/m})(0.15\text{ m})^2}{(2)(3.0\text{ kg})(9.8\text{ m/s}^2)(\sin 20)}$

For a correct answer — *1 point*

$d = 0.783\text{ m}$ (Note: $d = 0.767\text{ m}$ if $g = 10\text{ m/s}^2$ is used)

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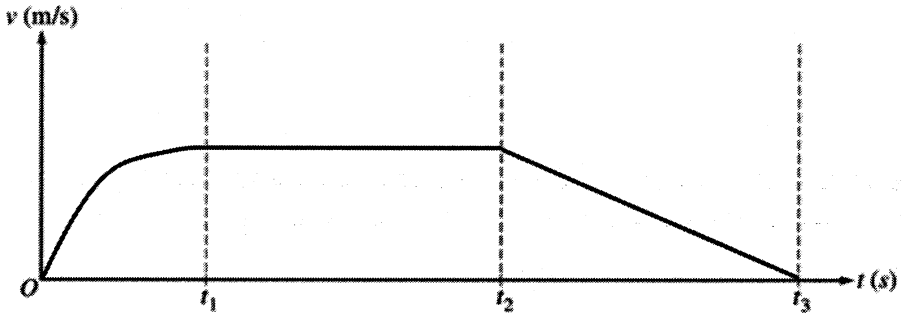
Question 2 (continued)

Distribution of points

(c) 3 points



For a concave down curve that starts at the origin $t = 0$ and becomes horizontal as $t = t_1$ — 1 point

For a horizontal line from $t = t_1$ to $t = t_2$ that is continuous with first section — 1 point

For a straight line with a negative slope from $t = t_2$ to the horizontal axis at $t = t_3$ that is continuous with second section — 1 point

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Question 2 (continued)

Distribution of points

(d)

i. 5 points

For correctly using conservation of energy to determine speed of block A — 1 point

$K_1 = U_{g2} + K_2$

$\frac{1}{2}mv_1^2 = mgh + \frac{1}{2}mv_2^2$

$\frac{1}{2}mv_1^2 = mg\frac{d}{2}\sin\theta + \frac{1}{2}mv_2^2$

For correctly substituting into the equation above — 1 point

$v_1^2 = gd\sin\theta + v_2^2$

$(2.29\text{ m/s})^2 = \left(9.8\text{ m/s}^2\right)(0.783\text{ m})(\sin 20) + v^2$

For a correct answer — 1 point

$v_A = 1.62$ m/s (Note: $v_A = 1.60$ m/s if $g = 10\text{ m/s}^2$ is used)

For correctly using conservation of energy to determine speed of block B — 1 point

$U_{g1} = K_2$

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

$mg\frac{d}{2}\sin\theta = \frac{1}{2}mv^2$

$v = \sqrt{\left(9.8\text{ m/s}^2\right)(0.783)(\sin 20)}$

Correct answer

$v_B = 1.62$ m/s (Note: $v_B = 1.64$ m/s if $g = 10\text{ m/s}^2$ is used)

For correctly using conservation of momentum to determine the speed of the blocks after the collision — 1 point

$m_A v_A + m_B v_B = (m_A + m_B)\, v_f$

$v_f = \frac{(3.0\text{ kg})(1.62\text{ m/s}) + (0.50\text{ kg})(-1.62\text{ m/s})}{(3.0\text{ kg} + 0.50\text{ kg})}$

Correct answer

$v_f = 1.16$ m/s (Note: $v_f = 1.14$ m/s if $g = 10\text{ m/s}^2$ is used)

Alternate solution:

For correctly calculating the acceleration of block A — *1 point*

$F = m_A a = m_A g\sin 20^\circ$

$a = g\sin 20^\circ = 3.35\text{ m/s}^2$

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Question 2 (continued)

Distribution of points

For correctly substituting into a correct kinematic equation — *1 point*

$v_{fA}^2 = v_{0A}^2 + 2a(d/2)$

$v_{fA}^2 = (2.29 \text{ m/s})^2 + 2\left(-3.35 \text{ m/s}^2\right)\left(\frac{0.783 \text{ m}}{2}\right)$

For a correct answer — *1 point*

$v_A = 1.62$ m/s *(Note: $v_A = 1.60$ m/s if $g = 10$ m/s^2 is used)*

For using a correct kinematic equation to determine the speed of block B — *1 point*

$v_{fB}^2 = v_{0B}^2 + 2a(d/2)$

$v_{fB}^2 = 0 + 2\left(3.35 \text{ m/s}^2\right)\left(\frac{0.783 \text{ m}}{2}\right)$

$v_{fB} = 1.62$ m/s

For correctly using conservation of momentum to determine the speed of the blocks after the collision — *1 point*

$m_A v_A + m_B v_B = (m_A + m_B)\, v_f$

$v_f = \dfrac{(3.0 \text{ kg})(1.62 \text{ m/s}) + (0.50 \text{ kg})(-1.62 \text{ m/s})}{(3.0 \text{ kg} + 0.50 \text{ kg})}$

Correct answer

$v_f = 1.16$ m/s *(Note: $v_f = 1.14$ m/s if $g = 10$ m/s^2 is used)*

ii. 1 point

For selecting "Up the ramp" — 1 point

(e)

i. 1 point

Correctly using the impulse equation

$J = m(v_2 - v_1)$

$J = (3.0 \text{ kg})(1.16 \text{ m/s} - 1.62 \text{ m/s})$

For an answer consistent with the speed of the blocks determined in part (d) — 1 point

$J = -1.38$ N•s (Note: $J = -1.38$ N•s if $g = 10$ m/s^2 is used)

Note: The negative sign is not needed since the question asks for magnitude

ii. 1 point

For selecting "Down the ramp" — 1 point

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Question 3

15 points total

Distribution of points

(a) 3 points

For using integral calculus to attempt to calculate the rotational inertia of the rod — 1 point

$I = \int r^2 dm \;\&\; \lambda = M/L \;\&\; dm = \lambda dr$

$I = \int \lambda r^2 dr$

For correctly integrating the formula above — 1 point

$I = \lambda\left[\frac{r^3}{3}\right]$

For integrating using the correct limits or correct constant of integration — 1 point

$I = \frac{\lambda}{3}\left(\left[r^3\right]_{r=-L/3}^{r=2L/3}\right) = \frac{\lambda}{3}\left[\left(\left(\frac{2L}{3}\right)^3 - \left(-\frac{L}{3}\right)^3\right)\right]$

$I = \frac{M}{3L}\left(\frac{8L^3}{27} - \left(-\frac{L^3}{27}\right)\right) = \left(\frac{M}{3L}\right)\left(\frac{9L^3}{27}\right)$

Correct answer:

$I = ML^2/9$

Alternate Solution

For using integral calculus to attempt to calculate the rotational inertia of the rod about its center — *1 point*

$I = \int r^2 dm \;\&\; \lambda = M/L \;\&\; dm = \lambda dr$

$I = \int \lambda r^2 dr = \lambda\left[\frac{r^3}{3}\right]$

For integrating using the correct limits or correct constant of integration — *1 point*

$I = \frac{\lambda}{3}\left(\left[r^3\right]_{r=-L/2}^{r=L/2}\right) = \frac{\lambda}{3}\left[\left(\left(\frac{L}{2}\right)^3 - \left(-\frac{L}{2}\right)^3\right)\right] = \frac{M}{3L}\left(\frac{L^3}{8} - \left(-\frac{L^3}{8}\right)\right) = \left(\frac{M}{3L}\right)\left(\frac{2L^3}{8}\right)$

$I = \frac{1}{12}ML^2$

For correctly using the Parallel-Axis Theorem — *1 point*

$I = I_{CM} + Mh^2 = \frac{1}{12}ML^2 + M\left(\frac{L}{6}\right)^2 = \left(\frac{1}{12} + \frac{1}{36}\right)ML^2 = \left(\frac{3+1}{36}\right)ML^2$

Correct answer:

$I = ML^2/9$

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Question 3 (continued)

Distribution of points

(b)

i. 2 points

For using a correct expression of Newton's 2nd law for the rotation of the rod — 1 point

$\tau = Fr_{\perp} = I\alpha$

$-Mg\left(\frac{L}{6}\right)\sin\theta = \frac{ML^2}{9}\alpha$

For expressing the equation as a differential equation — 1 point

$-\frac{3}{2}\frac{g}{L}\sin\theta = \frac{d^2\theta}{dt^2}$

ii. 2 points

For using the small-angle approximation; where $\sin\theta \approx \theta$ — 1 point

$-\frac{3}{2}\frac{g}{L}\theta = \frac{d^2\theta}{dt^2}$

For comparing above equation to the rotational form of simple harmonic motion or for solving the differential equation — 1 point

$-\frac{3}{2}\frac{g}{L}\theta = \frac{d^2\theta}{dt^2} = \alpha = -\theta\omega^2$

$\omega^2 = \left(\frac{2\pi}{T}\right)^2 = \frac{3}{2}\frac{g}{L}$

Correct answer:

$T = 2\pi\sqrt{\frac{2L}{3g}}$

(c) 1 point

For selecting appropriate variable to create a straight line relationship — 1 point

Example:

Horizontal axis: Length

Vertical axis: Period Squared

Note: Square root of Length and Period is also acceptable as is reversing the axes

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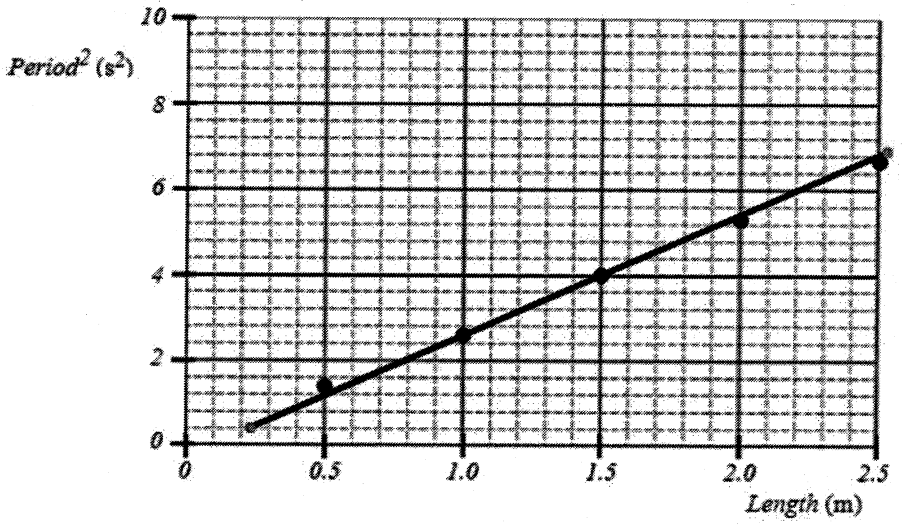
Question 3 (continued)

Distribution of points

(d) 4 points



For labeling both axes with appropriate variables and units — 1 point
For a correct scale that uses more than half the grid — 1 point
For correctly plotting data indicated in part (c) — 1 point
For drawing a straight line consistent with the given data — 1 point

(e) 3 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(6.0 - 2.0)}{(2.20 - 0.80)} = 2.86 \text{ s}^2/\text{m}$$

Note: linear regression gives slope = 2.67 s^2/m

For correctly relating g to the slope — 1 point

$$T = 2\pi\sqrt{\frac{2L}{3g}} \quad T^2 = \frac{(4\pi^2)2L}{3g} \quad slope = \frac{(4\pi^2) \times 2}{3g}$$

$$g = \frac{8\pi^2}{3 \times slope} = \frac{8\pi^2}{3 \times (2.86 \text{ s}^2/\text{m})}$$

For a correct answer — 1 point

$g = 9.20 \text{ m/s}^2$

Note: linear regression gives $g = 9.86 \text{ m/s}^2$

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2016 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	×	1.2857	=	_____
Number Correct (out of 35)				Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)
Question 2	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)
Question 3	_____	×	1.0000	=	_____
	(out of 15)				(Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
54-90	5
42-53	4
33-41	3
25-32	2
0-24	1

2016 AP Physics C: Mechanics
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Topic	Key	% Correct
1	Kinematics	A	66
2	Kinematics	B	38
3	Kinematics	E	87
4	Kinematics	A	72
5	System Of Particles & Linear Momentum	B	57
6	System Of Particles & Linear Momentum	D	44
7	Work/Energy/Power	C	77
8	Newton's Laws	C	67
9	Rotation & Circular Motion	D	64
10	Rotation & Circular Motion	D	65
11	Rotation & Circular Motion	C	62
12	Rotation & Circular Motion	B	29
13	Work/Energy/Power	D	14
14	Work/Energy/Power	C	74
15	Oscillations	A	56
16	Kinematics	C	66
17	Kinematics	A	75
18	System Of Particles & Linear Momentum	C	49
19	System Of Particles & Linear Momentum	C	60
20	Rotation & Circular Motion	B	69
21	Rotation & Circular Motion	E	73
22	Kinematics	A	45
23	Kinematics	A	54
24	Work/Energy/Power	D	87
25	Work/Energy/Power	B	63
26	Gravity	D	51
27	Gravity	B	34
28	Kinematics	D	74
29	Oscillations	D	18
30	Oscillations	E	34
31	Gravity	C	24
32	Gravity	E	7
33	Newton's Laws	D	59
34	Newton's Laws	B	59
35	Kinematics	C	77

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AP® Physics C: Mechanics Practice Exam

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2015

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

PLACE SEAL HERE

Form I
Form Code 4KBP6-S

80

PLACE SEAL HERE
DO NOT seal answer sheet inside

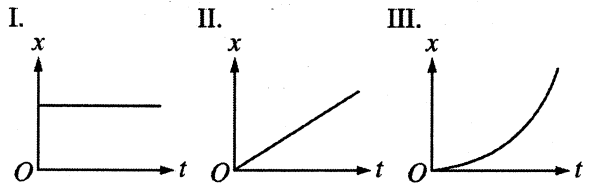
PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\text{m/s}^2$ in all problems.

Questions 1-3

The graphs below show position x plotted as a function of time t for each of three objects constrained to move along a straight, level path.



1. In which of the graphs is the magnitude of the momentum of the object increasing?

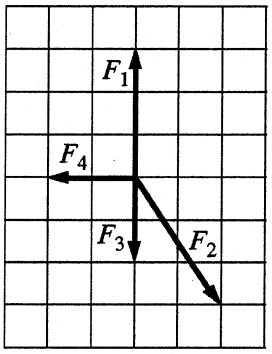
   (A) II only
   (B) III only
   (C) I and II
   (D) I and III
   (E) II and III

2. In which of the graphs does the object have a constant nonzero kinetic energy?

   (A) I only
   (B) II only
   (C) III only
   (D) I and II
   (E) I and III

3. In which of the graphs is the net force on the object zero?

   (A) I only
   (B) III only
   (C) I and II only
   (D) II and III only
   (E) I, II, and III



4. The coplanar forces F_1, F_2, F_3, and F_4 represented above can act on an object. If the object is initially at rest, which combination of the forces would result in static equilibrium?

   (A) F_1 and F_3 only
   (B) F_1, F_2, and F_4 only
   (C) F_2, F_3, and F_4 only
   (D) All four forces
   (E) No combination of the forces would result in equilibrium.

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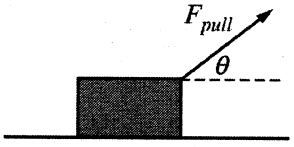

5. A block of mass M is being pulled to the right at a constant speed with a pull force F_{pull} that is at an angle of θ with respect to the horizontal, as shown in the figure above. The force of friction acting on the block has magnitude f. What is the magnitude of F_{pull}?

   (A) $f\cos\theta$
   (B) $f\sin\theta$
   (C) f
   (D) $f/\cos\theta$
   (E) $f/\sin\theta$

Questions 6-8

An astronaut hits a golf ball of mass m on the Moon, where there is no atmosphere and the acceleration due to gravity is $g/6$, where g is the acceleration due to gravity on Earth. Assume that the golf club is in contact with the ball for a time t. Just after losing contact with the club, the ball has an initial speed v directed at an angle θ above the horizontal.

6. What is the magnitude of the average force exerted by the club on the ball during contact?

   (A) mv
   (B) $mv\cos\theta$
   (C) $\frac{mv}{t}$
   (D) $\frac{mg}{6}$
   (E) $\frac{mg}{6}\cos\theta$

7. What is the work done by the club on the ball?

   (A) $\frac{1}{2}mv^2$
   (B) $\frac{1}{2}m(v\sin\theta)^2$
   (C) $\frac{1}{2}m(v\cos\theta)^2$
   (D) $6\left(\frac{1}{2}mv^2\right)$
   (E) $\left(\frac{1}{6}\right)\left(\frac{1}{2}mv^2\right)$

8. What is the maximum height above the Moon's surface attained by the ball?

   (A) vt
   (B) $6vt$
   (C) $\frac{v^2}{2g}$
   (D) $\frac{(v\sin\theta)^2}{2g}$
   (E) $6\left[\frac{(v\sin\theta)^2}{2g}\right]$

---

9. A simple pendulum of length L has a period T. What is the length of another simple pendulum of period $2T$, assuming that both pendulums swing with small amplitude?

   (A) $\frac{1}{2}L$
   (B) L
   (C) $\sqrt{2}L$
   (D) $2L$
   (E) $4L$

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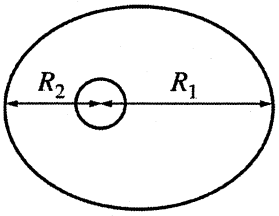
10. Pendulum 1 is displaced by a very small angle θ_1, is released from rest, and oscillates with a period T_1. Pendulum 2 is identical to pendulum 1, but it is displaced by a very small angle θ_2, is released from rest, and oscillates with a period T_2, where $\theta_1 > \theta_2$. Using the small angle approximation, how do the periods T_1 and T_2 compare?

(A) $T_1 > T_2$
(B) $T_1 = T_2$
(C) $T_1 < T_2$
(D) It cannot be determined without knowing the values of θ_1 and θ_2.
(E) It cannot be determined without knowing the length of the pendulums.

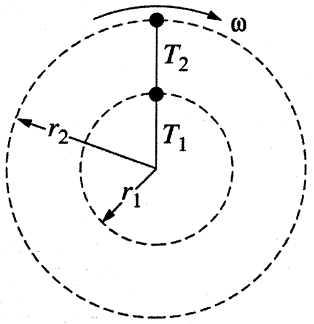
11. A newly discovered planet has three times the mass and five times the radius of Earth. What is the ratio of the acceleration due to gravity at the surface of the new planet to the acceleration due to gravity at the surface of Earth?

(A) 3/25
(B) 3/5
(C) 5/9
(D) 9/5
(E) 25/3



12. A satellite is in an elliptical orbit about a planet, as shown in the figure above. At apogee, a distance R_1 from the planet, the satellite's angular speed is ω. What is the angular speed of the satellite at perigee, a distance $R_2 = R_1/2$ from the planet?

(A) $(1/4)\omega$
(B) $(1/2)\omega$
(C) $(1/\sqrt{2})\omega$
(D) 2ω
(E) 4ω



13. Two objects of equal mass m are tied to a string and placed on a horizontal frictionless tabletop. The string and objects spin with angular velocity ω so that the objects move in circles of radius r_1 and r_2, as shown above. The tensions T_1 and T_2 must satisfy which of the following relations?

(A) $T_1 - T_2 = m\omega^2 r_1$
(B) $T_2 - T_1 = m\omega^2 r_1$
(C) $T_1 + T_2 = m\omega^2 r_2$
(D) $T_1 + T_2 = m\omega^2 r_1$
(E) $T_1 = T_2$

14. A block of mass 3 kg is swung on a cord in a horizontal circle of radius 2 m. The speed of the block is 6 m/s. The magnitude of the acceleration of the block is most nearly

(A) zero
(B) 10 m/s^2
(C) 18 m/s^2
(D) 36 m/s^2
(E) 54 m/s^2

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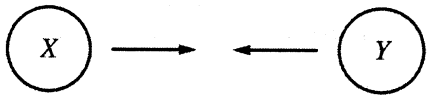
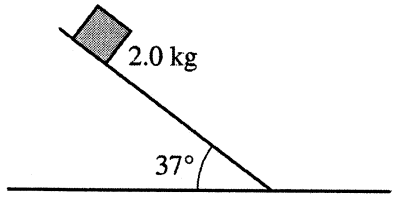


15. Two 1.0 kg balls have a perfectly elastic head-on collision, as shown in the figure above. Before the collision, ball X has a velocity of 2.0 m/s to the right and ball Y has a velocity of 4.0 m/s to the left. After the collision, ball X has a velocity of

(A) 0 m/s
(B) 2.0 m/s to the right
(C) 2.0 m/s to the left
(D) 4.0 m/s to the right
(E) 4.0 m/s to the left

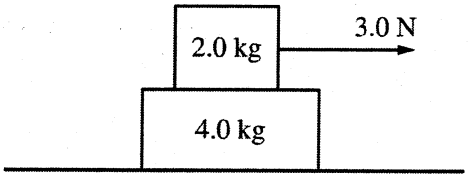
16. An object of mass m and velocity $3v$ toward the east has a completely inelastic collision with an object of mass $2m$ and velocity $2v$ toward the north. After the collision, the momentum of the combined object has a magnitude of

(A) $5mv$
(B) $7mv$
(C) $10mv$
(D) $12mv$
(E) $15mv$



17. A 2.0 kg block is released from rest at the top of a rough plane inclined at 37° to the horizontal, as shown above. The block slides down the incline with an acceleration of 4.0 m/s^2. What is the approximate magnitude of the force of friction on the block as it slides down the incline?

(A) 4.0 N
(B) 6.0 N
(C) 10 N
(D) 12 N
(E) 20 N



18. A 2.0 kg box is on top of a 4.0 kg box that is placed on a frictionless surface, as shown in the figure above. A 3.0 N force is applied to the top box. What is the minimum coefficient of friction between the two boxes needed to keep them moving together?

(A) 0.10
(B) 0.15
(C) 0.30
(D) 0.50
(E) 1.0

Questions 19-20

A juggler has three objects in the air simultaneously. The masses of the objects are m, $2m$, and $3m$. At a particular instant, their respective vertical velocities are $\vec{v}$, 0, and $-\vec{v}$, where positive velocity is upward.

19. What is the magnitude of the acceleration of the center of mass of the three-object system at this instant?

(A) zero
(B) $g/6$
(C) $g/3$
(D) $g/2$
(E) g

20. What is the velocity of the center of mass of the three-object system at this instant?

(A) $-\vec{v}/2$
(B) $-\vec{v}/3$
(C) zero
(D) $\vec{v}/3$
(E) $\vec{v}/2$

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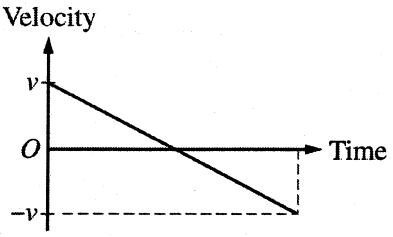
21. In a classroom demonstration, a teacher has a coin and feather in a long tube. The teacher uses a vacuum pump to remove all the air from the tube. The feather and coin are then dropped from the top of the tube at the same time. Which of the following describes what happens and why?

(A) The coin hits the bottom of the tube first because it weighs more.
(B) The coin hits the bottom of the tube first because it is more dense.
(C) The feather hits the bottom of the tube first because it weighs less.
(D) The coin and feather hit the bottom of the tube at the same time because they weigh the same.
(E) The coin and feather hit the bottom of the tube at the same time because they have the same acceleration.



22. The graph above shows velocity versus time for an object moving in a straight line, initially in the $+x$ direction. Which of the following is true for the motion of the object for the entire time shown on the graph?

(A) Its speed decreases with constant acceleration.
(B) Its speed increases with constant acceleration.
(C) Its speed decreases with acceleration that also decreases in magnitude.
(D) Its speed decreases to zero, then increases as the object moves in the $-x$ direction.
(E) Its acceleration decreases at a constant rate to zero, then increases at a constant rate.

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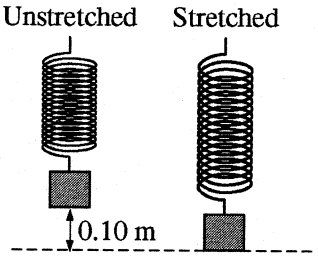
Questions 23-24

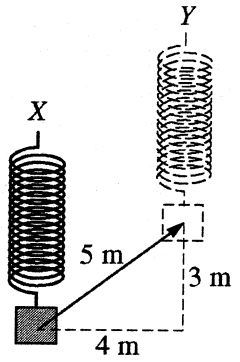


Note: Figure not drawn to scale.

A block is hung vertically from a spring of force constant 50 N/m and slowly lowered to equilibrium, stretching the spring by 0.10 m, as shown in the figure above.

23. If instead of being lowered slowly to equilibrium, the block—still attached to the spring—was released from rest and allowed to fall, which of the following would happen?

(A) It would descend 0.10 m and remain at that position.
(B) It would descend 0.10 m and then reverse its direction of motion.
(C) It would descend 0.20 m and remain at that position.
(D) It would descend 0.20 m and then reverse its direction of motion.
(E) It would descend more than 0.20 m and then reverse its direction of motion.



Note: Figure not drawn to scale.

24. The spring and attached block are allowed to come to rest at position *X* and are then moved to rest at position *Y* along the diagonal path shown above. What is the work done on the block by the spring in moving it along this path?

(A) 0 J
(B) 15 J
(C) 20 J
(D) 25 J
(E) It cannot be determined without being given the value of the mass of the block.

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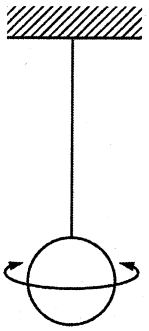


25. The sphere shown above, which hangs from a rigid wire, is given a twist and set into angular harmonic motion. The resulting equation of motion of the oscillating sphere is $\theta(t) = 0.1\cos(2t)$, where θ is in radians and t is in seconds. If the rotational inertia of the sphere is 10 kg•m^2, then the torsion constant of the wire is most nearly

(A) 7 kg•m^2/s^2
(B) 20 kg•m^2/s^2
(C) 30 kg•m^2/s^2
(D) 40 kg•m^2/s^2
(E) 50 kg•m^2/s^2

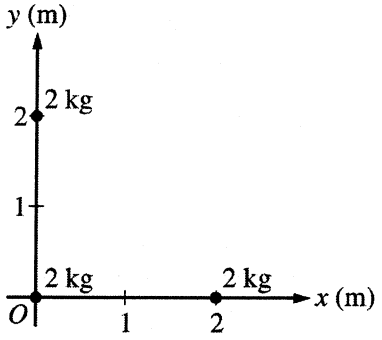
26. Assuming air resistance is negligible, how does a diver doing flips off a diving board change rotational speed in midair?

(A) By changing rotational inertia
(B) By maintaining a constant linear speed
(C) By changing linear momentum
(D) By exerting a net torque
(E) By changing angular momentum

27. A toy spacecraft is launched directly upward. When the toy reaches its highest point, a spring is released and the toy splits into two parts with masses of 0.01 kg and 0.09 kg, respectively. Immediately after the separation, the 0.01 kg part moves horizontally due east. Air resistance is negligible. True statements about the 0.09 kg part include which of the following?

I. It could move north immediately after the spring is released.
II. It takes longer to reach the ground than does the 0.01 kg part.
III. It strikes the ground closer to the launch point than does the 0.01 kg part.

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III



28. A system consists of three 2 kg objects located at coordinates (0, 2), (0, 0), and (2, 0), as shown in the figure above. What are the coordinates (x, y) of the center of mass of the system?

(A) (1/2 m, 1/2 m)
(B) (2/3 m, 2/3 m)
(C) (3/4 m, 3/4 m)
(D) (1 m, 1 m)
(E) (4/3 m, 4/3 m)

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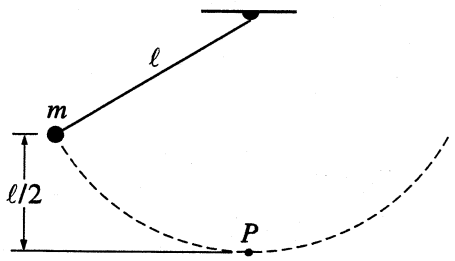
Questions 29-30 refer to the following.



A ball of mass m, suspended by a cord of length ℓ, is displaced along its arc until it is elevated a vertical distance of $\ell/2$ above its lowest position at point P, as shown above. The ball is then released from rest and swings like a simple pendulum.

29. The speed of the ball as it swings through point P is

(A) $\sqrt{g\ell}$

(B) $\sqrt{2g\ell}$

(C) $\sqrt{mg\ell}$

(D) $\frac{mg\ell}{2}$

(E) $mg\ell$

30. If air resistance and friction in the pivot are negligible, quantities that are conserved as the ball swings back and forth include which of the following?

I. Mechanical energy of the ball-Earth system
II. Linear momentum of the ball
III. Angular momentum of the ball about the pivot point

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

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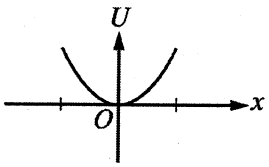
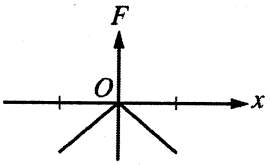
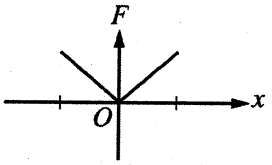
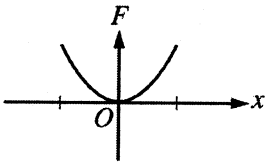
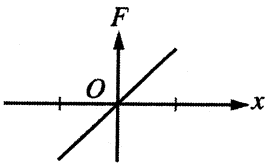


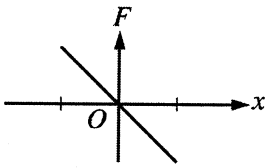
31. The graph above shows potential energy U versus position x for an object. Which of the following graphs shows the force F exerted on the object as a function of position x ?

(A)


(B)


(C)


(D)


(E)


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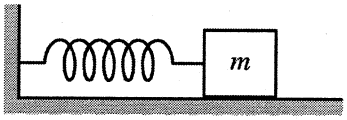

32. A block of mass m on a horizontal surface is attached to one end of a horizontal spring. The other end of the spring is fixed, as shown in the figure above. The block oscillates with negligible friction and an amplitude of 4.0 cm. How far from the equilibrium position is the block when the kinetic energy of the block is three times the potential energy of the system?

(A) 1 cm
(B) $\sqrt{2}$ cm
(C) 2 cm
(D) $2\sqrt{2}$ cm
(E) 3 cm

33. An Earth satellite in a circular orbit of radius R has a period T. What is the period of an Earth satellite in a circular orbit of radius $4R$?

(A) T
(B) $2T$
(C) $4T$
(D) $6T$
(E) $8T$

34. The net force on an object initially moving along the positive x-axis is given by $F(t) = \left(4t - t^3\right)$ for $t > 0$, where F is in newtons and along the x-axis, and t is in seconds. At what time does the object reach its maximum positive velocity?

(A) $\frac{3}{4}$ s
(B) $\frac{4}{3}$ s
(C) 2 s
(D) $\sqrt{6}$ s
(E) 3 s

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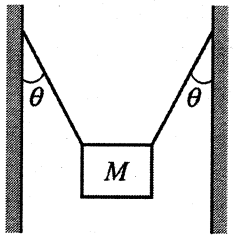

35. A heavy sign of mass M is hung between two buildings from two supporting wires, each making an angle θ with the vertical, as shown in the figure above. What is the tension in each wire?

(A) $\frac{Mg}{2\sin\theta}$

(B) $\frac{Mg}{2\cos\theta}$

(C) $\frac{Mg}{\sin\theta}$

(D) $\frac{2Mg}{\sin\theta}$

(E) $\frac{2Mg}{\cos\theta}$

STOP

END OF MECHANICS SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

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AP® Physics C: Mechanics Exam

SECTION II: Free Response

2015

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code Z-4FBP2-S

80

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

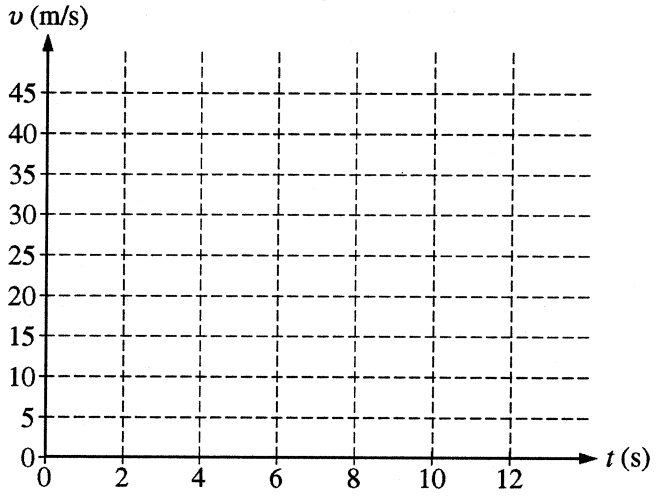
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

Mech. 1.

A new sports car is undergoing acceleration tests to determine its specifications. The following data on speed v versus time t are recorded for the car as it accelerates from rest along a straight track.

v (m/s)	0	14	23	30	35	39
t (s)	0	2	4	6	8	10

(a) On the axes below, plot v as a function of t and sketch a curve that best represents the data.



(b) Answer each of the following for the time period $t = 0$ s to $t = 10$ s.

i. Does the speed of the car increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

ii. Does the acceleration of the car increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

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GO ON TO THE NEXT PAGE.

(c) Explain how you would use your graph in part (a) to find the distance traveled by the car between $t = 2$ s and $t = 8$ s.

The equation for the speed v of the car as a function of time t found from the graph is $v(t) = -0.3t^2 + 7t$, where v is in meters per second and t is in seconds.

(d) Derive an expression for the acceleration of the car $a(t)$ as a function of time t.

(e) Calculate the position of the car as a function of time, $x(t)$, assuming that the car starts from rest at the origin of a coordinate system.

(f) Calculate the distance traveled by the car between $t = 2$ s and $t = 8$ s.

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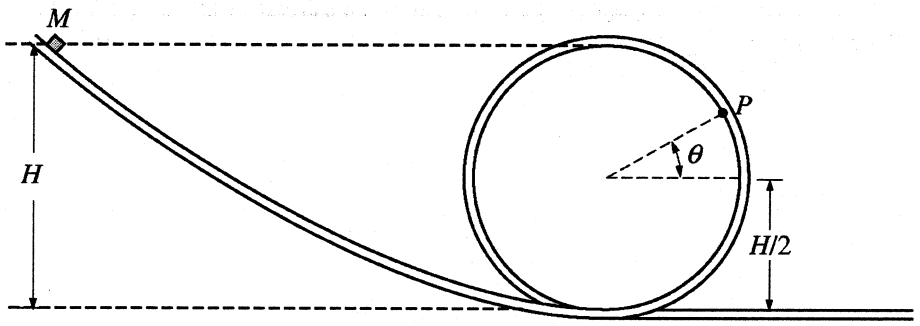
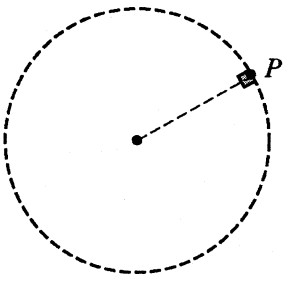


Mech. 2.

The model of a roller coaster shown above consists of a ramp and a circular loop. A small block of mass M starts from height H with speed $v = 0$ and slides without friction down the ramp and around the inside of the loop of radius $H/2$. Position P is a point on the loop at an angle θ with the horizontal, as shown above. Express all algebraic answers in terms of M, H, θ, and fundamental constants, as appropriate.

(a) Derive an expression for the speed of the block at position P.

(b) On the following diagram, draw and label vectors to represent the forces (not components) on the block when it is at position P. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot at position P.



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GO ON TO THE NEXT PAGE.

(c) Derive an expression for the magnitude of the force exerted by the loop on the block when it is at position P. 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 angle θ_L, in degrees, at which the block leaves the loop.

(e) The small block is replaced with a small sphere that also starts at height H. Now there is enough friction to allow the sphere to roll down the ramp without slipping. Identify how the new angle θ_n at which the sphere leaves the loop compares with the angle θ_L calculated in part (d).

____ $\theta_n < \theta_L$ ____ $\theta_n = \theta_L$ ____ $\theta_n > \theta_L$

Explain your reasoning.

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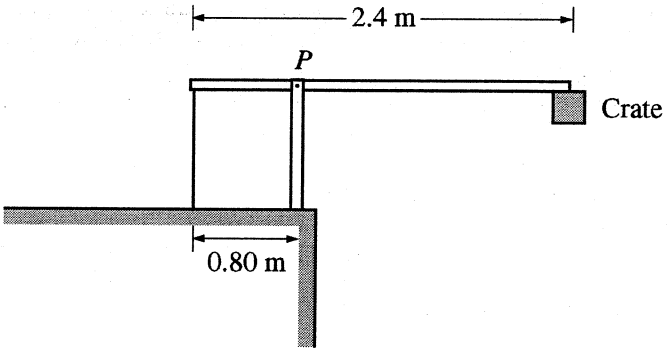
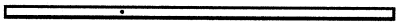


Mech. 3.

A uniform, rigid, thin board that is 2.4 m long and weighs 200 N is attached to a post by a pivot at point *P* and hangs over the edge of a building, as shown above. A crate weighing 400 N is attached to the right end of the board. The left end of the board, 0.80 m from the pivot, is attached to a light vertical wire anchored at the other end to keep the board from rotating.

(a) On the diagram below, draw and label vectors to represent all the forces (not components) acting on the board. Show each force vector originating at its point of application.



(b) Calculate the magnitudes of the forces exerted on the board by the post and by the wire. 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).

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GO ON TO THE NEXT PAGE.

(c) The rotational inertia of the board alone about its center is $\frac{1}{12}ML^2$, where M is the mass of the board and L is its length. Calculate the rotational inertia of the combined board-crate system about point P.

(d) Suppose that the wire breaks and the board begins to pivot about point P. Calculate each of the following.

i. The magnitude of the initial angular acceleration of the board-crate system

ii. The magnitude of the initial linear acceleration of the left end of the board

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Question 1: B

Question 2: B

Question 3: C

Question 4: B

Question 5: D

Question 6: C

Question 7: A

Question 8: E

Question 9: E

Question 10: B

Question 11: A

Question 12: E

Question 13: A

Question 14: C

Question 15: E

Question 16: A

Question 17: A

Question 18: A

Question 19: E

Question 20: B

Question 21: E

Question 22: D

Question 23: D

Question 24: B

Question 25: D

Question 26: A

Question 27: B

Question 28: B

Question 29: A

Question 30: A

Question 31: E

Question 32: C

Question 33: E

Question 34: C

Question 35: B

AP® PHYSICS
2015 SCORING GUIDELINES

GENERAL NOTES ABOUT 2015 PHYSICS SCORING GUIDELINES

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description.*

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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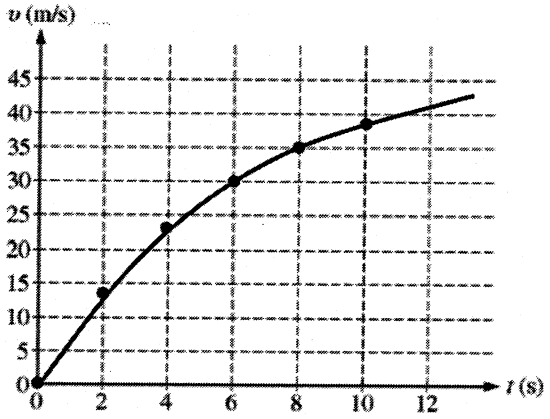
AP® PHYSICS C: MECHANICS
2015 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

(a) 3 points



For accurately plotting at least five points — 1 point
For a smooth curve with a positive slope — 1 point
For a concave down curve starting at the origin — 1 point

(b)

i. 1 point

The correct choice is "Increase"
For a correct justification — 1 point
Example: The speed increases as the magnitude of the velocity increases for each data point

ii. 1 point

The correct choice is "Decrease"
For a correct justification — 1 point
Example: Since the slope of the line decreases with time, the acceleration of the car must decrease with time

(c) 2 points

For mentioning area under the curve — 1 point
For specifically describing the area between $t = 2$ s and $t = 8$ s — 1 point
Example: To determine the distance traveled from a velocity-time graph, one should find the area under the curve. For time $t = 2$ s to $t = 8$ s, one can approximate the area using a trapezoid that approximately fills the area under the curve.

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AP® PHYSICS C: MECHANICS
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Question 1 (continued)

Distribution of points

(d) 2 points

For beginning with an indication that the acceleration is the derivative of velocity — 1 point

$a(t) = \frac{dv}{dt}$

For correctly evaluating the derivative — 1 point

$a(t) = \frac{d}{dt}\left(-0.3t^2 + 7t\right) = -0.6t + 7$

(e) 3 points

For an indication that the displacement is the integral of the velocity — 1 point

$\Delta x = \int_{t_0}^{t} v(t)dt$

For attempting to integrate with appropriate limits or constant of integration — 1 point

$\Delta x = \int_{0}^{t}\left(-0.3t^2 + 7t\right)\,dt$

For the correct answer — 1 point

$x(t) = -0.1t^3 + 3.5t^2$

(f) 3 points

For recognizing that the distance is the change in position — 1 point

$\Delta x = x(8) - x(2)$

For using the expression from part (e) to calculate $x(2)$ and $x(8)$ — 1 point

$x(2) = 13.2$ m

$x(8) = 172.8$ m

For the correct answer with units — 1 point

$\Delta x = 159.6$ m

Alternate solution — *Alternate points*

For using the integral of the speed and recognizing that the distance is the change in position — *1 point*

For using the correct limits or constant of integration — *1 point*

$\Delta x = \int_{2}^{8}\left(-0.3t^2 + 7t\right)\,dt$

$\Delta x = \frac{-0.3t^3}{3} + \frac{7t^2}{2}\Big|_2^8 = -51.2 + 224 - (-0.8 + 14)$

For the correct answer with units

$\Delta x = 159.6$ m — *1 point*

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Question 2

15 points total

Distribution of points

(a) 3 points

For a correct application of conservation of energy — 1 point

$K_1 + U_1 = K_2 + U_2$

$mgH = \frac{1}{2}mv^2 + mgy_P$

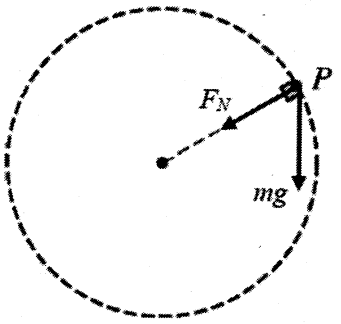
For relating y_p to H and θ — 1 point

$y_p = \frac{H}{2} + \frac{H}{2}\sin\theta$

For a correct final expression for v, which does not have to be simplified — 1 point

$v = \sqrt{gH(1-\sin\theta)}$

(b) 2 points



For correctly drawing and labeling a vector for the weight of the block — 1 point

For correctly drawing and labeling a vector for the normal force on the block — 1 point

One earned point is deducted (up to a maximum of two points) for each extraneous force drawn

(c) 5 points

For applying Newton's second law with more than one force — 1 point

For setting the sum of the forces in the radial direction equal to mv^2/R — 1 point

$F_N + w_{radial} = \frac{mv^2}{R}$

For using the correct radial component of the weight — 1 point

$w_{radial} = mg\sin\theta$

For correctly substituting for the speed and radius from part (a) — 1 point

$F_N + mg\sin\theta = \frac{mgH(1-\sin\theta)}{H/2}$

For an answer consistent with part (a) — 1 point

$F_N = mg(2 - 3\sin\theta)$

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Question 2 (continued)

		Distribution of points
(d)	2 points	
	For setting the normal force equal to zero (explicitly or implicitly) $0 = mg(2 - 3\sin\theta)$ $3\sin\theta = 2$ $\theta = \sin^{-1}(2/3)$	1 point
	For an answer consistent with part (c) $\theta = 41.8^\circ$	1 point
(e)	3 points	
	For correctly selecting $\theta_n < \theta_L$	1 point
	For indicating that the sphere will be moving slower (or has less kinetic energy) when it loses contact	1 point
	For indicating that some of the initial potential energy now goes into rotational kinetic energy	1 point
	Example: Since some of the energy must go into the rotational energy of the sphere, the sphere will have slower translational speed at every point on the track. Since the sphere moves slower than the block, the sphere will lose contact with the loop at a lower height and a smaller angle.	

