

AP[®] Physics C: Mechanics Practice Exam

From the 2015 Administration

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Note: This publication shows the page numbers that appeared in the **2014–15 AP Exam Instructions** book and in the actual exam. This publication was not repaginated to begin with page 1.

Exam Instructions

The following contains instructions taken from the *2014–15 AP Exam Instructions* book.

AP[®] Physics C: Mechanics Exam

Regularly Scheduled Exam Date: Monday afternoon, May 11, 2015

Late-Testing Exam Date: Friday afternoon, May 22, 2015

Section I Total Time: 45 min. Section II Total Time: 45 min.

Section I Total Time: 45 minutes

Calculator Allowed

Number of Questions: 35*

Percent of Total Score: 50%

Writing Instrument: Pencil required

**The number of questions may vary slightly depending on the form of the exam.*

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

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2014-15 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template(s)
- School Code and Home-School/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 in the testing room”

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 45 of the *2014-15 AP Coordinator's Manual*. See pages 43–46 of the *2014-15 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, he or she must hand copy, date, and sign the release statement on page 44 of the *2014-15 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 279–280 for a seating chart template and instructions. See the *2014-15 AP Coordinator's Manual* for exam seating requirements (pages 48–50, 88).

If you are giving the regularly scheduled exam, say:

It is Monday afternoon, May 11, and you