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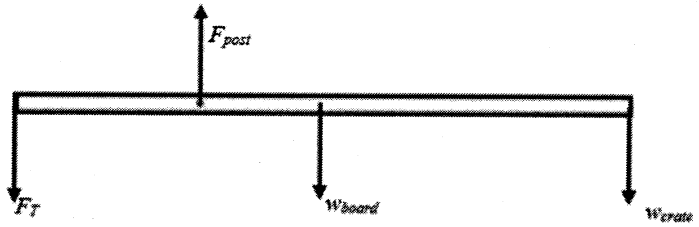
Question 3

15 points total

Distribution of points

(a) 3 points



For correctly drawing and labeling the three downward forces: tension, weight of the board, weight of the crate — 1 point

For correctly drawing and labeling the upward force exerted on the board by the post — 1 point

For drawing all of the forces at their respective points of action — 1 point

One earned point is deducted (up to a maximum of two points) for each extraneous force drawn

(b) 4 points

For summing the torques about any labeled point and setting that sum equal to zero — 1 point

Example using left end as pivot point:

$\tau_{cw} - \tau_{ccw} = 0$

$\tau_{w\text{-board}} + \tau_{w\text{-crate}} = \tau_{post}$

For substituting correct radii for all torques — 1 point

$(200\text{ N})(1.2\text{ m}) + (400\text{ N})(2.4\text{ m}) = (F_{post})(0.8\text{ m})$

For correctly calculating either the tension or the post force — 1 point

$F_{post} = 1500\text{ N}$

For a correct method for determining the remaining force and a consistent answer — 1 point

$F_{up} = F_{down}$

$F_{post} = w_{board} + w_{crate} + F_T$

$F_T = 1500\text{ N} - 200\text{ N} - 400\text{ N}$

$F_T = 900\text{ N}$

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Question 3 (continued)

Distribution of points

(c) 3 points

For correctly calculating the rotational inertia of the board about P — 1 point

$I_{\text{board}-P} = Md^2 + I_{\text{cm}} = Md^2 + \frac{1}{12}ML^2$

$I_{\text{board}-P} = \left(\frac{200\text{ N}}{9.8\text{ m/s}^2}\right)(0.4\text{ m})^2 + \frac{1}{12}\left(\frac{200\text{ N}}{9.8\text{ m/s}^2}\right)(2.4\text{ m})^2 = 13.1\text{ kg•m}^2$

(or 12.8 kg•m^2 using $g = 10\text{ m/s}^2$)

For correctly calculating the rotational inertia of the crate about P — 1 point

$I = m_{\text{crate}}r^2 = \left(\frac{400\text{ N}}{9.8\text{ m/s}^2}\right)(1.6)^2 = 104.5\text{ kg•m}^2$

(or 102.4 kg•m^2 using $g = 10\text{ m/s}^2$)

For recognizing that the total rotational inertia of the system about P is the sum of the inertia of the board and the crate about P — 1 point

$\Sigma I_P = 117.6\text{ kg•m}^2$ (or 115.2 kg•m^2 using $g = 10\text{ m/s}^2$)

(d)

i. 2 points

For summing torques about P, setting the sum equal to $I\alpha$, and substituting appropriate values — 1 point

$\Sigma\tau_P = w_{\text{board}}d_{\text{board}} + w_{\text{crate}}d_{\text{crate}} = I\alpha$

$(200\text{ N})(0.4\text{ m}) + (400\text{ N})(1.6\text{ m}) = 115.2\alpha$

For an answer consistent with part (c) — 1 point

$\alpha = 6.13\text{ rad/s}^2$ (or 6.25 rad/s^2 using $g = 10\text{ m/s}^2$)

ii. 2 points

For a correct relationship between angular and linear acceleration — 1 point

$a = r\alpha$

$a = (0.80\text{ m})(6.13\text{ rad/s}^2)$

For an answer consistent with part (d)i. — 1 point

$a = 4.9\text{ m/s}^2$ (or 5.0 m/s^2 using $g = 10\text{ m/s}^2$)

Units 1 point

For correct units on all answers — 1 point

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2015 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____ × 1.2857 = _____

Number Correct (out of 35) — Weighted Section I Score (Do not round)

Section II: Free Response

Question 1 _____ (out of 15) × 1.0000 = _____ (Do not round)

Question 2 _____ (out of 15) × 1.0000 = _____ (Do not round)

Question 3 _____ (out of 15) × 1.0000 = _____ (Do not round)

Sum = _____

Weighted Section II Score (Do not round)

Composite Score

_____ + _____ = _____

Weighted Section I Score + Weighted Section II Score = Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
59-90	5
47-58	4
36-46	3
29-35	2
0-28	1

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AP® Physics C: Mechanics Practice Exam

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2014

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

PLACE SEAL HERE

Form I
Form Code 4JBP6-S

80

PLACE SEAL HERE
DO NOT seal answer sheet inside

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

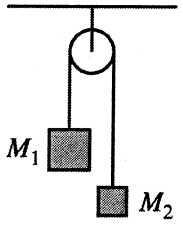
Note: To simplify calculations, you may use $g = 10\text{m/s}^2$ in all problems.

1. An object is released from rest from a great height and reaches its terminal velocity. Which of the following statements is true of the object while it is falling with terminal velocity?

   (A) There is no longer a gravitational force on it.
   (B) There is no longer a drag (air resistance) force on it.
   (C) Its acceleration is upward.
   (D) The magnitudes of the gravitational and drag forces on it are equal.
   (E) The gravitational and drag forces on it act in the same direction.

2. A student with a mass of 50 kg is standing on a bathroom scale while riding in an elevator. If the reading on the scale is 400 N, which of the following is a correct description of the elevator's motion?

   (A) Moving upward with increasing speed
   (B) Moving upward with constant speed
   (C) Moving downward with constant speed
   (D) Moving downward with increasing speed
   (E) Moving downward with decreasing speed



3. The system represented above consists of two objects of unequal masses, M_1 and M_2, with $M_1 > M_2$. The objects hang from the ends of a cord of negligible mass that passes over a pulley with negligible mass and friction. Which of the following is true about the changes in the gravitational potential energy, ΔU, and kinetic energy, ΔK, of the system soon after the objects are released from rest?

   (A) $\Delta U < 0$ and $\Delta K > 0$
   (B) $\Delta U = 0$ and $\Delta K > 0$
   (C) $\Delta U < 0$ and $\Delta K = 0$
   (D) $\Delta U = 0$ and $\Delta K = 0$
   (E) $\Delta U > 0$ and $\Delta K < 0$

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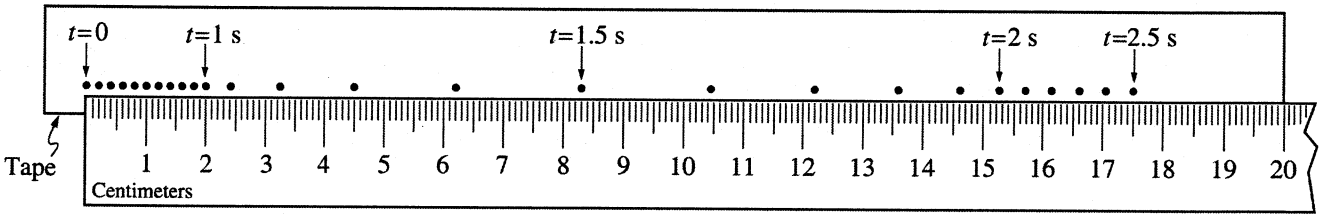
Questions 4-6

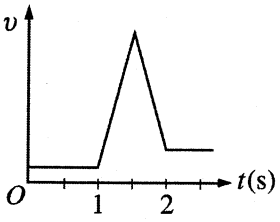
A tape attached to a moving object was pulled by the object through a marker that put dots on the tape at a constant rate of 10 dots per second for a period of 2.5 s. The figure below shows the marked tape next to a centimeter ruler.

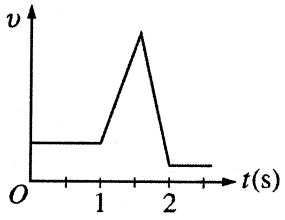


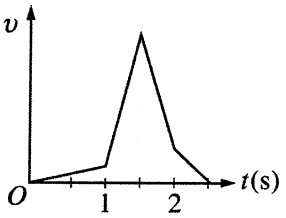
4. The average speed of the object for the total time recorded on the tape is most nearly

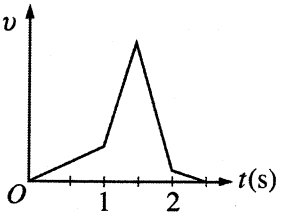
(A) 2.0 cm/s
(B) 3.3 cm/s
(C) 4.5 cm/s
(D) 5.5 cm/s
(E) 7.0 cm/s

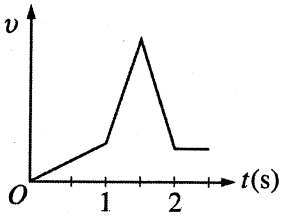
5. Which of the following best represents the graph of the velocity of the object versus time?

(A) 

(B) 

(C) 

(D) 

(E) 

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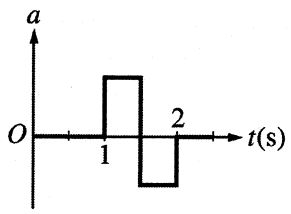
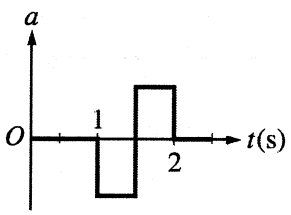
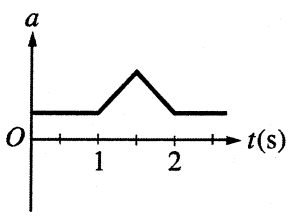
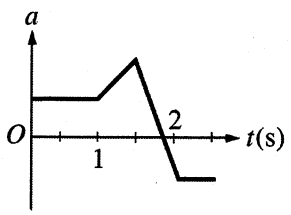
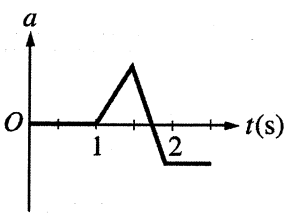
6. Which of the following best represents the graph of the acceleration of the object versus time?

(A) 

(B) 

(C) 

(D) 

(E) 

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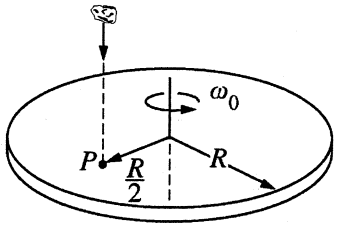
Questions 7-8



A turntable with mass m, radius R, and rotational inertia $\frac{mR^2}{2}$ initially rotates freely about an axis through its center at constant angular speed with negligible friction. A piece of clay, also of mass m, falls vertically onto the turntable, as shown above, and sticks to it at point P, a distance $\frac{R}{2}$ from the center of rotation.

7. What is the rotational inertia of the clay-turntable system after the collision?

(A) $\frac{1}{4}mR^2$

(B) $\frac{1}{2}mR^2$

(C) $\frac{3}{4}mR^2$

(D) mR^2

(E) $2mR^2$

8. What happens to the rotational speed of the turntable and the angular momentum of the clay-turntable system about the axis as a result of the collision?

	Rotational Speed	Angular Momentum
(A)	Stays the same	Increases
(B)	Stays the same	Stays the same
(C)	Stays the same	Decreases
(D)	Decreases	Stays the same
(E)	Decreases	Decreases

9. Which of the following must be true in order for a rotating platform to continue rotating with a constant angular velocity?

(A) There are no forces exerted on it.
(B) There is no friction exerted on it.
(C) There is zero net force exerted on it.
(D) There are no torques exerted on it.
(E) There is zero net torque exerted on it.

10. A newly discovered planet is found to have twice the radius and three times the mass of Earth. If the acceleration due to gravity at the surface of Earth is g, the acceleration due to gravity at the surface of the new planet is

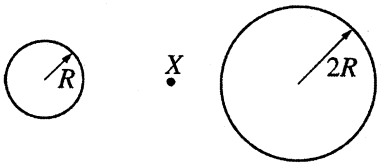
(A) $\frac{2g}{3}$

(B) $\frac{3g}{4}$

(C) g

(D) $\frac{4g}{3}$

(E) $\frac{3g}{2}$



11. At point X shown above, which is midway between the centers of two isolated planets of radii R and $2R$, the net gravitational force on an object is zero. If the mass of the smaller planet is M, the mass of the larger planet is

(A) $\frac{M}{4}$

(B) $\frac{M}{2}$

(C) M

(D) $2M$

(E) $4M$

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12. A particle moves along a straight line. Its speed in m/s is given by $v = a + bt^2$, where a and b are constants and t is time in seconds. How far does the particle move between $t = 1$ s and $t = 2$ s ?

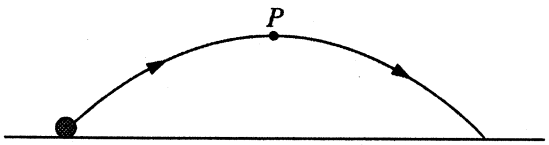
(A) $2b$

(B) $a + b$

(C) $a + 2b$

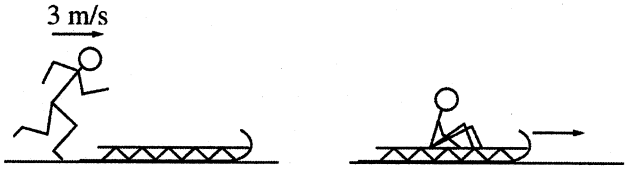
(D) $a + \frac{7}{3}b$

(E) $a + \frac{7}{2}b$



13. A ball is tossed and follows the trajectory shown above. Point P is the highest point on the trajectory, and air resistance is negligible. Which of the following statements is true of the ball while it is in motion?

(A) Its speed is constant.
(B) Its acceleration is constant.
(C) The horizontal component of its velocity is zero at point P.
(D) The vertical component of its velocity is a maximum at point P.
(E) Its kinetic energy is a maximum at point P.



Before Jump After Jump

14. As shown in the figure above, a child of mass 25 kg who is running at a speed of 3 m/s jumps onto a stationary sled of mass 5 kg on a frozen lake. The speed at which the child and sled begin to slide across the ice is most nearly

(A) 0.4 m/s
(B) 0.6 m/s
(C) 1.3 m/s
(D) 2.5 m/s
(E) 15 m/s

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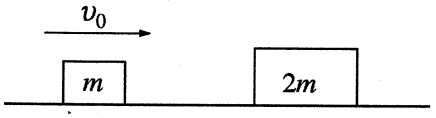
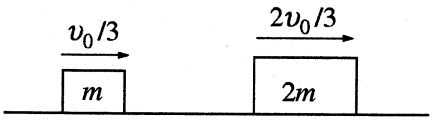


15. A block of mass m is initially sliding with speed v_0 on a horizontal frictionless surface, as shown above. It makes an elastic, head-on collision with another block of mass $2m$ that is initially at rest. Which of the following correctly shows the motion of the blocks after the collision?

(A)


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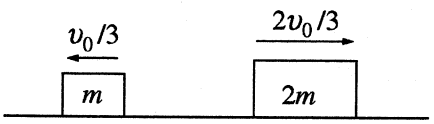
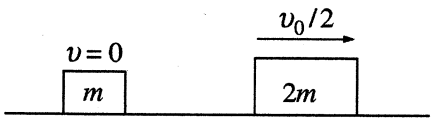
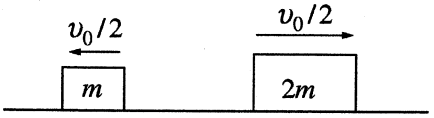
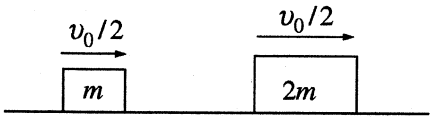
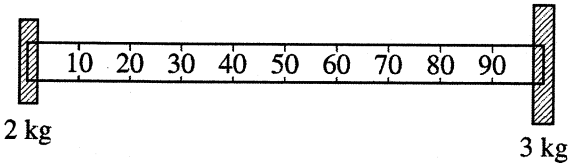


(C)


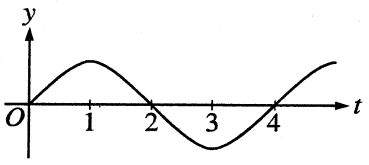
(D)


(E)




16. A 2 kg mass is attached to the 0 cm mark of a lightweight meter stick, and a 3 kg mass is attached to the 100 cm mark, as shown above. The center of mass of the combined system (meter stick and both masses) is located nearest which of the following marks on the meter stick?

(A) 33 cm
(B) 40 cm
(C) 60 cm
(D) 67 cm
(E) 75 cm



17. For a mass attached to a vertical spring, the vertical displacement y of the mass is given as a function of time t in the diagram above. At what time t does the mass experience a maximum positive acceleration?

(A) $t = 1$
(B) $t = 2$
(C) $t = 3$
(D) $t = 4$
(E) None of the above, since its acceleration is constant

18. For an object in simple harmonic motion with amplitude A, the kinetic energy will equal the potential energy when the displacement is

(A) zero
(B) $\pm A/4$
(C) $\pm A/2$
(D) $\pm A/\sqrt{2}$
(E) $\pm A$

19. Examples of simple harmonic motion include which of the following?

I. A mass, hanging from a spring, moves up and down in a uniform gravitational field.
II. A puck on an air table bounces back and forth between the walls of the table.
III. A ball bounces up and down on a table.

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

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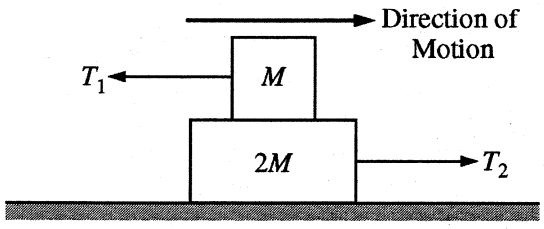
Questions 20-21



Two blocks are stacked on top of each other, as shown in the figure above. The top block, of mass M, is attached to a rope that pulls to the left with tension T_1. The bottom block, of mass $2M$, is attached to a rope that pulls to the right with tension T_2. The coefficient of friction between the blocks is μ. The blocks are at rest relative to each other and move to the right at constant speed relative to the frictionless surface.

20. What is the relationship between T_1 and T_2?

(A) $T_1 = 2T_2$

(B) $T_1 = \frac{1}{2}T_2$

(C) $T_1 = \mu T_2$

(D) $T_1 = \frac{1}{\mu}T_2$

(E) $T_1 = T_2$

21. The force of friction experienced by the top block is f_1, and the force of friction experienced by the bottom block is f_2. What is the relationship between f_1 and f_2?

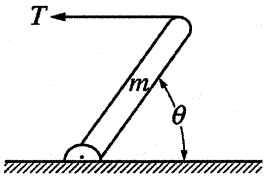
(A) $f_1 = 2f_2$

(B) $f_1 = \frac{1}{2}f_2$

(C) $f_1 = \mu f_2$

(D) $f_1 = \frac{1}{\mu}f_2$

(E) $f_1 = f_2$



22. A uniform beam of mass m is pivoted at one end and held in equilibrium at an angle θ by a horizontal wire, as shown above. The tension T in the wire is

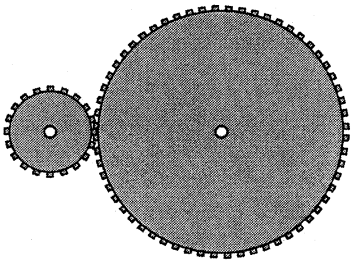
(A) $\frac{1}{2}mg\cot\theta$

(B) $mg\cot\theta$

(C) $mg\tan\theta$

(D) $2mg\tan\theta$

(E) mg



23. A gear containing 20 teeth on its circumference is meshed with a gear containing 60 teeth on its circumference, as shown above. If the angular speed of the 20-tooth gear is ω, what is the angular speed of the 60-tooth gear?

(A) $\frac{\omega}{60}$

(B) $\frac{\omega}{20}$

(C) $\frac{\omega}{3}$

(D) ω

(E) 3ω

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24. The angular displacement θ of a rotating wheel is described by the equation $\theta = \theta_0 + at^2 - bt^3$, where t is time and θ_0, a, and b are positive constants. The angular acceleration of the wheel as a function of time t is

(A) equal to a positive constant

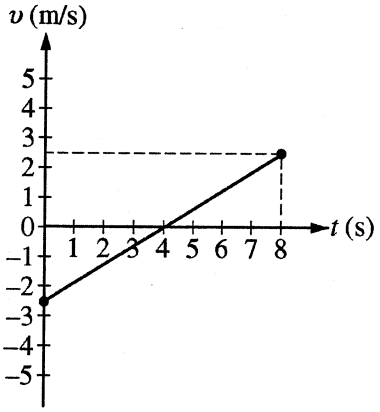
(B) zero

(C) $2a - 6bt$

(D) $2at - 3bt^2$

(E) $\theta_0 t + \frac{1}{3}at^3 - \frac{1}{4}bt^4$

Questions 25-27



The motion of an object moving along a straight line is described by the graph of velocity v versus time t above.

25. Which of the following is true about the speed of the object during the time interval from 0 to 8 s?

(A) It increases during the entire interval.
(B) It decreases during the entire interval.
(C) It remains the same.
(D) It first increases and then decreases.
(E) It first decreases and then increases.

26. Which of the following is true about the acceleration of the object during the time interval from 0 to 8 s?

(A) It increases during the entire interval.
(B) It decreases during the entire interval.
(C) It remains the same.
(D) It first increases and then decreases.
(E) It first decreases and then increases.

27. What is the net displacement of the object for the time interval from 0 to 8 s?

(A) 0 m
(B) 5 m
(C) 10 m
(D) 20 m
(E) It cannot be determined without knowing the initial position of the object.

---

28. An object starts from rest and accelerates uniformly in the horizontal direction, moving 32 m during the first 4 s. What are the magnitudes of the object's displacement and velocity after it accelerates for the first 3 s

	Magnitude of Displacement	Magnitude of Velocity
(A)	24 m	24 m/s
(B)	24 m	18 m/s
(C)	18 m	18 m/s
(D)	18 m	12 m/s
(E)	8 m	12 m/s

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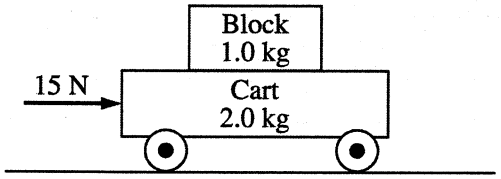

29. A 2.0 kg cart rolls with negligible friction on a horizontal surface, as shown in the figure above. The coefficient of static friction between the cart and the 1.0 kg block on top of the cart is 0.7. If a horizontal 15 N force is applied to the cart as shown and the block does not slide on the cart, the magnitude of the horizontal component of the force that the block exerts on the cart is most nearly

(A) 2 N
(B) 5 N
(C) 8 N
(D) 10 N
(E) 15 N

30. A car rounds a flat curve of radius R with a speed of v_0. The coefficient of friction between the tires and the road is μ. For the car not to slide on the road, which of the following statements must be true?

(A) The car's speed v_0 cannot be greater than μgR.
(B) The car's speed v_0 cannot be less than μgR.
(C) The radius R of the car's path cannot be greater than $v_0^2/\mu g$.
(D) The radius R of the car's path cannot be less than $v_0^2/\mu g$.
(E) The centripetal acceleration must be less than g.

31. If two balls collide and there are no external forces acting on the balls, quantities that must be the same for the two-ball system before and after the collision include which of the following?

I. Total kinetic energy
II. Total momentum
III. Momentum in the x-direction

(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

32. Two objects, X and Y, are released from rest at the same height. Object X has three times the mass of object Y. Just before reaching the ground, object Y has momentum p_Y and kinetic energy K_Y. If air resistance is negligible, what are the momentum and kinetic energy of object X just before it reaches the ground?

	Momentum	Kinetic Energy
(A)	p_Y	K_Y
(B)	$3p_Y$	$3K_Y$
(C)	$3p_Y$	$6K_Y$
(D)	$6p_Y$	$3K_Y$
(E)	$6p_Y$	$6K_Y$

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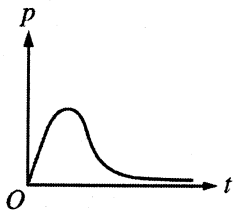
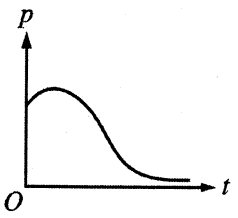
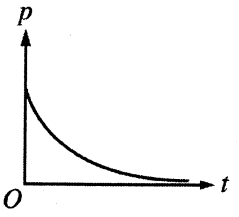
Questions 33-34

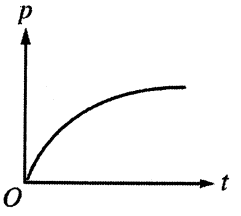
A very light ball is released from rest at time $t = 0$ and falls through the air, which provides significant resistance.

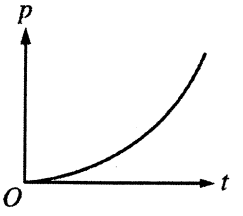
33. Which graph best represents the magnitude of the momentum of the ball?

(A)


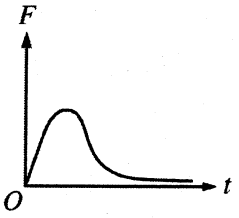
(B)


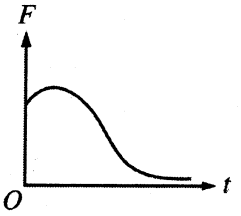
(C)


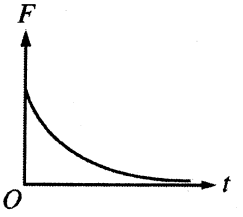
(D)


(E)


34. Which graph best represents the magnitude of the net force on the ball?

(A)


(B)


(C)


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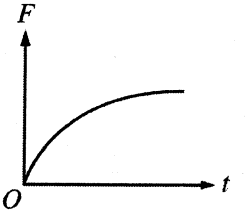
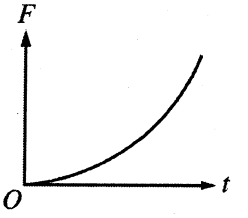


(E)


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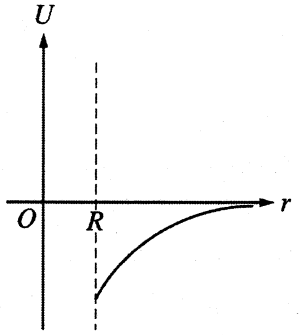
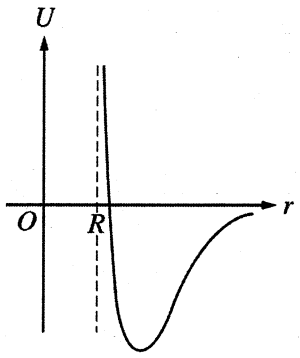
35. A satellite can move in a circular orbit about a massive planet of radius R. Which of the following graphs could represent the gravitational potential energy U of this satellite as a function of the radius r of the orbit?

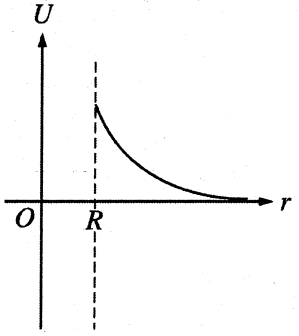
(A)



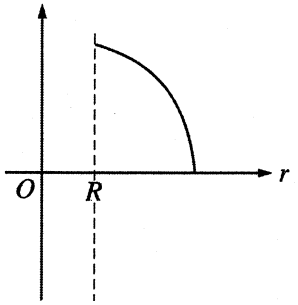
(B)



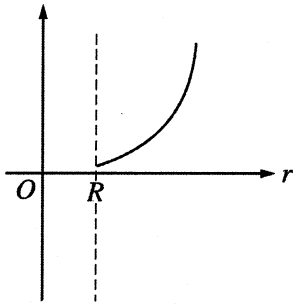
(C)



(D)



(E)



STOP

END OF MECHANICS SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

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AP® Physics C: Mechanics Exam

SECTION II: Free Response

2014

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4JBP6-S

80

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

Mech 1.

Experiment 1: A block of mass 1.5 kg is placed on a long board. You are to design an experiment to determine the coefficient of static friction between the block and the board.

(a)

i. From the following list of available equipment, check those additional items you would use for the purpose of determining the coefficient of static friction.

____ Ruler	____ Spring scale	____ String
____ Meterstick	____ Pulley	____ Protractor
____ Photogate	____ Stopwatch	____ Mass hanger
____ Clamps and supports	____ Objects of various known masses	

ii. Sketch a diagram of your experimental setup and label the pieces of equipment that would be used.

iii. 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.

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GO ON TO THE NEXT PAGE.

(b) Explain how to use the measurements described in part (a) to calculate the coefficient of static friction. Include a free-body diagram in your explanation that shows all forces (not components) acting on the block while the measurements are being made.

Experiment 2: In a second experiment, the coefficient of kinetic friction between the block and the board is determined to be 0.10. The board is now inclined at an angle of 25° above the horizontal. The block is released from rest at the top of the incline and slides 2.0 m down the incline.

(c) Calculate the work done by kinetic friction as the block slides down the incline.

(d) The mass of the block is now increased without changing the coefficient of kinetic friction, and experiment 2 is repeated. How does each of the following change?

i. The magnitude of the frictional force

__ Increases __ Decreases __ Remains the same

ii. The magnitude of the velocity of the block as it reaches the bottom of the incline

__ Increases __ Decreases __ Remains the same

iii. The kinetic energy of the block at the bottom of the incline

__ Increases __ Decreases __ Remains the same

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Mech 2.

A satellite of mass m is in a stable circular orbit around Earth at a distance R_1 from the center of Earth. The mass of Earth is M_e.

(a) Derive an expression for the following in terms of m, R_1, M_e, and fundamental constants, as appropriate.

i. The orbital speed v_1 of the satellite

ii. The total energy of the satellite in this orbit, assuming gravitational potential energy to be zero at an infinite distance from the center of Earth

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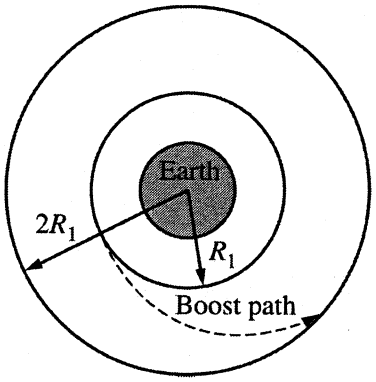
GO ON TO THE NEXT PAGE.

The satellite's booster rockets fire and lift the satellite to a higher circular orbit of radius $2R_1$. The satellite follows the path shown in the diagram below, moving a total distance S during the orbital change. The component of the rockets' force parallel to the path is given by the equation $F = F_0\left(1 - \frac{x}{S}\right)$, where x is the variable distance traveled along the path at any moment.



(b) Derive an expression for the total work done on the satellite by the force F in terms of F_0 and S.

(c) If the total distance S is equal to $3R_1$, derive an expression for F_0 in terms of M_e, R_1, m, and fundamental constants, as appropriate.

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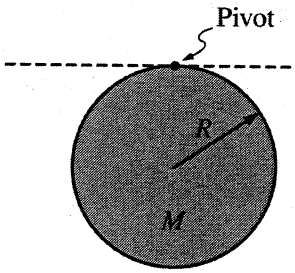

Figure 1

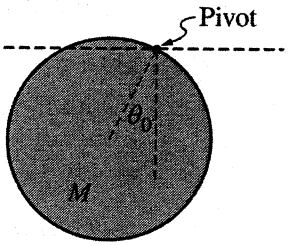

Figure 2

Mech 3.

A uniform disk of mass M and radius R is suspended vertically from a pivot on its edge so that it is free to swing without friction, as shown in Figure 1 above. The disk is raised to an initial angular displacement θ_0 with respect to the vertical, as shown in Figure 2 above, and released from rest. The rotational inertia of the disk about its center of mass is $I = MR^2/2$. Express all algebraic answers in terms of the given quantities and fundamental constants, as appropriate.

(a) Derive an expression for the rotational inertia of the disk about the pivot.

(b) Derive an expression for the maximum angular velocity of the disk during its swing.

(c) Using Newton's second law in either translational or rotational form, as appropriate, write a differential equation that could be used to determine the angular displacement of the disk θ as a function of time t. Do not solve the equation.

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GO ON TO THE NEXT PAGE.

(d) Derive an expression for the period for small-amplitude oscillations of the disk.

(e) Suppose the disk is replaced with another uniform disk with twice the radius, and the pivot point is again on the edge of the disk. How will the period of small-amplitude oscillations be affected by the new disk?

__ It will increase. __ It will decrease. __ It will remain the same.

__ There is not enough information to determine the period.

Justify your answer.

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GO ON TO THE NEXT PAGE.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Question 1: D

Question 2: D

Question 3: A

Question 4: E

Question 5: A

Question 6: A

Question 7: C

Question 8: D

Question 9: E

Question 10: B

Question 11: C

Question 12: D

Question 13: B

Question 14: D

Question 15: B

Question 16: C

Question 17: C

Question 18: D

Question 19: A

Question 20: E

Question 21: E

Question 22: A

Question 23: C

Question 24: C

Question 25: E

Question 26: C

Question 27: A

Question 28: D

Question 29: B

Question 30: D

Question 31: D

Question 32: B

Question 33: D

Question 34: C

Question 35: A

AP® PHYSICS C - MECHANICS
2014 SCORING GUIDELINES

Question 1

15 points total | **Distribution of points**

(a)

i. 1 point

For selecting equipment consistent with the diagram drawn in part (a)-ii — 1 point

ii. 1 point

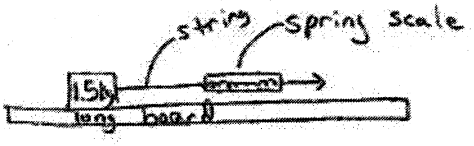
For labeling a diagram consistent with the procedure in described part (a)-iii — 1 point

iii. 2 points

For listing specific quantities to be measured that can be used to determine the coefficient of static friction — 1 point

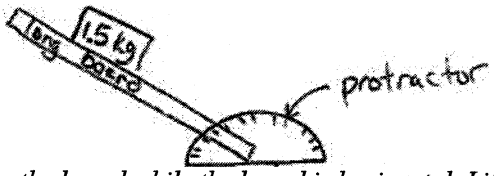
For indicating which equipment will be used to take the measurements listed above — 1 point

Example:



Pull the spring scale to the right until the block starts to move. Use the spring scale to measure the maximum force exerted on the block.

Alternate Example:



Place the block on the board while the board is horizontal. Lift one end of the board until the block begins to slide. Use a protractor to measure the angle at which the block begins to slide.

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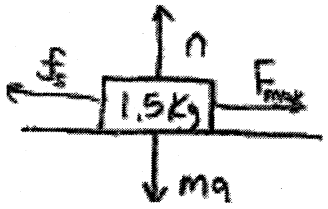
Question 1 (continued)

Distribution of points

(b) 5 points

The experiment described by the student must attempt to measure the coefficient of static friction μ_s, not the coefficient of kinetic friction.

Solution for example shown above:



For vectors indicating the normal force up and the force of gravity down — 1 point
For a vector indicating the horizontal applied force — 1 point
For a vector indicating the static friction opposite the applied force — 1 point
Note: One point is deducted if there are any extraneous vectors or any vectors not starting on and pointing away from the block.

For setting the net force equal to zero — 1 point

$F_{net} = ma = 0$

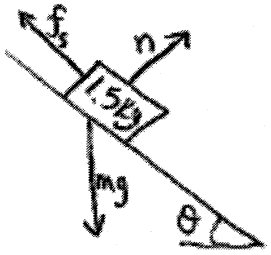
$F_{\max} - f_s = 0$

$f_s = \mu_s mg$

For a correct expression for the coefficient of static friction — 1 point

$\mu_s = \dfrac{F_{\max}}{mg}$

Solution for alternate example: — *Alternate points*



For a vector indicating the force of gravity down — *1 point*
For a vector indicating the normal force perpendicular to the incline — *1 point*
For a vector indicating the static friction up the incline — *1 point*
Note: One point is deducted if there are any extraneous vectors or any vectors not starting on and pointing away from the block

For setting the net force equal to zero — *1 point*

$F_{net} = ma = 0$

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Question 1 (continued)

Distribution of points

$F_{\max} - f_s = 0$

$F_{\max}$ is the component of gravity along the plane, and f_s depends on the component of gravity perpendicular to the plane

$mg\sin\theta - \mu_s mg\cos\theta = 0$

For a correct expression for the coefficient of static friction 1 point

$\mu_s = \tan\theta$

(c) 3 points

For a correct equation to solve for the work done 1 point

$W = F \bullet d = -f_k d$

$W = -\mu_k mg\cos\theta d$

For correctly substituting for the force of kinetic friction 1 point

$W = -(0.10)(1.5\text{ kg})\left(9.8\text{ m/s}^2\right)(\cos 25)(2.0\text{ m})$

For a correct answer 1 point

$W = -2.7$ J

Note: Answers without the negative sign only lose the answer point.

(d)

i. 1 point

For selecting "Increases" 1 point

ii. 1 point

For selecting "Remains the same" 1 point

iii. 1 point

For selecting "Increases" 1 point

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Question 2

15 points total

Distribution of points

(a)

i. 3 points

Set the gravitational force equal to the centripetal force.

$F_g = F_C$

For a correct expression for the gravitational force — 1 point

For a correct expression for the centripetal force — 1 point

$$\frac{GM_e m}{R_1^2} = \frac{mv_1^2}{R_1}$$

For a correct answer — 1 point

$$v_1 = \sqrt{\frac{GM_e}{R_1}}$$

ii. 3 points

For an expression of the total energy as the sum of the gravitational potential energy and the kinetic energy of the satellite — 1 point

$E = U_g + K$

For substituting a correct expression for the kinetic energy of the satellite — 1 point

$$E = -\frac{GM_e m}{R_1} + \frac{1}{2}mv_1^2$$

$$E = -\frac{GM_e m}{R_1} + \frac{1}{2}m\left(\frac{GM_e}{R_1}\right)$$

For a correct answer — 1 point

$$E = -\frac{GM_e m}{2R_1}$$

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Question 2 (continued)

Distribution of points

(b) 4 points

For a correct equation for the work done expressed as the integral of the force — 1 point

$W = \int F \cdot ds$

For substituting the given expression for force into the above equation — 1 point

$W = \int_0^S F_0\left(1 - \frac{x}{S}\right)dx$

For integrating with the correct limits — 1 point

$W = F_0\left[x - \frac{x^2}{2S}\right]_0^S$

$W = F_0\left(S - \frac{S^2}{2S} - 0\right) = F_0\left(\frac{S}{2}\right)$

For a correct answer — 1 point

$W = \frac{F_0 S}{2}$

(c) 5 points

For a correct statement relating work and change in energy — 1 point

$W = \Delta E$

For substituting the correct initial radius into the expression for potential energy — 1 point

For substituting the correct final radius into the expression for potential energy — 1 point

$W = \Delta E = -\frac{GM_e m}{4R_1} - \left(-\frac{GM_e m}{2R_1}\right)$

For a correct substitution of the answer from part (b) — 1 point

$\frac{F_0 S}{2} = -\frac{GM_e m}{4R_1} + \frac{GM_e m}{2R_1}$

$\frac{F_0(3R_1)}{2} = \frac{GM_e m}{4R_1}$

For an answer consistent with part (b) and the change in energy — 1 point

$F_0 = \frac{GM_e m}{6R_1^2}$

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Question 3

15 points total

Distribution of points

(a) 2 points

For a correct expression of the parallel axis theorem — 1 point

$I = I_{CM} + Md^2$

Substitute into the above expression

$I = \frac{1}{2}MR^2 + MR^2$

For a correct answer — 1 point

$I = \frac{3}{2}MR^2$

(b) 4 points

For a correct expression of the conservation of energy for the disk — 1 point

$K_1 + U_1 = K_2 + U_2$

For correctly setting the initial gravitational potential energy equal to the rotational kinetic energy at the bottom of the swing — 1 point

$mgh_1 = \frac{1}{2}I\omega^2$

For substituting a correct expression for the initial height — 1 point

$Mg\left(R - R\cos\theta_0\right) = \frac{1}{2}\left(\frac{3}{2}MR^2\right)\omega^2$

$g\left(1 - \cos\theta_0\right) = \frac{3}{4}R\omega^2$

For an answer consistent with part (a) — 1 point

$\omega = \sqrt{\frac{4g}{3R}\left(1 - \cos\theta_0\right)}$

(c) 3 points

For using a correct expression of Newton's 2nd law for rotational motion — 1 point

$\tau = I\alpha = \frac{3}{2}MR^2\alpha$

For substituting a correct expression for torque into the above equation — 1 point

$-Mg\sin\theta R = \frac{3}{2}MR^2\alpha$

For expressing the above equation as a differential equation (Note: Any appropriate manipulation of this equation is acceptable, including a subsequent small angle approximation.) — 1 point

$-g\sin\theta = \frac{3}{2}R\frac{d^2\theta}{dt^2}$

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Question 3 (continued)

Distribution of points

(d) 4 points

For using a correct expression for simple harmonic motion — 1 point

$a = -\omega^2 x$

$\frac{d^2\theta}{dt^2} = -\omega^2\theta$

For substituting the small angle approximation ($\sin\theta \approx \theta$) into the answer from part (c) — 1 point

$-g\theta = \frac{3}{2}R\frac{d^2\theta}{dt^2}$

$-\frac{2g}{3R}\theta = \frac{d^2\theta}{dt^2}$

$\omega = \sqrt{\frac{2g}{3R}}$

For relating the correct expression for the angular velocity to the equation for period — 1 point

$\omega = \sqrt{\frac{2g}{3R}} = \frac{2\pi}{T}$

For a correct answer — 1 point

$T = 2\pi\sqrt{\frac{3R}{2g}}$

(e) 2 points

For selecting "It will increase" — 1 point

For a correct justification — 1 point

Example:

The period of the disk is proportional to the square root of the radius of the disk, $T \propto \sqrt{R}$. A doubling of the radius of the disk will increase the period by a factor of $\sqrt{2}$.

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2014 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	× 1.2857 =	_____
Number Correct (out of 35)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 2	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 3	_____ (out of 15)	× 1.0000 =	_____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
55-90	5
44-54	4
37-43	3
29-36	2
0-28	1

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AP Physics C: Mechanics Practice Exam

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2013

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

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Form I
Form Code 4JBP4-S

80

PLACE SEAL HERE
DO NOT seal answer sheet inside

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

Questions 1-3

An object of mass 10 kg starts from rest at time $t = 0$ and moves in a straight line. For time $t > 0$, the object's velocity v as a function of time t is given by $v = 2t + 3t^2$, where v is in m/s and t is in seconds.

1. How far does the object travel during the first 10 s of its motion?

   (A) 62 m
   (B) 320 m
   (C) 383 m
   (D) 1100 m
   (E) 1600 m

2. What is the instantaneous net force that acts on the object at $t = 2$ s ?

   (A) 140 N
   (B) 160 N
   (C) 320 N
   (D) 1280 N
   (E) 2560 N

3. How much work is done by the net force between $t = 0$ and $t = 1$ s ?

   (A) 5 J
   (B) 50 J
   (C) 125 J
   (D) 250 J
   (E) 500 J

4. Persons X, Y, and Z walk along a circular path of radius 50 m. Person X walks halfway around the path, Person Y walks 3/4 of the way around the path, and Person Z walks completely around the path. Which of the following correctly lists the walkers in order of the magnitudes of their displacement vectors from the least to the greatest?

   (A) $X < Y < Z$
   (B) $X < Z < Y$
   (C) $Y < X < Z$
   (D) $Y < Z < X$
   (E) $Z < Y < X$

5. A small particle starts from rest from the origin of an xy-coordinate system and travels in the xy-plane. Its acceleration in the x-direction is $2.0\,\text{m/s}^2$, and its acceleration in the y-direction is $1.0\,\text{m/s}^2$. What is the x-coordinate of the particle when its y-coordinate is 12 m?

   (A) 3.0 m
   (B) 6.0 m
   (C) 12 m
   (D) 24 m
   (E) 48 m

6. If the speed of an object moving in a straight line is increasing at a constant rate, the net force acting on the object is

   (A) zero
   (B) constant, but not zero
   (C) decreasing at a constant rate
   (D) increasing at a constant rate
   (E) changing at a rate proportional to the average velocity

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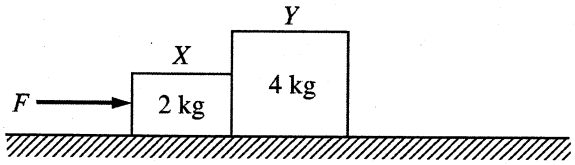


7. A force F accelerates a system of two blocks, X and Y, on a horizontal frictionless surface, as shown above. The acceleration is 4 m/s^2. The force with which block Y pushes on block X has magnitude

(A) zero
(B) 6 N
(C) 8 N
(D) 16 N
(E) 24 N

8. A hoop of mass m and radius r rolls with constant speed on a horizontal surface without slipping. What is the hoop's translational kinetic energy divided by its rotational kinetic energy?

(A) 4
(B) 2
(C) 1
(D) 1/2
(E) 1/4

9. The rotational inertia of a sphere of mass M and radius R about a diameter is $\frac{2}{5}MR^2$. The rotational inertia about an axis tangent to the sphere is

(A) $\frac{3}{2}MR^2$

(B) $\frac{7}{5}MR^2$

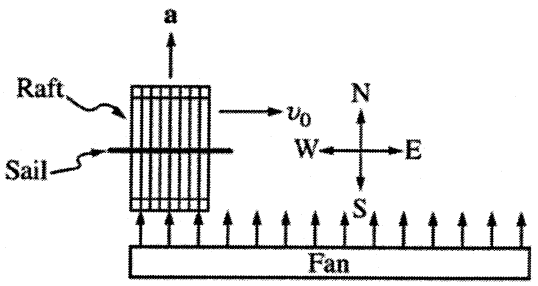
(C) MR^2

(D) $\frac{1}{2}MR^2$

(E) $\frac{2}{5}MR^2$

10. All of the following are vector quantities EXCEPT

(A) rotational kinetic energy
(B) torque
(C) angular momentum
(D) angular velocity
(E) centripetal acceleration



Top View

11. The toy raft shown in the top view above is sliding due east on frictionless ice at constant speed v_0 when a fan blows on its sail, producing a constant acceleration **a** directed to the north. Which of the following could indicate the path of the raft while the fan is blowing?

(A)


(B)


(C)


(D)

(E)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12. The velocity v in meters per second of an object moving in a straight line is given as a function of time t in seconds by $v = 4t^3 + 2t$. The total distance the object travels between $t = 1$ s and $t = 2$ s is

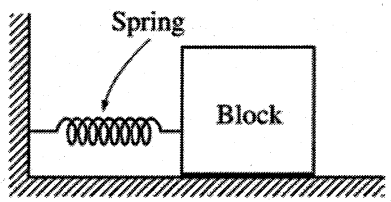
(A) 12 m
(B) 18 m
(C) 24 m
(D) 30 m
(E) 36 m

13. Two small spheres, each with a mass of 3.0 kg, are placed 6.0 m apart. Which of the following is the order of magnitude of the gravitational attraction between them?

(A) 10^{-15} N
(B) 10^{-13} N
(C) 10^{-11} N
(D) 10^{-9} N
(E) 10^{-7} N

14. A satellite of mass m is in a circular orbit with speed v_0 at a distance r from the center of Earth. What is the ratio of its escape speed from the orbit to its orbital speed, v_e/v_0 ?

(A) $\sqrt{2}$
(B) 2
(C) 1
(D) $\frac{1}{2}$
(E) $\frac{1}{\sqrt{2}}$



15. The block shown above is attached to a rigid wall by means of an ideal spring and moves on a horizontal surface with negligible friction. The block oscillates with a period T. If a second ideal spring, identical to the first, is placed above the first spring and attached to the wall and the block, the new oscillation period of the block is

(A) $T/2$
(B) $T/\sqrt{2}$
(C) T
(D) $\sqrt{2}T$
(E) $2T$

16. An object on the end of a spring of force constant k moves in simple harmonic motion with amplitude A and frequency f. Which of the following is a possible expression for the potential energy of the spring as a function of time t ?

(A) $\frac{1}{2}kA^2\sin^2(2\pi ft)$
(B) $kA^2\cos^2(2\pi ft)$
(C) $kA\sin(2\pi ft)$
(D) $\frac{1}{2}kA\cos(2\pi ft)$
(E) $kA(\sin 2\pi ft + \cos 2\pi ft)$

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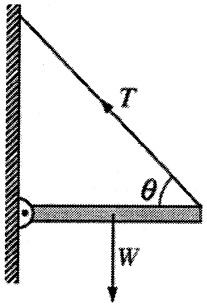
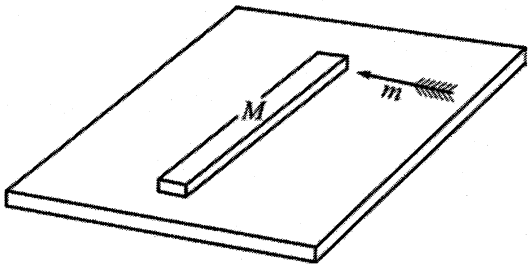
17. A wheel with rotational inertia 0.04 kg•m^2 and radius 0.02 m is turning at the rate of 10 revolutions per second when a frictional torque is applied to stop it. How much work is done by the torque in stopping the wheel?

(A) –0.0008 J
(B) -0.4π J
(C) –2 J
(D) $-2\pi^2$ J
(E) $-8\pi^2$ J



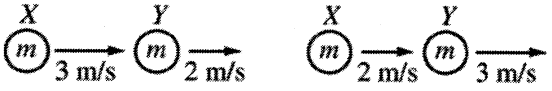
18. A uniform beam of weight W is attached to a wall by a pivot at one end and is held horizontal by a cable attached to the other end of the beam and to the wall, as shown above. T is the tension in the cable, which makes an angle θ with the beam. Which of the following is equal to T?

(A) $\frac{W}{2\cos\theta}$
(B) $\frac{W}{2\sin\theta}$
(C) $\frac{W}{\cos\theta}$
(D) $\frac{W}{\sin\theta}$
(E) W



19. An arrow of mass m and speed v_0 strikes and sticks to one end of a meterstick of mass M as shown in the diagram above. The meterstick is initially at rest on a horizontal surface and free to move without friction. The speed of the center of mass of the stick-arrow system after the arrow strikes is given by which of the following expressions?

(A) $\frac{1}{2}(M+m){v_0}^2$
(B) $\frac{mv_0}{M}$
(C) $\frac{mv_0}{M+m}$
(D) $\frac{v_0}{2}$
(E) 0



20. Object X of mass m is moving to the right with a speed of 3 m/s when it collides with object Y of mass m that is moving to the right with a speed of 2 m/s, as shown above. After the collision, X is moving to the right with a speed of 2 m/s and Y is moving to the right with a speed of 3 m/s. Which of the following is true of the collision?

(A) It is elastic because momentum is conserved.
(B) It is elastic because kinetic energy is conserved.
(C) It is inelastic because momentum is not conserved.
(D) It is inelastic because kinetic energy is not conserved.
(E) More information is needed to determine whether the collision is elastic or inelastic.

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Questions 21-22

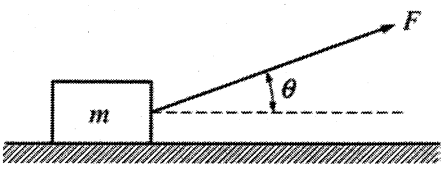
A 20 kg box moving at an initial speed of 10 m/s slides 25 m to the right on a horizontal floor before it comes to a complete stop.

21. What is the coefficient of friction between the box and the floor?

(A) 0.10
(B) 0.20
(C) 0.40
(D) 0.60
(E) 0.80

22. Which of the following best describes the frictional forces exerted on the box and on the floor while the box is sliding?

	Box	Floor
(A)	None	None
(B)	To the right	To the right
(C)	To the right	To the left
(D)	To the left	None
(E)	To the left	To the right



23. A block of mass m is pulled across a rough horizontal surface at constant speed by a force of magnitude F, which acts at an angle of θ to the horizontal, as shown above. The coefficient of kinetic friction between the block and the surface is

(A) $\frac{F}{mg}$

(B) $\frac{F\sin\theta}{mg}$

(C) $\frac{F\cos\theta}{mg}$

(D) $\frac{F\sin\theta}{mg - F\cos\theta}$

(E) $\frac{F\cos\theta}{mg - F\sin\theta}$

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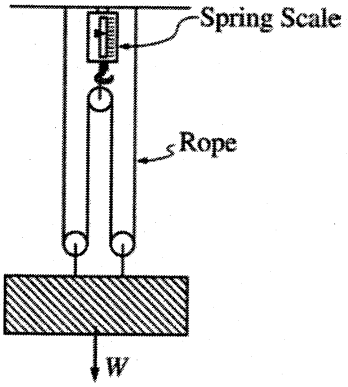


24. The rope-and-pulley system of negligible mass shown above supports a block of weight W that is at rest. If the tension throughout the rope is uniform, what is the reading on the spring scale?

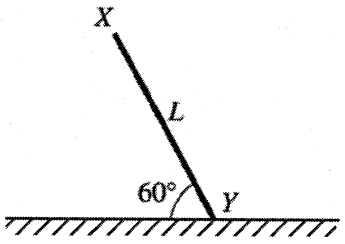
(A) W

(B) $\frac{W}{2}$

(C) $\frac{W}{3}$

(D) $\frac{W}{4}$

(E) $\frac{W}{8}$



25. The uniform rod of length L shown above is supported by holding end X so that the rod makes an angle $60°$ with the horizontal floor. There is no friction acting between the rod and the floor. When the support at X is removed, the rod falls under the influence of gravity. Which of the following best describes the movement of end Y as the rod falls?

(A) It moves $\frac{1}{2}L$ to the left.

(B) It remains at rest.

(C) It moves $\frac{1}{4}L$ to the right.

(D) It moves $\frac{1}{2}L$ to the right.

(E) It moves $\frac{3}{4}L$ to the right.

26. In an experiment, an object is released from rest from the top of a building. Its speed v is measured as it reaches a point that is a distance d from the point of release. If this distance was doubled, what would the new speed be, assuming air resistance is negligible?

(A) v
(B) $\sqrt{2}v$
(C) $2v$
(D) $4v$
(E) $8v$

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27. A particle moves on a straight line with a speed v that changes with time t according to the equation $v = v_0 e^{-\beta t}$, where v_0 and β are constants. The acceleration a of the particle is related to its speed by which of the following equations?

(A) $a = -\beta v$

(B) $a = -\beta v^2$

(C) $a = -\beta v t$

(D) $a = -v/t$

(E) $a = -v_0/t$

28. The relationship between the magnitude of the restoring force F and the resultant displacement x from equilibrium for a nonlinear spring is given by the equation $F = kx^2$. What is the potential energy of the spring when it has been compressed a distance x_0 ?

(A) kx_0^3

(B) $\frac{1}{2} kx_0^2$

(C) $\frac{1}{2} kx_0^3$

(D) $\frac{1}{3} kx_0^2$

(E) $\frac{1}{3} kx_0^3$

29. The period T of a pendulum of length L is measured to determine g at the surface of Earth. The equation used is $T = 2\pi\sqrt{L/g}$. The mass of the pendulum bob is 10.0 kg, and the length of the pendulum is 1.00 m. Which of the following would contribute most to the expected error in the result?

(A) A 10% uncertainty in the measurement of the mass

(B) Approximating the value of π as 3.14

(C) Variation in the value of g as the pendulum bob moves along its arc

(D) Using the average period of 10 timed oscillations instead of the period of 1 timed oscillation

(E) Starting the pendulum swinging by releasing it from a horizontal position

30. If a person goes to the bottom of a deep mine shaft on a planet of uniform density, which of the following is true?

(A) The person's weight is exactly the same as at the surface.

(B) The person's weight is greater than at the surface.

(C) The person's weight is less than at the surface.

(D) The person's weight may increase or decrease, depending on the density of the planet.

(E) The gravitational force on the person changes in direction but not in magnitude.

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GO ON TO THE NEXT PAGE.

31. A certain satellite in a circular orbit of radius r remains vertically above a certain point on Earth's equator. Which of the following expressions correctly gives r in terms of ω (the angular velocity of Earth's rotation about its axis), M (the mass of Earth), and G (the universal gravitational constant) ?

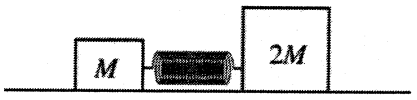
(A) $r = \dfrac{\omega^2}{GM}$

(B) $r = \dfrac{GM}{\omega}$

(C) $r^2 = \dfrac{GM}{\omega}$

(D) $r^3 = \omega^2 GM$

(E) $r^3 = \dfrac{GM}{\omega^2}$



32. Two blocks of masses M and $2M$ are on a frictionless horizontal surface, as shown above, and are held in place with a compressed spring of negligible mass between them. If the blocks are then released and the block of mass $2M$ leaves the spring with a velocity v, the velocity of the center of mass of the blocks is

(A) zero

(B) $-\dfrac{v}{2}$

(C) $-\dfrac{2v}{3}$

(D) $-\dfrac{3v}{2}$

(E) $-2v$

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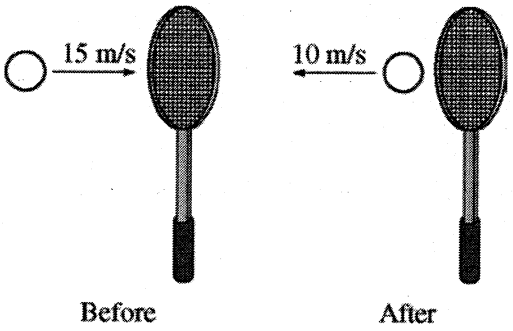
Questions 33-34



A 0.060 kg tennis ball moving at 15 m/s strikes a tennis racket and rebounds at 10 m/s in the opposite direction, as shown above. The ball is in contact with the racket for 0.030 s.

33. What is the magnitude of the average force exerted by the racket on the ball?

(A) 5 N
(B) 10 N
(C) 20 N
(D) 25 N
(E) 50 N

34. How does the magnitude of the average force exerted by the ball on the racket compare to the magnitude of the average force exerted by the racket on the ball?

(A) It is less.
(B) It is equal.
(C) It is greater.
(D) It cannot be determined without knowing the mass of the racket.
(E) It cannot be determined without knowing the recoil speed of the racket.

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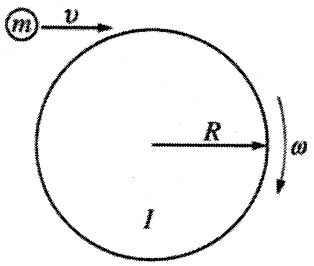

Top view

35. A circular platform has a radius R and rotational inertia I. The platform rotates around a fixed pivot at its center with negligible friction and an initial angular velocity ω. A child of mass m (represented by the small circle in the figure above) runs tangentially with speed v and jumps on the outer edge of the platform. When the child is standing on the outer edge of the platform, the new angular velocity is

(A) ω

(B) $\dfrac{I\omega}{I + mR^2}$

(C) $\dfrac{I\omega + mvR}{I + mR^2}$

(D) $\left(\dfrac{I\omega^2 + mv^2}{I}\right)^{1/2}$

(E) $\left(\dfrac{I\omega^2 + mv^2}{I + mR^2}\right)^{1/2}$

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S T O P

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2013

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ ☐☐ ☐☐☐☐
   Month Day Year
3. Six-digit school code
   ☐☐☐☐☐☐
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   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code Z-4BBP2-S2

80

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

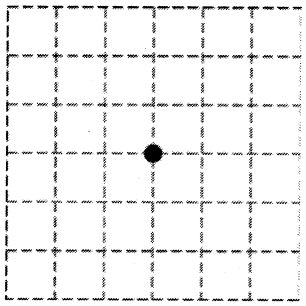
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

Mech. 1.

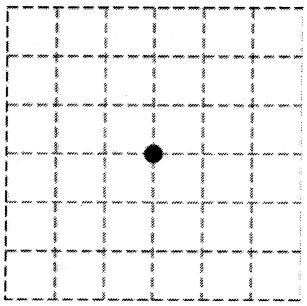
A ball of mass m and cross-sectional area A is released from rest near the surface of Earth. The ball experiences a resistive force due to the air that is proportional to the ball's velocity, $\mathbf{F}_r = -bA\mathbf{v}$, where b is a positive constant. Determine all algebraic answers in terms of m, b, A, and fundamental constants.

(a) Draw free-body diagrams for the ball for the following situations. Give each vector a descriptive label and draw them approximately to scale.

A Short Time After the Ball is Released



Once the Ball Has Reached Terminal Velocity



(b) Calculate the terminal velocity v_T of the ball.

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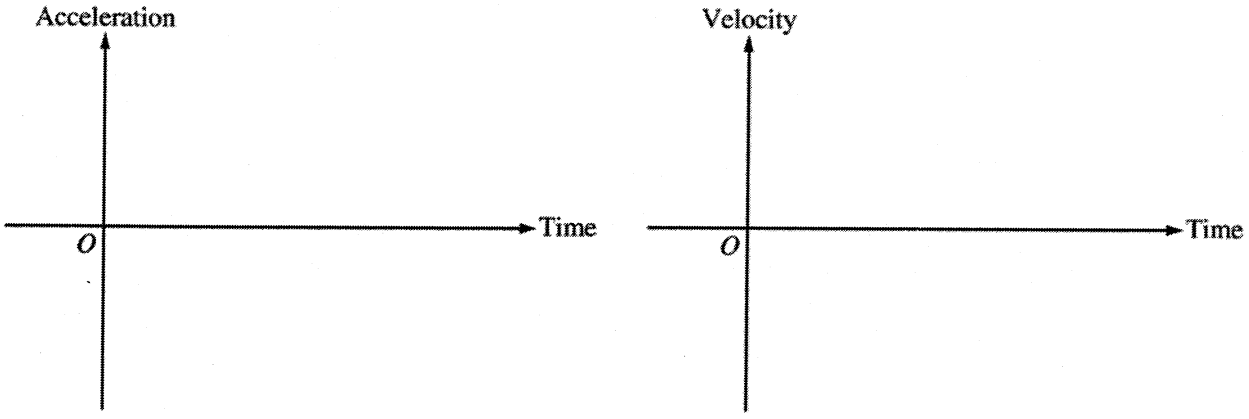
GO ON TO THE NEXT PAGE.

(c) Starting from Newton's laws, derive an expression for the time required for the ball to reach one third the terminal velocity.

(d) Sketch the following two graphs of the ball's motion from when the ball is released at time $t = 0$ until it approaches terminal velocity.



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GO ON TO THE NEXT PAGE.

Mech. 2.

A 0.30 kg cart moving at 2.0 m/s to the right collides with a 0.10 kg cart, initially moving at 3.0 m/s to the left. After the collision, the 0.10 kg cart moves to the right with a speed of 1.2 m/s. Assume friction is negligible.

(a) Calculate the magnitude and direction of the velocity of the 0.30 kg cart after the collision.

(b) Is this an elastic collision? Justify your answer.

The 0.30 kg cart is now removed. The 0.10 kg cart continues to move to the right and then collides with and compresses an ideal spring whose right end is attached to a fixed wall.

(c) Calculate the potential energy of the spring when it reaches maximum compression.

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(d) The maximum compression of the spring is 0.10 m. Calculate the spring constant of the spring.

(e) Suppose instead that the spring is nonlinear such that the force F due to the spring when it is compressed a distance x is $F = -bx^3$. Calculate the value of the constant b if the spring is compressed 0.10 m.

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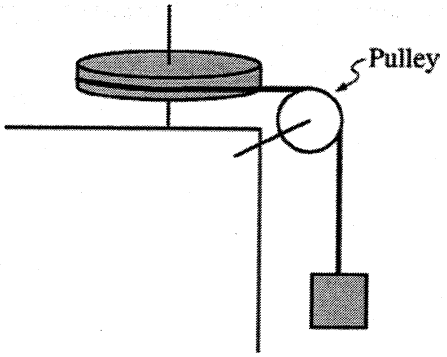
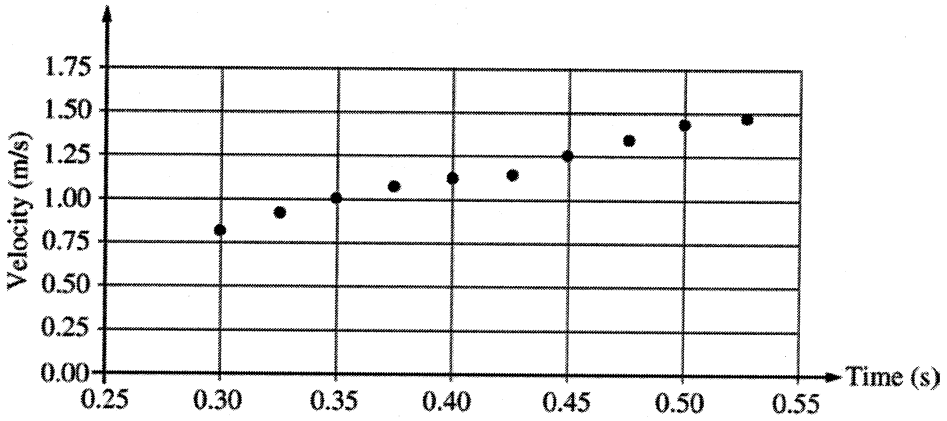


Mech. 3.

A solid disk of radius 0.10 m is mounted on a vertical axis. A string of negligible mass is wrapped around the rim of the disk; passes over a small, lightweight, frictionless pulley as shown above; and is tied to a block of mass 0.05 kg. The system is released from rest, and a computer records the velocity of the falling block as a function of time, as shown below.



(a) Using the graph above, calculate the acceleration of the falling block.

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GO ON TO THE NEXT PAGE.

(b) Use your result from part (a) to calculate the rotational inertia of the disk.

(c) Calculate the angular momentum of the disk at time $t = 0.45$ s.

(d) The disk is removed and replaced with a hoop of the same mass and radius, but with all of its mass concentrated near the rim of the hoop and connected to the axis by lightweight spokes. The experiment is then repeated. Is the angular acceleration of the hoop greater than, less than, or the same as that of the solid disk?

____ Greater than ____ Less than ____ The same

Justify your answer.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Question 1: D

Question 2: A

Question 3: C

Question 4: E

Question 5: D

Question 6: B

Question 7: D

Question 8: C

Question 9: B

Question 10: A

Question 11: A

Question 12: B

Question 13: C

Question 14: A

Question 15: B

Question 16: A

Question 17: E

Question 18: B

Question 19: C

Question 20: B

Question 21: B

Question 22: E

Question 23: E

Question 24: B

Question 25: C

Question 26: B

Question 27: A

Question 28: E

Question 29: E

Question 30: C

Question 31: E

Question 32: A

Question 33: E

Question 34: B

Question 35: C

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Question 1 (continued)

Distribution of points

(c) 4 points

For a correct differential equation expressing Newton's 2nd law — 1 point

$F = ma = mg - bAv$

$m\frac{dv}{dt} = mg - bAv$

Solving the differential equation for v

$\frac{m}{bA}\frac{dv}{dt} = \frac{mg}{bA} - v$ where $v_T = \frac{mg}{bA}$

$\frac{m}{bA}\frac{dv}{dt} = v_T - v$

$\frac{dv}{v_T - v} = \frac{bA}{m}dt$

$\int_0^v \frac{dv}{v_T - v} = \int_0^t \frac{bA}{m}dt$

This is of the form $\int \frac{du}{u} = \ln|u|$, where $u = v_T - v$ and $du = -dv$.

$[-\ln|v_T - v|]_0^v = \left[\frac{bA}{m}t\right]_0^t$

$\ln(v_T - v) - \ln(v_T) = -\frac{bA}{m}t$

$\ln\left(\frac{v_T - v}{v_T}\right) = -\frac{bA}{m}t$

$\frac{v_T - v}{v_T} = e^{-bAt/m}$

$v(t) = v_T\left(1 - e^{-bAt/m}\right)$

For a correct expression of velocity as a function of time — 1 point

$v(t) = \frac{mg}{bA}\left(1 - e^{-bAt/m}\right)$

For substituting $v_T/3$ into the above equation — 1 point

$v_T/3 = v_T\left(1 - e^{-bAt/m}\right)$

Solving the above equation for time

$1/3 = 1 - e^{-bAt/m}$

$e^{-bAt/m} = 1 - 1/3 = 2/3$

$-bAt/m = \ln(2/3)$

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Question 1 (continued)

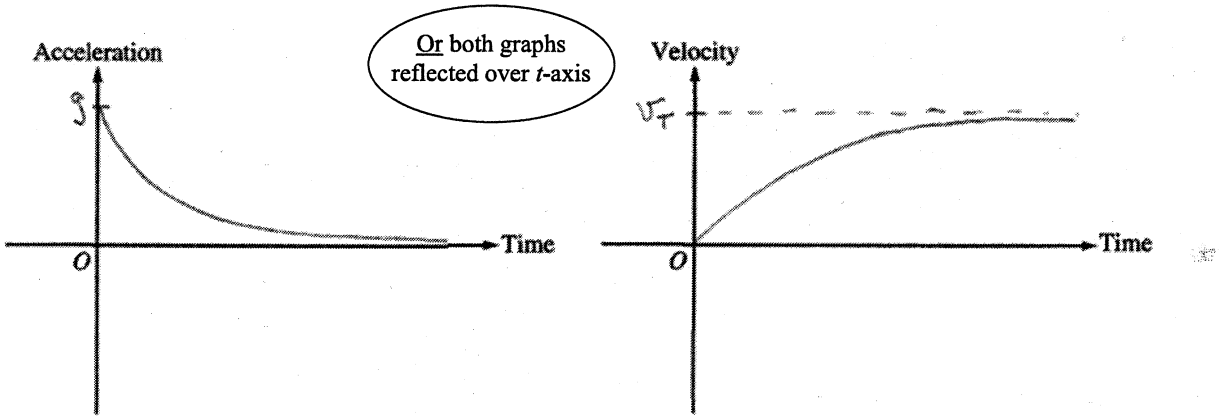
Distribution of points

For a correct answer — 1 point

$t = -\frac{m}{bA}\ln\left(\frac{2}{3}\right)$ (negative sign required) or $t = \frac{m}{bA}\ln\left(\frac{3}{2}\right)$ (with no negative sign)

Note: If the differential equation is incorrect, the student could still earn credit for solving the equation and substituting.

(d) 5 points



For an acceleration graph that does NOT begin at the origin	1 point
For an acceleration graph that has a horizontal asymptote of $a = 0$	1 point
For a velocity graph that begins at the origin	1 point
For a velocity graph that has a horizontal asymptote of $v = v_T$ or $-v_T$, as appropriate	1 point
For having both graphs with proper and accurate curvature	1 point

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Question 2

15 points total

Distribution of points

(a) 4 points

For a correct statement of the conservation of momentum — 1 point

$p_i = p_f$

$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$

For correctly substituting into the above equation — 1 point

$(0.30 \text{ kg})(2.0 \text{ m/s}) + (0.10 \text{ kg})(-3.0 \text{ m/s}) = (0.30 \text{ kg}) v_{1f} + (0.10 \text{ kg})(1.2 \text{ m/s})$

For a correct answer with units — 1 point

$v_{1f} = 0.60 \text{ m/s}$

For correctly indicating the direction is to the right — 1 point

(b) 2 points

For answering "no", or that the collision is inelastic — 1 point

For a correct justification — 1 point

Examples:

No, the collision is not elastic. As shown in the calculations below, the final kinetic energy is less than the initial kinetic energy.

$K_i = \frac{1}{2}(0.30 \text{ kg})(2.0 \text{ m/s})^2 + \frac{1}{2}(0.10 \text{ kg})(-3.0 \text{ m/s})^2 = 1.05 \text{ J}$

$K_f = \frac{1}{2}(0.30 \text{ kg})(0.60 \text{ m/s})^2 + \frac{1}{2}(0.10 \text{ kg})(1.2 \text{ m/s})^2 = 0.126 \text{ J}$

No, the collision is not elastic. Since $v_{1f} < v_{1i}$ and $v_{2f} < v_{2i}$, K_f must be less than K_i.

No, the collision is not elastic. The final relative velocity is less than the initial relative velocity.

(c) 3 points

For a correct statement of the conservation of energy — 1 point

$K_1 = U_{S2}$ or $\frac{1}{2} m_1 v_1^2 = U_{S2}$

For correctly substituting into the above equation — 1 point

$U_{S2} = \frac{1}{2}(0.10 \text{ kg})(1.2 \text{ m/s})^2$

For a correct answer with units — 1 point

$U_{S2} = 0.072 \text{ J}$

Note: If the student uses the wrong cart, mixes up values for mass and/or velocity, or has a sign error, only the first point can be earned.

Question 2 (continued)

Distribution of points

(d) 3 points

For a correct expression for the potential energy of a spring — 1 point

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

Substituting into the above equation

$(0.072\ \text{J}) = \left(\frac{1}{2}\right)(k)(0.10\ \text{m})^2$

For an answer consistent with part (c) — 1 point

For correct units — 1 point

$k = 14.4\ \text{N/m}\ \left(\text{or kg/s}^2\right)$

Note: There was no penalty for a sign error. If the wrong cart was used in part (c), then an acceptable answer is $k = 10.8\ \text{N/m}$.

(e) 3 points

For setting up a correct integral — 1 point

$U = -\int F dx = \int bx^3 dx$

For a correct equation for the potential energy of the spring — 1 point

$U = \frac{1}{4}bx^4$

Substituting into the above equation

$(0.072) = \left(\frac{1}{4}\right)(b)(0.10\ \text{m})^4$

For an answer consistent with part (c) and with correct sign and units — 1 point

$b = 2880\ \text{N/m}^3\ \left[\text{or kg/}\left(\text{m}^2\cdot\text{s}^2\right)\right]$

Note: If the wrong cart was used in part (c), then an acceptable answer is $b = 2160\ \text{N/m}^3$.

AP® PHYSICS C: MECHANICS
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Question 3

15 points total

Distribution of points

(a) 4 points

For correctly expressing the acceleration as the slope or rate of change of velocity — 1 point

$a = \text{slope} = \dfrac{\Delta v}{\Delta t}$

For using two points from a best-fit line to calculate the slope/acceleration (not data points unless the data points are on the line) — 1 point

$a = \dfrac{(1.52 - 0.71)\ \text{m/s}}{(0.55 - 0.25)\ \text{s}}$

For a reasonable numerical value for a — 1 point

For correct units (was earned even if numerical answer was not correct) — 1 point

$a = 2.7\ \text{m/s}^2$ (acceptable range of answers: 2.5 to 3.3)

(b) 5 points

For a correct expression of Newton's 2nd law for rotational motion — 1 point

$\tau = I\alpha$

$TR = I\alpha$

For a correct substitution for the angular acceleration in terms of the linear acceleration — 1 point

$\alpha = a/R$

$TR = I(a/R)$

$I = \dfrac{TR^2}{a}$

For a correct expression of Newton's 2nd law for translational motion — 1 point

$F_{net} = ma$

$mg - T = ma$

$T = m(g - a)$

Substituting the expression for T into the expression for the rotational inertia

$I = \dfrac{TR^2}{a} = \dfrac{m(g-a)R^2}{a}$

Substituting values into the above equation

$I = \dfrac{(0.05\ \text{kg})\left(9.8\ \text{m/s}^2 - 2.7\ \text{m/s}^2\right)(0.10\ \text{m})^2}{\left(2.7\ \text{m/s}^2\right)}$

For a numerical answer consistent with part (a) — 1 point

For correct units — 1 point

$I = 0.0013\ \text{kg}\cdot\text{m}^2$ (the acceptable range for a gives a range of 0.000985 to 0.00146, or using $g = 10\ \text{m/s}^2$ a range of 0.00101 to 0.0015

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Question 3 (continued)

Distribution of points

(c) 4 points

For a correct expression for angular momentum — 1 point
$L = I\omega$

For correct substitution into any proper rotational kinematics expression — 1 point
$\omega = \alpha t$ and $\alpha = a/R$ or $\omega = v/R$ and $v = at$
$L = Iat/R$
Substituting into the above equation
$L = \left(0.0013 \text{ kg}\cdot\text{m}^2\right)\left(2.7 \text{ m/s}^2\right)(0.45 \text{ s})/(0.10 \text{ m})$

For a numerical answer consistent with part (a) and part (b) — 1 point

For correct units — 1 point
$L = 0.016 \text{ kg}\cdot\text{m}^2/\text{s}$

An alternate solution using $L = Iv/R$ and using the graph to determine v at $t = 0.45$ s was also acceptable.

(d) 2 points

For correctly selecting "Less than" — 1 point

For a correct justification — 1 point

Examples:

The same force is applied to the system (or the same torque acts on the hoop/disk). Rotational inertia is higher for a hoop than a disk, so the acceleration will decrease.

Since the potential energy stays the same and the rotational inertia of a hoop is greater than that of a disk, more of the energy goes into rotating the disk and less into moving the block. So the linear acceleration of the block will be less with the hoop than with a disk. Since $\alpha = a/R$, the angular acceleration of the hoop will be less.

A derivation of $a = \dfrac{mgR^2}{I + mR^2}$, $\alpha = \dfrac{mgR}{I + mR^2}$, or an equivalent expression, and an explanation that the rotational inertia of the hoop is larger.

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2013 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	× 1.2857 =	_____
Number Correct (out of 35)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 2	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 3	_____ (out of 15)	× 1.0000 =	_____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
63-90	5
51-62	4
40-50	3
29-39	2
0-28	1

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AP Physics C: Mechanics Practice Exam

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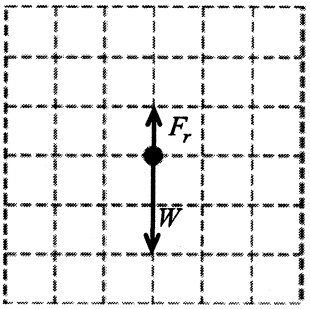
Question 1

15 points total

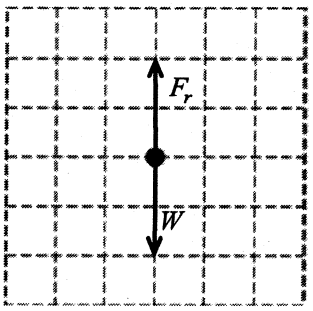
Distribution of points

(a) 4 points

A Short Time After the Ball is Released



Once the Ball Has Reached Terminal Velocity



For having all four forces properly labeled and in the proper direction — 1 point
For having both W vectors of equal length — 1 point
For having $F_r < W$ a short time after the ball is released — 1 point
For having $F_r = W$ at terminal velocity — 1 point
Note: 1 earned point was deducted if there were any extraneous forces

(b) 2 points

For setting the resistive force equal to the weight when at terminal velocity — 1 point
$F_r = W$
Substituting correct expressions for both forces
$bAv_T = mg$
For the correct magnitude of the terminal velocity — 1 point
$v_T = \frac{mg}{bA}$

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AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2012

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

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Minimum 20% post-consumer waste

Form I
Form Code 4IBP4-S
80

PLACE SEAL HERE
DO NOT seal answer sheet inside

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

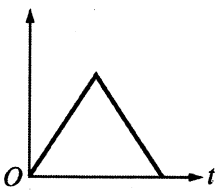
Note: To simplify calculations, you may use $g = 10\text{m/s}^2$ in all problems.

Questions 1-2

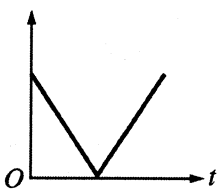


A ball is struck at time $t = 0$ and follows the parabolic path shown in the diagram above. The following graphs show quantities possibly associated with the motion as a function of time t. Assume that air resistance is negligible and that the positive directions are upward and to the right.

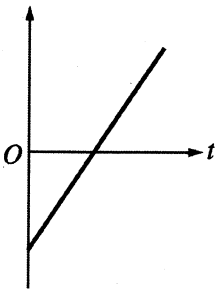
(A)



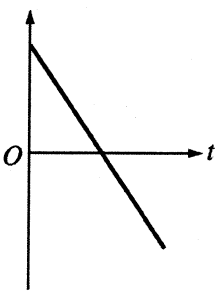
(B)



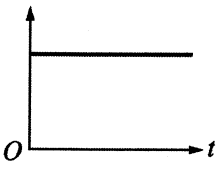
(C)



(D)

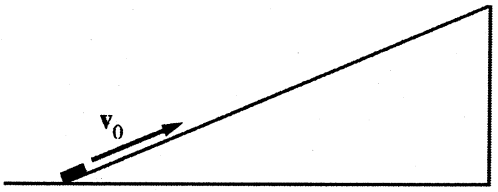


(E)



1. Which graph represents the horizontal component of the velocity of the ball?

2. Which graph represents the vertical component of the velocity of the ball?



3. An object with initial velocity v_0, as shown above, slides up and then down a long, frictionless, inclined plane. Which of the following is true of the object as it moves?

(A) It has a constant acceleration while moving up the plane and a greater acceleration when moving down the plane.
(B) It has a constant acceleration while moving up the plane and a smaller acceleration when moving down the plane.
(C) It moves with a constant velocity both up and down the plane.
(D) It has the same acceleration as it moves up and down the plane.
(E) It has a continually varying acceleration as it moves up and down the plane.

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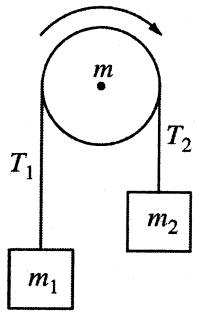
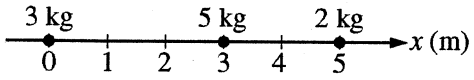


4. Two blocks of masses m_1 and m_2 are connected by a massless string that passes over a wheel of mass m, as shown above. The string does not slip on the wheel and exerts forces T_1 and T_2 on the blocks. When the wheel is released from rest in the position shown, it undergoes an angular acceleration and rotates clockwise. Which of the following statements about T_1 and T_2 is correct?

(A) $T_1 = T_2$ because the wheel has mass.
(B) $T_1 = T_2$ because both blocks have the same acceleration.
(C) $T_1 > T_2$ because m_1 is farther from the wheel than m_2.
(D) $T_1 > T_2$ because m_1 accelerates upward.
(E) $T_2 > T_1$ because an unbalanced clockwise torque is needed to accelerate the wheel clockwise.



5. Three objects are located along the x-axis as shown above. The center of mass of the objects is at $x =$

(A) 1.0 m
(B) 1.5 m
(C) 2.0 m
(D) 2.5 m
(E) 3.0 m

6. Which of the following is equivalent to a unit of momentum?

(A) Joule
(B) Newton
(C) Joule · second
(D) Newton · second
(E) Newton · meter

7. Two objects are dropped from rest from the same height. Object A falls through a distance d_A during a time t, and object B falls through a distance d_B during a time $2t$. If air resistance is negligible, what is the relationship between d_A and d_B?

(A) $d_A = \frac{1}{4} d_B$
(B) $d_A = \frac{1}{2} d_B$
(C) $d_A = 2d_B$
(D) $d_A = 4d_B$
(E) It cannot be determined from the information given.

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8. The maximum mass that can be hung vertically from a string without breaking the string is 10 kg. A length of this string that is 2 m long is used to rotate a 0.5 kg object in a circle on a frictionless table with the string horizontal. The maximum speed that the mass can attain under these conditions without the string breaking is most nearly

(A) 5 m/s
(B) 10 m/s
(C) 14 m/s
(D) 20 m/s
(E) 100 m/s

9. An object moving on a horizontal, frictionless surface makes a glancing collision with another object initially at rest on the surface. In this case which of the following is true about momentum and kinetic energy?

(A) Momentum is always conserved, and kinetic energy may be conserved.
(B) Kinetic energy is always conserved, and momentum may be conserved.
(C) Momentum is always conserved, and kinetic energy is never conserved.
(D) Both momentum and kinetic energy are always conserved.
(E) Neither momentum nor kinetic energy is conserved.

10. A particle of mass m starts from rest at position $x = 0$ and time $t = 0$. It moves along the positive x-axis under the influence of a single force $F_x = bt$, where b is a constant. The velocity v of the particle is given by

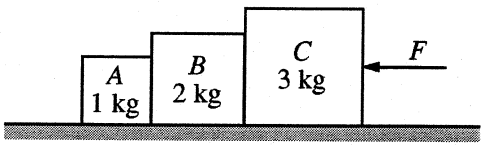
(A) $\frac{bt}{m}$

(B) $\frac{bt^2}{2m}$

(C) $\frac{bt^2}{m}$

(D) $\frac{b\sqrt{t}}{m}$

(E) $\frac{b}{mt}$

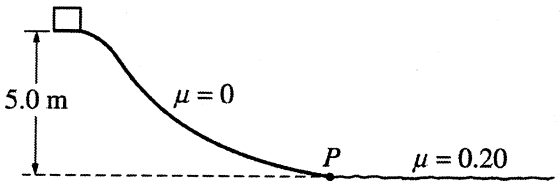


11. Three blocks, A, B, and C, of masses 1, 2, and 3 kg, respectively, are initially at rest on a frictionless surface as indicated in the figure above. What force F has to be applied on block C to accelerate the three blocks at 2 m/s^2 ?

(A) 0.33 N
(B) 1.5 N
(C) 3.0 N
(D) 6.0 N
(E) 12 N

12. An electrical motor provides 0.50 W of mechanical power. How much time will it take the motor to lift a 0.1 kg mass at constant speed from the floor to a shelf 2.0 m above the floor?

(A) 0.25 s
(B) 0.40 s
(C) 1.0 s
(D) 2.0 s
(E) 4.0 s



13. A block slides from rest with negligible friction down the track above, descending a vertical height of 5.0 m to point P at the bottom. It then slides on the horizontal surface. The coefficient of friction between the block and the horizontal surface is 0.20. How far does the block slide on the horizontal surface before it comes to rest?

(A) 0.40 m
(B) 1.0 m
(C) 2.5 m
(D) 10 m
(E) 25 m

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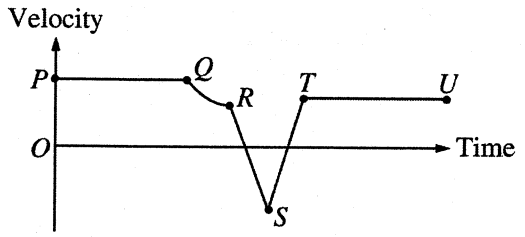


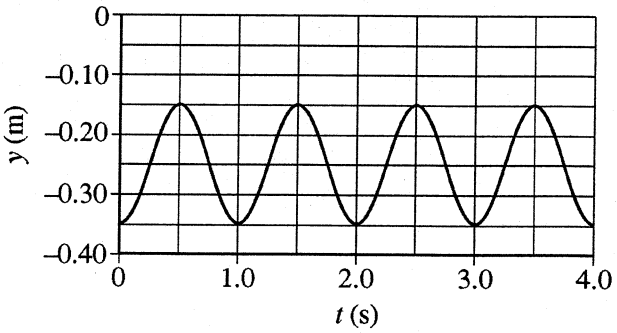
14. The graph above shows velocity as a function of time for an object moving along a straight line. For which of the following sections of the graph is the acceleration constant and nonzero?

(A) QR only
(B) ST only
(C) PQ and TU only
(D) RS and ST only
(E) PQ, RS, ST, and TU

15. The velocity of a particle moving along the x-axis is given as a function of time by the expression $v(t) = 3.0t^2 - 2.0t + 4.0$, where v is in meters per second and t is in seconds. What is the acceleration of the particle at $t = 2.0$ s?

(A) 4.0 m/s^2
(B) 6.0 m/s^2
(C) 8.0 m/s^2
(D) 10.0 m/s^2
(E) 12.0 m/s^2

Questions 16-17



An unstretched ideal spring hangs vertically from a fixed support. A 0.4 kg object is then attached to the lower end of the spring. The object is pulled down to a distance of 0.35 m below the unstretched position and released from rest at time $t = 0$. A graph of the subsequent vertical position y of the lower end of the spring as a function of t is given above, where $y = 0$ when the spring was initially unstretched.

16. At which of the following times is the upward velocity of the object the greatest?

(A) 0.00 s
(B) 0.25 s
(C) 0.50 s
(D) 0.75 s
(E) 1.00 s

17. What is the spring constant of the spring?

(A) 16 N/m
(B) 20 N/m
(C) 32 N/m
(D) 40 N/m
(E) 64 N/m

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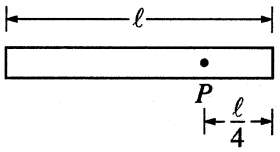
18. Identical net forces act for the same length of time on two different spherical masses. Which of the following describes the change in linear momentum of the smaller mass compared to that of the larger mass?

(A) It is smaller than the change in linear momentum of the larger mass but not zero.
(B) It is larger than the change in linear momentum of the larger mass.
(C) It is equal to the change in linear momentum of the larger mass.
(D) It is zero.
(E) It depends on the relative diameters of the two masses.



19. The uniform thin rod shown above has mass m and length ℓ. The moment of inertia of the rod about an axis through its center and perpendicular to the rod is $(1/12)m\ell^2$. What is the moment of inertia of the rod about an axis perpendicular to the rod and passing through point P, which is halfway between the center and the end of the rod?

(A) $\frac{1}{3}m\ell^2$
(B) $\frac{1}{6}m\ell^2$
(C) $\frac{1}{12}m\ell^2$
(D) $\frac{1}{48}m\ell^2$
(E) $\frac{7}{48}m\ell^2$

20. A certain one-dimensional conservative force is given as a function of x by the expression $F = -kx^3$, where F is in newtons and x is in meters. A possible potential energy function U for this force is

(A) $U = -\frac{1}{2}kx^2$
(B) $U = \frac{1}{2}kx^2$
(C) $U = -\frac{1}{4}kx^4$
(D) $U = \frac{1}{4}kx^4$
(E) $U = -3kx^2$

21. Which of the following is a differential equation that correctly describes Newton's second law for a simple harmonic oscillator of mass m and restoring force constant k?

(A) $kx = m\frac{d^2x}{dt^2}$
(B) $-kx = m\frac{d^2x}{dt^2}$
(C) $-kv = m\frac{dv}{dt}$
(D) $kx = m\frac{dx}{dt}$
(E) $mg - kv = m\frac{dv}{dt}$

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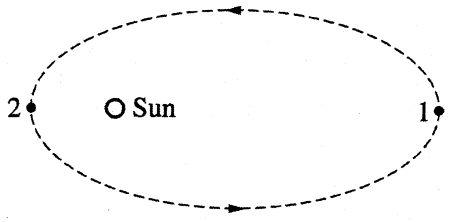
Questions 22-24



Note: Figure not drawn to scale.

The elliptical orbit of a comet is shown above. Positions 1 and 2 are, respectively, the farthest and nearest positions to the Sun, and at position 1 the distance from the comet to the Sun is 10 times that at position 2.

22. At position 2, the comet's kinetic energy is

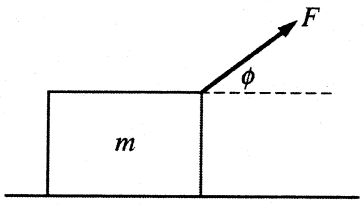
(A) the same as at position 1
(B) less than at position 1
(C) at its maximum value for the orbit
(D) at its minimum value for the orbit, but greater than zero
(E) equal to zero

23. What is the ratio v_1/v_2 of the speed of the comet at position 1 to the speed at position 2 ?

(A) 1/100
(B) 1/10
(C) 1
(D) 10
(E) 100

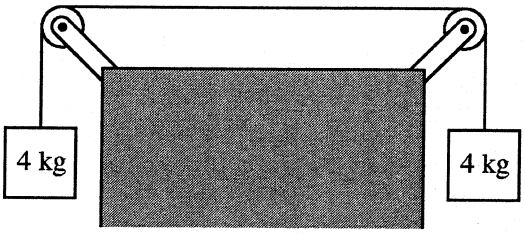
24. What is the ratio F_1/F_2 of the force on the comet at position 1 to the force on the comet at position 2 ?

(A) 1/100
(B) 1/10
(C) 1
(D) 10
(E) 100



25. A block of mass m is pulled across a rough surface, as shown above. The coefficient of friction between the block and the surface is μ_k. The force F that pulls the block is exerted at the angle ϕ shown. Which of the following is an expression for the magnitude of the frictional force on the block if it is moving at constant speed?

(A) $\mu_k mg$
(B) $\mu_k F\cos\phi$
(C) $\mu_k(F\sin\phi + mg)$
(D) $\mu_k(F\sin\phi - mg)$
(E) $\mu_k(mg - F\sin\phi)$



26. Two 4 kg blocks hang from a rope that passes over two frictionless pulleys, as shown in the figure above. What is the tension in the horizontal portion of the rope if the blocks are not moving and the rope and the two pulleys have negligible mass?

(A) 4 N
(B) 8 N
(C) 20 N
(D) 40 N
(E) 80 N

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27. A person throws a ball of mass 0.20 kg. The ball starts from rest, accelerates horizontally and uniformly through a distance of 0.90 m, and leaves the person's hand at 30 m/s. The average horizontal force applied to the ball by the person's hand is

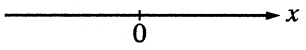
(A) 3.3 N
(B) 16.7 N
(C) 81 N
(D) 100 N
(E) 200 N

28. A railroad car of mass 1500 kg rolls to the right at 4 m/s and collides with another railroad car of mass 3000 kg that is rolling to the left at 3 m/s. The cars stick together. Their speed immediately after the collision is

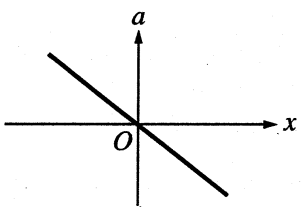
(A) $\frac{2}{3}$ m/s
(B) 1 m/s
(C) $\frac{5}{3}$ m/s
(D) $\frac{10}{3}$ m/s
(E) 7 m/s

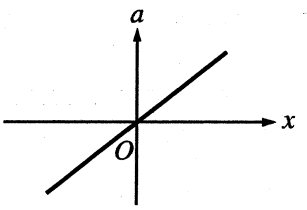
29. A meterstick of negligible mass is placed on a fulcrum at the 0.4 m mark, with a 1 kg mass hung at the zero mark and a 0.5 kg mass hung at the 1.0 m mark. The meterstick is held horizontal and released. Immediately after release, the magnitude of the net torque on the meterstick about the fulcrum is most nearly

(A) 1 N·m
(B) 2 N·m
(C) 2.5 N·m
(D) 7 N·m
(E) 7.5 N·m



30. An object undergoes simple harmonic motion along the x-axis shown above, where $x = 0$ is the object's equilibrium position. Which of the following graphs best shows the relationship between the object's acceleration a and its displacement x from equilibrium? (Assume positive a to be acceleration directed to the right.)

(A)


(B)


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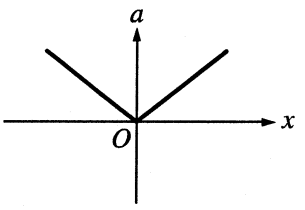
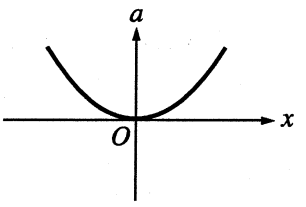
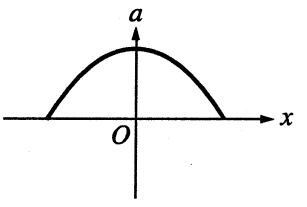


(D)


(E)


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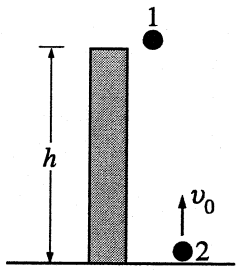

31. Ball 1 is dropped from rest at time $t = 0$ from a tower of height h, as shown above. At the same instant, ball 2 is launched upward from the ground with initial speed v_0. If air resistance is negligible, at what time t will the two balls pass each other?

(A) $\frac{1}{4}\frac{h}{v_0}$

(B) $\frac{1}{2}\frac{h}{v_0}$

(C) $\frac{h}{v_0}$

(D) $2\frac{h}{v_0}$

(E) $4\frac{h}{v_0}$

32. Suppose that the potential energy of a particle constrained to move along the x-axis can be described by the function $U(x) = \frac{1}{2}kx^2 - \alpha x$, where both k and α are positive constants. Stable equilibrium points, about which the particle oscillates, are located at

(A) $x = 0$ only

(B) $x = \frac{\alpha}{k}$ only

(C) $x = \frac{2\alpha}{k}$ only

(D) $x = 0$ and $\frac{\alpha}{k}$

(E) $x = 0$ and $\frac{2\alpha}{k}$

33. A ball of mass m falls vertically, hits the floor with a speed v_i, and rebounds with a speed v_f. What is the magnitude of the impulse exerted on the ball by the floor?

(A) $2m(v_f - v_i)$

(B) $m(v_f - v_i)$

(C) $m(v_f + v_i)$

(D) mv_i

(E) mv_f

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Questions 34-35

A particle moves in a circle in such a way that the x- and y-coordinates of its motion, given in meters as functions of time t in seconds, are:

$$x = 5\cos(3t)$$
$$y = 5\sin(3t).$$

34. What is the radius of the circle?

(A) $\frac{5}{3}$ m

(B) $\frac{5}{2}$ m

(C) 5 m

(D) 10 m

(E) 15 m

35. Which of the following is true of the speed of the particle?

(A) It is always equal to 5 m/s.
(B) It is always equal to 15 m/s.
(C) It oscillates with a range of 0 to 5 m/s.
(D) It oscillates with a range of 0 to 15 m/s.
(E) It oscillates with a range of 5 to 15 m/s.

STOP

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

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AP® Physics C: Mechanics Exam

SECTION II: Free Response

2012

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
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Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

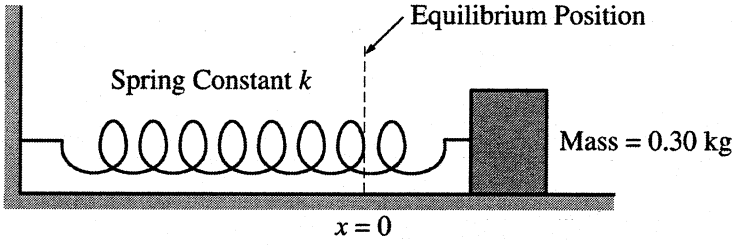
Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Minimum 20% post-consumer waste

Form I
Form Code 4IBP-S2
80

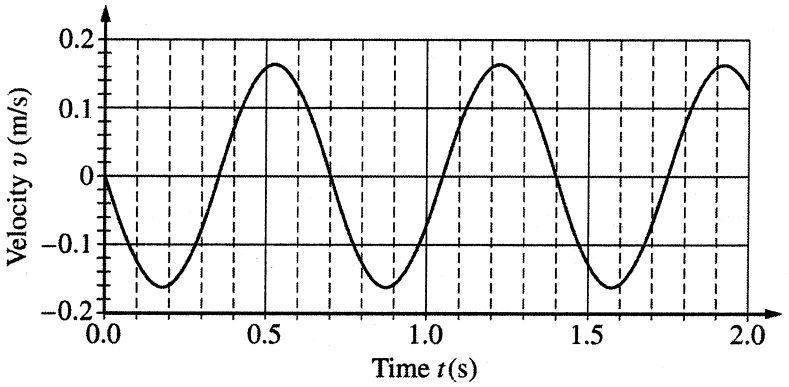
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech. 1.

Experiment 1. A block of mass 0.30 kg is placed on a frictionless table and is attached to one end of a horizontal spring of spring constant k, as shown above. The other end of the spring is attached to a fixed wall. The block is set into oscillatory motion by stretching the spring and releasing the block from rest at time $t = 0$. A motion detector is used to record the position of the block as it oscillates. The resulting graph of velocity v versus time t is shown below. The positive direction for all quantities is to the right.



(a) Determine the equation for $v(t)$, including numerical values for all constants.

(b) Given that the equilibrium position is at $x = 0$, determine the equation for $x(t)$, including numerical values for all constants.

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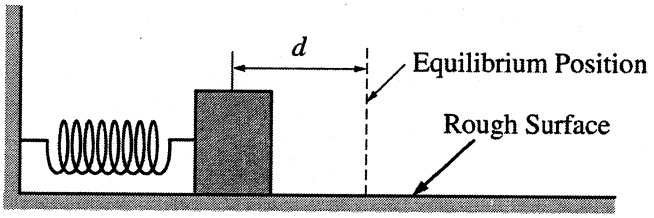
GO ON TO THE NEXT PAGE.

(c) Calculate the value of k.

Experiment 2. The block and spring arrangement is now placed on a rough surface, as shown below. The block is displaced so that the spring is compressed a distance d and released from rest.

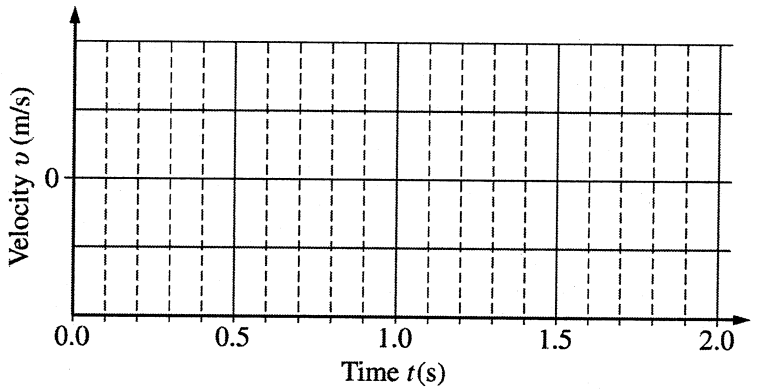


(d) On the dots below that represent the block, draw and label the forces (not components) that act on the block when the spring is compressed a distance $x = d/2$ and the block is moving in the direction indicated below each dot.

Toward the equilibrium position

Away from the equilibrium position

(e) Draw a sketch of v versus t in this case. Assume that there is a negligible change in the period and that the positive direction is still to the right.



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GO ON TO THE NEXT PAGE.

Mech. 2.

You are to perform an experiment investigating the conservation of mechanical energy involving a transformation from initial gravitational potential energy to translational kinetic energy.

(a) You are given the equipment listed below, all the supports required to hold the equipment, and a lab table. On the list below, indicate each piece of equipment you would use by checking the line next to each item.

____ Track	____ Meterstick	____ Set of objects of different masses
____ Cart	____ Electronic balance	____ Lightweight low-friction pulley
____ String	____ Stopwatch	

(b) Outline a procedure for performing the experiment. Include a diagram of your experimental setup. Label the equipment in your diagram. Also include a description of the measurements you would make and a symbol for each measurement.

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GO ON TO THE NEXT PAGE.

(c) Give a detailed account of the calculations of gravitational potential energy and translational kinetic energy both before and after the transformation, in terms of the quantities measured in part (b).

(d) After your first trial, your calculations show that the energy increased during the experiment. Assuming you made no mathematical errors, give a reasonable explanation for this result.

(e) On all other trials, your calculations show that the energy decreased during the experiment. Assuming you made no mathematical errors, give a reasonable physical explanation for the fact that the average energy you determined decreased. Include references to conservative and nonconservative forces, as appropriate.

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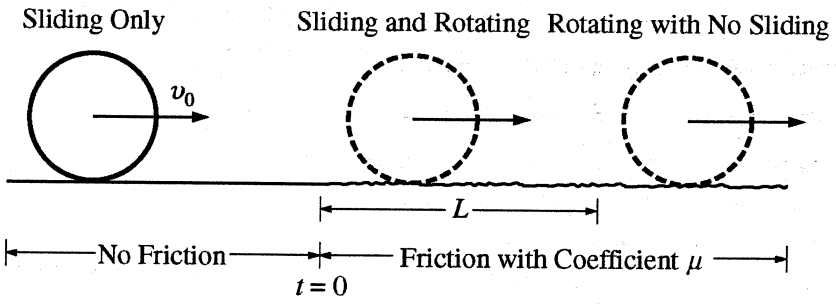

Mech. 3.

A ring of mass M, radius R, and rotational inertia MR^2 is initially sliding on a frictionless surface at constant velocity v_0 to the right, as shown above. At time $t = 0$ it encounters a surface with coefficient of friction μ and begins sliding and rotating. After traveling a distance L, the ring begins rolling without sliding. Express all answers to the following in terms of M, R, v_0, μ, and fundamental constants, as appropriate.

(a) Starting from Newton's second law in either translational or rotational form, as appropriate, derive a differential equation that can be used to solve for the magnitude of the following as the ring is sliding and rotating.

i. The linear velocity v of the ring as a function of time t

ii. The angular velocity ω of the ring as a function of time t

(b) Derive an expression for the magnitude of the following as the ring is sliding and rotating.

i. The linear velocity v of the ring as a function of time t

ii. The angular velocity ω of the ring as a function of time t

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GO ON TO THE NEXT PAGE.

(c) Derive an expression for the time it takes the ring to travel the distance L.

(d) Derive an expression for the magnitude of the velocity of the ring immediately after it has traveled the distance L.

(e) Derive an expression for the distance L.

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GO ON TO THE NEXT PAGE.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Answer Key for AP Physics C: Mechanics Practice Exam, Section I

Multiple-Choice Questions	
Question #	**Key**
1	E
2	D
3	D
4	E
5	D
6	D
7	A
8	D
9	A
10	B
11	E
12	E
13	E
14	D
15	D
16	B
17	A
18	C
19	E
20	D
21	B
22	C
23	B
24	A
25	E
26	D
27	D
28	A
29	A
30	A
31	C
32	B
33	C
34	C
35	B

AP® PHYSICS
2012 SCORING GUIDELINES

General Notes About 2012 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer owing to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS C: MECHANICS
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Question 1

15 points total

Distribution of points

(a) 4 points

For writing a correct trigonometric equation for velocity as a function of time, including the negative sign
$v(t) = -v_{max}\sin(\omega t) = -v_{max}\sin(2\pi t/T)$ — 1 point

For using $\omega = 2\pi f$ or $\omega = \frac{2\pi}{T}$ to solve for ω — 1 point

For using the correct period of 0.70 s from the graph — 1 point
$\omega = \frac{2\pi}{0.70\text{s}} = 9.0$ rad/s

For using the correct value of the maximum speed from the graph (acceptable range of values for v_{max}: 0.15 m/s to 0.17 m/s) — 1 point
$v(t) = (-0.16)\sin(9.0t)$

Note: One point is deducted if incorrect phase shift ϕ is used. Full credit is awarded for a correct answer with no work shown. Students are also given credit if the value of k from part (c) is used to calculate ω using $\omega = \sqrt{k/m}$.

(b) 2 points

Take the integral of the velocity determined in part (a)
$x(t) = \int v(t)dt = \int(-0.16 \text{ m/s})\sin((9.0 \text{ rad/s})t)dt$

For a correct trigonometric expression consistent with integrating the answer from part (a) — 1 point

For a correct x_{max} consistent with the integrating the answer from part (a) — 1 point
$x_{max} = (0.16 \text{ m/s})/(9.0 \text{ rad/s}) = 0.018$ m
$x(t) = (0.018)\cos(9.0t)$

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AP® PHYSICS C: MECHANICS
2012 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) continued

Alternate solution — *Alternate points*

For solving for a maximum displacement consistent with the answer from part (a) — *1 point*

$v_{max} = x_{max}\omega$

$x_{max} = \frac{v_{max}}{\omega} = \frac{(0.16 \text{ m/s})}{(9.0 \text{ rad/s})}$

$x_{max} = 0.018 \text{ m}$

For a correct trigonometric expression consistent with the answer from part (a) — *1 point*

$x(t) = (0.018)\cos(9.0t)$

Note: Full credit is awarded for a correct answer with no work shown. One earned point is deducted for incorrect initial conditions (e.g., subtracting a constant from the cosine function).

(c) 2 points

For a correct relationship between the period and the spring constant — 1 point

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

For substituting correct values from previous parts into a correct expression — 1 point

$k = \frac{4\pi^2 m}{T^2} = \frac{(4\pi^2)(0.30 \text{ kg})}{(0.70 \text{ s})^2}$

$k = 24 \text{ N/m}$

Alternate solution #1 — *Alternate points*

For a correct expression relating angular frequency and the spring constant — *1 point*

$\omega = \sqrt{\frac{k}{m}}$

For substituting correct values from previous parts into a correct expression — *1 point*

$k = m\omega^2 = (0.30 \text{ kg})(9.0 \text{ rad/s})^2$

$k = 24 \text{ N/m}$

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Question 1 (continued)

Distribution of points

(c) continued

Alternate solution #2 — *Alternate points*

For a correct statement of the conservation of energy, applied to the position of maximum displacement and the equilibrium position — *1 point*

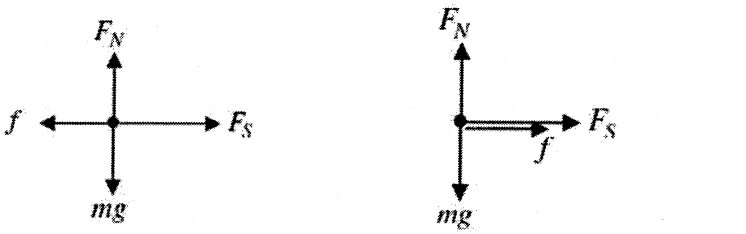
$\frac{1}{2}kx_{max}^2 = \frac{1}{2}mv_{max}^2$

For substituting correct values from previous parts into a correct expression — *1 point*

$k = \frac{mv_{max}^2}{x_{max}^2} = \frac{(0.30\text{ kg})(0.16\text{ m/s})^2}{(0.018\text{ m})^2}$

$k = 24\text{ N/m}$

(d) 4 points



Toward the equilibrium position — Away from the equilibrium position

For drawing and labeling F_N and mg correctly on both diagrams — 1 point

On diagram of the block moving toward the equilibrium position:

For a correctly drawn and labeled spring force to the right — 1 point

For a correctly drawn and labeled friction force to the left — 1 point

On diagram of the block moving away from the equilibrium position:

For a correctly drawn and labeled spring force and friction force to the right — 1 point

Notes

- Length of vectors is not considered, only direction.
- There is a 1-point maximum deduction for any vectors not touching (or at least almost touching) the dot or for any extraneous forces. Vectors can be drawn from the dot outward OR toward the dot, pointing inward and touching the dot.

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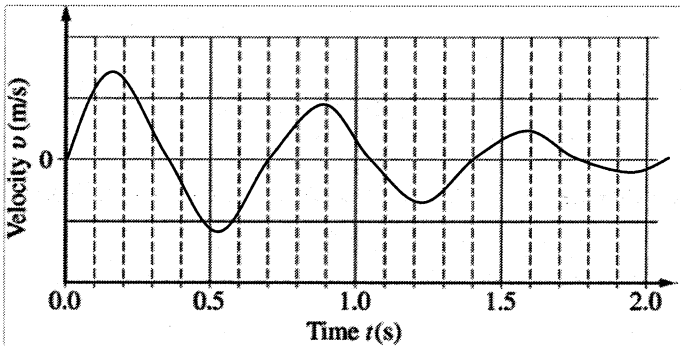
Question 1 (continued)

Distribution of points

(e) 3 points



For a graph passing through equilibrium at 0.35 s intervals	1 point
For a graph displaying damped oscillations	1 point
For a graph that starts at zero with an increasing positive velocity	1 point

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Question 2

15 points total

Distribution of points

(a) 1 point

For choosing the meterstick and stopwatch, regardless of what else is checked — 1 point

(b) 4 points

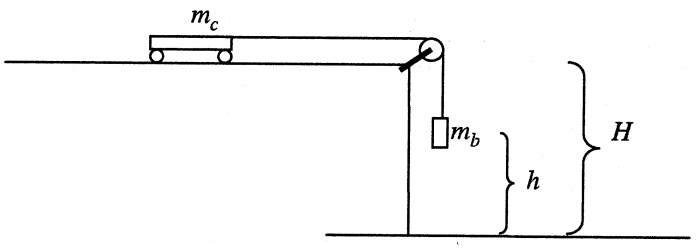
For a procedure that indicates the height needed to calculate gravitational potential energy — 1 point

For a procedure that indicates distance and time measurements to calculate velocity — 1 point

For a diagram and a clear indication of the height measurement — 1 point

For a diagram and a clear indication of the distance measurement — 1 point

Example #1



- Use the electronic balance to determine the mass m_c of the cart and the mass m_b of one object.
- Attach the object to the cart using the string.
- Place the cart on the track and hang the object so that the string passes through the pulley.
- Allow the object to fall a distance h from its initial position to the floor, using the meterstick to measure the distance fallen.
- Use the stopwatch to measure the time t it takes the object to fall the distance h.
- Measure the height H of the table.

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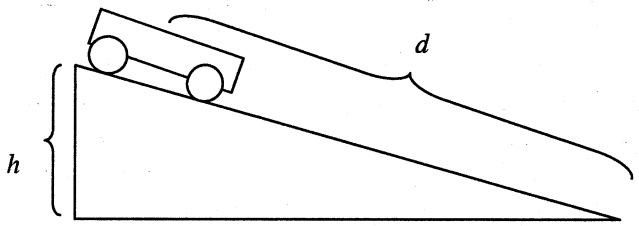
Question 2 (continued)

Distribution of points

(b) continued

Example #2



- Use the electronic balance to determine the mass m of the cart.
- Set the track at an incline, and measure the height h of the incline.
- Place the cart at the top of the incline, and release from rest.
- Using the stopwatch, measure the time t it takes for the cart to move down the incline.
- Measure the distance d that the cart moves down the incline.

(c) 6 points

For a clear indication of the initial potential energy of the system	1 point
For a clear indication of the final potential energy of the system	1 point
For a clear indication of the initial kinetic energy of the system	1 point
For a clear indication of the final kinetic energy of the system	1 point
For a correct calculation of the instantaneous velocity of the system	2 points

Example #1

Initial gravitational potential energy: $U_{g0} = m_c gH + m_b gh$

Final gravitational potential energy: $U_{gf} = m_c gH$

Initial kinetic energy: $K_0 = 0$

Final kinetic energy: $K_f = \frac{1}{2}(m_c + m_b)v_f^2$

Acceleration is constant, so $d = \frac{1}{2}(v_0 + v_f)t$, where d is the distance along the track.

$v_f = \frac{2h}{t}$

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Question 2 (continued)

Distribution of points

(c) continued

Example #2

Initial gravitational potential energy: $U_{g0} = mgh$

Final gravitational potential energy $U_{gf} = 0$

Initial kinetic energy $K_0 = 0$

Final kinetic energy $K_f = \frac{1}{2}mv_f^2$

Acceleration is constant, so $d = \frac{1}{2}(v_0 + v_f)t$.

$v_f = \frac{2d}{t}$

(d) 2 points

For identifying a reasonable cause for the increase in energy — 1 point

For a reasonable explanation related to the cause identified — 1 point

Example
An unintentional push was applied to the cart, thus increasing the initial energy.

(e) 2 points

For identifying a reasonable cause for the decrease in energy related to the nonconservative forces acting on the system — 1 point

For a reasonable explanation related to the cause identified — 1 point

Example
Friction acting on the object decreases the speed, thereby decreasing the energy.

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Question 3

15 points total | **Distribution of points**

(a)

i. 3 points

For starting with Newton's second law for translation, with friction as the net force — 1 point
$\Sigma F = -f = Ma$

For a correct expression for the frictional force — 1 point
$f = \mu Mg$

For indicating that linear acceleration is the time derivative of velocity — 1 point
$a = \frac{dv}{dt}$

$\frac{dv}{dt} = -\mu g$

ii. 3 points

For starting with Newton's second law for rotation, with a correct substitution for the rotational inertia — 1 point
$\tau = MR^2\alpha$

For a correct expression for the torque, using the frictional force — 1 point
$\tau = \mu MgR$

For indicating that the angular acceleration is the time derivative of the angular velocity — 1 point
$\alpha = \frac{d\omega}{dt}$

$\frac{d\omega}{dt} = \frac{\mu g}{R}$

(b)

i. 2 points

For setting up the integral of the function determined in part (a)-i — 1 point
$\int_{v_0}^{v} dv = -\int_0^t \mu g dt$

For the correct answer — 1 point
$v = v_0 - \mu g t$

Alternate solution | *Alternate points*

For a clear substitution of the acceleration from part (a)-i into the kinematics equation — *1 point*
$a = -\mu g$

$v = v_0 + at$

For the correct answer — *1 point*
$v = v_0 - \mu g t$

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2012 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(b) continued

ii. 2 points

For setting up the integral of the function determined in part (a)-ii — 1 point

$\int_0^{\omega} d\omega = \int_0^{t} (\mu g/R)dt$

For the correct answer — 1 point

$\omega = \mu g t/R$

Alternate solution — *Alternate points*

For a clear substitution of the angular acceleration from part (a)-ii into the correct rotational kinematics equation — *1 point*

$\alpha = \frac{\mu g}{R}$

$\omega = \omega_0 + \alpha t$

For the correct answer — *1 point*

$\omega = \mu g t/R$

(c) 2 points

For indicating that the linear speed is equal to $R\omega$ when the slipping stops — 1 point

$v = R\omega$

$v_0 - \mu g t = R\left(\frac{\mu g t}{R}\right)$

For the correct answer — 1 point

$t = \frac{v_0}{2\mu g}$

(d) 1 point

For substituting the time found in part (c) into a correct kinematics equation — 1 point

$v = v_0 - \mu g\left(\frac{v_0}{2\mu g}\right)$

$v = v_0/2$

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Question 3 (continued)

Distribution of points

(e) 2 points

For setting up the integral of the velocity function determined in part (b)-i — 1 point

$L = \int_0^t (v_0 - vgt)\,dt$

For the correct answer, with correct supporting work — 1 point

$L = \left[v_0 t - \frac{1}{2}\mu g t^2 \right]_0^{\frac{v_0}{2\mu g}}$

$L = \frac{3v_0^2}{8\mu g}$

Alternate solution #1 — *Alternate points*

For substituting the velocity from part (d) and the acceleration from part (a)-i into a correct equation that solves for L — *1 point*

$v^2 = v_0^2 + 2a\Delta x$

$\left(\frac{v_0}{2}\right)^2 = v_0^2 + 2(-\mu g)L$

For the correct answer, with correct supporting work — *1 point*

$L = \frac{3v_0^2}{8\mu g}$

Alternate solution #2 — *Alternate points*

For substituting the velocity from part (d) and the acceleration from part (a)-i into a correct equation that solves for L — *1 point*

Note: The time determined in part (c) must also be substituted.

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

$L = v_0\left(\frac{v_0}{2\mu g}\right) + \frac{1}{2}(-\mu g)\left(\frac{v_0}{2\mu g}\right)^2$

For the correct answer, with correct supporting work — *1 point*

$L = \frac{3v_0^2}{8\mu g}$

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2012 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____ × 1.2857 = _____
Number Correct (out of 35) — Weighted Section I Score (Do not round)

Section II: Free Response

Question 1 _____ (out of 15) × 1.0000 = _____ (Do not round)

Question 2 _____ (out of 15) × 1.0000 = _____ (Do not round)

Question 3 _____ (out of 15) × 1.0000 = _____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____ + _____ = _____
Weighted Section I Score — Weighted Section II Score — Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
54-90	5
42-53	4
33-41	3
25-32	2
0-24	1

2018

AP CollegeBoard

AP Physics C: Mechanics

Free-Response Questions

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ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 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,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ $\text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta \vec{p}$

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

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

$\Delta E = W = \int \vec{F} \cdot d\vec{r}$

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

$P = \frac{dE}{dt}$

$P = \vec{F} \cdot \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

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

$I = \int r^2 dm = \sum m r^2$

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

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
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
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

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

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \cdot d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$\vec{E} = \rho \vec{J}$

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I \Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \cdot d\vec{A}$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\mathcal{E} = -L \frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

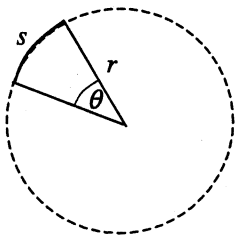
$a^2 + b^2 = c^2$

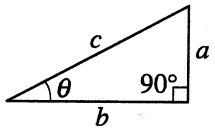
$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

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





CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}(x^n) = nx^{n-1}$$

$$\frac{d}{dx}(e^{ax}) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^{ax} dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

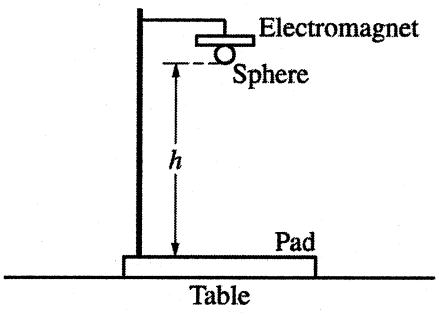
$$\vec{A}\cdot\vec{B} = AB\cos\theta$$

$$|\vec{A}\times\vec{B}| = AB\sin\theta$$

2018 AP® PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. 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. A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

   (a) While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

   ____ Greater than ____ Less than ____ Equal to

   Justify your answer.

   The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

   (b) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

   Vertical axis: _____

   Horizontal axis: _____

   Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

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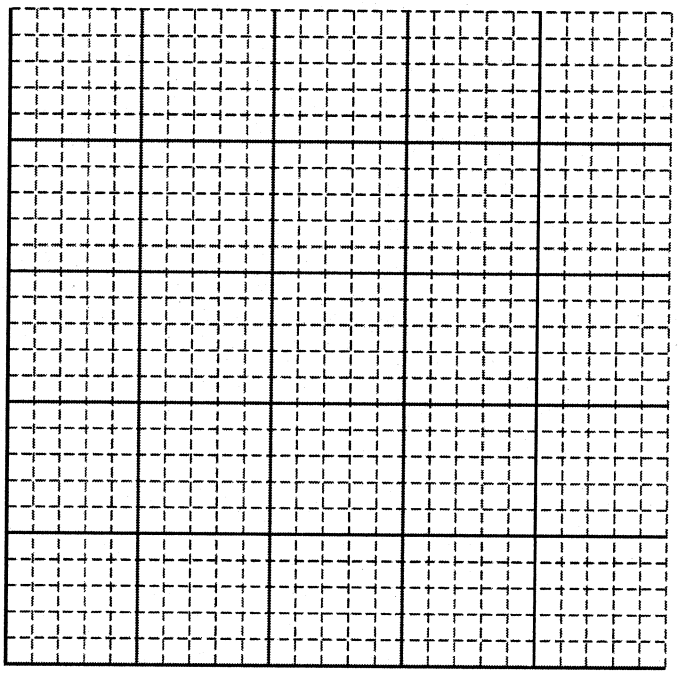
(c) Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(d) Using the straight line, calculate an experimental value for g.

Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\ \text{m/s}^2$, $B = -0.524\ \text{m/s}$, and $C = +0.080\ \text{m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. Derive an expression for the velocity of the sphere as a function of time.

ii. Calculate the new experimental value for g.

iii. Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)ii.

iv. Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

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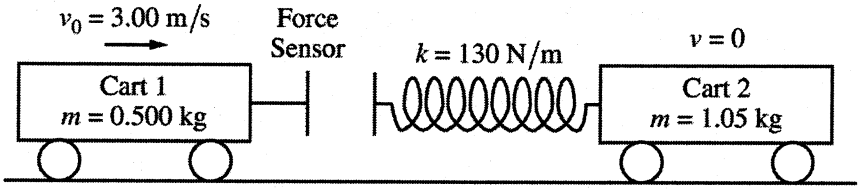
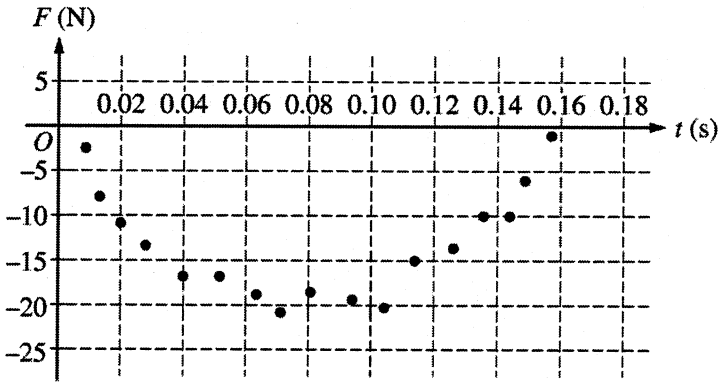


2. Two carts are on a horizontal, level track of negligible friction. Cart 1 has a sensor that measures the force exerted on it during a collision with cart 2, which has a spring attached. Cart 1 is moving with a speed of $v_0 = 3.00$ m/s toward cart 2, which is at rest, as shown in the figure above. The total mass of cart 1 and the force sensor is 0.500 kg, the mass of cart 2 is 1.05 kg, and the spring has negligible mass. The spring has a spring constant of $k = 130$ N/m. The data for the force the spring exerts on cart 1 are shown in the graph below. A student models the data as the quadratic fit $F = (3200\ \text{N/s}^2)t^2 - (500\ \text{N/s})t$.



(a) Using integral calculus, calculate the total impulse delivered to cart 1 during the collision.

(b)

i. Calculate the speed of cart 1 after the collision.

ii. In which direction does cart 1 move after the collision?

____ Left ____ Right

____ The direction is undefined, because the speed of cart 1 is zero after the collision.

(c)

i. Calculate the speed of cart 2 after the collision.

ii. Show that the collision between the two carts is elastic.

(d)

i. Calculate the speed of the center of mass of the two-cart–spring system.

ii. Calculate the maximum elastic potential energy stored in the spring.

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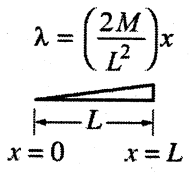

3. A triangular rod, shown above, has length L, mass M, and a nonuniform linear mass density given by the equation $\lambda = \frac{2M}{L^2}x$, where x is the distance from one end of the rod.

(a) Using integral calculus, show that the rotational inertia of the rod about its left end is $ML^2/2$.

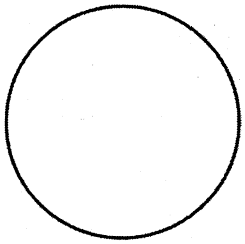

Figure 1

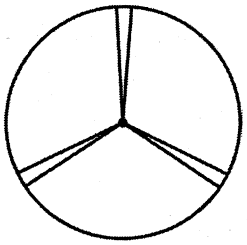

Figure 2

The thin hoop shown above in Figure 1 has a mass M, radius L, and a rotational inertia around its center of ML^2. Three rods identical to the rod from part (a) are now fastened to the thin hoop, as shown in Figure 2 above.

(b) Derive an expression for the rotational inertia I_{tot} of the hoop-rods system about the center of the hoop. Express your answer in terms of M, L, and physical constants, as appropriate.

The hoop-rods system is initially at rest and held in place but is free to rotate around its center. A constant force F is exerted tangent to the hoop for a time Δt.

(c) Derive an expression for the final angular speed ω of the hoop-rods system. Express your answer in terms of M, L, F, Δt, and physical constants, as appropriate.

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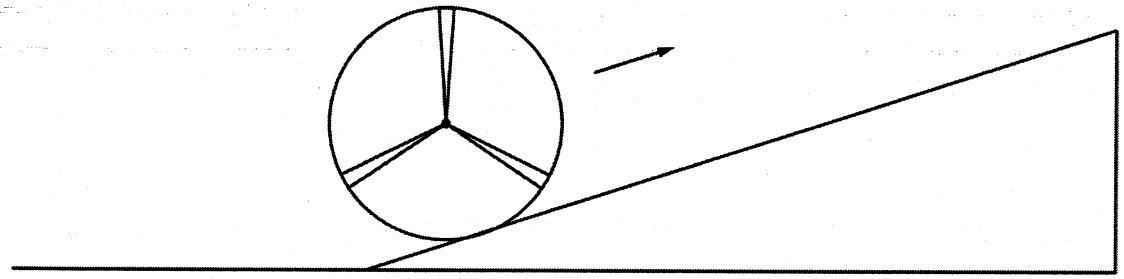
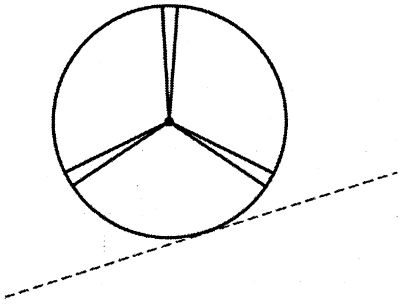


The hoop-rods system is rolling without slipping along a level horizontal surface with the angular speed ω found in part (c). At time $t = 0$, the system begins rolling without slipping up a ramp, as shown in the figure above.

(d)

i. On the figure of the hoop-rods system below, draw and label the forces (not components) that act on the system. Each force must be represented by a distinct arrow starting at, and pointing away from, the point at which the force is exerted on the system.



ii. Justify your choice for the direction of each of the forces drawn in part (d)i.

(e) Derive an expression for the change in height of the center of the hoop from the moment it reaches the bottom of the ramp until the moment it reaches its maximum height. Express your answer in terms of M, L, I_{tot}, ω, and physical constants, as appropriate.

STOP

END OF EXAM

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AP Physics C: Mechanics

Scoring Guidelines

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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 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. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. 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 embeds the application of that equation to the problem in other work, 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description.*

5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the 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.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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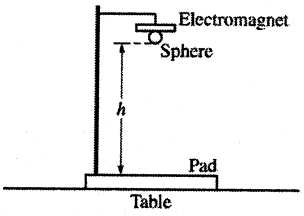
AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1

15 points total

Distribution of points



A student wants to determine the value of the acceleration due to gravity g for a specific location and sets up the following experiment. A solid sphere is held vertically a distance h above a pad by an electromagnet, as shown in the figure above. The experimental equipment is designed to release the sphere when the electromagnet is turned off. A timer also starts when the electromagnet is turned off, and the timer stops when the sphere lands on the pad.

(a) 2 points

While taking the first data point, the student notices that the electromagnet actually releases the sphere after the timer begins. Would the value of g calculated from this one measurement be greater than, less than, or equal to the actual value of g at the student's location?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Less than" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Because the measured time to fall the same distance will be larger, the acceleration must be less.		
Example: Because the time is larger and $a \propto 1/t^2$, then g must decrease.		

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AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

The electromagnet is replaced so that the timer begins when the sphere is released. The student varies the distance h. The student measures and records the time Δt of the fall for each particular height, resulting in the following data table.

h (m)	0.10	0.20	0.60	0.80	1.00
Δt (s)	0.105	0.213	0.342	0.401	0.451

(b) 1 point

Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for g.

Vertical axis: _____

Horizontal axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given in the table. Label each row you use and include units.

For correctly indicating two variables that will yield a straight line that could be used to determine a value for g		1 point
Example: Vertical Axis: h *Horizontal Axis:* $(\Delta t)^2$		
Note: Student earns full credit if axes are reversed or if they use another acceptable combination.		

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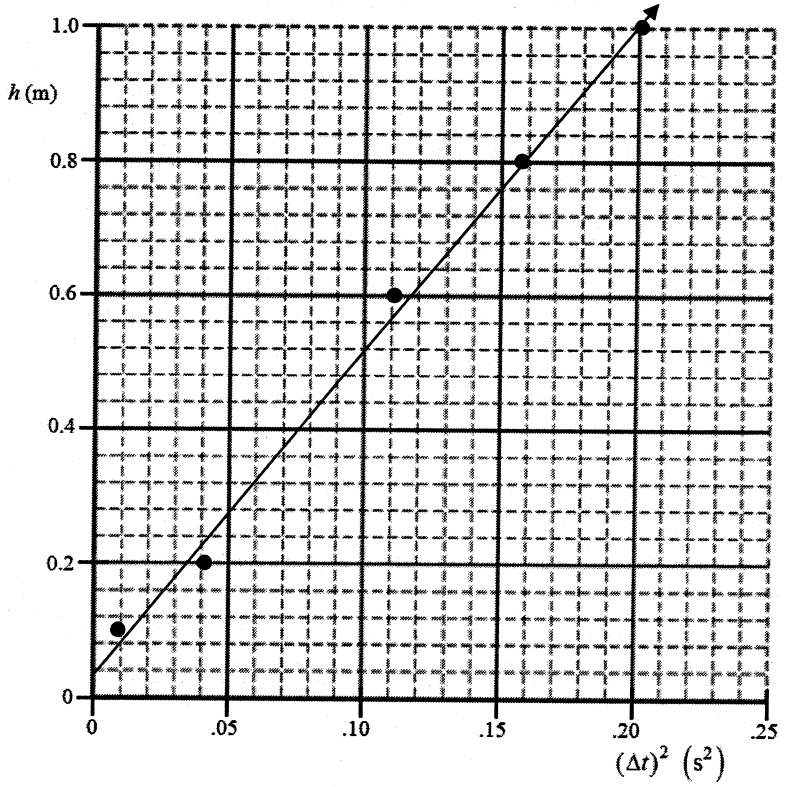
AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(c) 4 points

Plot the data points for the quantities indicated in part (b) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axis with variables and units consistent with part (b)		1 point
For correctly plotting data consistent with part (b)		1 point
For drawing a straight line consistent with the plotted data		1 point

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Question 1 (continued)

Distribution of points

(d) 2 points

Using the straight line, calculate an experimental value for g.

For using points on the line rather than the data to calculate the slope		1 point
$\text{slope} = \dfrac{\Delta h}{\Delta(\Delta t)^2} = \dfrac{(0.80 - 0.20)\text{ m}}{(0.160 - 0.039)\text{ s}^2} = 4.96\text{ m/s}^2$ (Linear regression = 4.83 m/s^2)		
For correctly relating the slope to the acceleration due to gravity		1 point
$\text{slope} = \frac{1}{2}g \therefore g = 2 \times \text{slope} = 2 \times (4.96\text{ m/s}^2)$		
$g = 9.92\text{ m/s}^2$ (Linear regression = 9.66 m/s^2)		

Another student fits the data in the table to a quadratic equation. The student's equation for the distance fallen y as a function of time t is $y = At^2 + Bt + C$, where $A = 5.75\text{ m/s}^2$, $B = -0.524\text{ m/s}$, and $C = +0.080\text{ m}$. Vertically down is the positive direction.

(e) Using the student's equation above, do the following.

i. 1 point

Derive an expression for the velocity of the sphere as a function of time.

For correctly taking the time derivative of the given equation		1 point
$y = y_0 + v_1 t + \frac{1}{2}at^2 = At^2 + Bt + C$		
$v(t) = \dfrac{dy}{dt} = 2At + B$		
Note: Credit is earned for substituting numbers: $v(t) = (11.5\text{ m/s}^2)t - 0.524\text{ m/s}$.		

ii. 2 points

Calculate the new experimental value for g.

For correctly relating the given equation to a correct kinematic equation		1 point
$\Delta y = y - y_0 = v_1 t + \frac{1}{2}at^2$		
$y = y_0 + v_1 t + \frac{1}{2}at^2 = At^2 + Bt + C$		
For correctly relating the equation to the value of g		1 point
$A = \frac{1}{2}a = \frac{1}{2}g$		
$g = 2A = (2)(5.75\text{ m/s}^2) = 11.5\text{ m/s}^2$		

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Question 1 (continued)

Distribution of points

iii. 1 point

Using $9.81\ \text{m/s}^2$ as the accepted value for g at this location, calculate the percent error for the value found in part (e)(ii).

For correctly calculating the percent error		1 point
$\%\text{error} = \frac{\lvert\text{acc} - \text{exp}\rvert}{\text{acc}} \times 100\% = \frac{\lvert(11.5\ \text{m/s}^2) - (9.81\ \text{m/s}^2)\rvert}{(9.81\ \text{m/s}^2)} \times 100\%$		
$\%\text{error} = 17.2\%$		
Note: Credit is earned if percent error is expressed as positive or negative.		

iv. 2 points

Assuming the sphere is at a height of 1.40 m at $t = 0$, calculate the velocity of the sphere just before it strikes the pad.

For relating the coefficients of the equation to the kinematic variables		1 point
$y = At^2 + Bt + C \ \therefore v_1 = B = -0.524\ \text{m/s}$		
$a = 2A = 2 \times (5.75\ \text{m/s}^2) = 11.5\ \text{m/s}^2$		
$y_0 = C = 0.080\ \text{m}$		
For correctly using an appropriate kinematics equation to determine the velocity of the sphere		1 point
$v_2^2 = v_1^2 + 2a\Delta y$		
$v = \sqrt{v_1^2 + 2a\Delta y} = \sqrt{(-0.524\ \text{m/s})^2 + (2)(11.5\ \text{m/s}^2)(1.40\ \text{m} - 0.080\ \text{m})}$		
$v = 5.54\ \text{m/s}$		
Alternate solution:		*Alternate Points*
For correctly determining the time of fall for the sphere		*1 point*
$y = At^2 + Bt + C$		
$1.40 = (5.75\ \text{m/s}^2)t^2 + (-0.524\ \text{m/s})t + (0.080\ \text{m})$		
$5.75t^2 - 0.524t - 1.32 = 0$		
$t = 0.53\ \text{s}$ or $-0.44\ \text{s} \ \therefore t = 0.53\ \text{s}$		
For correctly using the equation from part (e)(i)		*1 point*
$v(t) = (11.5\ \text{m/s}^2)(0.53\ \text{s}) - 0.524\ \text{m/s}$		
$v = 5.54\ \text{m/s}$		

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Question 1 (continued)

Distribution of points

(e)

iv. (continued)

Alternate Solution — Conservation of Energy		
For relating the coefficients of the equation to the initial height and speed		1 point
$y = At^2 + Bt + C \ \therefore v_1 = B = -0.524$ m/s		
$y_0 = C = 0.080$ m		
For correctly using conservation of energy to determine the velocity of the sphere		1 point
$U_i + K_i = U_f + K_f$		
$mgh + \frac{1}{2}mv_1^2 = \frac{1}{2}mv^2$		
$v = \sqrt{2(11.5)(1.40-0.080)+(-0.524)^2} = 5.54$ m/s		

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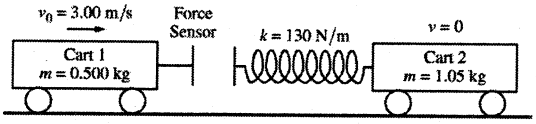
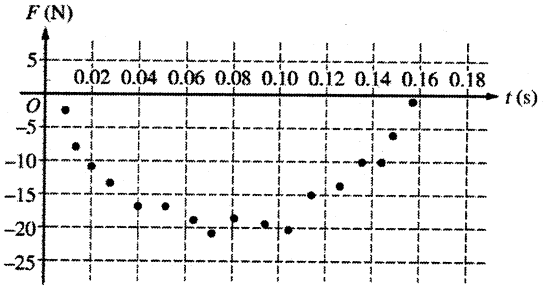
Question 2

15 points total

Distribution of points



Two carts are on a horizontal, level track of negligible friction. Cart 1 has a sensor that measures the force exerted on it during a collision with cart 2, which has a spring attached. Cart 1 is moving with a speed of $v_0 = 3.00$ m/s toward cart 2, which is at rest, as shown in the figure above. The total mass of cart 1 and the force sensor is 0.500 kg, the mass of cart 2 is 1.05 kg, and the spring has negligible mass. The spring has a spring constant of $k = 130$ N/m. The data for the force the spring exerts on cart 1 are shown in the graph below. A student models the data as the quadratic fit $F = 3200\ \text{N/s}^2\ t^2 - 500\ \text{N/s}\ t$.



(a) 3 points

Using integral calculus, calculate the total impulse delivered to cart 1 during the collision.

For using the given force equation in the integral to determine the impulse delivered to the cart		1 point
$J = \int F \cdot dt = \int 3200t^2 - 500t\ dt$		
For integrating the force using the correct limits or constant of integration		1 point
$J = \int_{t=0}^{t=0.16\text{ s}} \left(3200t^2 - 500t\right)dt = \left[\frac{3200}{3}t^3 - 250t^2\right]_{t=0}^{t=0.16}$		
$J = \left(\left(\frac{3200}{3}\right)(0.16)^3 - (250)(0.16)^2\right) - 0$		
For a correct answer		1 point
$J = -2.03$ N•s		

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Question 2 (continued)

Distribution of points

(b)

i. 1 point

Calculate the speed of cart 1 after the collision.

For correct substitution into the impulse-momentum equation of the answer from part (a) to determine the speed of cart 1		1 point
$J = m_1(v_{1f} - v_{1i}) \therefore v_{1f} = \frac{J}{m_1} + v_{1i} = \frac{(-2.03\ \text{N•s})}{(0.500\ \text{kg})} + (3.00\ \text{m/s})$		
$v_{1f} = -1.06\ \text{m/s}$		

ii. 1 point

In which direction does cart 1 move after the collision?

____ Left ____ Right

____ The direction is undefined, because the speed of cart 1 is zero after the collision.

For correctly selecting "Left"		1 point

(c)

i. 2 points

Calculate the speed of cart 2 after the collision.

For using a correct equation to determine the speed of cart 2		1 point
$-J = -m_1(v_{1f} - v_{1i}) = m_2 v_{2f} \therefore v_{2f} = \frac{-J}{m_2}$		
For correct substitution of the answer from part (a)		1 point
$v_{2f} = \frac{(2.03\ \text{N•s})}{(1.05\ \text{kg})}$		
$v_{2f} = 1.93\ \text{m/s}$		

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Question 2 (continued)

Distribution of points

(c)

i. (continued)

Alternate solution		*Alternate Points*
For using the conservation of momentum to calculate the speed of cart 2 after the collision		*1 point*
$m_1 v_{1i} = m_1 v_{1f} + m_2 v_{2f} \therefore v_{2f} = \dfrac{m_1 (v_{1i} - v_{1f})}{m_2}$		
For correct substitution of the answer from part (b)(i)		*1 point*
$v_{2f} = \dfrac{(0.500 \text{ kg})((3.00 \text{ m/s}) - (-1.06 \text{ m/s}))}{(1.05 \text{ kg})} = 1.93 \text{ m/s}$		

ii. 2 points

Show that the collision between the two carts is elastic.

For indicating that the initial and final kinetic energies must be equal		1 point
$K_{1i} = K_{1f} + K_{2f}$		
For correct substitutions of answers from parts (b)(i) and (c)(i) into the calculations of the initial and final kinetic energies		1 point
$\left(\frac{1}{2}\right)(0.500 \text{ kg})(3.00 \text{ m/s})^2 = \left(\frac{1}{2}\right)(0.500 \text{ kg})(-1.06 \text{ m/s})^2 + \left(\frac{1}{2}\right)(1.05 \text{ kg})(1.93 \text{ m/s})^2$		
$2.25 \text{ J} \approx 2.24 \text{ J}$		

(d)

i. 2 points

Calculate the speed of the center of mass of the two-cart-spring system.

For using the equation for the conservation of momentum to calculate the speed for the center of mass of the system		1 point
$m_1 v_{1i} = (m_1 + m_2) v_{cm} \therefore v_{cm} = \dfrac{m_1 v_{1i}}{(m_1 + m_2)}$		
For correct substitution into the equation above		1 point
$v_{cm} = \dfrac{(0.500 \text{ kg})(3.00 \text{ m/s})}{(0.500 \text{ kg} + 1.05 \text{ kg})} = 0.97 \text{ m/s}$		

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Question 2 (continued)

Distribution of points

(d) (continued)

ii. 3 points

Calculate the maximum elastic potential energy stored in the spring.

For using conservation of energy to calculate the maximum elastic potential energy stored in the spring		1 point
$K_i = K_f + U_{Sf}$		
For using the speed of the center of mass of the system for kinetic energy		1 point
$\frac{1}{2}m_1 v_{1i}^2 = \frac{1}{2}(m_1 + m_2)v_{cm}{}^2 + U_{Sf}$		
$U_{Sf} = \frac{1}{2}m_1 v_{1i}^2 - \frac{1}{2}(m_1 + m_2)v_{cm}{}^2$		
For correct substitution into above equation		1 point
$U_S = \left(\frac{1}{2}\right)(0.500\text{ kg})(3.00\text{ m/s})^2 - \frac{1}{2}(0.500\text{ kg} + 1.05\text{ kg})(0.97\text{ m/s})^2$		
$U_S = 1.52\text{ J}$		
Alternate Solution:		*Alternate Points*
For correctly determining the magnitude of the maximum force exerted between the carts		1 point
Set $\frac{dF}{dt} = 0 = 6400t - 500 \therefore 6400t = 500 \therefore t = 0.078\text{ s}$		
$F_{MAX} = 3200(0.078)^2 - 500(0.078) = -19.5$		
$\lvert F_{MAX}\rvert = 19.5\text{ N}$		
Note: Can estimate from the graph, and accept the range of 20 N to 21 N.		
For calculating the maximum compression of the spring		1 point
$F_{MAX} = -kx_{MAX}$		
$x_{MAX} = -\frac{F_{MAX}}{k} = -\frac{(-19.5\text{ N})}{(130\text{ N/m})} = 0.15\text{ m}$		
Note: If estimating from the graph, accept the range from 0.15 m to 0.16 m.		
For substituting into an equation for the elastic potential energy at maximum spring compression		1 point
$U_S = \frac{1}{2}kx_{MAX}^2 = \left(\frac{1}{2}\right)(130\text{ N/m})(0.15\text{ m})^2$		
$U_S = 1.46\text{ J}$		
Note: If estimating from the graph, accept range from 1.46 J to 1.70 J.		

Units point: 1 point for correct units on all calculated answers

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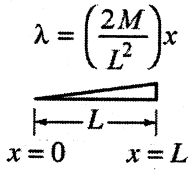
Question 3

15 points total

Distribution of points



A triangular rod, shown above, has length L, mass M, and a nonuniform linear mass density given by the equation $\lambda = \frac{2M}{L^2}x$, where x is the distance from one end of the rod.

(a) 3 points

Using integral calculus, show that the rotational inertia of the rod about its left end is $ML^2/2$.

For relating x to r properly in an integral to calculate the moment of inertia		1 point
$I = \int r^2 dm = \int x^2 dm$		
For correctly using the linear mass density to substitute into the equation above		1 point
$m = \int \lambda dx = \int (2M/L^2)x dx \therefore dm = (2M/L^2)x dx$		
$I = \int (2M/L^2)x^3 dx$		
For integrating using the correct limits or constant of integration		1 point
$I = \int_{x=0}^{x=L} (2M/L^2)x^3 dx = \left[\frac{(2M/L^2)x^4}{4}\right]_{x=0}^{x=L} = \frac{2M}{L^2}\left(\frac{L^4}{4} - 0\right) = ML^2/2$		

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Question 3 (continued)

Distribution of points

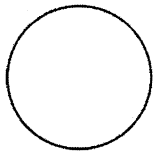

Figure 1



Figure 2

The thin hoop shown above in Figure 1 has a mass M, radius L, and a rotational inertia around its center of ML^2. Three rods identical to the rod from part (a) are now fastened to the thin hoop, as shown in Figure 2 above.

(b) 2 points

Derive an expression for the rotational inertia I_{tot} of the hoop-rods system about the center of the hoop. Express your answer in terms of M, L, and physical constants, as appropriate.

For setting the total rotational inertia for the hoop-rod system equal to the sum of the rotational inertias of the hoop and the three rods		1 point
$I = 3I_{rod} + I_{hoop}$		
$I = 3\left(ML^2/2\right) + ML^2$		
For a correct answer with work		1 point
$I = \frac{5}{2}ML^2$		

The hoop-rods system is initially at rest and held in place but is free to rotate around its center. A constant force F is exerted tangent to the hoop for a time Δt.

(c) 3 points

Derive an expression for the final angular speed ω of the hoop-rods system. Express your answer in terms of M, L, F, Δt, and physical constants, as appropriate.

For using an appropriate equation to determine the final angular speed of the hoop		1 point
$\tau\Delta t = I(\omega_2 - \omega_1)$		
$Fr\Delta t = I\omega$		
$\omega = \frac{Fr\Delta t}{I}$		
For relating the lever arm to the length of the rod		1 point
$\omega = \frac{FL\Delta t}{I}$		
For correct substitution from part (b)		1 point
$\omega = \frac{FL\Delta t}{\left(\frac{5}{2}\right)ML^2} = \frac{2F\Delta t}{5ML}$		

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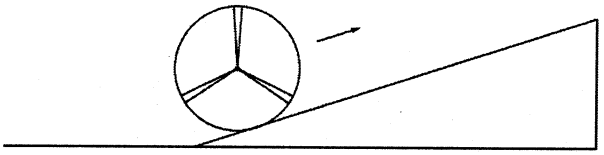
Question 3 (continued)

Distribution of points

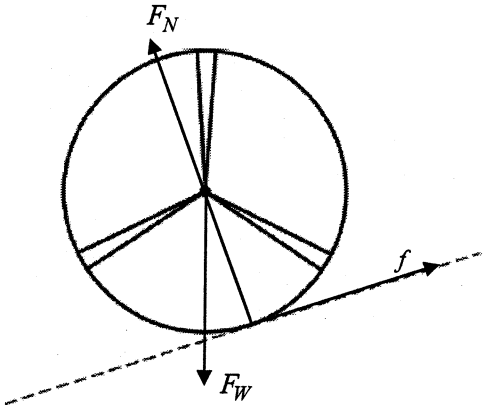


The hoop-rods system is rolling without slipping along a level horizontal surface with the angular speed ω found in part (c). At time $t = 0$, the system begins rolling without slipping up a ramp, as shown in the figure above.

(d)

i. 3 points

On the figure of the hoop-rods system below, draw and label the forces (not components) that act on the system. Each force must be represented by a distinct arrow starting at, and pointing away from, the point at which the force is exerted on the system.



For drawing the weight of the hoop-rod system in the correct direction		1 point
For drawing the normal force in the correct direction		1 point
For drawing the frictional force in the correct direction		1 point
Note: A maximum of two points can be earned if there are any extraneous vectors or any vector has an incorrect point of exertion.		

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Question 3 (continued)

Distribution of points

ii. 1 point

Justify your choice for the direction of each of the forces drawn in part (d)(i).

For a correct justification of the direction of the forces in part (d)(i)		1 point
Example: The normal force is always perpendicular to the surface, so it will be directed up and to the left. The gravitational force is always vertically downward. The friction will be opposite of the direction of rotation; therefore, it is directed up the incline.		

(e) 3 points

Derive an expression for the change in height of the center of the hoop from the moment it reaches the bottom of the ramp until the moment it reaches its maximum height. Express your answer in terms of M, L, I_{tot}, ω, and physical constants, as appropriate.

For including both linear and rotational kinetic energy in an equation for the conservation of energy to determine the final height of the hoop		1 point
$K_1 = U_{g2}$		
$\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = mgH$		
$H = \frac{\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2}{mg}$		
For correct substitution of $v = L\omega$		1 point
$H = \frac{\frac{1}{2}m(L\omega)^2 + \frac{1}{2}I_{tot}\omega^2}{mg}$		
$H = \frac{\frac{1}{2}\left(m_{tot}L^2 + I_{tot}\right)\omega^2}{m_{tot}g}$		
For correct substitution of inertias into energy equation		1 point
$H = \frac{\frac{1}{2}\left((3M + M)L^2 + I_{tot}\right)\omega^2}{(3M + M)g} = \frac{\left(4ML^2 + I_{tot}\right)\omega^2}{8Mg}$		

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2017

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AP Physics C: Mechanics

Free-Response Questions

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ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 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,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ $\text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

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

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

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

$P = \frac{dE}{dt}$

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

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

$I = \int r^2 dm = \sum m r^2$

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

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
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
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

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

$x = x_{\max} \cos(\omega t + \phi)$

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

$I = \frac{dQ}{dt}$

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

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

$\vec{E} = \rho \vec{J}$

$I = N e v_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

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

$\mathcal{E} = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

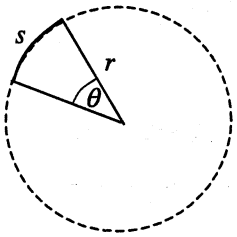
$a^2 + b^2 = c^2$

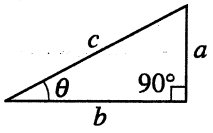
$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

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





CALCULUS!

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}(x^n) = nx^{n-1}$$

$$\frac{d}{dx}(e^{ax}) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n dx = \frac{1}{n+1}x^{n+1},\ n \neq -1!$$

$$\int e^{ax} dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)dx = -\frac{1}{a}\cos(ax)$$

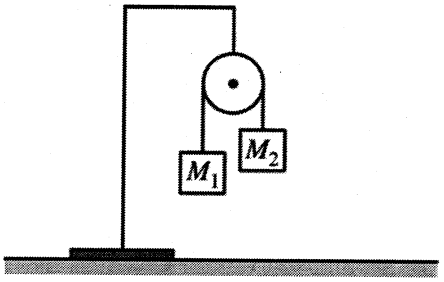
VECTOR PRODUCTS!

$$\vec{A}\cdot\vec{B} = AB\cos\theta$$

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

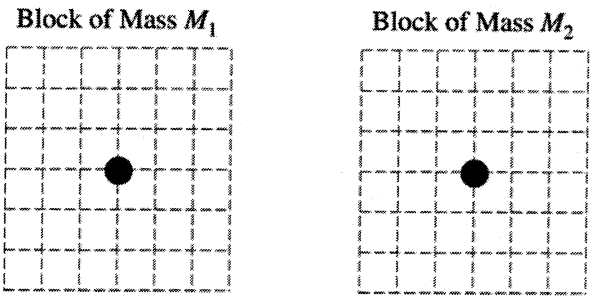
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. 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. An Atwood's machine consists of two blocks connected by a light string that passes over a frictionless pulley of negligible mass, as shown in the figure above. The masses of the two blocks, M_1 and M_2, can be varied. M_2 is always greater than M_1.

   (a) On the dots below, which represent the blocks, draw and label the forces (not components) that act on the blocks. Each force must be represented by a distinct arrow starting on and pointing away from the appropriate dot. The relative lengths of the arrows should show the relative magnitudes of the forces.



   (b) Using the forces in your diagrams above, write an equation applying Newton's second law to <u>each</u> block and use these two equations to derive the magnitude of the acceleration of the blocks and show that it is given by the equation: $a = \frac{(M_2 - M_1)}{(M_1 + M_2)} g$

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The magnitude of the acceleration a was measured for different values of M_1 and M_2, and the data are shown below.

M_1 (kg)	1.0	2.0	5.0	6.0	10.0
M_2 (kg)	2.0	3.0	12.0	8.0	14.0
a (m/s^2)	3.02	1.82	4.21	1.15	1.71

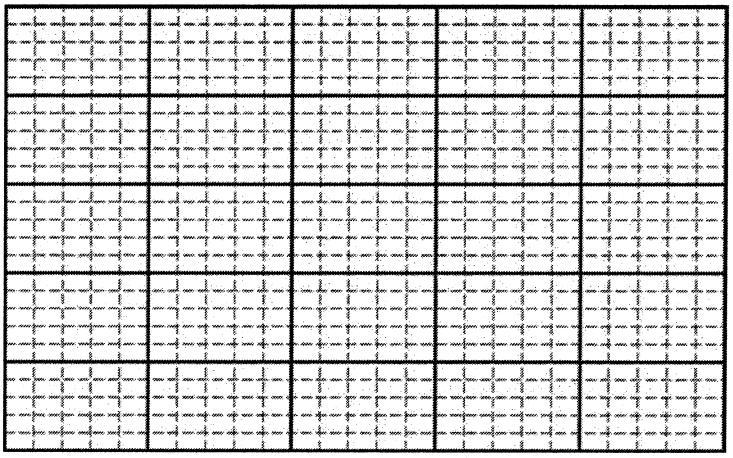
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Vertical axis: _____

Horizontal axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the data points for the quantities indicated in part (c) on the graph below. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best represents the data.



(e) Using your straight line, determine an experimental value for g.

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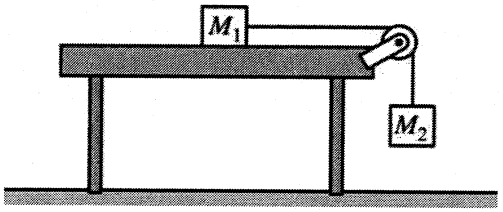

The experiment is now repeated with a modification. The Atwood's machine is now set up so that the block of mass M_1 is on a smooth, horizontal table and the block of mass M_2 is hanging over the side of the table, as shown in the figure above.

(f) For the same values of M_1 and M_2, is the magnitude of the tension in the string when the blocks are moving higher, lower, or equal to the magnitude of the tension in the string when the blocks are moving in the first experiment?

____ Higher ____ Lower ____ Equal to

Justify your answer.

(g) The value determined for the acceleration due to gravity g is lower than in the first experiment. Give one physical factor that could account for this lower value and explain how this factor affected the experiment.

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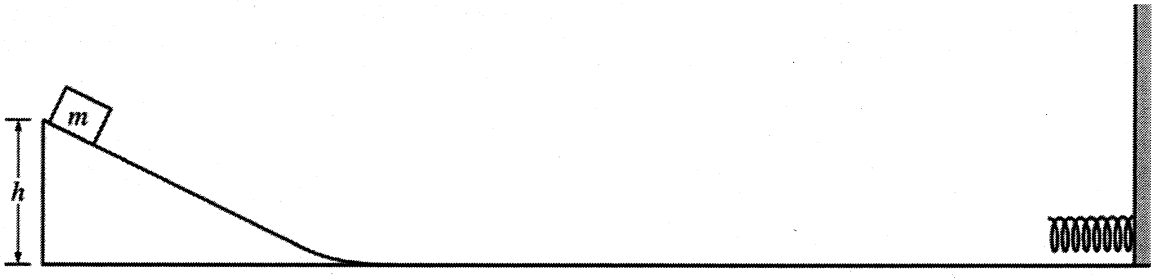

Note: Figure not drawn to scale.

2. A block of mass m starts at rest at the top of an inclined plane of height h, as shown in the figure above. The block travels down the inclined plane and makes a smooth transition onto a horizontal surface. While traveling on the horizontal surface, the block collides with and attaches to an ideal spring of spring constant k. There is negligible friction between the block and both the inclined plane and the horizontal surface, and the spring has negligible mass. Express all algebraic answers for parts (a), (b), and (c) in terms of m, h, k, and physical constants, as appropriate.

(a)

i. Derive an expression for the speed of the block just before it collides with the spring.

ii. Is the speed halfway down the incline greater than, less than, or equal to one-half the speed at the bottom of the inclined plane?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

(b) Derive an expression for the maximum compression of the spring.

(c) Determine an expression for the time from when the block collides with the spring to when the spring reaches its maximum compression.

The block is again released from rest at the top of the incline, and when it reaches the horizontal surface it is moving with speed v_0. Now suppose the block experiences a resistive force as it slides on the horizontal surface. The magnitude of the resistive force F is given as a function of speed v by $F = \beta v^2$, where β is a positive constant with units of $\mathrm{kg/m}$.

(d)

i. Write, but do NOT solve, a differential equation for the speed of the block on the horizontal surface as a function of time t before it reaches the spring. Express your answer in terms of m, h, k, β, v, and physical constants, as appropriate.

ii. Using the differential equation from part (d)i, show that the speed of the block $v(t)$ as a function of time t can be written in the form $\frac{1}{v(t)} = \frac{1}{v_0} + \frac{\beta t}{m}$, where v_0 is the speed at $t = 0$.

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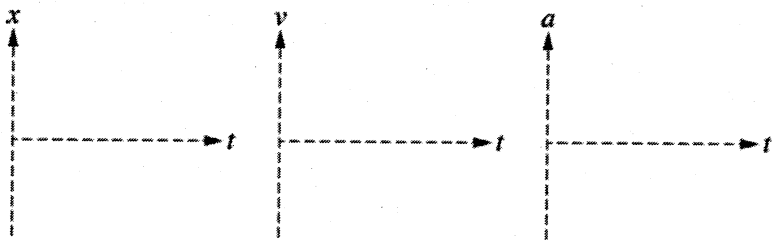
(e) Sketch graphs of position x as a function of time t, velocity v as a function of time t, and acceleration a as a function of time t for the block as it is moving on the horizontal surface before it reaches the spring.



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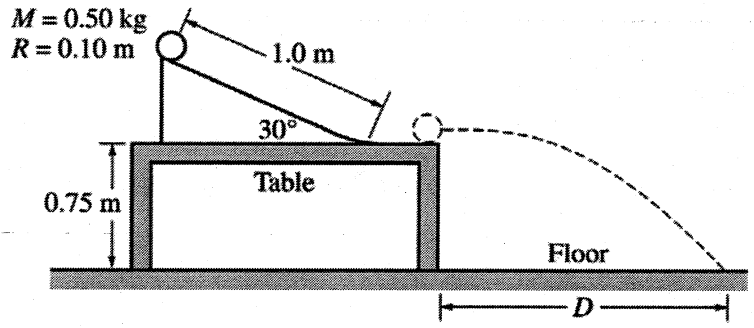

3. A uniform solid cylinder of mass $M = 0.50$ kg and radius $R = 0.10$ m is released from rest, rolls without slipping down a 1.0 m long inclined plane, and is launched horizontally from a horizontal table of height 0.75 m. The inclined plane makes an angle of 30° with the horizontal. The cylinder lands on the floor a distance D away from the edge of the table, as shown in the figure above. There is a smooth transition from the inclined plane to the horizontal table, and the motion occurs with no frictional energy losses. The rotational inertia of a cylinder around its center is $MR^2/2$.

(a) Calculate the total kinetic energy of the cylinder as it reaches the horizontal table.

(b) Calculate the angular velocity of the cylinder around its axis at the moment it reaches the floor.

(c) Calculate the ratio of the rotational kinetic energy to the total kinetic energy for the cylinder at the moment it reaches the floor.

(d) Calculate the horizontal distance D.

A sphere of the same mass and radius is now rolled down the same inclined plane. The rotational inertia of a sphere around its center is $\frac{2}{5}MR^2$.

(e)

i. Is the total kinetic energy of the sphere at the moment it reaches the floor greater than, less than, or equal to the total kinetic energy of the cylinder at the moment it reaches the floor?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

ii. Is the rotational kinetic energy of the sphere at the moment it reaches the floor greater than, less than, or equal to the rotational kinetic energy of the cylinder at the moment it reaches the floor?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

iii. Is the horizontal distance the sphere travels from the table to where it hits the floor greater than, less than, or equal to the horizontal distance the cylinder travels from the table to where it hits the floor?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

STOP

END OF EXAM

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AP® Physics C: Mechanics 2016 Free-Response Questions

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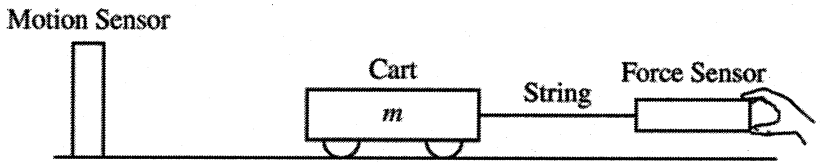
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech.1.

A cart of mass m is pulled along a level dynamics track as shown above. A force sensor is attached to the cart with a string and used to measure the horizontal force exerted on the cart to the right. A motion sensor is used to measure the acceleration of the cart with the positive direction toward the right. Friction is not negligible.

(a) On the dot below, which represents the cart, draw and label the forces (not components) that act on the cart. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



A student pulls the force sensor with a constant force, and the cart accelerates. This is repeated for several trials, with a different constant force used for each trial. The data are recorded in the table below.

Trial	1	2	3	4	5
Force sensor reading (N)	0.32	0.38	0.44	0.50	0.60
Acceleration $\left(\mathrm{m/s^2}\right)$	0.12	0.22	0.33	0.50	0.70

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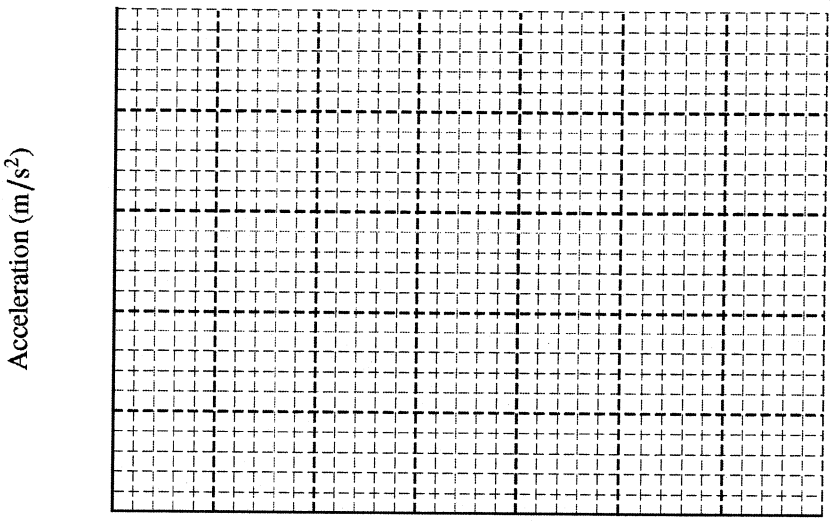
(b)

i. On the grid below, plot data points for the acceleration of the cart as a function of the force sensor reading. Clearly scale all axes. Draw a straight line that best represents the data.



ii. Using the straight line from the graph, calculate the mass of the cart.

iii. Using the straight line from the graph, determine the magnitude of the force of friction.

The above experiment is repeated by using a constant force sensor reading of 0.45 N. The cart starts from rest at time $t = 0$ s and is pulled for a time of 2.0 s along the dynamics track.

(c)

i. Determine the acceleration of the cart.

ii. The string breaks at time $t = 2.0$ s. Calculate the time it takes for the cart to stop after the string breaks.

The experiment and analysis in parts (a) and (b) are repeated with a cart that has the same mass but a greater force of friction.

(d)

i. Will the slope of your new line be greater than, less than, or equal to the slope of your line in part (b)i?

____ Greater than ____ Less than ____ Equal to

ii. Will the horizontal intercept of your new line be greater than, less than, or equal to the horizontal intercept of your line in part (b)i?

____ Greater than ____ Less than ____ Equal to

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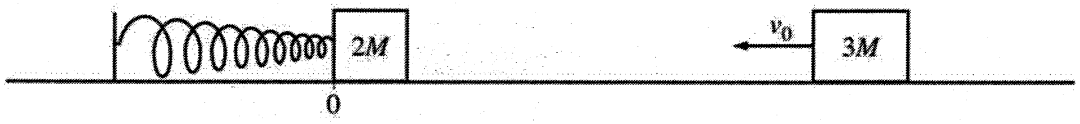
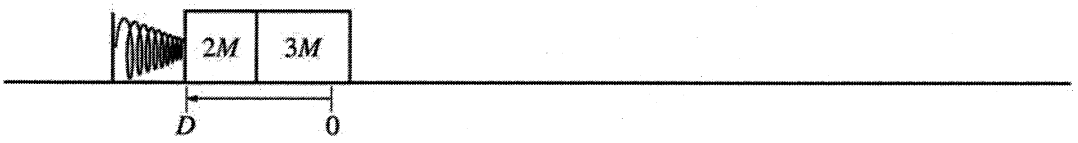


Mech.2.

A block of mass $2M$ rests on a horizontal, frictionless table and is attached to a relaxed spring, as shown in the figure above. The spring is nonlinear and exerts a force $F(x) = -Bx^3$, where B is a positive constant and x is the displacement from equilibrium for the spring. A block of mass $3M$ and initial speed v_0 is moving to the left as shown.

(a) On the dots below, which represent the blocks of mass $2M$ and $3M$, draw and label the forces (not components) that act on each block before they collide. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.

Block of Mass $2M$ Block of Mass $3M$



The two blocks collide and stick to each other. The two-block system then compresses the spring a maximum distance D, as shown above. Express your answers to parts (b), (c), and (d) in terms of M, B, v_0, and physical constants, as appropriate.

(b) Derive an expression for the speed of the blocks immediately after the collision.

(c) Determine an expression for the kinetic energy of the two-block system immediately after the collision.

(d) Derive an expression for the maximum distance D that the spring is compressed.

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(e)

i. In which direction is the net force, if any, on the block of mass $2M$ when the spring is at maximum compression?

____ Left ____ Right ____ The net force on the block of mass $2M$ is zero.

Justify your answer.

ii. Which of the following correctly describes the magnitude of the net force on each of the two blocks when the spring is at maximum compression?

____ The magnitude of the net force is greater on the block of mass $2M$.

____ The magnitude of the net force is greater on the block of mass $3M$.

____ The magnitude of the net force on each block has the same nonzero value.

____ The magnitude of the net force on each block is zero.

Justify your answer.

(f) Do the two blocks, which remain stuck together and attached to the spring, exhibit simple harmonic motion after the collision?

____ Yes ____ No

Justify your answer.

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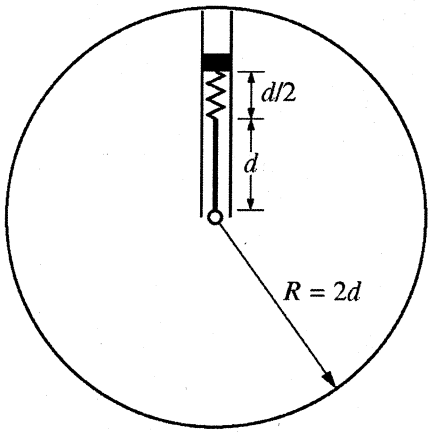

Figure 1

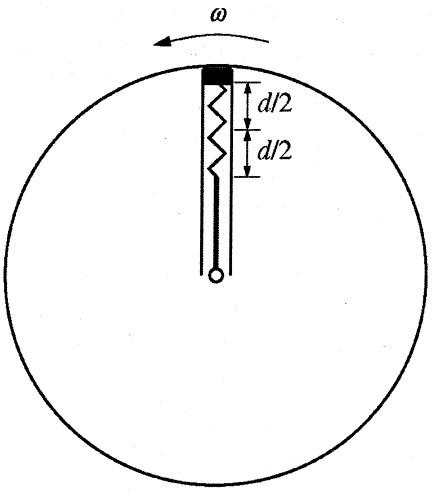

Figure 2

Mech.3.

A uniform rod of length d has one end fixed to the central axis of a horizontal, frictionless circular platform of radius $R = 2d$. Fixed at the other end of the rod is an ideal spring of negligible mass to which a block is attached. The block is set in frictionless grooves so that it can only move along a radius of the platform, as shown in Figure 1 above. The equilibrium length of the spring is $d/2$. Below is a table showing the mass of the block and the masses and rotational inertias of the rod and platform.

	Mass	Rotational Inertia
Block	m	
Rod	$m_R = 3m$	$\frac{m_R d^2}{3}$ (about the end of the rod)
Platform	$m_P = 5m$	$\frac{m_P R^2}{2}$ (about the central axis)

A motor begins to slowly rotate the platform counterclockwise as viewed from above until the platform reaches a constant angular speed ω. Under these conditions, the spring has stretched by an additional length $d/2$, as shown in Figure 2.

Answer the following questions for the platform rotating at constant angular speed ω. Express all algebraic answers in terms of m, d, ω, and physical constants, as appropriate.

(a) Derive an expression for the spring constant of the spring.

(b)

i. Determine an expression for the rotational inertia of the block around the axis of the platform.

ii. Derive an expression for the rotational inertia of the entire system about the axis of the platform.

(c) Determine an expression for the angular momentum of the entire system about the axis of the platform.

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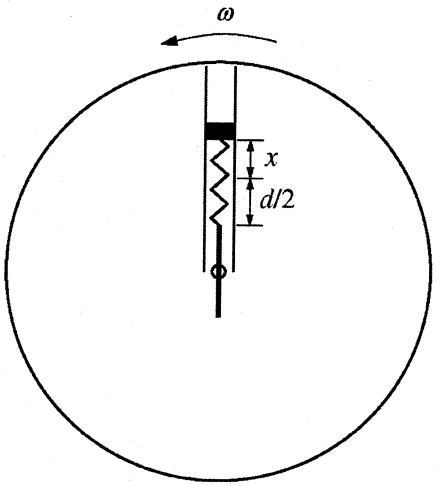

Figure 3

While the system continues to rotate, a small mechanism in the pivot moves the rod slowly until the center of the rod is positioned on the axis, as shown in Figure 3 above. The same constant angular speed ω is maintained by the motor driving the platform.

(d) Derive an expression for the distance x that the spring is stretched when the rod reaches the position shown in Figure 3 above.

For parts (e), (f), and (g), assume the center of the rod is still moving toward the axis of the platform.

(e) Is the angular momentum of the entire system increasing, decreasing, or staying the same?

_____ Increasing _____ Decreasing _____ Staying the same

Justify your answer.

(f) In order to keep the system rotating with constant angular speed ω, is the motor doing positive work, negative work, or no work on the rotating system?

_____ Positive _____ Negative _____ No work

Justify your answer.

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(g) On the block in Figure 4 below, draw a single vector representing the direction of the acceleration of the block. Draw the vector so that it is starting on, and pointing away from, the block.

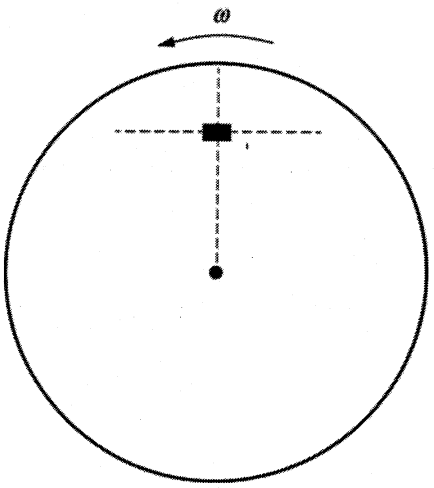

Figure 4

STOP

END OF EXAM

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AP® Physics C: Mechanics 2016 Scoring Guidelines

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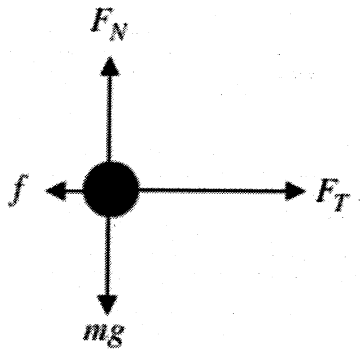
AP® PHYSICS C: MECHANICS
2016 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

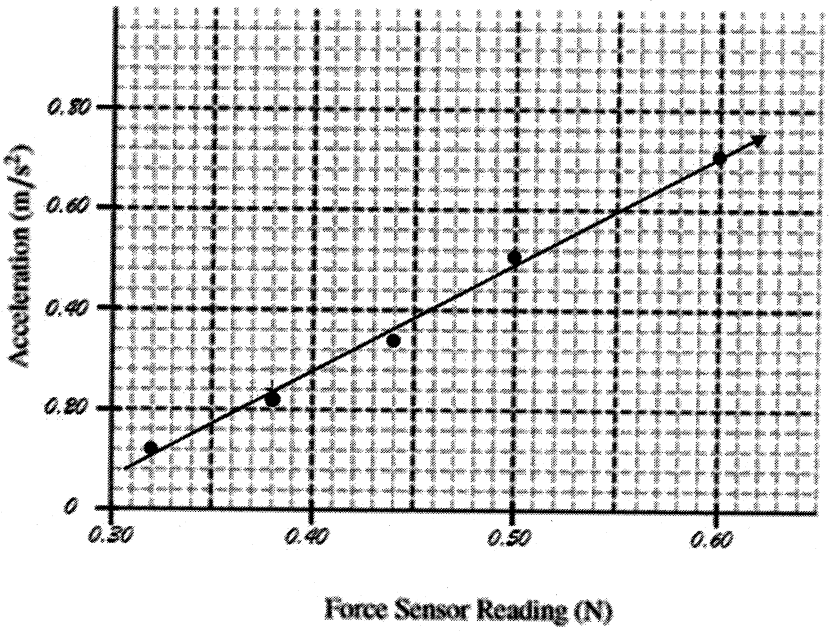
(a) 3 points



For correctly drawing and labeling the force of tension — 1 point
For correctly drawing and labeling the force of friction — 1 point
For correctly drawing and labeling both forces in the vertical direction — 1 point
Note: A maximum of two points may be earned if there are any extraneous vectors.

(b)

i. 3 points



For a correct scale that uses more than half the grid — 1 point
For correctly plotting the given data — 1 point
For drawing a straight line consistent with the given data — 1 point
Note: Full credit can be earned if the axes are switched.

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Question 1 (continued)

Distribution of points

(b)

ii. 2 points

For correctly calculating slope using the best-fit straight line and not data points — 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(0.70 - 0.16)}{(0.60 - 0.35)}\text{kg}^{-1} = 2.16\ \text{kg}^{-1}$$

Note: Linear regression gives slope $= 2.12\ \text{kg}^{-1}$.

For correctly calculating the mass of the cart using the slope — 1 point

$$m = \frac{1}{\text{slope}} = \frac{1}{\left(2.16\ \text{kg}^{-1}\right)}$$

Correct answer:

$m = 0.463$ kg (Note: linear regression gives $m = 0.472$ kg)

iii. 1 point

For an answer with correct units consistent with the x-intercept of the graph from (b) i. — 1 point

$f = 0.272$ N

(c)

i. 1 point

Applying Newton's second law and substituting the values from part (b)

$$\sum F = ma = F_a - f$$

$$a = \frac{F_a - f}{m} = \frac{0.45\ \text{N} - 0.272\ \text{N}}{0.463\ \text{kg}}$$

For an answer with correct units consistent with part (b), either from the graph or calculated using the mass and frictional force. — 1 point

$a = 0.376\ \text{m/s}^2$

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Question 1 (continued)

Distribution of points

(c)

ii. 3 points

For using a correct equation to solve for the speed of the cart when the string breaks, with an acceleration consistent with part (c) i. — 1 point

$v_2 = v_1 + at$

$v_2 = 0 + \left(0.376 \text{ m/s}^2\right)(2.0 \text{ s})$

$v_2 = 0.752 \text{ m/s}$

For recognizing that the acceleration of the cart after the string breaks is due to the frictional force determined in part (b) — 1 point

Use a correct equation to solve for the time for the cart to stop after the string breaks

$v_2 = v_1 + at$

$0 = v_1 - \frac{f}{m}t$

For using the final velocity before the string breaks as the initial velocity for the cart stopping in the correct equation for time — 1 point

$t = \frac{mv_1}{f}$

$t = \frac{(0.463 \text{ kg})(0.752 \text{ m/s})}{(0.272 \text{ N})}$

Correct answer

$t = 1.28$ s

Alternate solution — *Alternate points*

For setting the magnitude of the impulse before the string breaks equal to the magnitude of the impulse after the string breaks — *1 point*

$F_1 t_1 = F_2 t_2$

For correctly using the proper force (e.g., the tension force minus the friction force) for F_1 — *1 point*

For correctly using the proper force (e.g., the friction force) for F_2 — *1 point*

Correct answer

$t = 1.28$ s

(d)

i. 1 point

For selecting "Equal to" — 1 point

ii. 1 point

For selecting "Greater than" — 1 point

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Question 2

15 points total

Distribution of points

(a) 2 points



For correctly drawing and labeling vectors on the block of mass $2M$ — 1 point

For correctly drawing and labeling vectors on the block of mass $3M$ using symbols for the vectors that are physically correct and different from those on the block of mass $2M$ — 1 point

Note: A maximum of one point can be earned if there are any extraneous vectors.

(b) 2 points

Using a proper expression for conservation of momentum

$p_1 = p_2$

For correctly substituting into the above equation — 1 point

$3Mv_0 = (3M + 2M)v_f$

For a correct answer — 1 point

$v_f = \frac{3}{5}v_0$

(c) 1 point

Using a proper expression for kinetic energy of the two-block system

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

$K = \frac{1}{2}(5M)\left(\frac{3}{5}v_0\right)^2$

For an answer consistent with part (b) — 1 point

$K = \frac{9}{10}Mv_0^2$

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Question 2 (continued)

Distribution of points

(d) 4 points

For a correct expression of the conservation of energy 1 point

$\Delta K_{\text{system}} + \Delta U_{\text{system}} = 0$

$K_0 = U_{\text{final}}$

For attempting to integrate the spring force equation 1 point

$\frac{9}{10}Mv_0^2 = -\int_{x_1}^{x_2} -Bx^3 dx$

$\frac{9}{10}Mv_0^2 = \int_{x_1}^{x_2} Bx^3 dx$

For using the correct limits of integration or an appropriate constant of integration 1 point

$\frac{9}{10}Mv_0^2 = \int_0^D Bx^3 dx$

$\frac{9}{10}Mv_0^2 = \left[\frac{Bx^4}{4}\right]_0^D$

For an answer consistent with the speed from (b) or the kinetic energy from part (c) 1 point

$D = \sqrt[4]{\frac{18Mv_0^2}{5B}}$

(e)

i. 2 points

For selecting the correct answer "Right" with a reasonable attempt at a justification 1 point

If the incorrect selection is made, no points are earned for the justification.

For an indication that at maximum compression the block of mass $2M$ has an acceleration to the right due to the forces acting on the block of mass $2M$ or an acceleration to the right due to the external spring force acting on the system of blocks 1 point

Example: At maximum compression the two-block system is instantaneously at rest. The only horizontal external force acting on the system is due to the spring. This force is directed to the right. The system and therefore the block of mass $2M$ is accelerated to the right, which implies that the net force acting on the block of mass $2M$ is also to the right.

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Question 2 (continued)

Distribution of points

(e)

ii. 2 points

The magnitude of the net force is greater on the block of mass $3M$.
If the incorrect selection is made, no points are earned for the justification.
For an indication that both blocks will have the same acceleration — 1 point
For a correct justification for why the net force is greater on the block of mass $3M$ — 1 point
Example:
Because the blocks stick together, both blocks must have the same acceleration. Because the block of mass $3M$ has more mass, the net force on it must be greater than the net force on the block of mass $2M$.

(f) 2 points

For selecting the correct answer "No," with a reasonable attempt at a justification — 1 point
If the incorrect selection is made, no points are earned for the justification.
If the correct answer is selected without any justification, the point is not earned for the selection.
For an indication that the spring does not apply a linear force and that simple harmonic motion is the resulting motion of a linear restoring force — 1 point

$\left(a = -\frac{k}{m}\Delta x\right)$

Example:
Because the blocks are sticking together and are attached to the spring, the spring will apply a restoring force to the blocks. However, because the restoring force exerted by a nonlinear spring is not proportional to the blocks' displacement from equilibrium, the blocks do not exhibit simple harmonic motion.

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Question 3

15 points total

Distribution of points

(a) 3 points

For an indication that the spring force equals the mass times the centripetal acceleration — 1 point

$F_S = F_C = ma_C$

$kx = mr\omega^2$

For a correct substitution for x in the equation — 1 point

For a correct substitution for r in the equation that can be used to solve for k — 1 point

$k\left(\frac{d}{2}\right) = m(2d)\omega^2$

Correct answer:

$k = 4m\omega^2$

(b)

i. 1 point

Substitute values for the block into the equation for rotational inertia

$I = \sum mr^2 = m(2d)^2$

For a correct answer or an answer consistent with the radius used in part (a) — 1 point

$I = 4md^2$

ii. 2 points

For an indication that the rotational inertia of the system must include the platform, the rod, and the object — 1 point

$I = I_P + I_R + I_O$

$I = \frac{m_P R^2}{2} + \frac{m_R d^2}{3} + mr^2$

For correctly substituting into the equation the rotational inertia of the platform, the rod, and the object consistent with (b) i. — 1 point

$I = \frac{5m(2d)^2}{2} + \frac{3m\,d^2}{3} + 4md^2$

$I = (10 + 1 + 4)md^2$

Correct answer:

$I = 15md^2$

(c) 1 point

Using a correct expression of angular momentum

$L = I\omega$

For an answer consistent with the answer from part (b) ii. — 1 point

$L = 15md^2\omega$

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Question 3 (continued)

Distribution of points

(d) 3 points

For indicating that the spring force equals the mass times the centripetal acceleration — 1 point

$F_S = F_C = ma_C$

$kx = mr\omega^2$

For a correct substitution for k, or a substitution consistent with part (a), in the equation — 1 point

For a correct substitution for r in the equation that can be used to solve for x — 1 point

$\left(4m\omega^2\right)x = m(d + x)\omega^2$

$4x = d + x$

$3x = d$

Correct answer:

$x = d/3$

(e) 2 points

For selecting "Decreasing" — 1 point

If the wrong selection is made, no points are earned for the justification.

For a correct justification — 1 point

Example: The rotational inertia I of the system decreases while the angular velocity w stays the same. Because the angular momentum is Iw, it decreases.

(f) 2 points

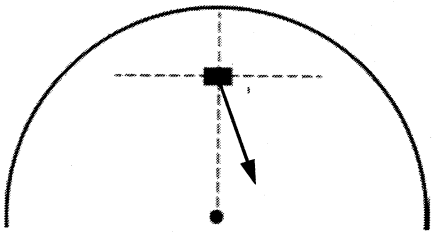
For selecting "Negative" — 1 point

If the wrong selection is made, no points are earned for the justification.

For a correct justification — 1 point

Example: Because the angular velocity is constant and the rotational inertia has decreased, the rotational kinetic energy has decreased. Therefore, work must be negative.

(g) 1 point



For an arrow starting on the box and pointing down and to the right — 1 point

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AP® Physics C: Mechanics
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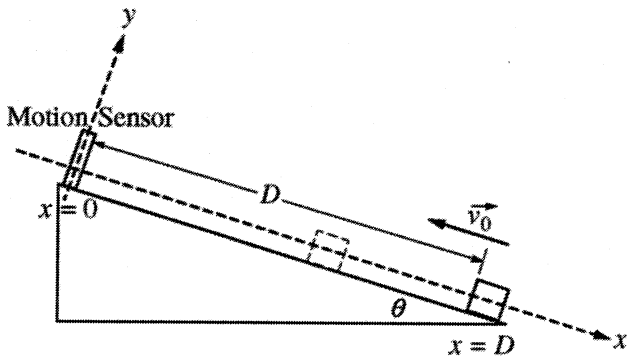
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech.1.

A block of mass m is projected up from the bottom of an inclined ramp with an initial velocity of magnitude v_0. The ramp has negligible friction and makes an angle θ with the horizontal. A motion sensor aimed down the ramp is mounted at the top of the incline so that the positive direction is down the ramp. The block starts a distance D from the motion sensor, as shown above. The block slides partway up the ramp, stops before reaching the sensor, and then slides back down.

(a) Consider the motion of the block at some time t after it has been projected up the ramp. Express your answers in terms of m, D, v_0, t, θ and physical constants, as appropriate.

i. Determine the acceleration a of the block.

ii. Determine an expression for the velocity v of the block.

iii. Determine an expression for the position x of the block.

(b) Derive an expression for the position x_{min} of the block when it is closest to the motion sensor. Express your answer in terms of m, D, v_0, θ, and physical constants, as appropriate.

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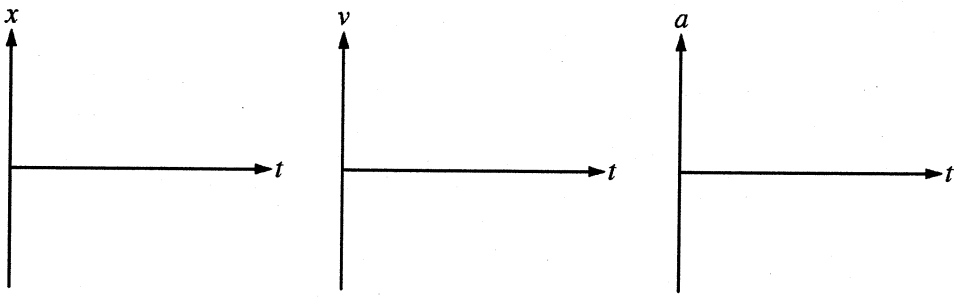
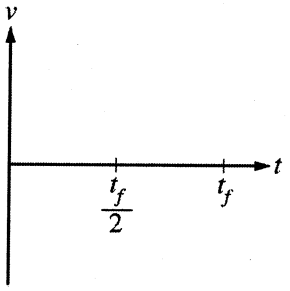
(c) On the axes provided below, sketch graphs of position x, velocity v, and acceleration a as functions of time t for the motion of the block while it goes up and back down the ramp. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



(d) After the block slides back down and leaves the bottom of the ramp, it slides on a horizontal surface with a coefficient of friction given by μ_k. Derive an expression for the distance the block slides before stopping. Express your answer in terms of m, D, v_0, θ, μ_k, and physical constants, as appropriate.

(e) Suppose the ramp now has friction. The same block is projected up with the same initial speed v_0 and comes back down the ramp. On the axes provided below, sketch a graph of the velocity v as a function of time t for the motion of the block while it goes up and back down the ramp, arriving at the bottom of the ramp at time t_f. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



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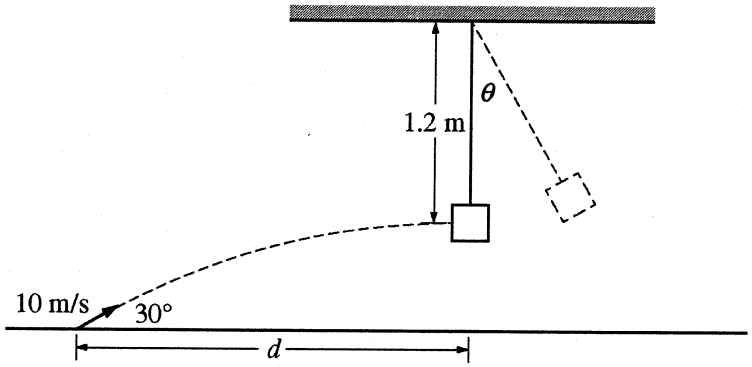

Mech.2.

A small dart of mass 0.020 kg is launched at an angle of 30° above the horizontal with an initial speed of 10 m/s. At the moment it reaches the highest point in its path and is moving horizontally, it collides with and sticks to a wooden block of mass 0.10 kg that is suspended at the end of a massless string. The center of mass of the block is 1.2 m below the pivot point of the string. The block and dart then swing up until the string makes an angle θ with the vertical, as shown above. Air resistance is negligible.

(a) Determine the speed of the dart just before it strikes the block.

(b) Calculate the horizontal distance d between the launching point of the dart and a point on the floor directly below the block.

(c) Calculate the speed of the block just after the dart strikes.

(d) Calculate the angle θ through which the dart and block on the string will rise before coming momentarily to rest.

(e) The block then continues to swing as a simple pendulum. Calculate the time between when the dart collides with the block and when the block first returns to its original position.

(f) In a second experiment, a dart with more mass is launched at the same speed and angle. The dart collides with and sticks to the same wooden block.

i. Would the angle θ that the dart and block swing to increase, decrease, or stay the same?

_____ Increase _____ Decrease _____ Stay the same

Justify your answer.

ii. Would the period of oscillation after the collision increase, decrease, or stay the same?

_____ Increase _____ Decrease _____ Stay the same

Justify your answer.

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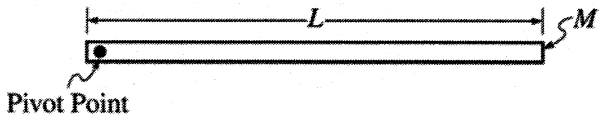
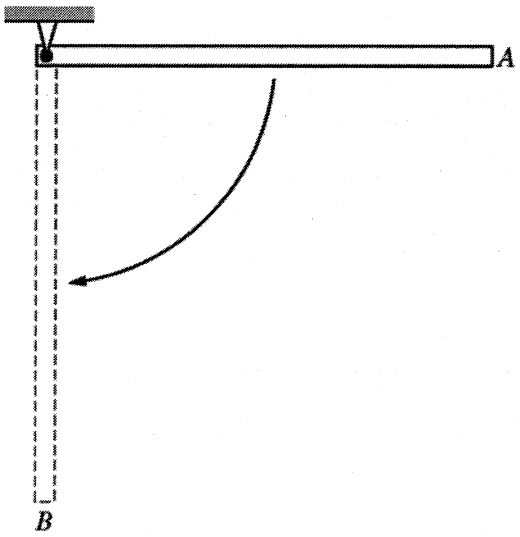


Mech.3.

A uniform, thin rod of length L and mass M is allowed to pivot about its end, as shown in the figure above.

(a) Using integral calculus, derive the rotational inertia for the rod around its end to show that it is $ML^2/3$.



The rod is fixed at one end and allowed to fall from the horizontal position A through the vertical position B.

(b) Derive an expression for the velocity of the free end of the rod at position B. Express your answer in terms of M, L, and physical constants, as appropriate.

An experiment is designed to test the validity of the expression found in part (b). A student uses rods of various lengths that all have a uniform mass distribution. The student releases each of the rods from the horizontal position A and uses photogates to measure the velocity of the free end at position B. The data are recorded below.

Length (m)	0.25	0.50	0.75	1.00	1.25	1.50
Velocity (m/s)	2.7	3.8	4.6	5.2	5.8	6.3

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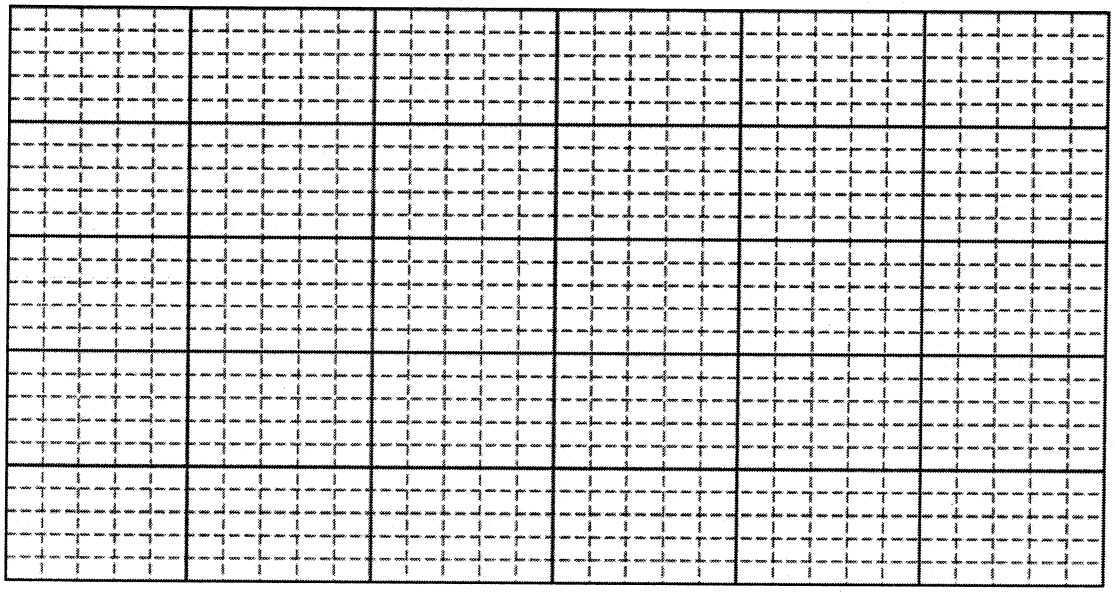
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity g.

Horizontal axis: _____

Vertical axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given. Label each row you use and include units.

(d) Plot the straight line data points on the grid below. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



(e)

i. Using your straight line, determine an experimental value for g.

ii. Describe two ways in which the effects of air resistance could be reduced.

STOP

END OF EXAM

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Question 1

15 points total

Distribution of points

(a)

i. 1 points

Using Newton's second law with down the incline as the positive direction

$F_{net} = ma$

$mg\sin\theta = ma$

For a correct expression of a positive acceleration — 1 point

$a = g\sin\theta$

ii. 2 points

Using a correct kinematics equation to solve for velocity

$v_2 = v_1 + at$

For substitution into a correct kinematics equation consistent with the acceleration from part (a)i — 1 point

For having a negative sign on v_0 — 1 point

$v = -v_0 + (g\sin\theta)t$

iii. 1 points

Using a correct kinematics equation to solve for position

$x = x_0 + v_1 t + \frac{1}{2}at^2$

For substitution into a correct kinematics equation consistent with expressions from parts (a)i and (a)ii — 1 point

$x = D - v_0 t + \frac{1}{2}(g\sin\theta)t^2$

(b) 2 points

Using an equation that can be solved for the closest position to the sensor

$v_2^2 = v_1^2 + 2ad$

For substitution into a correct kinematic equation consistent with part (a) — 1 point

For setting v_2 to zero and using D for the initial position — 1 point

$0 = v_0^2 + 2(g\sin\theta)(x - D)$

$x = D - \frac{v_0^2}{2g\sin\theta}$

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Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution: *Alternate points*

Using a conservation of energy approach to find the highest point the cart moves along the incline

$K_1 + U_{g1} = K_2 + U_{g2}$

$K_1 = U_{g2}$

$\frac{1}{2}mv_0^2 = mgh_2$

For using the correct energy statement with the correct initial velocity *1 point*

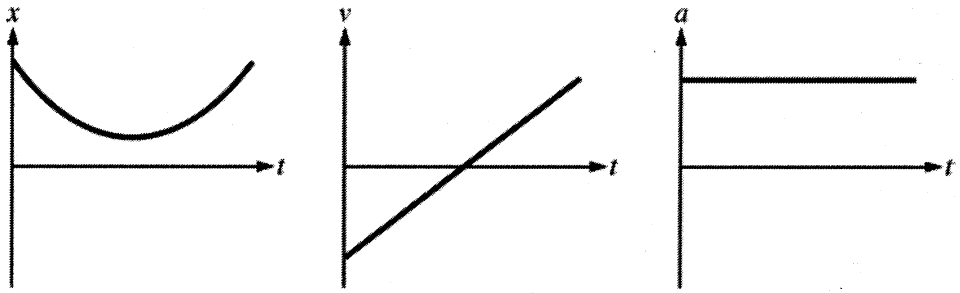
For a correct statement of the height of the cart along the incline *1 point*

$h = (D - x)\sin\theta$

$\frac{1}{2}v_0^2 = g(D - x)(\sin\theta)$

$x = D - \frac{v_0^2}{2g\sin\theta}$

(c) 4 points



For a position graph that is a parabola that does not cross the t-axis and has a vertex that does not touch the t-axis — 1 point

For a velocity graph that is a straight line and crosses the t-axis — 1 point

For an acceleration graph that is a horizontal line — 1 point

For a set of graphs that are consistent with each other — 1 point

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Question 1 (continued)

Distribution of points

(d) 2 points

Using an equation that can be solved for the distance

$v_2^2 = v_1^2 + 2ad$

For a correct expression of the frictional force — 1 point

$f = -\mu_k mg = ma$

$a = -\mu_k g$

$0 = v_0^2 - 2\mu_k gd$

For a correct answer — 1 point

$d = \dfrac{v_0^2}{2\mu_k g}$

Alternate solution: — *Alternate points*

Using an equation that can be solved for the distance

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

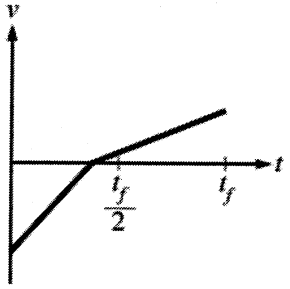
For a correct expression of the frictional force — *1 point*

$-\mu_k mgd = \frac{1}{2}m\left(0 - v_0^2\right)$

For a correct answer — *1 point*

$d = \dfrac{v_0^2}{2\mu_k g}$

(e) 3 points



The graph has two straight line portions.

For having a change in slope at $v = 0$ — 1 point

For having slope values of each segment that have the same sign and the correct relative magnitudes (segment I slope magnitude greater than segment II slope magnitude, as shown in the graph above) — 1 point

For having a graph that crosses the t-axis earlier than $t_f/2$ and extends to t_f — 1 point

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Question 2

15 points total

Distribution of points

(a) 1 point

Writing an equation to solve for the speed when the dart is at its maximum height

$v = v_x = v_0(\cos\theta)$

$v = (10\ \text{m/s})(\cos 30°)$

For a correct answer — 1 point

$v = 8.7\ \text{m/s}$

(b) 2 points

Writing an equation to solve for time using motion in the vertical direction

$v_y = v_{y0} + a_y t$

$0 = (10\ \text{m/s})(\sin 30) + \left(-9.8\ \text{m/s}^2\right)t$

For a correct value for the time — 1 point

$t = 0.51\ \text{s}$ (or $t = 0.50\ \text{s}$ if using $g = 10\ \text{m/s}^2$)

For substituting into an equation for the horizontal motion consistent with the speed from part (a), or for determining the correct answer — 1 point

$x = v_x t$

$x = (8.7\ \text{m/s})(0.51\ \text{s})$

$x = 4.4\ \text{m}$

(c) 3 points

For a correct expression of conservation of momentum — 1 point

$p_i = p_f$

For a correct expression that represents a totally inelastic collision between the dart and the block — 1 point

$m_1 v_{1i} = (m_1 + m_2)v_f$

$(0.020\ \text{kg})(8.66\ \text{m/s}) = (0.020\ \text{kg} + 0.10\ \text{kg})v_f$

For an answer consistent with the speed from part (a) and correct mass substitutions — 1 point

$v = 1.4\ \text{m/s}$

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Question 2 (continued)

Distribution of points

(d) 3 points

For a correct expression of conservation of energy — 1 point

$K_1 + U_{g1} = K_2 + U_{g2}$

$\frac{1}{2}mv_1^2 = mgh_2$

For a correct expression for the height reached by the block — 1 point

$h = L - L(\cos\theta)$

For substituting the speed value from part (c) into a correct conservation of energy equation — 1 point

$\frac{1}{2}mv_1^2 = mgL(1 - \cos\theta)$

$\cos\theta = 1 - \frac{v_1^2}{2gL}$

$\cos\theta = 1 - \frac{(1.44\ \text{m/s})^2}{2(9.8\ \text{m/s}^2)(1.2\ \text{m})}$

$\theta = 24°$

(e) 2 points

For substituting the correct length into the correct equation for the period — 1 point

$T = 2\pi\sqrt{\frac{\ell}{g}} = 2\pi\sqrt{\frac{(1.2\ \text{m})}{(9.8\ \text{m/s}^2)}} = 2.2\ \text{s}$

For correctly dividing the period in half to solve for the time — 1 point

$t = T/2 = (2.2\ \text{s})/2$

$t = 1.1\ \text{s}$

(f)

i. 2 points

For selecting "Increase" — 1 point

For a correct justification of the larger angle for the block-dart system — 1 point

Example: A more massive dart would cause the speed after the collision with the block to increase. A greater speed after the collision would cause the block to reach a greater height and thus the angle θ would increase.

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Question 2 (continued)

Distribution of points

(f) (continued)

ii. 2 points

For selecting "Stay the same" 1 point
For a correct justification 1 point
Example: A more massive dart would not affect the period of the pendulum. Only changing the length of the string would change the period.
Note: If the student correctly points out the changes to the simple pendulum could be outside the small angle approximation, then the student's entire answer will be considered (both check box and justification are consistent and physically correct).

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AP® PHYSICS C: MECHANICS
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Question 3

15 points total

Distribution of points

(a) 3 points

Writing an integral to derive the rotational inertia of the rod

$I = \int r^2 dm$

For a correct expression for dm — 1 point

$\lambda = M/L$, $M = \lambda L$, $dm = \lambda dr$

For using the correct limits of integration or a correct constant of integration — 1 point

$I = \int_{r=0}^{r=L} \lambda r^2 dr$

For correctly evaluating the integral above, leading to the answer $ML^2/3$ — 1 point

$I = \left[\frac{\lambda r^3}{3}\right]_{r=0}^{r=L} = \frac{1}{3}\lambda\left(L^3 - 0\right) = \frac{1}{3}\left(\frac{M}{L}\right)\left(L^3\right) = \frac{1}{3}ML^2$

(b) 4 points

For using any expression of conservation of energy — 1 point

$K_1 + U_{g1} = K_2 + U_{g2}$

For a correct energy expression relating gravitational potential energy to rotational kinetic energy — 1 point

$mgh_1 = \frac{1}{2}I\omega_2^2$

For correctly substituting $L/2$ for the change in height — 1 point

$Mg(L/2) = \frac{1}{2}\left(\frac{1}{3}ML^2\right)\omega^2$

For using $v = r\omega$ with $r = L$ to solve for the velocity of the end of the rod — 1 point

$\frac{MgL}{2} = \frac{1}{6}ML^2\left(\frac{v}{L}\right)^2$

$v = \sqrt{3gL}$

(c) 1 point

For correctly identifying a relationship between length and velocity that will result in a straight line — 1 point

Example 1: Horizontal axis: velocity
Vertical axis: $\sqrt{\text{length}}$

Example 2: Horizontal axis: $(\text{velocity})^2$
Vertical axis: length

Note: Each of the above axis choices can also be switched to yield a straight line.

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AP® PHYSICS C: MECHANICS
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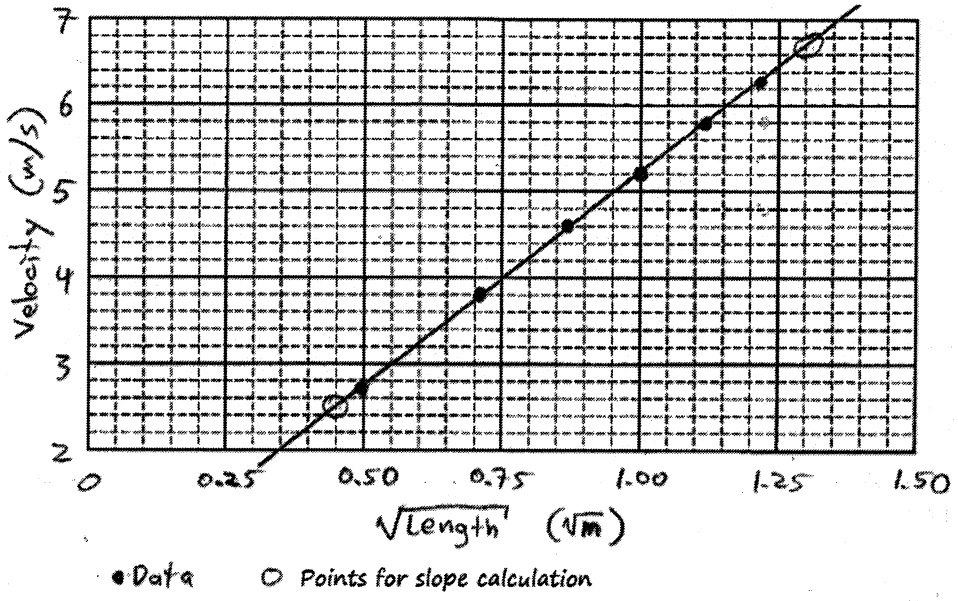
Question 3 (continued)

Distribution of points

(d) 3 points



For a correct scale that uses at least half the grid and for correctly labeling the axes, including units — 1 point

For plotting data consistent with quantities in the data table in part (c) — 1 point

For drawing a straight line consistent with the data in part (c) — 1 point

(e)

i. 2 points

For correctly calculating the slope using the straight line drawn in part (d), and not using data points unless the points lie on the line — 1 point

$$m = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(6.70 - 2.50)}{(1.30 - 0.45)} = 4.94 \ \sqrt{\text{m}}/\text{s}$$

For correctly calculating g using the slope — 1 point

$$m = \sqrt{3g}$$

$$g = m^2/3 = \left(4.94 \ \sqrt{\text{m}}/\text{s}\right)^2/3 = 8.1 \ \text{m}/\text{s}^2$$

Alternate Solution — *Alternate points*

For stating that linear regression was used and getting one of the results noted below — *1 point*

For correctly calculating g using the slope — *1 point*

When plotting velocity as a function of $\sqrt{\text{length}}$ *, the slope is* $4.94 \ \sqrt{\text{m}}/\text{s}$ *and* $g = 8.14 \ \text{m}/\text{s}^2$ *.*

When plotting the square of velocity as a function of length, the slope is $25.77 \ \text{m}/\text{s}^2$ *and* $g = 8.59 \ \text{m}/\text{s}^2$ *.*

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AP® PHYSICS C: MECHANICS
2015 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(e) (continued)

ii. 2 points

For one example that directly decreases the effect of air resistance — 1 point
For another example that directly decreases the effect of air resistance — 1 point
Some examples include:
- Do the experiment in a vacuum
- Use shorter rod lengths
- Use more massive (or denser) rods
- Use a more aerodynamic shape for the rods

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AP® Physics C: Mechanics
2014 Free-Response Questions

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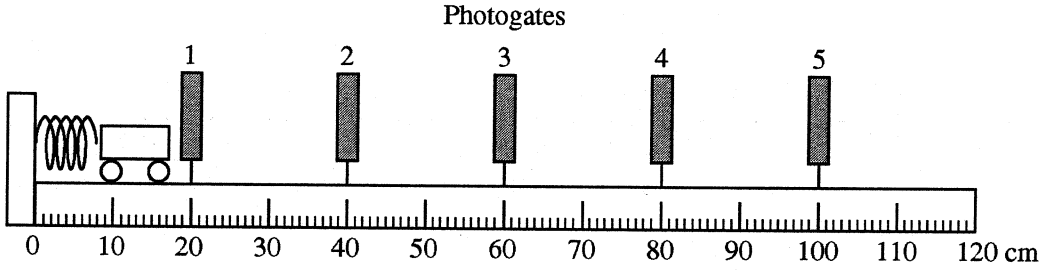
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech. 1.

In an experiment, a student wishes to use a spring to accelerate a cart along a horizontal, level track. The spring is attached to the left end of the track, as shown in the figure above, and produces a nonlinear restoring force of magnitude $F_s = As^2 + Bs$, where s is the distance the spring is compressed, in meters. A measuring tape, marked in centimeters, is attached to the side of the track. The student places five photogates on the track at the locations shown.

(a) Derive an expression for the potential energy U as a function of the compression s. Express your answer in terms of A, B, s, and fundamental constants, as appropriate.

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In a preliminary experiment, the student pushes the cart of mass 0.30 kg into the spring, compressing the spring 0.040 m. For this spring, $A = 200\ \text{N/m}^2$ and $B = 150\ \text{N/m}$. The cart is released from rest. Assume friction and air resistance are negligible only during the short time interval when the spring is accelerating the cart.

(b) Calculate the following:

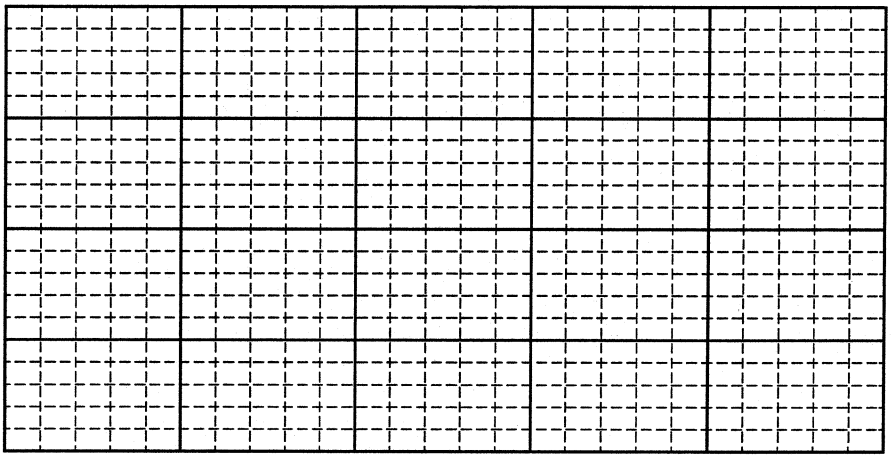
i. The speed of the cart immediately after it loses contact with the spring

ii. The impulse given to the cart by the spring

In a second experiment, the student collects data using the photogates. Each photogate measures the speed of the cart as it passes through the gate. The student calculates a spring compression that should give the cart a speed of 0.320 m/s after the cart loses contact with the spring. The student runs the experiment by pushing the cart into the spring, compressing the spring the calculated distance, and releasing the cart. The speeds are measured with a precision of ±0.002 m/s. The positions are measured with a precision of ±0.005 m.

Photogate	1	2	3	4	5
Cart speed (m/s)	0.412	0.407	0.399	0.374	0.338
Photogate position (m)	0.20	0.40	0.60	0.80	1.00

(c) On the axes below, plot the data points for the speed v of the cart as a function of position x. Clearly scale and label all axes, as appropriate.



(d)

i. Compare the speed of the cart measured by photogate 1 to the predicted value of the speed of the cart just after it loses contact with the spring. List a physical source of error that could account for the difference.

ii. From the measured speed values of the cart as it rolls down the track, give a physical explanation for any trend you observe.

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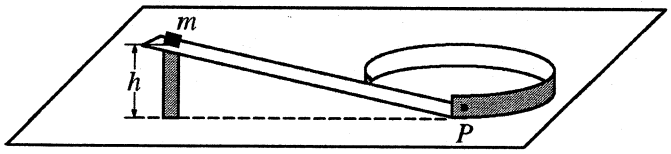
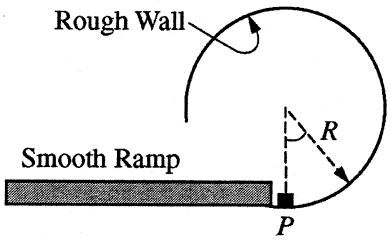


Side View



Top View

Mech. 2.

A small block of mass m starts from rest at the top of a frictionless ramp, which is at a height h above a horizontal tabletop, as shown in the side view above. The block slides down the smooth ramp and reaches point P with a speed v_0. After the block reaches point P at the bottom of the ramp, it slides on the tabletop guided by a circular vertical wall with radius R, as shown in the top view. The tabletop has negligible friction, and the coefficient of kinetic friction between the block and the circular wall is μ.

(a) Derive an expression for the height of the ramp h. Express your answer in terms of v_0, m, and fundamental constants, as appropriate.

A short time after passing point P, the block is in contact with the wall and moves with a speed of v.

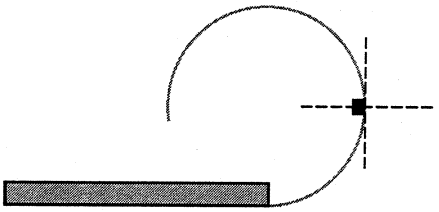
(b)

i. Is the vertical component of the net force on the block upward, downward, or zero?

____ Upward ____ Downward ____ Zero

Justify your answer.

ii. On the figure below, draw an arrow starting on the block to indicate the direction of the horizontal component of the net force on the moving block when it is at the position shown.



Top View

Justify your answer.

Express your answers to the following in terms of v_0, v, m, R, μ, and fundamental constants, as appropriate.

(c) Determine an expression for the magnitude of the normal force N exerted on the block by the circular wall as a function of v.

(d) Derive an expression for the magnitude of the tangential acceleration of the block at the instant the block has attained a speed of v.

(e) Derive an expression for $v(t)$, the speed of the block as a function of time t after passing point P on the track.

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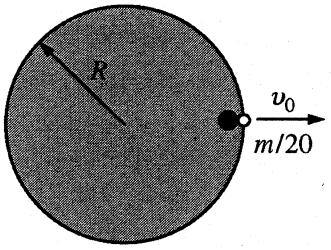
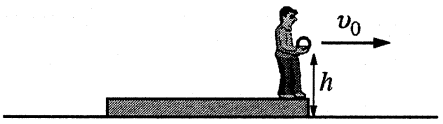


Top View



Side View

Mech. 3.

A large circular disk of mass m and radius R is initially stationary on a horizontal icy surface. A person of mass $m/2$ stands on the edge of the disk. Without slipping on the disk, the person throws a large stone of mass $m/20$ horizontally at initial speed v_0 from a height h above the ice in a radial direction, as shown in the figures above. The coefficient of friction between the disk and the ice is μ. All velocities are measured relative to the ground. The time it takes to throw the stone is negligible. Express all algebraic answers in terms of m, R, v_0, h, μ, and fundamental constants, as appropriate.

(a) Derive an expression for the length of time it will take the stone to strike the ice.

(b) Assuming that the disk is free to slide on the ice, derive an expression for the speed of the disk and person immediately after the stone is thrown.

(c) Derive an expression for the time it will take the disk to stop sliding.

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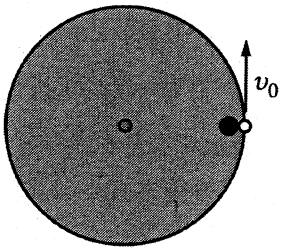

Top View

The person now stands on a similar disk of mass m and radius R that has a fixed pole through its center so that it can only rotate on the ice. The person throws the same stone horizontally in a tangential direction at initial speed v_0, as shown in the figure above. The rotational inertia of the disk is $mR^2/2$.

(d) Derive an expression for the angular speed ω of the disk immediately after the stone is thrown.

(e) The person now stands on the disk at rest $R/2$ from the center of the disk. The person now throws the stone horizontally with a speed v_0 in the same direction as in part (d). Is the angular speed of the disk immediately after throwing the stone from this new position greater than, less than, or equal to the angular speed found in part (d) ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

STOP

END OF EXAM

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AP® Physics C: Mechanics 2014 Scoring Guidelines

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AP® PHYSICS C - MECHANICS
2014 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

(a) 2 points

For using a correct expression for the potential energy of a spring expressed as the integral of the force — 1 point

$$U_S = \int F(x)dx$$

$$U_S = \int_0^s \left(Ax^2 + Bx\right)dx$$

Evaluate the definite integral to get an answer with the correct magnitude.

$$U_S = \left[\frac{1}{3}Ax^3 + \frac{1}{2}Bx^2\right]_0^s$$

For any correct answer with a local minimum at $x = 0$ — 1 point

$$U_S = \frac{1}{3}As^3 + \frac{1}{2}Bs^2$$

Note: Full credit is given for any consistent use of sign, since the guidelines are concerned with the magnitude. Full credit is also given if there is a constant term added to the correct expression.

(b)

i. 3 points

For any statement of conservation of mechanical energy — 1 point

$$U_S = K$$

For using the expression for potential energy from part (a) and a correct expression for kinetic energy — 1 point

$$\frac{1}{3}As^3 + \frac{1}{2}Bs^2 = \frac{1}{2}mv^2$$

Solve for v^2

$$v^2 = 2\left(\frac{1}{3}As^3 + \frac{1}{2}Bs^2\right)\Big/m$$

For correct substitution — 1 point

$$v^2 = 2\left(\left(\frac{1}{3}\right)\left(200\text{N/m}^2\right)(0.040\text{ m})^3 + \left(\frac{1}{2}\right)(150\text{N/m})(0.040\text{ m})^2\right)\Big/(0.30\text{ kg})$$

$$v^2 = 0.828\text{ m}^2/\text{s}^2$$

$$v = 0.91\text{ m/s}$$

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AP® PHYSICS C - MECHANICS
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Question 1 (continued)

Distribution of points

(b) continued

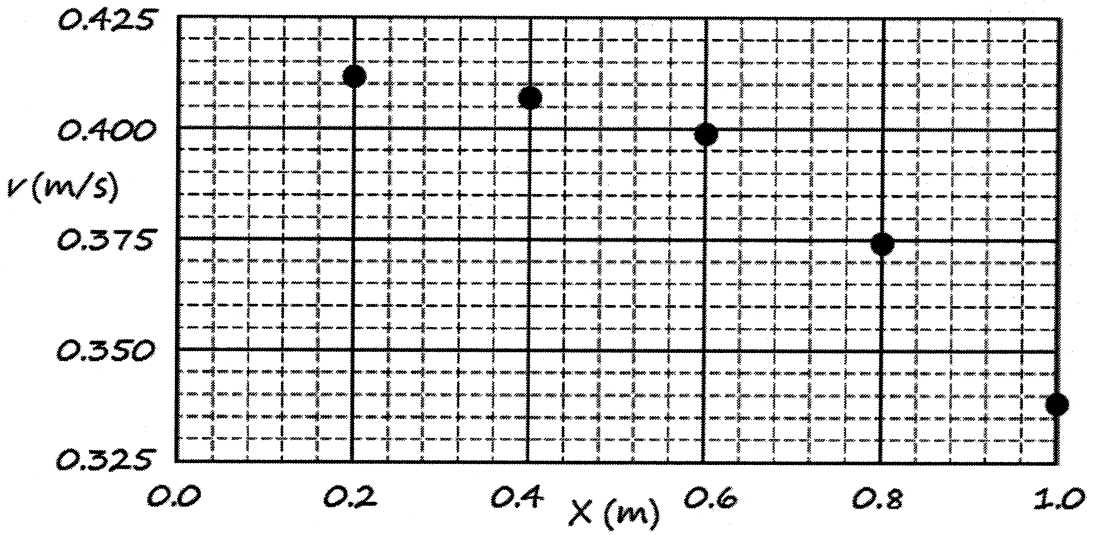
ii. 3 points

For using a correct expression for impulse in terms of change in velocity — 1 point
$J = \Delta p = m(v_2 - v_1)$
For substitution of values consistent with the answer in part (b)i — 1 point
$J = (0.30\ \text{kg})(0.91\ \text{m/s} - 0)$
$J = 0.27\ \text{kg•m/s}$ or N•s

Units 1 point

For correct units in both answers in part (b) — 1 point

(c) 3 points



For correctly labeling both axes with variables and units — 1 point
For correctly scaling both axes with scales that are linear and such that the curvature in the data is apparent — 1 point
For correctly plotting the data points — 1 point

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AP® PHYSICS C - MECHANICS
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Question 1 (continued)

Distribution of points

(d) i. 2 points

For stating that the measured initial speed of the cart is greater than the predicted value — 1 point

For correctly identifying a source of error regarding the initial speed of the cart — 1 point

Examples:

The student compressed the spring more than was determined. This would lead to more potential energy in the spring and greater kinetic energy for the cart. The cart would therefore move faster than predicted.

The table is not level, sloping downward would result in a greater measured speed.

The constants A and B for the spring are not accurate. The true values are larger than what is given. This would lead to smaller predicted potential energy of the spring and a smaller predicted value for the kinetic energy of the cart. Therefore, the cart would move faster than predicted

ii. 2 points

For correctly identifying the trend — 1 point

For a correct physical explanation for the cart slowing down — 1 point

Examples:

Friction in the axles and air resistance against the cart are slowing it down.

The track is not perfectly level and the cart is going uphill. This is slowing down the cart.

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Question 2

15 points total | **Distribution of points**

(a) 3 points

For some correct application of conservation of energy — 1 point

$U_i = K_f$

For substituting correct expressions for potential and kinetic energy — 1 point

$mgh_i = \frac{1}{2}mv_f^2$

$gh = \frac{1}{2}v_0^2$

For a correct answer — 1 point

$h = \frac{v_0^2}{2g}$

Alternate solution — *Alternate points*

For using correct kinematics and dynamics equations — *1 point*

$v_f^2 = v_i^2 + 2a(s_f - s_i)$

$F = ma$

For substituting correct variables — *1 point*

$mg\sin\theta = ma$, $\sin\theta = h/L$ *where L is the length of the ramp, so* $a = gh/L$

$v_0^2 = 0 + 2\left(\frac{gh}{L}\right)L$

For a correct answer — *1 point*

$h = \frac{v_0^2}{2g}$

(b)

i. 2 points

For selecting "Zero" — 1 point

For a correct explanation of why the vertical component of the net force is zero. The explanation must be linked to the fact that there is no acceleration. — 1 point

Example:

The block does not accelerate vertically, therefore the component of the net force in the vertical direction must be zero.

Note: No credit is earned if an incorrect choice is selected.

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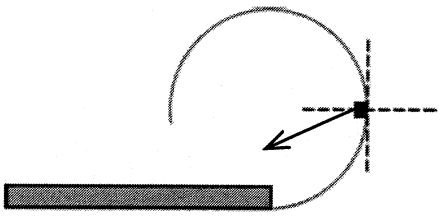
Question 2 (continued)

Distribution of points

(b) (continued)

ii. 3 points



Top View

For drawing a single arrow pointing into the third quadrant — 2 points

For correct justification of both components — 1 point

Example:

The horizontal component of the net force must provide a centripetal force and also slow down the block. So it must point inward and against the direction of motion.

Note: If components are drawn, partial credit can be earned for the following.

For drawing an arrow pointing left (toward the center of the circle) with correct justification — *1 point*

For drawing an arrow pointing toward the bottom of the page with correct justification — *1 point*

A point is deducted for each incorrect vector drawn, with a maximum 2 point deduction

(c) 1 point

The normal force exerted by the wall is the centripetal force.

$F_N = F_C$

For a correct answer — 1 point

$F_N = mv^2/R$

Note: Since the statement of part (c) says to "determine" an expression, credit is given for just stating the correct answer.

(d) 3 points

For correctly using the frictional force in an expression of Newton's second law — 1 point

$-F_f = ma_t$

$-\mu F_N = ma_t$

For substituting the normal force from part (c) into a correct expression — 1 point

$-\mu mv^2/R = ma_t$

For an answer consistent with part (c) — 1 point

$a_t = -\mu v^2/R$

Note: Since the question asks for the magnitude of the acceleration, the negative sign is not needed but students are not penalized for including it.

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Question 2 (continued)

Distribution of points

(e) 3 points

For substituting dv/dt for a into the answer from part (d), or substituting dv/dt for a and the friction force for F_{net} into Newton's second law — 1 point

$$\frac{dv}{dt} = -\frac{\mu v^2}{R} \quad \text{or} \quad m\frac{dv}{dt} = -F_f$$

For including the negative sign — 1 point

Substituting for F_f produces the same relationship as the first equation above.

For separation of variables and using correct limits — 1 point

$$\frac{1}{v^2}dv = -\frac{\mu}{R}dt$$

$$\int_{v_0}^{v}\frac{1}{v^2}dv = \int_0^t -\frac{\mu}{R}dt$$

Integrate the equation to solve for v.

$$\left[-\frac{1}{v}\right]_{v_0}^{v} = \left[-\frac{\mu t}{R}\right]_0^t$$

$$\frac{1}{v} - \frac{1}{v_0} = \frac{\mu t}{R}$$

$$v = \frac{Rv_0}{R + \mu v_0 t} \quad \text{or} \quad \frac{v_0}{1 + \mu v_0 t/R}$$

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AP® PHYSICS C - MECHANICS
2014 SCORING GUIDELINES

Question 3

15 points total

Distribution of points

(a) 2 points

For using a correct kinematics expression for the vertical motion — 1 point

$y - y_0 = v_1 t + \frac{1}{2}at^2$

$h = 0 + \frac{1}{2}gt^2$

For a correct answer — 1 point

$t = \sqrt{2h/g}$

(b) 3 points

For a statement of conservation of momentum or Newton's third law — 1 point

$p_i = p_f$

For substituting the momentum of the stone into a correct expression for conservation of momentum — 1 point

For substituting the momentum of the person-disk system into a correct expression for conservation of momentum — 1 point

$0 = m_1 v_1 + m_2 v_2$

$0 = \left(\frac{m}{20}\right)(v_0) + \left(m + \frac{m}{2}\right)v$

$\frac{3}{2}mv = -\frac{1}{20}mv_0$

$v = -\frac{1}{30}v_0$

Note: Since the question asks for speed, the negative sign is not needed. There is no penalty for including it.

(c) 3 points

For using a correct expression of Newton's second law with friction as the net force — 1 point

$f = ma$

$\mu mg = ma$

$a = \mu g$

For correctly substituting the velocity from part (b) and the acceleration into an appropriate kinematics equation — 1 point

$v_2 = v_1 + at$

$0 = -\frac{1}{30}v_0 + \mu g t$

For an answer consistent with part (b) — 1 point

$t = \frac{v_0}{30\mu g}$

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Question 3 (continued)

Distribution of points

(c) (continued)

Alternate Solution — *Alternate points*

For using a correct expression for impulse and change in momentum, with friction as the force — *1 point*

$Ft = \Delta p = m(v_2 - v_1)$

$-\mu mgt = m(v_2 - v_1)$

For correct substitutions — *1 point*

$-\mu mgt = m\left(0 - \frac{1}{30}v_0\right)$

For an answer consistent with part (b) — *1 point*

$t = \frac{v_0}{30\mu g}$

(d) 4 points

For a statement of conservation of total angular momentum — 1 point

$L_i = L_f$

$L = mrv$ for linear motion

$L = I\omega$ for rotation

For substituting the angular momentum of the stone into a correct expression of conservation of angular momentum — 1 point

For substituting the angular momentum of the person into a correct expression of conservation of angular momentum — 1 point

For substituting the angular momentum of the disk into a correct expression of conservation of angular momentum — 1 point

$0 = m_s r_s v_s + I_D\omega_D + I_P\omega_P$

$0 = \left(\frac{m}{20}Rv_0\right) - \left(\frac{mR^2}{2}\omega + \frac{m}{2}R^2\omega\right)$

$\left(\frac{m}{20}Rv_0\right) = \left(\frac{mR^2}{2}\omega + \frac{m}{2}R^2\omega\right) = mR^2\omega$

$\omega = \frac{\frac{m}{20}Rv_0}{mR^2}$

$\omega = \frac{v_0}{20R}$

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Question 3 (continued)

Distribution of points

(e) 3 points

For selecting "Less than" 1 point
For correctly identifying a decrease in the stone's angular momentum 1 point
For correctly identifying a decrease in the person's rotational inertia 1 point

Example: If the stone is thrown from a point closer to the center of the disk, its angular momentum around the center of the disk decreases, resulting in a decrease of the angular momentum gained by the disk/person system. In addition, the person's rotational inertia is decreased, which decreases the rotational inertia of the disk-person system. The effect of this decrease in the rotational inertia of the person is less than the effect of the decrease in the angular momentum. Therefore, the disk/person system must have a decrease in its angular speed.

Example: From angular momentum conservation, we have

$$L_{stone} = L_{disk+person}$$

$$L_{stone} = \left(I_{disk} + I_{person}\right)\omega$$

$$\boxed{m_{stone}v_0 r = \left(\frac{mR^2}{2} + \frac{m}{2}r^2\right)\omega}$$

where r is the distance of the person from the center of the disk. If r is decreased from R to $R/2$, then the stone's rotational inertia (left-hand-side of the boxed equation) is reduced to half of its previous value. The person's rotational inertia is reduced to one quarter of its previous value, but the combined disk+person rotational inertia (included in right-hand-side of boxed equation) is still greater than half of its previous value. Solving for ω therefore yields a value that is less than it was previously.

Note: If neither the stone nor the person are explicitly mentioned, one point may still be earned for the justification. If just one of either the stone or person are explicitly mentioned, both points for the justification may be earned.

Note: Indicating a decrease in the torque is equivalent to indicating a decrease in the change in angular momentum.

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PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

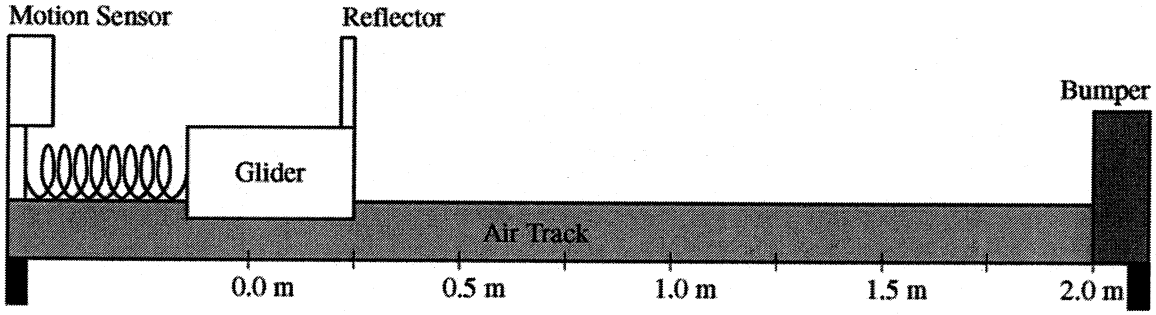

Figure 1

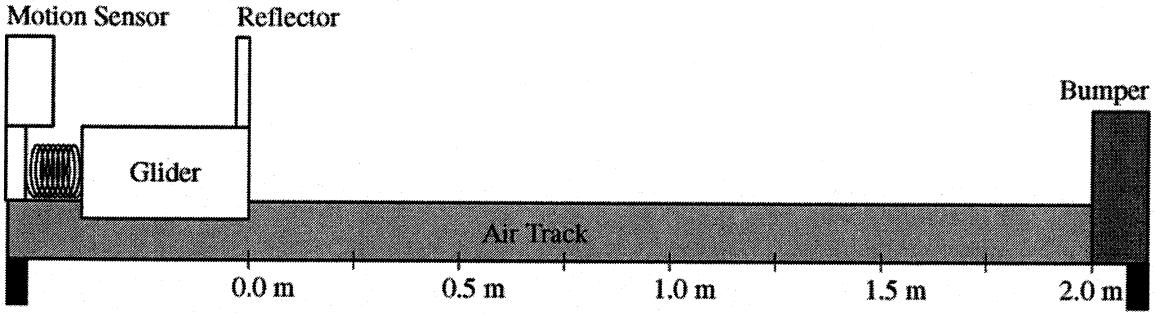

Figure 2

Mech 1.

A student places a 0.40 kg glider on an air track of negligible friction and holds it so that it touches an uncompressed ideal spring, as shown in Figure 1 above. The student then pushes the glider back to compress the spring by 0.25 m, as shown in Figure 2. At time $t = 0$, the student releases the glider, and a motion sensor begins recording the velocity of the reflector at the front of the glider as a function of time. The data points are shown in the table below. At time $t = 0.79$ s, the glider loses contact with the spring.

Time (s)	0	0.25	0.50	0.75	1.00	1.50	2.00
Velocity (m/s)	0	0.25	0.43	0.48	0.50	0.49	0.51

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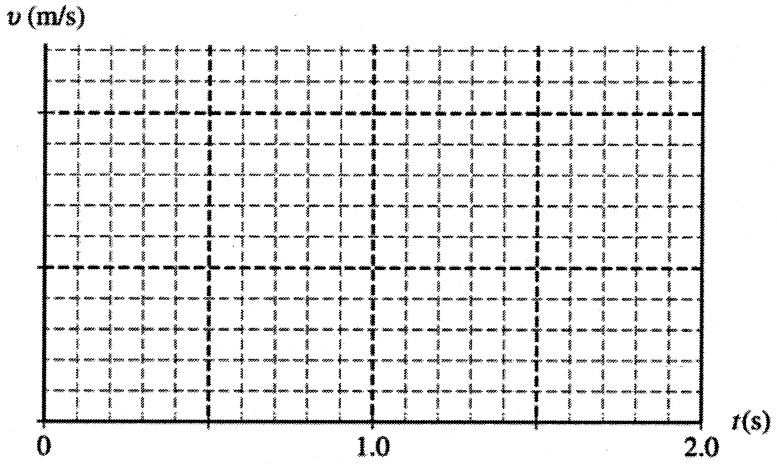
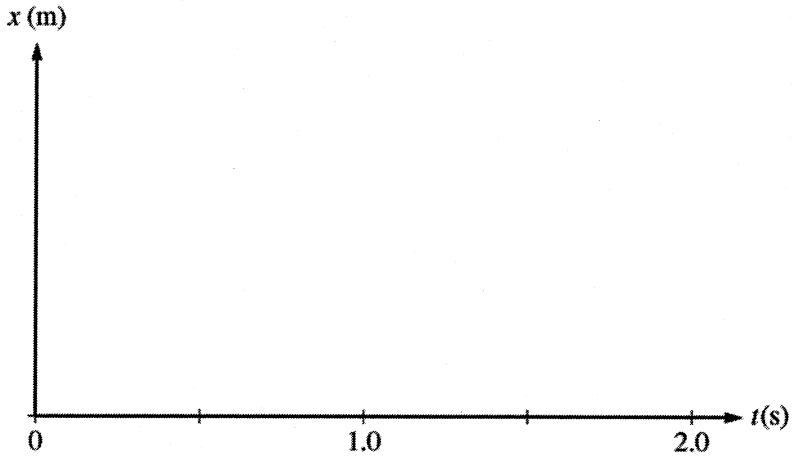
(a) On the axes below, plot the data points for velocity v as a function of time t for the glider, and draw a smooth curve that best fits the data. Be sure to label an appropriate scale on the vertical axis.



(b) The student wishes to use the data to plot position x as a function of time t for the glider.

i. Describe a method the student could use to do this.

ii. On the axes below, sketch the position x as a function of time t for the glider. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



(c) Calculate the time at which the glider makes contact with the bumper at the far right.

(d) Calculate the force constant of the spring.

(e) The experiment is run again, but this time the glider is attached to the spring rather than simply being pushed against it.

i. Determine the amplitude of the resulting periodic motion.

ii. Calculate the period of oscillation of the resulting periodic motion.

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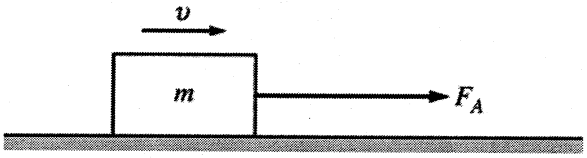


Mech 2.

A box of mass m initially at rest is acted upon by a constant applied force of magnitude F_A, as shown in the figure above. The friction between the box and the horizontal surface can be assumed to be negligible, but the box is subject to a drag force of magnitude kv where v is the speed of the box and k is a positive constant. Express all your answers in terms of the given quantities and fundamental constants, as appropriate.

(a) The dot below represents the box. Draw and label the forces (not components) that act on the box.

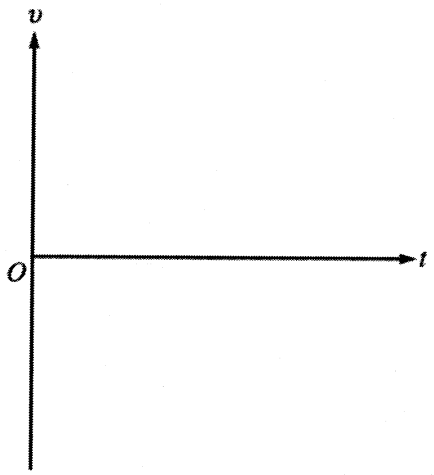
●

(b) Write, but do not solve, a differential equation that could be used to determine the speed v of the box as a function of time t. 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) Determine the magnitude of the terminal velocity of the box.

(d) Use the differential equation from part (b) to derive the equation for the speed v of the box as a function of time t. Assume that $v = 0$ at time $t = 0$.

(e) On the axes below, sketch a graph of the speed v of the box as a function of time t. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



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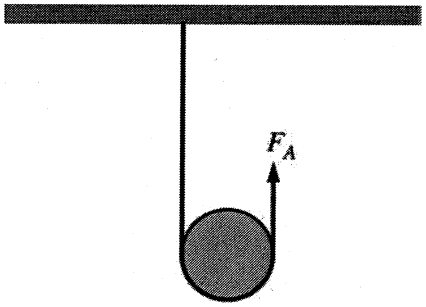

Note: Figure not drawn to scale.

Mech 3.

A disk of mass $M = 2.0$ kg and radius $R = 0.10$ m is supported by a rope of negligible mass, as shown above. The rope is attached to the ceiling at one end and passes under the disk. The other end of the rope is pulled upward with a force F_A. The rotational inertia of the disk around its center is $MR^2/2$.

(a) Calculate the magnitude of the force F_A necessary to hold the disk at rest.

At time $t = 0$, the force F_A is increased to 12 N, causing the disk to accelerate upward. The rope does not slip on the disk as the disk rotates.

(b) Calculate the linear acceleration of the disk.

(c) Calculate the angular speed of the disk at $t = 3.0$ s.

(d) Calculate the increase in total mechanical energy of the disk from $t = 0$ to $t = 3.0$ s.

(e) The disk is replaced by a hoop of the same mass and radius. Indicate whether the linear acceleration of the hoop is greater than, less than, or the same as the linear acceleration of the disk.

__ Greater than __ Less than __ The same as

Justify your answer.

STOP

END OF EXAM

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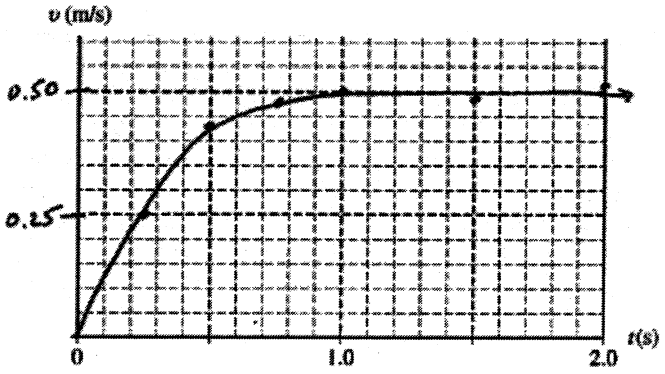
AP® PHYSICS C: MECHANICS
2013 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a) 3 points



For labeling the axes with appropriate values 1 point
For a smooth curve that begins with increasing v and is concave down 1 point
For a horizontal line near $v = 0.50$ m/s, beginning between $t = 0.79$ and 1.0 s 1 point

(b)

i. 1 point

For a correct method of plotting position x as a function of time t 1 point

Examples

Plot the area under the velocity curve from part (a) as a function of time.

$x = \int v dt$

The slope of x as a function of t would yield the v versus t graph in part (a).

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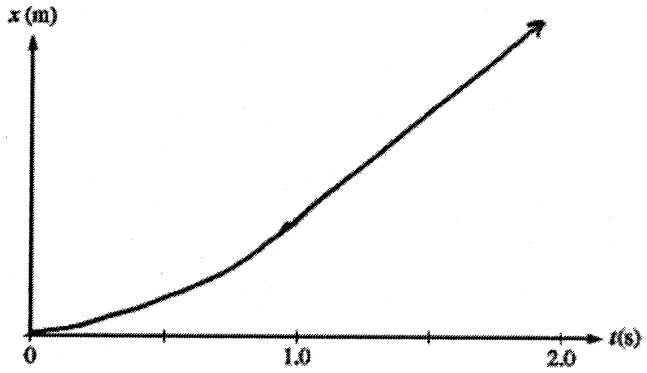
Question 1 (continued)

Distribution of points

ii. 3 points



For a smooth curve that begins with increasing x and is concave up for $t < 0.79$ s, ending between $t = 0.79$ s and 1.0 s — 1 point

For a straight line with a positive slope, beginning between $t = 0.79$ s and 1.0 s — 1 point

For a smooth transition of the curve from non-linear to linear in the region between $t = 0.79$ s and 1.0 s — 1 point

(c) 3 points

For using the graph to determine the distance traveled during the first part of the motion, beginning at $t = 0$ and ending somewhere between 0.79 s (when the glider and spring lose contact) and 2 s (the maximum time shown on the velocity graph — 1 point

For calculating using the graph between 0 and 1.0 s,

$d_1 \approx$ (2.9 large grid squares)(0.125 m/square) = 0.36 m

(1 square = 0.25 m/s × 0.5 s = 0.125 m)

For a correct expression indicating constant velocity during the last part of the motion — 1 point

$d_2 = v\Delta t = v(t - 1.0\text{ s})$

For adding the two distances and solving for the time at which the glider hits the bumper — 1 point

$d_1 + d_2 = 2.0$ m

$0.36\text{ m} + (0.50\text{ m/s})(t - 1.0\text{ s}) = 2.0\text{ m}$

$$t = \frac{(2.0 - 0.36)\text{ m}}{0.50\text{ m/s}} + 1.0\text{ s} = 4.3\text{ s}$$

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Question 1 (continued)

Distribution of points

Alternate Solution

Alternate Points

For using the given information about the spring compression and the time at which the glider loses contact with the spring to arrive at $t_1 = 0.79$ s *at* $d_1 = 0.25$ m — *1 point*

$d_2 = 2.0 \text{ m} - 0.25 \text{ m} = 1.75 \text{ m}$

For a correct expression indicating constant velocity during the last part of the motion — *1 point*

$t_2 = d_2/v = 1.75 \text{ m}/0.50 \text{ m/s} = 3.5 \text{ s}$

For adding the two times — *1 point*

$t = t_1 + t_2 = 0.79 \text{ s} + 3.5 \text{ s}$

$t = t_1 + t_2 = 4.29 \text{ s}$

(d) 2 points

For a correct expression of conservation of energy in terms of the spring constant k and the velocity v — 1 point

$U_{S1} = K_2$

$\frac{1}{2}kx_1^2 = \frac{1}{2}mv_2^2$

$k = \frac{mv_2^2}{x_1^2}$

$k = \frac{mv_2^2}{x_1^2} = \frac{(0.40 \text{ kg})(0.50 \text{ m/s})^2}{(0.25 \text{ m})^2}$

For a correct answer, with correct units — 1 point

$k = 1.6 \text{ N/m}$

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Question 1 (continued)

	Distribution of points
(e)	
i. 1 point	
For the correct amplitude $x_m = 0.25$ m	1 point
ii. 2 points	
For some work that uses a correct expression for the period of a spring $T = 2\pi\sqrt{\frac{m}{k}}$	1 point
For correct substitution of consistent values $T = 2\pi\sqrt{\frac{(0.40\text{ kg})}{(1.6\text{ N/m})}} = 3.1$ s	1 point
Alternate Solution	*Alternate Points*
For recognizing that the 0.79 s of contact time is one quarter of a period	*1 point*
For giving the period as four times the contact time $T = 4(0.79\text{ s}) = 3.2$ s	*1 point*

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Last Saved By:	Windows SOE Manager
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Number of Pages:	4
Number of Words:	465 (approx.)
Number of Characters:	2,651 (approx.)

AP® PHYSICS C: MECHANICS
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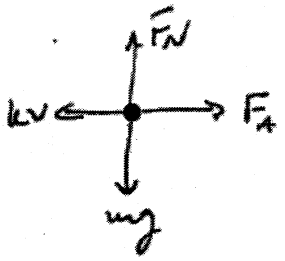
Question 2

15 points total

Distribution of points

(a) 4 points



For correctly showing and labeling the applied force directed to the right — 1 point
For correctly showing and labeling the downward gravitational force — 1 point
For correctly showing and labeling the upward normal force — 1 point
For correctly showing and labeling the drag force directed to the left — 1 point
One earned point was deducted for having any extraneous vectors

(b) 2 points

$F_{net} = ma$

For the correct substitution into Newton's second law — 1 point

$F_A - kv = ma$

For a correct differential equation — 1 point

$$F_A - kv = m\frac{dv}{dt}$$

(c) 1 point

Set $\frac{dv}{dt} = 0$ in the equation from part (b)

$F_A - kv = 0$

For the correct expression for the terminal velocity — 1 point

$$v_T = \frac{F_A}{k}$$

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Question 2 (continued)

Distribution of points

(d) 5 points

Use the differential equation from part (b)

$$F_A - kv = m\frac{dv}{dt}$$

For demonstrating separation of variables — 1 point

$$\frac{1}{m}dt = \frac{1}{F_A - kv}dv$$

For demonstrating that the equation must be integrated — 1 point

$$\int\frac{1}{m}dt = \int\frac{1}{F_A - kv}dv$$

For demonstrating substitution using initial and final values (or evaluating the constant of integration using the boundary conditions) — 1 point

$$\int_0^t \frac{1}{m}dt = \int_0^{v(t)} \frac{1}{F_A - kv}dv$$

$$\left[\frac{t}{m}\right]_0^t = -\frac{1}{k}\left[\ln(F_A - kv)\right]_0^{v(t)}$$

For attempting to solve for $v(t)$ — 1 point

$$-\frac{kt}{m} = \ln\left(\frac{F_A - kv(t)}{F_A}\right)$$

$$e^{-kt/m} = \frac{F_A - kv(t)}{F_A} = 1 - \frac{kv(t)}{F_A}$$

$$\frac{kv(t)}{F_A} = 1 - e^{-kt/m}$$

For a correct answer — 1 point

$$v(t) = \frac{F_A}{k}\left(1 - e^{-kt/m}\right)$$

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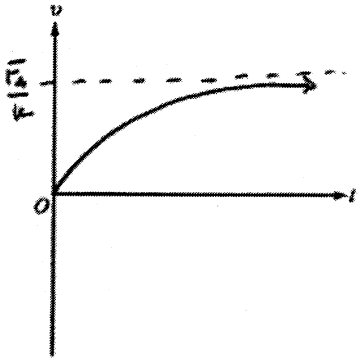
Question 2 (continued)

Distribution of points

(e) 3 points



For a graph that begins at the origin, with a non-negative slope everywhere, and is concave downward — 1 point

For a graph with a horizontal asymptote — 1 point

For the correct label of the expression for the asymptote or maximum on the vertical axis — 1 point

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Question 3

15 points total

Distribution of points

(a) 2 points

For a correct expression indicating that $F_{net} = 0$ — 1 point

$2F_A - Mg = 0$

$F_A = Mg/2$

$F_A = (2.0\text{ kg})\left(9.8\text{ m/s}^2\right)/2$

For a correct answer — 1 point

$F_A = 9.8\text{ N}$ (or 10 N using $g = 10\text{ m/s}^2$)

(b) 5 points

For a correct expression of Newton's second law for translational motion — 1point

$F_{net} = Ma$

$F_A + T - Mg = Ma$ (equation 1)

For using a correct expression of torque in Newton's second law for rotational motion — 1 point

$\tau = I\alpha$

$F_A R - TR = \left(MR^2/2\right)\alpha$ or $F_A R - TR = I\alpha$

For substituting for the angular acceleration in terms of the linear acceleration ($\alpha = a/R$) — 1 point

$F_A R - TR = \left(MR^2/2\right)(a/R)$

$F_A - T = Ma/2$ (equation 2)

For combining equations 1 and 2 to solve for the linear acceleration — 1 point

Add the two equations

$2F_A - Mg = (3/2)Ma$

$a = (2/3)((2F_A/M) - g)$

$a = (2/3)\left((2(12\text{ N})/2.0\text{ kg}) - 9.8\text{ m/s}^2\right)$

For a correct answer, with units — 1 point

$a = 1.47\text{ m/s}^2$ (1.33 m/s^2 using $g = 10\text{ m/s}^2$)

(c) 2 points

For using the relationship between linear and angular acceleration in the equation for angular speed — 1 point

$\omega = \omega_0 + \alpha t$ and $\alpha = a/R$

$\omega_0 = 0$, so $\omega = \alpha t/R$

$\omega = \left(1.47\text{ m/s}^2\right)(3.0\text{ s})/(0.10\text{ m})$

1 point

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Question 3 (continued)

Distribution of points

For an answer with units, consistent with previous work
$\omega = 44$ rad/s (40 rad/s using $g = 10$ m/s^2)

(d) 4 points

Express the change in mechanical energy as the sum of the change in potential energy and the change in kinetic energy
$\Delta E = \Delta U_g + \Delta K$

For a correct expression for the change in kinetic energy including both translational and rotational kinetic energy — 1 point
$\Delta K = \frac{1}{2}M\left(v^2 - v_0^2\right) + \frac{1}{2}I\left(\omega^2 - \omega_0^2\right)$

For a correct expression for the change in potential energy, including a correct expression of the height h in terms of the time — 1 point
$\Delta U_g = Mgh = Mg\left(\frac{1}{2}at^2\right)$

v_0 and ω_0 are zero, so $\Delta E = Mg\left(\frac{1}{2}at^2\right) + \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

For simplifying the expression using the relationship between linear velocity and angular velocity — 1 point
$\Delta E = Mg\left(\frac{1}{2}at^2\right) + \frac{1}{2}M(R\omega)^2 + \frac{1}{2}\left(MR^2/2\right)\omega^2$

$\Delta E = \frac{1}{2}Mgat^2 + \frac{3}{4}MR\omega^2$

For correctly substituting given values and answers from previous parts into a correct expression — 1 point
$\Delta E = \frac{1}{2}(2.0\text{ kg})\left(9.8\text{ m/s}^2\right)\left(1.47\text{ m/s}^2\right)(3.0\text{ s})^2 + \frac{3}{4}(2.0\text{ kg})(0.10\text{ m})^2(44\text{ rad/s})^2$

$\Delta E = 159$ J (144 J using $g = 10$ m/s^2)

(e) 2 points

For selecting "Less than" — 1 point
For a correct justification — 1 point

Example
The rotational inertia of a hoop is greater than that of a solid disk of the same mass and radius, therefore the acceleration of the hoop would be less.

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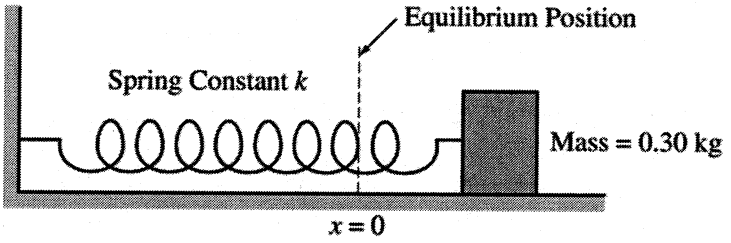
2012 AP® PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

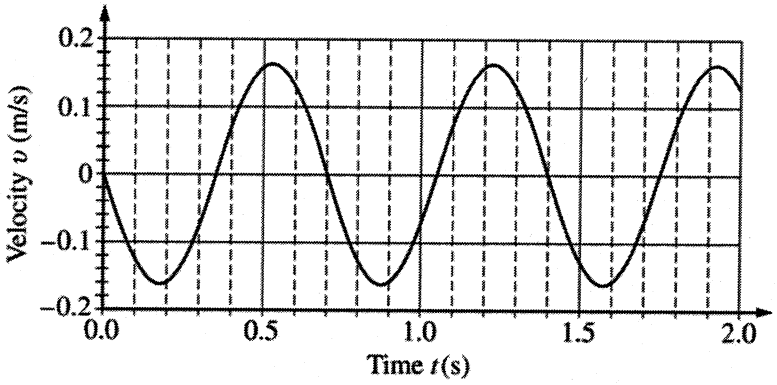
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



Mech. 1.

Experiment 1. A block of mass 0.30 kg is placed on a frictionless table and is attached to one end of a horizontal spring of spring constant k, as shown above. The other end of the spring is attached to a fixed wall. The block is set into oscillatory motion by stretching the spring and releasing the block from rest at time $t = 0$. A motion detector is used to record the position of the block as it oscillates. The resulting graph of velocity v versus time t is shown below. The positive direction for all quantities is to the right.



(a) Determine the equation for $v(t)$, including numerical values for all constants.

(b) Given that the equilibrium position is at $x = 0$, determine the equation for $x(t)$, including numerical values for all constants.

(c) Calculate the value of k.

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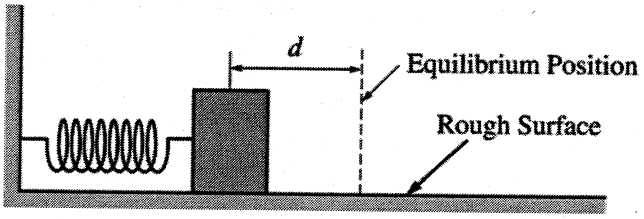
Experiment 2. The block and spring arrangement is now placed on a rough surface, as shown below. The block is displaced so that the spring is compressed a distance d and released from rest.

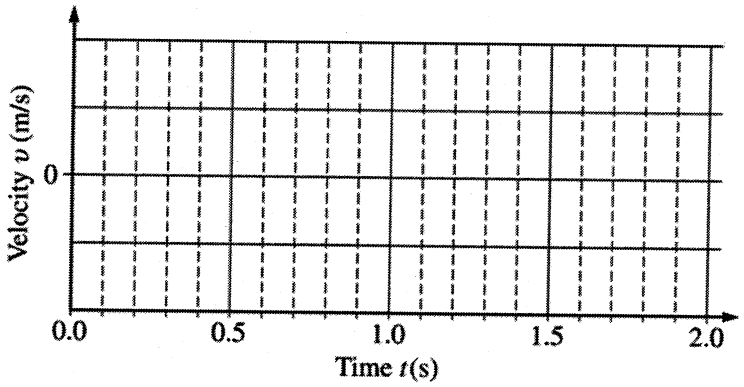


(d) On the dots below that represent the block, draw and label the forces (not components) that act on the block when the spring is compressed a distance $x = d/2$ and the block is moving in the direction indicated below each dot.

Toward the equilibrium position

Away from the equilibrium position

(e) Draw a sketch of v versus t in this case. Assume that there is a negligible change in the period and that the positive direction is still to the right.



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Mech. 2.

You are to perform an experiment investigating the conservation of mechanical energy involving a transformation from initial gravitational potential energy to translational kinetic energy.

(a) You are given the equipment listed below, all the supports required to hold the equipment, and a lab table. On the list below, indicate each piece of equipment you would use by checking the line next to each item.

____ Track	____ Meterstick	____ Set of objects of different masses
____ Cart	____ Electronic balance	____ Lightweight low-friction pulley
____ String	____ Stopwatch	

(b) Outline a procedure for performing the experiment. Include a diagram of your experimental setup. Label the equipment in your diagram. Also include a description of the measurements you would make and a symbol for each measurement.

(c) Give a detailed account of the calculations of gravitational potential energy and translational kinetic energy both before and after the transformation, in terms of the quantities measured in part (b).

(d) After your first trial, your calculations show that the energy increased during the experiment. Assuming you made no mathematical errors, give a reasonable explanation for this result.

(e) On all other trials, your calculations show that the energy decreased during the experiment. Assuming you made no mathematical errors, give a reasonable physical explanation for the fact that the average energy you determined decreased. Include references to conservative and nonconservative forces, as appropriate.

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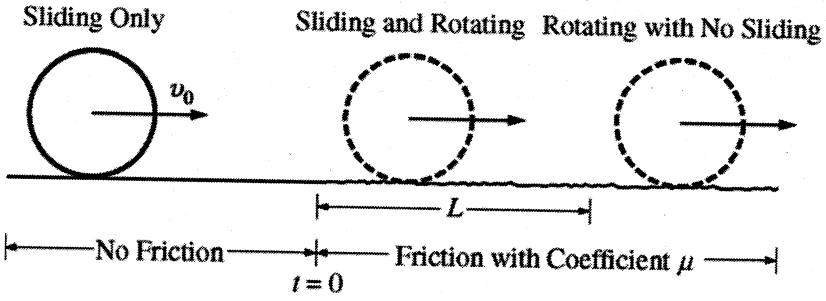

Mech. 3.

A ring of mass M, radius R, and rotational inertia MR^2 is initially sliding on a frictionless surface at constant velocity v_0 to the right, as shown above. At time $t = 0$ it encounters a surface with coefficient of friction μ and begins sliding and rotating. After traveling a distance L, the ring begins rolling without sliding. Express all answers to the following in terms of M, R, v_0, μ, and fundamental constants, as appropriate.

(a) Starting from Newton's second law in either translational or rotational form, as appropriate, derive a differential equation that can be used to solve for the magnitude of the following as the ring is sliding and rotating.

i. The linear velocity v of the ring as a function of time t

ii. The angular velocity ω of the ring as a function of time t

(b) Derive an expression for the magnitude of the following as the ring is sliding and rotating.

i. The linear velocity v of the ring as a function of time t

ii. The angular velocity ω of the ring as a function of time t

(c) Derive an expression for the time it takes the ring to travel the distance L.

(d) Derive an expression for the magnitude of the velocity of the ring immediately after it has traveled the distance L.

(e) Derive an expression for the distance L.

STOP

END OF EXAM

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AP® Physics C: Mechanics
2012 Scoring Guidelines

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AP® PHYSICS
2012 SCORING GUIDELINES

General Notes About 2012 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer owing to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS C: MECHANICS
2012 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

(a) 4 points

For writing a correct trigonometric equation for velocity as a function of time, including the negative sign
$v(t) = -v_{max}\sin(\omega t) = -v_{max}\sin(2\pi t/T)$ — 1 point

For using $\omega = 2\pi f$ or $\omega = \frac{2\pi}{T}$ to solve for ω — 1 point

For using the correct period of 0.70 s from the graph — 1 point
$\omega = \frac{2\pi}{0.70\text{s}} = 9.0$ rad/s

For using the correct value of the maximum speed from the graph (acceptable range of values for v_{max}: 0.15 m/s to 0.17 m/s) — 1 point
$v(t) = (-0.16)\sin(9.0t)$

Note: One point is deducted if incorrect phase shift ϕ is used. Full credit is awarded for a correct answer with no work shown. Students are also given credit if the value of k from part (c) is used to calculate ω using $\omega = \sqrt{k/m}$.

(b) 2 points

Take the integral of the velocity determined in part (a)
$x(t) = \int v(t)dt = \int(-0.16 \text{ m/s})\sin((9.0 \text{ rad/s})t)dt$

For a correct trigonometric expression consistent with integrating the answer from part (a) — 1 point

For a correct x_{max} consistent with the integrating the answer from part (a) — 1 point
$x_{max} = (0.16 \text{ m/s})/(9.0 \text{ rad/s}) = 0.018$ m
$x(t) = (0.018)\cos(9.0t)$

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AP® PHYSICS C: MECHANICS
2012 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) continued

Alternate solution — *Alternate points*

For solving for a maximum displacement consistent with the answer from part (a) — *1 point*

$v_{max} = x_{max}\omega$

$x_{max} = \frac{v_{max}}{\omega} = \frac{(0.16 \text{ m/s})}{(9.0 \text{ rad/s})}$

$x_{max} = 0.018 \text{ m}$

For a correct trigonometric expression consistent with the answer from part (a) — *1 point*

$x(t) = (0.018)\cos(9.0t)$

Note: Full credit is awarded for a correct answer with no work shown. One earned point is deducted for incorrect initial conditions (e.g., subtracting a constant from the cosine function).

(c) 2 points

For a correct relationship between the period and the spring constant — 1 point

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

For substituting correct values from previous parts into a correct expression — 1 point

$k = \frac{4\pi^2 m}{T^2} = \frac{(4\pi^2)(0.30 \text{ kg})}{(0.70 \text{ s})^2}$

$k = 24 \text{ N/m}$

Alternate solution #1 — *Alternate points*

For a correct expression relating angular frequency and the spring constant — *1 point*

$\omega = \sqrt{\frac{k}{m}}$

For substituting correct values from previous parts into a correct expression — *1 point*

$k = m\omega^2 = (0.30 \text{ kg})(9.0 \text{ rad/s})^2$

$k = 24 \text{ N/m}$

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Question 1 (continued)

Distribution of points

(c) continued

Alternate solution #2 — *Alternate points*

For a correct statement of the conservation of energy, applied to the position of maximum displacement and the equilibrium position — *1 point*

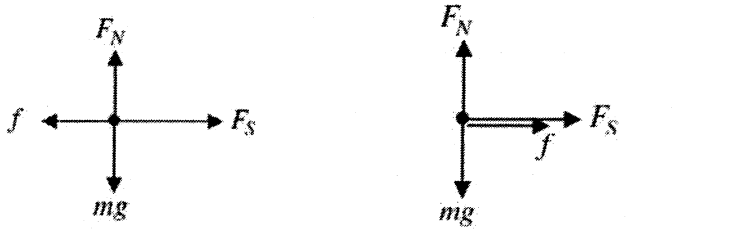
$$\frac{1}{2}kx_{\max}^2 = \frac{1}{2}mv_{\max}^2$$

For substituting correct values from previous parts into a correct expression — *1 point*

$$k = \frac{mv_{\max}^2}{x_{\max}^2} = \frac{(0.30\text{ kg})(0.16\text{ m/s})^2}{(0.018\text{ m})^2}$$

$$k = 24\text{ N/m}$$

(d) 4 points



Toward the equilibrium position — Away from the equilibrium position

For drawing and labeling F_N and mg correctly on both diagrams — 1 point

On diagram of the block moving toward the equilibrium position:

For a correctly drawn and labeled spring force to the right — 1 point

For a correctly drawn and labeled friction force to the left — 1 point

On diagram of the block moving away from the equilibrium position:

For a correctly drawn and labeled spring force and friction force to the right — 1 point

Notes

- Length of vectors is not considered, only direction.
- There is a 1-point maximum deduction for any vectors not touching (or at least almost touching) the dot or for any extraneous forces.Vectors can be drawn from the dot outward OR toward the dot, pointing inward and touching the dot.

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AP® PHYSICS C: MECHANICS
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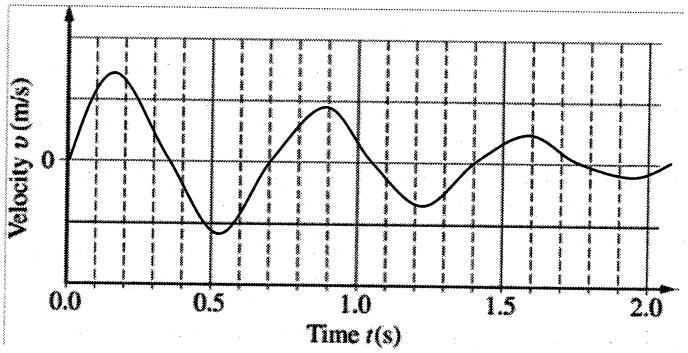
Question 1 (continued)

Distribution of points

(e) 3 points



For a graph passing through equilibrium at 0.35 s intervals — 1 point

For a graph displaying damped oscillations — 1 point

For a graph that starts at zero with an increasing positive velocity — 1 point

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Question 2

15 points total

Distribution of points

(a) 1 point

For choosing the meterstick and stopwatch, regardless of what else is checked — 1 point

(b) 4 points

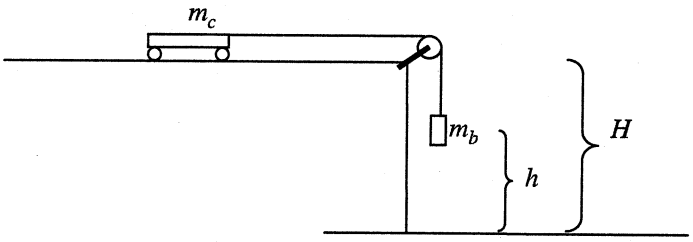
For a procedure that indicates the height needed to calculate gravitational potential energy — 1 point

For a procedure that indicates distance and time measurements to calculate velocity — 1 point

For a diagram and a clear indication of the height measurement — 1 point

For a diagram and a clear indication of the distance measurement — 1 point

Example #1



- Use the electronic balance to determine the mass m_c of the cart and the mass m_b of one object.
- Attach the object to the cart using the string.
- Place the cart on the track and hang the object so that the string passes through the pulley.
- Allow the object to fall a distance h from its initial position to the floor, using the meterstick to measure the distance fallen.
- Use the stopwatch to measure the time t it takes the object to fall the distance h.
- Measure the height H of the table.

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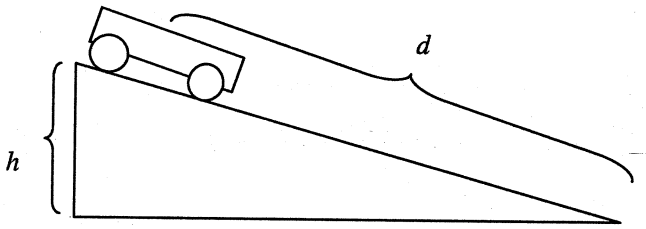
Question 2 (continued)

Distribution of points

(b) continued

Example #2



- Use the electronic balance to determine the mass m of the cart.
- Set the track at an incline, and measure the height h of the incline.
- Place the cart at the top of the incline, and release from rest.
- Using the stopwatch, measure the time t it takes for the cart to move down the incline.
- Measure the distance d that the cart moves down the incline.

(c) 6 points

For a clear indication of the initial potential energy of the system	1 point
For a clear indication of the final potential energy of the system	1 point
For a clear indication of the initial kinetic energy of the system	1 point
For a clear indication of the final kinetic energy of the system	1 point
For a correct calculation of the instantaneous velocity of the system	2 points

Example #1

Initial gravitational potential energy: $U_{g0} = m_c gH + m_b gh$

Final gravitational potential energy: $U_{gf} = m_c gH$

Initial kinetic energy: $K_0 = 0$

Final kinetic energy: $K_f = \frac{1}{2}(m_c + m_b)v_f^2$

Acceleration is constant, so $d = \frac{1}{2}(v_0 + v_f)t$, where d is the distance along the track.

$v_f = \frac{2h}{t}$

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Question 2 (continued)

Distribution of points

(c) continued

Example #2

Initial gravitational potential energy: $U_{g0} = mgh$

Final gravitational potential energy $U_{gf} = 0$

Initial kinetic energy $K_0 = 0$

Final kinetic energy $K_f = \frac{1}{2}mv_f^2$

Acceleration is constant, so $d = \frac{1}{2}(v_0 + v_f)t$.

$v_f = \frac{2d}{t}$

(d) 2 points

For identifying a reasonable cause for the increase in energy — 1 point

For a reasonable explanation related to the cause identified — 1 point

Example
An unintentional push was applied to the cart, thus increasing the initial energy.

(e) 2 points

For identifying a reasonable cause for the decrease in energy related to the nonconservative forces acting on the system — 1 point

For a reasonable explanation related to the cause identified — 1 point

Example
Friction acting on the object decreases the speed, thereby decreasing the energy.

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Question 3

15 points total | **Distribution of points**

(a)

i. 3 points

For starting with Newton's second law for translation, with friction as the net force
$\Sigma F = -f = Ma$ — 1 point

For a correct expression for the frictional force
$f = \mu Mg$ — 1 point

For indicating that linear acceleration is the time derivative of velocity
$a = \frac{dv}{dt}$ — 1 point

$\frac{dv}{dt} = -\mu g$

ii. 3 points

For starting with Newton's second law for rotation, with a correct substitution for the rotational inertia
$\tau = MR^2\alpha$ — 1 point

For a correct expression for the torque, using the frictional force
$\tau = \mu MgR$ — 1 point

For indicating that the angular acceleration is the time derivative of the angular velocity
$\alpha = \frac{d\omega}{dt}$ — 1 point

$\frac{d\omega}{dt} = \frac{\mu g}{R}$

(b)

i. 2 points

For setting up the integral of the function determined in part (a)-i
$\int_{v_0}^{v} dv = -\int_0^t \mu g dt$ — 1 point

For the correct answer
$v = v_0 - \mu gt$ — 1 point

Alternate solution — *Alternate points*

For a clear substitution of the acceleration from part (a)-i into the kinematics equation
$a = -\mu g$
$v = v_0 + at$ — *1 point*

For the correct answer
$v = v_0 - \mu gt$ — *1 point*

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Question 3 (continued)

Distribution of points

(b) continued

ii. 2 points

For setting up the integral of the function determined in part (a)-ii — 1 point

$\int_0^{\omega} d\omega = \int_0^{t} (\mu g/R)\,dt$

For the correct answer — 1 point

$\omega = \mu g t/R$

Alternate solution — *Alternate points*

For a clear substitution of the angular acceleration from part (a)-ii into the correct rotational kinematics equation — *1 point*

$\alpha = \frac{\mu g}{R}$

$\omega = \omega_0 + \alpha t$

For the correct answer — *1 point*

$\omega = \mu g t/R$

(c) 2 points

For indicating that the linear speed is equal to $R\omega$ when the slipping stops — 1 point

$v = R\omega$

$v_0 - \mu g t = R\left(\frac{\mu g t}{R}\right)$

For the correct answer — 1 point

$t = \frac{v_0}{2\mu g}$

(d) 1 point

For substituting the time found in part (c) into a correct kinematics equation — 1 point

$v = v_0 - \mu g\left(\frac{v_0}{2\mu g}\right)$

$v = v_0/2$

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Question 3 (continued)

Distribution of points

(e) 2 points

For setting up the integral of the velocity function determined in part (b)-i — 1 point

$L = \int_0^t (v_0 - vgt)\,dt$

For the correct answer, with correct supporting work — 1 point

$L = \left[v_0 t - \frac{1}{2}\mu g t^2 \right]_0^{\frac{v_0}{2\mu g}}$

$L = \frac{3v_0^2}{8\mu g}$

Alternate solution #1 — *Alternate points*

For substituting the velocity from part (d) and the acceleration from part (a)-i into a correct equation that solves for L — *1 point*

$v^2 = v_0^2 + 2a\Delta x$

$\left(\frac{v_0}{2}\right)^2 = v_0^2 + 2(-\mu g)L$

For the correct answer, with correct supporting work — *1 point*

$L = \frac{3v_0^2}{8\mu g}$

Alternate solution #2 — *Alternate points*

For substituting the velocity from part (d) and the acceleration from part (a)-i into a correct equation that solves for L — *1 point*

Note: The time determined in part (c) must also be substituted.

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

$L = v_0\left(\frac{v_0}{2\mu g}\right) + \frac{1}{2}(-\mu g)\left(\frac{v_0}{2\mu g}\right)^2$

For the correct answer, with correct supporting work — *1 point*

$L = \frac{3v_0^2}{8\mu g}$

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AP® Physics C: Mechanics
2011 Free-Response Questions

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2011 AP® PHYSICS C: MECHANICS FREE-RESPONSE QUESTIONS

PHYSICS C: MECHANICS
SECTION II
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3 Questions

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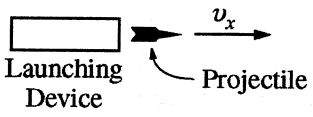

Mech. 1.

A projectile is fired horizontally from a launching device, exiting with a speed v_x. While the projectile is in the launching device, the impulse imparted to it is J_p, and the average force on it is F_{avg}. Assume the force becomes zero just as the projectile reaches the end of the launching device. Express your answers to parts (a) and (b) in terms of v_x, J_p, F_{avg}, and fundamental constants, as appropriate.

(a) Determine an expression for the time required for the projectile to travel the length of the launching device.
(b) Determine an expression for the mass of the projectile.

The projectile is fired horizontally into a block of wood that is clamped to a tabletop so that it cannot move. The projectile travels a distance d into the block before it stops. Express all algebraic answers to the following in terms of d and the given quantities previously indicated, as appropriate.

(c) Derive an expression for the work done in stopping the projectile.
(d) Derive an expression for the average force F_b exerted on the projectile as it comes to rest in the block.

Now a new projectile and block are used, identical to the first ones, but the block is <u>not</u> clamped to the table. The projectile is again fired into the block of wood and travels a new distance d_n into the block while the block slides across the table a short distance D. Assume the following: the projectile enters the block with speed v_x, the average force F_b between the projectile and the block has the same value as determined in part (d), the average force of friction between the table and the block is f_T, and the collision is instantaneous so the frictional force is negligible during the collision.

(e) Derive an expression for d_n in terms of d, D, f_T, and F_b, as appropriate.
(f) Derive an expression for d_n in terms of d, the mass m of the projectile, and the mass M of the block.

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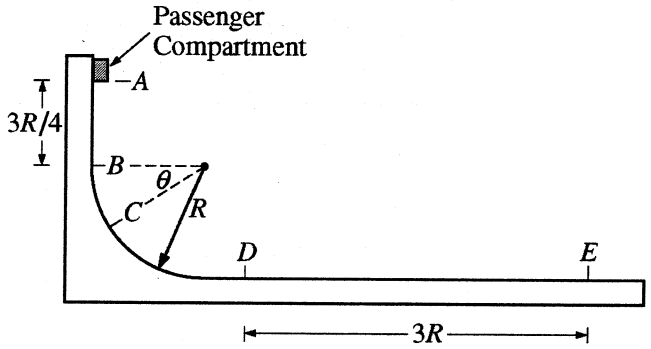

Mech. 2.
An amusement park ride features a passenger compartment of mass M that is released from rest at point A, as shown in the figure above, and moves along a track to point E. The compartment is in free fall between points A and B, which are a distance of $3R/4$ apart, then moves along the circular arc of radius R between points B and D. Assume the track is frictionless from point A to point D and the dimensions of the passenger compartment are negligible compared to R.

(a) On the dot below that represents the passenger compartment, draw and label the forces (not components) that act on the passenger compartment when it is at point C, which is at an angle θ from point B.



(b) In terms of θ and the magnitudes of the forces drawn in part (a), determine an expression for the magnitude of the centripetal force acting on the compartment at point C. If you need to draw anything besides 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) Derive an expression for the speed v_D of the passenger compartment as it reaches point D in terms of M, R, and fundamental constants, as appropriate.

A force acts on the compartment between points D and E and brings it to rest at point E.

(d) If the compartment is brought to rest by friction, calculate the numerical value of the coefficient of friction μ between the compartment and the track.

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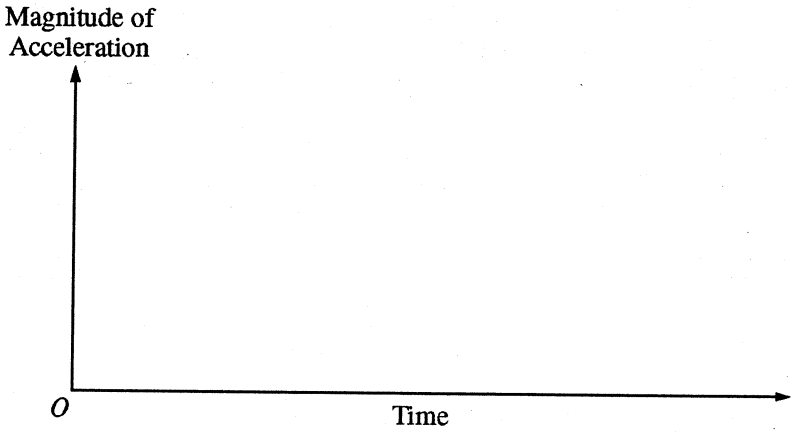
(e) Now consider the case in which there is no friction between the compartment and the track, but instead the compartment is brought to rest by a braking force $-k\mathbf{v}$, where k is a constant and $\mathbf{v}$ is the velocity of the compartment. Express all algebraic answers to the following in terms of M, R, k, v_D, and fundamental constants, as appropriate.

i. Write, but do NOT solve, the differential equation for $v(t)$.

ii. Solve the differential equation you wrote in part i.

iii. On the axes below, sketch a graph of the magnitude of the acceleration of the compartment as a function of time. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



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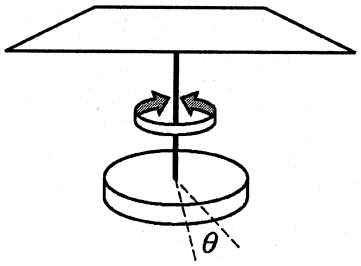

Mech. 3.

The torsion pendulum shown above consists of a disk of rotational inertia I suspended by a flexible rod attached to a rigid support. When the disk is twisted through a small angle θ, the twisted rod exerts a restoring torque τ that is proportional to the angular displacement: $\tau = -\beta\theta$, where β is a constant. The motion of a torsion pendulum is analogous to the motion of a mass oscillating on a spring.

(a) In terms of the quantities given above, write but do NOT solve the differential equation that could be used to determine the angular displacement θ of the torsion pendulum as a function of time t.
(b) Using the analogy to a mass oscillating on a spring, determine the period of the torsion pendulum in terms of the given quantities and fundamental constants, as appropriate.

To determine the torsion constant β of the rod, disks of different, known values of rotational inertia are attached to the rod, and the data below are obtained from the resulting oscillations.

Rotational Inertia I of Disk $\left(\text{kg}\cdot\text{m}^2\right)$	Average Time for Ten Oscillations (s)	Period T (s)	T^2 $\left(\text{s}^2\right)$
0.025	22.4	2.24	5.0
0.036	26.8	2.68	7.2
0.049	29.5	2.95	8.7
0.064	33.3	3.33	11.1
0.081	35.9	3.59	12.9

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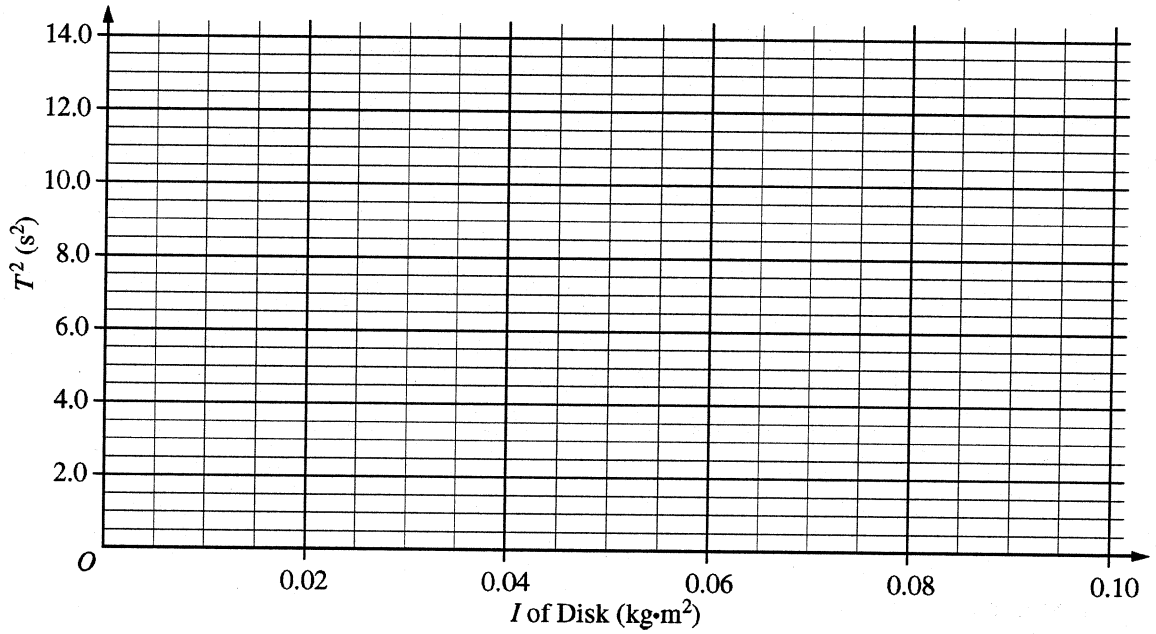
(c) On the graph below, plot the data points. Draw a straight line that best represents the data.



(d) Determine the equation for your line.

(e) Calculate the torsion constant β of the rod from your line.

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

END OF EXAM

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AP® Physics C: Mechanics
2011 Scoring Guidelines

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AP® PHYSICS C: MECHANICS
2011 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

(a) 2 points

$$\mathbf{J} = \int \mathbf{F}\, dt$$

For a correct equation relating the given force, time and impulse
$J_p = F_{avg}\Delta t$ 1 point

For the correct answer
$\Delta t = J_p / F_{avg}$ 1 point

Alternate solution
For using both kinematics and Newton's second law *Alternate points*
$v_x = 0 + a_{avg}\Delta t$ *1 point*

$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$

Combining the above equations

$$F_{avg} = m\left(\frac{v_x}{\Delta t}\right)$$

$F_{avg}\Delta t = mv_x = J_p$

For the correct answer
$\Delta t = J_p / F_{avg}$ *1 point*

(b) 2 points

For the correct relationship between impulse and the change in momentum
$\mathbf{J} = \Delta\mathbf{p} = m\Delta\mathbf{v}$ 1 point

$J_p = m(v_x - 0) = mv_x$

For the correct answer
$m = J_p / v_x$ 1 point

Note: A correct kinematics and Newton's laws approach is also acceptable.

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Question 1 (continued)

Distribution of points

(c) 3 points

For using the work-energy theorem — 1 point

$W = \Delta K$

$W = 0 - \frac{1}{2}mv_x^2$

For substituting the expression for m from part (b) — 1 point

$W = -\frac{1}{2}\frac{J_p}{v_x}v_x^2$

$W = -\frac{1}{2}J_p v_x$

For an indication that the work done is negative — 1 point

Alternate Solution — *Alternate points*

Using kinematics and Newton's second law to determine the average net force

$v_f^2 - v_i^2 = 2a_{avg}d$

$-v_x^2 = 2a_{avg}d$

$a_{avg} = -\frac{v_x^2}{2d}$

$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$

$F_{net} = m\left(-\frac{v_x^2}{2d}\right)$

For substituting this expression for the force into the equation for work — *1 point*

$W = \int \mathbf{F}\cdot d\mathbf{r} = F_{avg}d = m\left(-\frac{v_x^2}{2d}\right)d$

$W = -m\frac{v_x^2}{2}$

For substituting the expression for m from part (b) — *1 point*

$W = -\frac{J_p}{v_x}\frac{v_x^2}{2}$

$W = -\frac{1}{2}J_p v_x$

For an indication that the work done is negative — *1 point*

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AP® PHYSICS C: MECHANICS
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Question 1 (continued)

Distribution of points

(d) 2 points

$W = \int \mathbf{F} \cdot d\mathbf{r} = \mathbf{F}_{avg} \cdot \mathbf{r}$

For using F_b as the average force in the equation for work — 1 point

$W = F_b d$

$F_b = \frac{W}{d}$

For substituting the expression for W from part (c), with or without a negative sign — 1 point

$F_b = \frac{J_p v_x}{2d}$

(e) 4 points

Applying the work-energy relationship

$K_i + W = K_f$

For correctly relating the initial kinetic energy of the projectile with the work done by the block on the projectile and the work done on the block by friction with the table — 1 point

$K_i + W_{block} + W_{friction} = 0$

For substituting for the work done by the block on the projectile (i.e., the energy lost to heat in the block-projectile collision) — 1 point

$K_i - F_b d_n + W_{friction} = 0$

For substituting the work done on the block by friction with the table (i.e., the energy lost to heat as the block slides to rest on the table) — 1 point

$K_i - F_b d_n - f_T D = 0$

The initial kinetic energy of the projectile is the same as in the first case when the block was clamped. Therefore, it can be equated to the work done in stopping the projectile from part (d).

For substituting $F_b d$ for the initial kinetic energy of the block — 1 point

$F_b d - F_b d_n - f_T D = 0$

$F_b d_n = F_b d - f_T D$

Full credit could not be earned for just writing this equation. The student needed to have some indication that the work-energy relationship was being applied, and that F_d was associated with the initial kinetic energy.

$d_n = \frac{F_b d - f_T D}{F_b}$

$d_n = d - \frac{f_T}{F_b} D$

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Question 1 (continued)

Distribution of points

(f) 2 points

For a correct application of conservation of momentum to the block-projectile collision 1 point

$m v_x = (M + m)V$

$V = \frac{m}{(M + m)} v_x$

The kinetic energy of the block/projectile system immediately after the collision is equal to the work done by friction in stopping it.

$\frac{1}{2}(M + m)V^2 = f_T D$

For substituting for V 1 point

$\frac{1}{2}(M + m)\left(\frac{m}{(M + m)} v_x\right)^2 = f_T D$

$\frac{1}{2}\frac{m^2 v_x^2}{(M + m)} = f_T D$

$\frac{m}{M + m}\left(\frac{1}{2} m v_x^2\right) = f_T D$

From part (c) the kinetic energy factor in the equation above is equal to the total work done. From part (d) that work is equal to $F_b d$.

$\frac{m}{M + m} F_b d = f_T D$

Using the expression $F_b d_n = F_b d - f_T D$ from part (e) to substitute for $f_T D$

$\frac{m}{M + m} F_b d = F_b d - F_b d_n$

$\frac{m}{M + m} d = d - d_n$

$d_n = d\left(1 - \frac{m}{M + m}\right)$

Note: Because the work for parts (e) and (f) is interrelated, the two parts are scored as a whole. Credit is earned for work related to part (f) even when it is shown in part (e) and vice versa.

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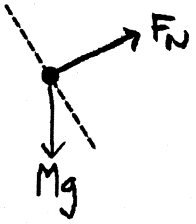
AP® PHYSICS C: MECHANICS
2011 SCORING GUIDELINES

Question 2

15 points total

Distribution of points

(a) 2 points



For either a weight force or a normal force, correctly drawn and labeled — 1 point
For the second correct force and no additional forces, arrows or components — 1 point

(b) 1 point

For a correct expression for the centripetal force in terms of the forces drawn in part (a) — 1 point
For the example above:
$F_c = F_N - Mg\sin q$

Alternate Solution — *Alternate points*
Applying conservation of energy, with the loss of potential energy equal to the kinetic energy at point C

$Mg\,\Delta h = Mu_C^2/2$

$u_C^2 = 2g\,\Delta h$

$\Delta h = 3R/4 + R\sin q$

$u_C^2 = 2g(3R/4 + R\sin q)$

$F_c = Mu_C^2/R$

$F_c = M(2g(3R/4 + R\sin q))/R$

For a correct answer — *1 point*
$F_c = 2Mg(3/4 + \sin q)$

(c) 2 points

For applying conservation of energy, with the loss of potential energy equal to the kinetic energy at point D — 1 point

$Mg\,\Delta h = Mu_D^2/2$

$u_D^2 = 2g\,\Delta h$

$\Delta h = 3R/4 + R = 7R/4$

$u_D^2 = 2g(7R/4)$

For a correct answer — 1 point
$u_D = \sqrt{(7/2)gR}$

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Question 2 (continued)

Distribution of points

(d) 3 points

Work-energy approach

For equating the work done by the friction force to the kinetic energy of the compartment at point D — 1 point

$W = \Delta K = 0 - \frac{1}{2}Mu_D^2$

For a correct expression for the frictional force — 1 point

$f = \mu N = \mu Mg$

$W = \mathbf{F}\cdot\Delta\mathbf{r} = fd\cos 180 = -(\mu Mg)d$

$(\mu Mg)d = \frac{1}{2}Mu_D^2$

For substituting the expression for u_D from part (c), and $d = 3R$ — 1 point

$(\mu Mg)3R = \frac{1}{2}M\left(\frac{7}{2}gR\right)$

$3\mu = \frac{1}{2}\left(\frac{7}{2}\right)$

$\mu = 7/12$

Note: Full credit is also earned for setting the initial potential energy at point A, $U_A = mg\left(\frac{7R}{4}\right)$, equal to the work done by the frictional force, and solving for μ.

Alternate solution — *Alternate points*

For using both Newton's second law and a correct kinematics equation — *1 point*

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

$u_f^2 - u_i^2 = 2ad$

For a correct expression for the frictional force — *1 point*

$f = \mu N = \mu Mg$

$-\mu Mg = Ma$

$a = -\mu g$

Substituting for a, and the final and initial speeds in the kinematic equation

$-u_D^2 = 2(-\mu g)d$

For substituting the expression for u_D from part (c), and $d = 3R$ — *1 point*

$\frac{7}{2}gR = 2(\mu g)3R$

$\mu = 7/12$

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Question 2 (continued)

Distribution of points

(e)

i. 2 points

$SF = ma$

For substituting the braking force into Newton's second law as the net force — 1 point

For substituting the time derivative of velocity for the acceleration — 1 point

$-ku = M(du/dt)$

ii. 2 points

For separating the variables and integrating — 1 point

$du/u = -(k/M)\,dt$

$$\int_{u_D}^{u} du/u = -(k/M)\int_{0}^{t} dt$$

$$\ln u\Big|_{u_D}^{u} = -(k/M)t$$

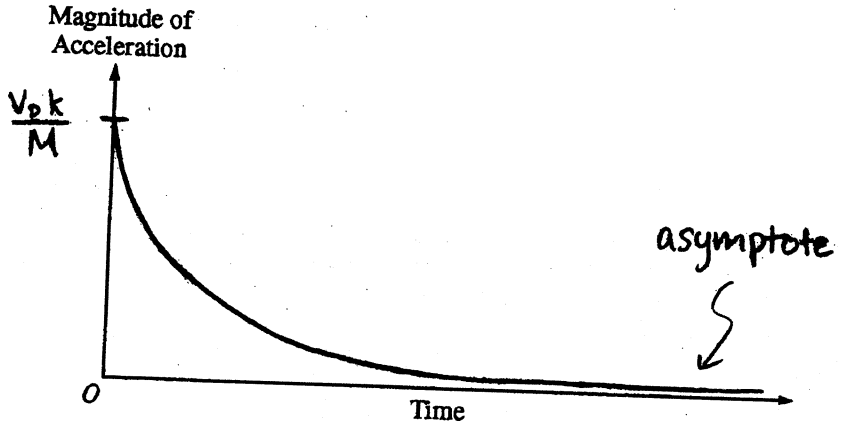
$$\ln u - \ln u_D = \ln(u/u_D) = -(k/M)t$$

$$u/u_D = e^{-kt/M}$$

For a correct expression for the velocity as a function of time — 1 point

$u = u_D e^{-kt/M}$

iii. 3 points



Taking the derivative of the equation for u from part (e) ii

$a = du/dt = d\left(u_D e^{-kt/M}\right)/dt = -(k/M)\,u_D e^{-kt/M}$

At $t = 0$, $a = -ku_D/M$

For a graph with a finite intercept on the vertical axis — 1 point

For a graph that is concave upward and asymptotic to zero — 1 point

For labeling the initial acceleration with the correct value — 1 point

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AP® PHYSICS C: MECHANICS
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Question 3

15 points total | **Distribution of points**

(a) 3 points

For a statement of Newton's second law for rotation — 1 point

$\Sigma\tau = I\alpha$

For substituting the given torque expression for the net torque $\Sigma\tau$ — 1 point

$I\alpha = -\beta\theta$

For substituting the second derivative of angular position for angular acceleration — 1 point

$I\dfrac{d^2\theta}{dt^2} = -\beta\theta$

(b) 3 points

Applying Newton's second law for translation to a mass on a spring gives

$m\dfrac{d^2x}{dt^2} = -kx$, and $\omega = \sqrt{\dfrac{k}{m}}$.

For this torsion pendulum, $I\dfrac{d^2\theta}{dt^2} = -\beta\theta$.

Comparing differential equations, I is analogous to m and β is analogous to k.

For the correct expression for ω — 1 point

$\omega = \sqrt{\dfrac{\beta}{I}}$

For the correct relationship between ω and T — 1 point

$T = \dfrac{2\pi}{\omega}$

For the correct answer — 1 point

$T = 2\pi\sqrt{\dfrac{I}{\beta}}$

Alternate Solution — *Alternate points*

The period of a mass on a spring is $T = 2\pi\sqrt{\dfrac{m}{k}}$.

For recognizing that I is analogous to m — *1 point*

For recognizing that β *is analogous to k* — *1 point*

For the correct answer — *1 point*

$T = 2\pi\sqrt{\dfrac{I}{\beta}}$

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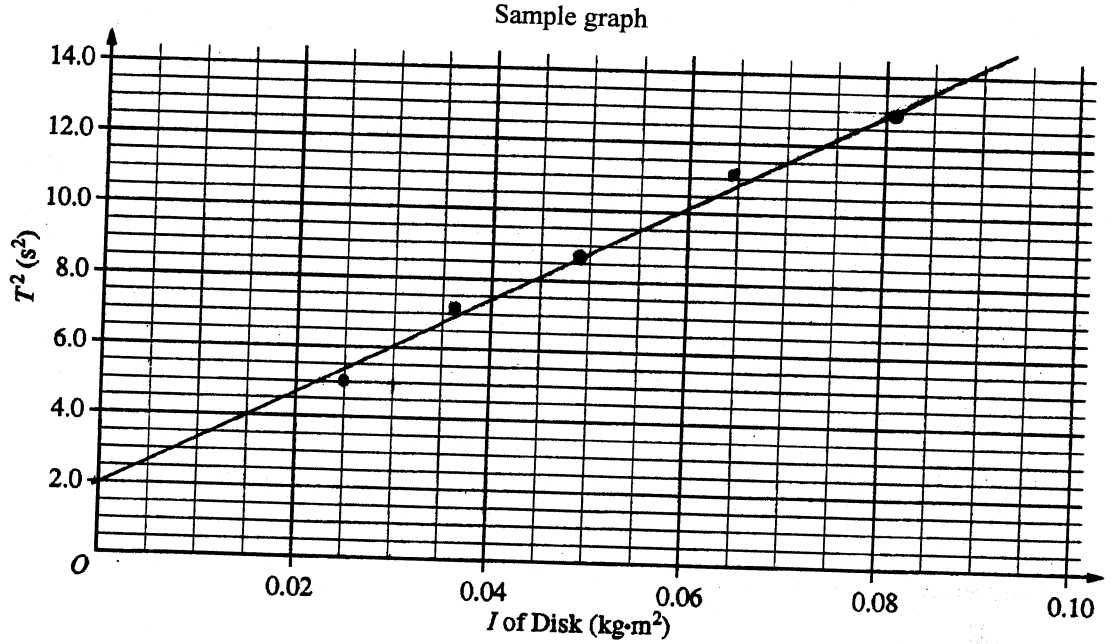
Question 3 (continued)

Distribution of points

(c) 2 points

Sample graph



For correctly plotting the data — 1 point

For drawing a reasonable, best-fit straight line — 1 point

Note: For correctly plotted data, a reasonable, best-fit straight line does NOT pass through the origin.

(d) 3 points

The general equation for a straight line is $y(x) = mx + b$, where m is the slope and b is the y-intercept.

$T^2 = mI + b$

$m = \Delta(T^2)/\Delta I$

For using two points from the best-fit line to calculate the slope — 1 point

Example from the graph shown: $m = \dfrac{(11.5\ \text{s}^2 - 2.0\ \text{s}^2)}{(0.07\ \text{kg·m}^2 - 0.00\ \text{kg·m}^2)}$

$m = 135\ \text{s}^2/\text{kg·m}^2$

For an intercept calculated or directly read from the graph — 1 point

$b = 2.0\ \text{s}^2$

For using the variables T^2 and I in the equation — 1 point

$T^2 = (135\ \text{s}^2/\text{kg·m}^2)I + 2.0\ \text{s}^2$

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Question 3 (continued)

Distribution of points

(e) 3 points

Using the equation from part (b)

$T = 2\pi\sqrt{\frac{I}{\beta}}$

$T^2 = 4\pi^2 \frac{I}{\beta} = \frac{4\pi^2}{\beta} I$

For comparing this to part (d) and noting that $\frac{4\pi^2}{\beta}$ is the slope of the line — 1 point

$\frac{4\pi^2}{\beta} = m$

For using the value of the slope determined in part (d) — 1 point

$\beta = \frac{4\pi^2}{m} = \frac{4\pi^2}{135\ \text{s}^2/\text{kg}\cdot\text{m}^2}$

$\beta = 0.292\ \text{kg}\cdot\text{m}^2/\text{s}^2$

For the correct units on the numerical answer — 1 point

(f) 1 point

For a correct physical explanation for the intercept that mentions the effect of the flexible rod — 1 point

Example: The intercept is the square of the period of oscillation of the flexible rod.

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AP® Physics C: Mechanics
2010 Free-Response Questions

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PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. 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.



Mech. 1.

Students are to conduct an experiment to investigate the relationship between the terminal speed of a stack of falling paper coffee filters and its mass. Their procedure involves stacking a number of coffee filters, like the one shown in the figure above, and dropping the stack from rest. The students change the number of filters in the stack to vary the mass m while keeping the shape of the stack the same. As a stack of coffee filters falls, there is an air resistance (drag) force acting on the filters.

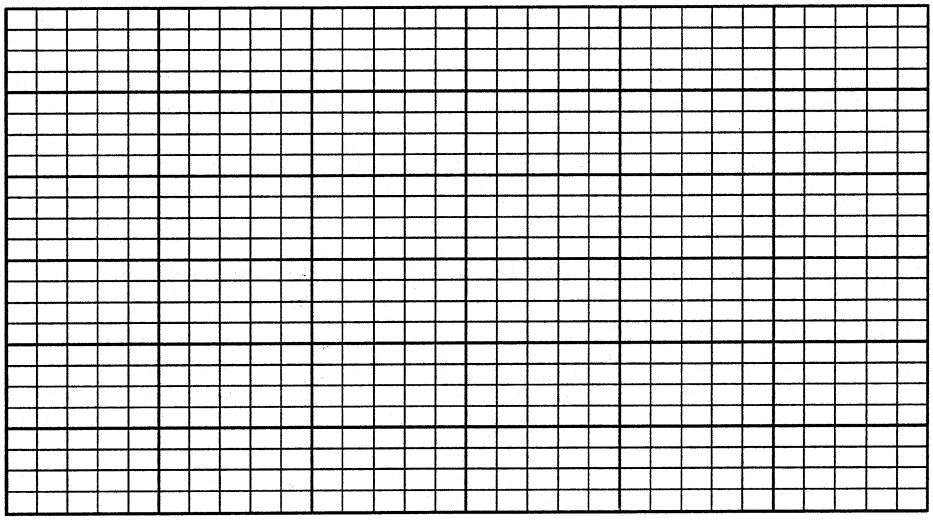
(a) The students suspect that the drag force F_D is proportional to the square of the speed v: $F_D = Cv^2$, where C is a constant. Using this relationship, derive an expression relating the terminal speed v_T to the mass m.

The students conduct the experiment and obtain the following data.

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06

(b)

(i) Assuming the functional relationship for the drag force above, use the grid below to plot a linear graph as a function of m to verify the relationship. Use the empty boxes in the data table, as appropriate, to record any calculated values you are graphing. Label the vertical axis as appropriate, and place numbers on both axes.



m (kg)

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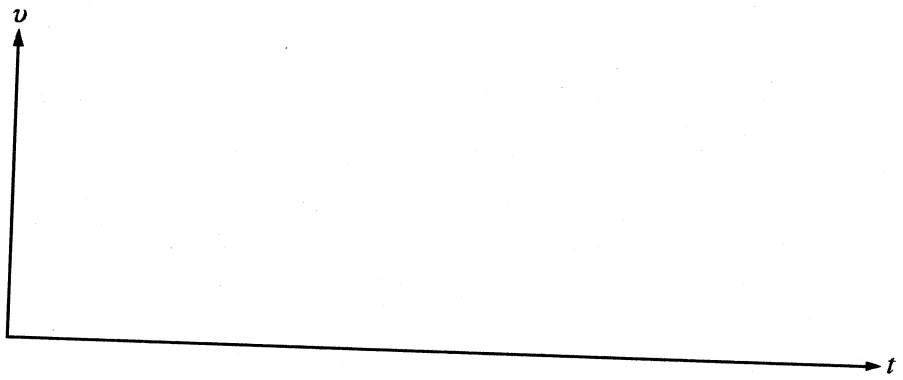
(ii) Use your graph to calculate C.

A particular stack of filters with mass m is dropped from rest and reaches a speed very close to terminal speed by the time it has fallen a vertical distance Y.

(c)

(i) Sketch an approximate graph of speed versus time from the time the filters are released up to the time $t = T$ that the filters have fallen the distance Y. Indicate time $t = T$ and terminal speed $v = v_T$ on the graph.



(ii) Suppose you had a graph like the one sketched in (c)(i) that had a numerical scale on each axis. Describe how you could use the graph to approximate the distance Y.

(d) Determine an expression for the approximate amount of mechanical energy dissipated, ΔE, due to air resistance during the time the stack falls a distance y, where $y > Y$. Express your answer in terms of y, m, v_T, and fundamental constants.

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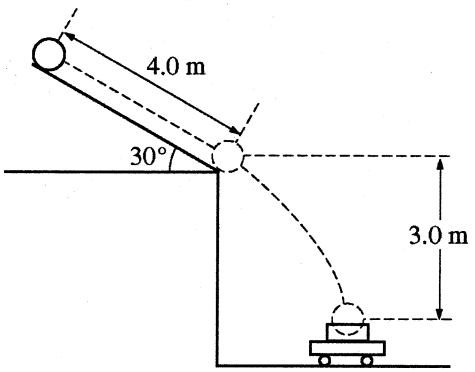
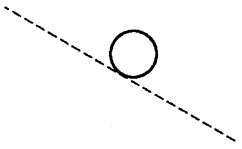


Note: Figure not drawn to scale.

Mech. 2.

A bowling ball of mass 6.0 kg is released from rest from the top of a slanted roof that is 4.0 m long and angled at 30°, as shown above. The ball rolls along the roof without slipping. The rotational inertia of a sphere of mass M and radius R about its center of mass is $\frac{2}{5}MR^2$.

(a) On the figure below, draw and label the forces (not components) acting on the ball at their points of application as it rolls along the roof.



(b) Calculate the force due to friction acting on the ball as it rolls along the roof. 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 linear speed of the center of mass of the ball when it reaches the bottom edge of the roof.

(d) A wagon containing a box is at rest on the ground below the roof so that the ball falls a vertical distance of 3.0 m and lands and sticks in the center of the box. The total mass of the wagon and the box is 12 kg. Calculate the horizontal speed of the wagon immediately after the ball lands in it.

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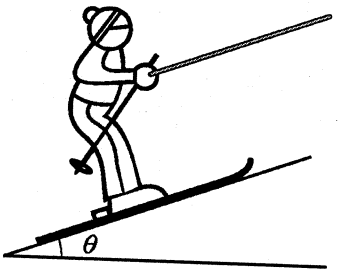


Mech. 3.

A skier of mass m will be pulled up a hill by a rope, as shown above. The magnitude of the acceleration of the skier as a function of time t can be modeled by the equations

$$a = a_{max} \sin\frac{\pi t}{T} \qquad (0 < t < T)$$
$$= 0 \qquad (t \geq T),$$

where a_{max} and T are constants. The hill is inclined at an angle θ above the horizontal, and friction between the skis and the snow is negligible. Express your answers in terms of given quantities and fundamental constants.

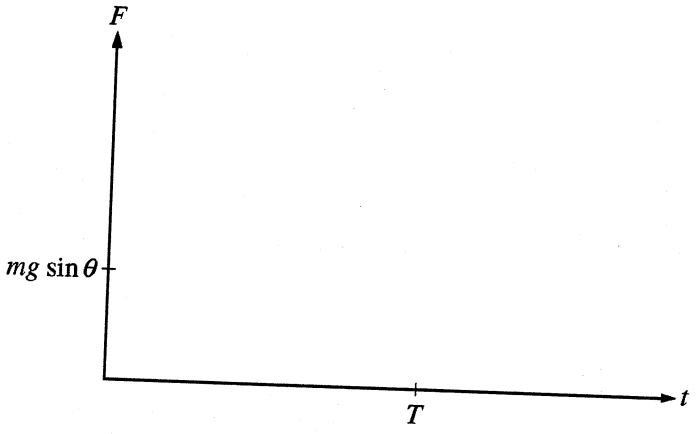
(a) Derive an expression for the velocity of the skier as a function of time during the acceleration. Assume the skier starts from rest.

(b) Derive an expression for the work done by the net force on the skier from rest until terminal speed is reached.

(c) Determine the magnitude of the force exerted by the rope on the skier at terminal speed.

(d) Derive an expression for the total impulse imparted to the skier during the acceleration.

(e) Suppose that the magnitude of the acceleration is instead modeled as $a = a_{max}e^{-\pi t/2T}$ for all $t > 0$, where a_{max} and T are the same as in the original model. On the axes below, sketch the graphs of the force exerted by the rope on the skier for the two models, from $t = 0$ to a time $t > T$. Label the original model F_1 and the new model F_2.



END OF EXAM

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AP® Physics C: Mechanics
2010 Scoring Guidelines

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AP® PHYSICS
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong — for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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AP® PHYSICS C: MECHANICS
2010 SCORING GUIDELINES

Question 1

15 points total

Distribution of points

(a) 2 points

Starting with Newton's second law:

$F_{net} = mg - Cv^2 = ma$

For correctly indicating that at terminal velocity ($v = v_T$), the net force and acceleration are zero — 1 point

$mg - Cv_T^2 = 0$

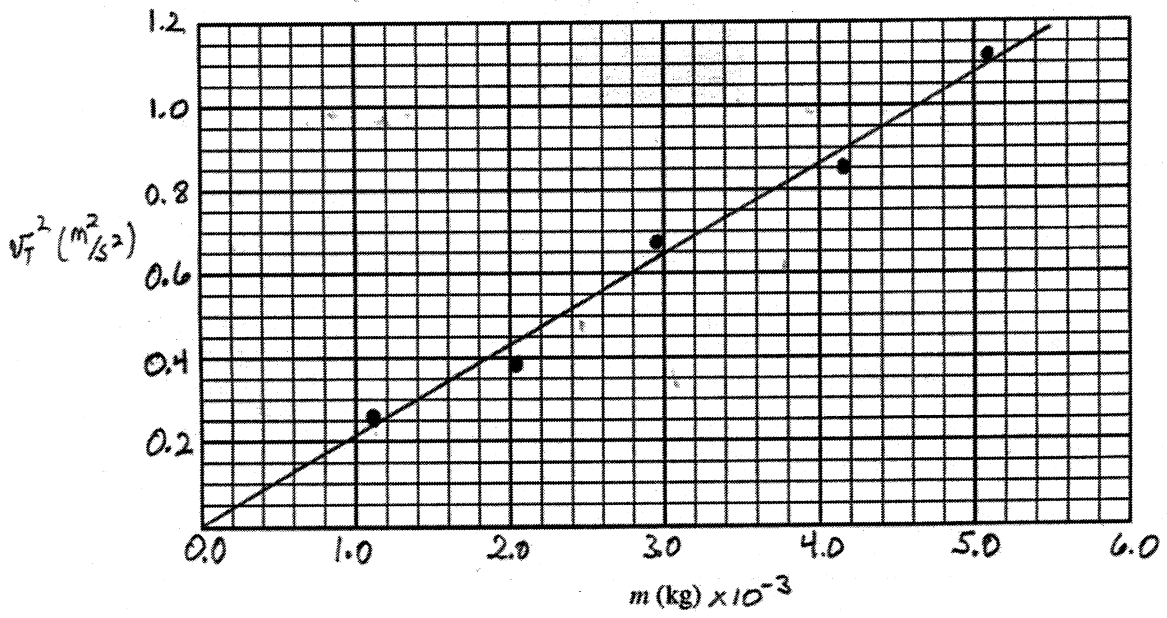
For a correct relationship between v_T and m — 1 point

$v_T^2 = \frac{g}{C}m$

(b)

(i) 4 points

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
v_T^2 (m^2/s^2)	0.26	0.38	0.67	0.85	1.12



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AP® PHYSICS C: MECHANICS
2010 SCORING GUIDELINES

Question 1 (continued)

Distribution of points

(b) (i) (continued)

For recording in the table a row of calculated data points that involve only v_T or a combination of v_T and g — 1 point

For graphing v_T^2 (or the equivalent) on the vertical axis to obtain a linear graph — 1 point

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

For drawing a reasonable best-fit straight line — 1 point

Note: Correct graphs of v_T versus $\sqrt{m}$ are given credit provided the quantities being plotted are clearly indicated.

(ii) 3 points

For a correct calculation of the slope, using points on the student's best-fit line (not points from the data table) — 1 point

Using the example graph shown:

$$\text{slope} = \frac{(0.95 - 0.30)\,\text{m}^2/\text{s}^2}{\left[(4.4 - 1.4) \times 10^{-3}\right]\,\text{kg}} = 217\ \text{m}^2/\text{kg}\cdot\text{s}^2$$

For a correct expression relating the slope to C — 1 point

$$\text{slope} = 217\,\text{m}^2/\text{kg}\cdot\text{s}^2 = \frac{g}{C}$$

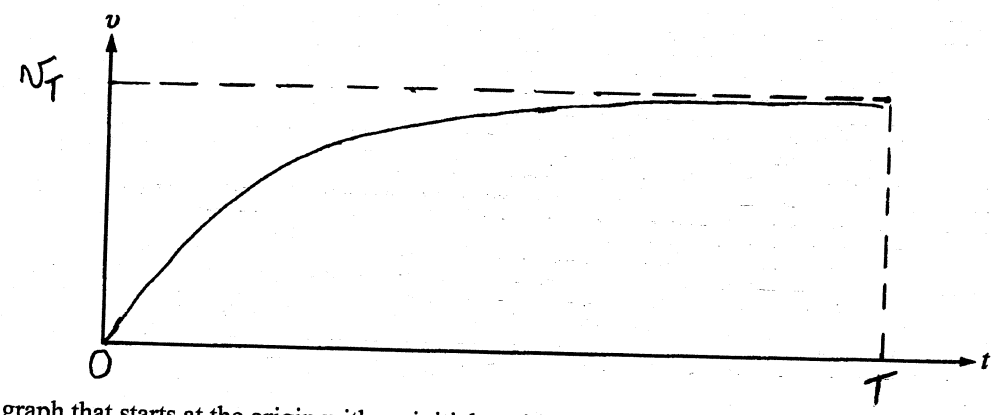
$$C = \frac{g}{\text{Slope}} = \frac{9.8\ \text{m/s}^2}{217\ \text{m}^2/\text{kg}\cdot\text{s}^2}$$

For correct units on C

$C = 0.045$ kg/m (0.046 kg/m using $g = 10\ \text{m/s}^2$) — 1 point

(c)

(i) 3 points



For a graph that starts at the origin with an initial positive slope — 1 point

For a graph that is concave down throughout — 1 point

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AP® PHYSICS C: MECHANICS
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Question 1 (continued)

Distribution of points

For labeling v_T and T at a point where the slope of the graph approaches zero — 1 point

(c) (continued)

(ii) 1 point

For a verbal statement that clearly indicates the distance Y is the area under the curve between times $t = 0$ and $t = T$
Or an equivalent statement referring to the area under the curve when the v versus t graph ends at T
Or an equivalent mathematical expression with limits: $Y = \int_0^T v(t)\,dt$ — 1 point

(d) 2 points

For a correct indication that the mechanical energy dissipated is the change in mechanical energy during the time the stack falls a distance y — 1 point

$\Delta E = \left(U_{final} + K_{final}\right) - \left(U_{initial} + K_{initial}\right)$ $\left(\text{or } \Delta E = \int_0^y Cv^2 dy\right)$

$\Delta E = \Delta U + \Delta K$

For correct substitutions of y, m, and v_T — 1 point

$\Delta U = -mgy$

$\Delta K = \frac{1}{2}mv_T^2$

$\Delta E = \frac{1}{2}mv_T^2 - mgy$ (or any equation with an additional negative sign that has the correct relative signs for potential and kinetic energies)

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AP® PHYSICS C: MECHANICS
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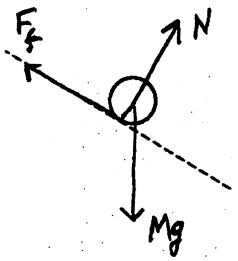
Question 2

15 points total

Distribution of points

(a) 3 points



For each correct force for which the vector is drawn with the correct direction, label and point of application, 1 point was awarded. 3 points
One earned point was deducted if any components or extraneous forces are present.

(b) 5 points

Starting with Newton's second law (linear form):
$F_{net} = Ma$

For expressing F_{net} in terms of gravitational and frictional forces 1 point
For including the correct component of the weight 1 point
$Mg \sin\theta - F_f = Ma$

$\tau = I\alpha$

For correct substitution of torque into Newton's second law (angular form) 1 point
$RF_f = I\alpha$

$RF_f = (2/5)MR^2\alpha$

For the correct relationship between angular and linear acceleration (either explicitly stated or used in the calculation) 1 point
$\alpha = a/R$

$RF_f = (2/5)MR^2(a/R)$

Solving for Ma
$Ma = (5/2)F_f$

Substituting into the linear equation above
$Mg \sin\theta - F_f = (5/2)F_f$

$F_f = (2/7)Mg \sin\theta = (2/7)(6.0\text{ kg})(9.8\text{ m/s}^2)(\sin 30°)$

For the correct value of F_f 1 point
$F_f = 8.4\text{ N}$

Notes: Credit is awarded for solutions that use the value of v calculated in (c) to calculate acceleration and, from there, the value of the frictional force.
If $Mg \cos\theta$ is used, the point was awarded for a value of 14.5 N.

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AP® PHYSICS C: MECHANICS
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Question 2 (continued)

Distribution of points

(c) 3 points

For an expression of conservation of energy — 1 point

For including gravitational potential energy, translational kinetic energy and rotational kinetic energy in a correct energy equation or statement — 1 point

$Mg\Delta h = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$

$Mgd\sin\theta = \frac{1}{2}Mv^2 + \frac{1}{2}\left(\frac{2}{5}MR^2\right)\omega^2$

$\omega = v/R$

$Mgd\sin\theta = \frac{1}{2}Mv^2 + \frac{1}{5}Mv^2 = \frac{7}{10}Mv^2$

$v = \sqrt{(10/7)gd\sin\theta} = \sqrt{(10/7)\left(9.8\ \text{m/s}^2\right)(4.0\ \text{m})(\sin 30°)}$

For a correct numerical answer — 1 point

$v = 5.3$ m/s

Alternate solution (kinematics method) — *Alternate points*

For determination of the linear acceleration in terms of mass and frictional force — *1 point*

$a = 5F_f/2M$ from work shown in part (b)

$a = 5(8.4\ \text{N})/2(6.0\ \text{kg}) = 3.5\ \text{m/s}^2$

For a correct substitution into an appropriate kinematics equation using $v_0 = 0$ — *1 point*

$v^2 = v_0^2 + 2ad = 2ad$

$v = \sqrt{2ad} = \sqrt{(2)\left(3.5\ \text{m/s}^2\right)(4.0\ \text{m})}$

For a correct numerical answer — *1 point*

$v = 5.3$ m/s

(d) 3 points

For a correct statement of conservation of momentum — 1 point

$M_i v_i = M_f v_f$

$v_f = \left(M_i/M_f\right)v_i$

For correctly equating v_i with the horizontal component of the ball as it leaves the roof — 1 point

For setting M_f equal to the total mass of the ball and the wagon/box — 1 point

$v_f = \left(M_i/M_f\right)v\cos\theta = [(6.0\ \text{kg})/(18.0\ \text{kg})]\left(5.3\ \text{m/s}^2\right)\cos 30°$

$v_f = 1.5$ m/s

Units 1 point

For correct units in at least two of the parts (b), (c) and (d) — 1 point

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AP® PHYSICS C: MECHANICS
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Question 3

15 points total

Distribution of points

(a) 4 points

For a correct relationship between velocity and acceleration — 1 point

$v = \int a(t)\,dt$ **OR** $v = \int_0^t a(t)\,dt$ **OR** $\frac{dv}{dt} = a$

For a correct substitution of the expression for acceleration into the integral relationship — 1 point

$v = \int \left(a_{\max} \sin\frac{\pi t}{T}\right) dt$ **OR** $v = \int_0^t \left(a_{\max} \sin\frac{\pi t}{T}\right) dt \qquad (0 < t < T)$

For a correct evaluation of the integral, with an integration constant or correct limits — 1 point

$v = -\frac{a_{\max} T}{\pi} \cos\frac{\pi t}{T} + C$ **OR** $v = -\frac{a_{\max} T}{\pi} \cos\frac{\pi t}{T}\Big|_0^t \qquad (0 < t < T)$

For a correct determination of the integration constant or evaluation between the limits — 1 point

$v(0) = -\frac{a_{\max} T}{\pi} + C = 0 \Rightarrow C = \frac{a_{\max} T}{\pi}$ **OR** $v = -\frac{a_{\max} T}{\pi}\left(\cos\frac{\pi t}{T} - 1\right) \quad (0 < t < T)$

$v = \frac{a_{\max} T}{\pi}\left(1 - \cos\frac{\pi t}{T}\right) \qquad (0 < t < T)$

(b) 2 points

For indicating that the work done by the net force is equal to the change in kinetic energy — 1 point

$W = \frac{1}{2} m\left(v_f^2 - v_i^2\right)$

For a correct substitution of velocity from (a) into the work-energy expression — 1 point

$v_f = v_T = \frac{a_{\max} T}{\pi}(1 - \cos\pi) = \frac{2a_{\max} T}{\pi}$

$v_i = v_0 = \frac{a_{\max} T}{\pi}(1 - \cos 0) = 0$

$W = \frac{1}{2} m\left(\frac{2a_{\max} T}{\pi}\right)^2$

$W = \frac{2ma_{\max}^2 T^2}{\pi^2}$

Alternate solution (integral form) — *Alternate points*

$W = \int F \cdot dx$

For a correct substitution of the expression for force into the integral — *1 point*

$W = \int ma_{\max} \sin\frac{\pi t}{T}\,dx$

For a correct expression for dx in terms of time — *1 point*

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Question 3 (continued)

Distribution of points

(b) (continued)

$$W = \int_0^T ma_{\max} \sin\frac{\pi t}{T}\left(\frac{a_{\max}T}{\pi}\left(1-\cos\frac{\pi t}{T}\right)\right)dt$$

$$W = \frac{ma_{\max}^2 T}{\pi}\int_0^T \left(\sin\frac{\pi t}{T} - \left(\sin\frac{\pi t}{T}\cos\frac{\pi t}{T}\right)\right)dt$$

$$W = \frac{ma_{\max}^2 T}{\pi}\int_0^T \left(\sin\frac{\pi t}{T} - \frac{1}{2}\sin\frac{2\pi t}{T}\right)dt$$

$$W = \frac{ma_{\max}^2 T^2}{\pi^2}\left(-\cos\frac{\pi t}{T} - \frac{1}{4}\cos\frac{2\pi t}{T}\right)\Big|_0^T$$

$$W = \frac{2ma_{\max}^2 T^2}{\pi^2}$$

(c) 1 point

Starting with Newton's second law:
$F_{net} = F_{rope} - mg\sin\theta = ma$
At terminal velocity, the net force and acceleration are zero:
$F_{rope} - mg\sin\theta = 0$
For a correct expression for the force — 1 point
$F_{rope} = mg\sin\theta$

(d) 2 points

$J = \int F\,dt$
For a correct substitution of force into the impulse-time relationship — 1 point
$J = ma_{\max}\int_0^T \sin\frac{\pi t}{T}dt$

$J = \frac{ma_{\max}T}{\pi}\left(-\cos\frac{\pi t}{T}\right)\Big|_0^T$
For evaluation at the limits of integration — 1 point
$J = \frac{ma_{\max}T}{\pi}[-\cos\pi + \cos 0]$

$J = \frac{2ma_{\max}T}{\pi}$

Alternate solution (impulse-momentum) — *Alternate points*

$J = \Delta p = mv_T$

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AP® PHYSICS C: MECHANICS
2010 SCORING GUIDELINES

Question 3 (continued)

Distribution of points

(d) (continued)

For a correct substitution of the velocity

$$J = \frac{ma_{\max}T}{\pi}\left(1 - \cos\frac{\pi t}{T}\right)$$ *1 point*

For setting $t = T$

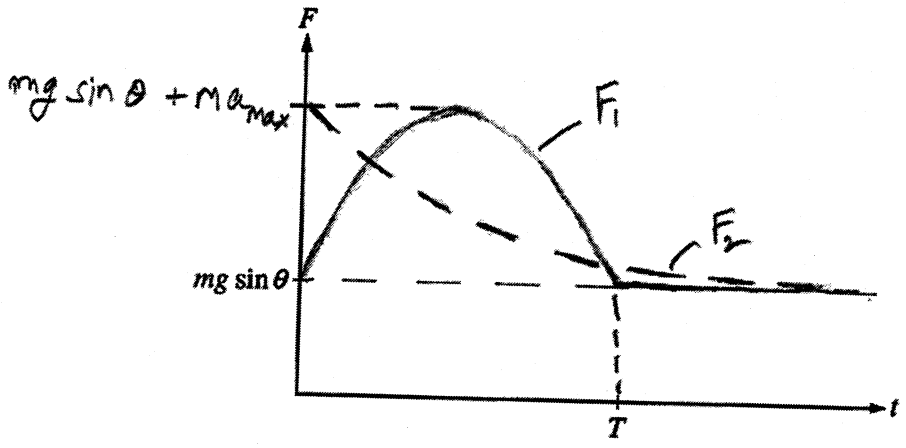
$$J = \frac{ma_{\max}T}{\pi}(1 - \cos\pi)$$ *1 point*

$$J = \frac{2ma_{\max}T}{\pi}$$

(e) 6 points

$$F_1 = mg\sin\theta + ma_{\max}\sin\left(\frac{\pi t}{T}\right) \quad (0 < t < T)$$

$$F_2 = mg\sin\theta + ma_{\max}e^{-\pi t/2T}$$



For a graph labeled F_1:

for starting at $mg\sin\theta$ — 1 point

for half a sine wave with a maximum at $\sim T/2$ — 1 point

for returning to original starting point at $t = T$ — 1 point

for a horizontal line at the original starting point for $t > T$ — 1 point

For a graph labeled F_2:

for starting on the vertical axis at a point above the starting point of F_1 (if there is no F_1 graph, this point was awarded if the F_2 graph starts above $mg\sin\theta$) — 1 point

for an exponential decay graph — 1 point

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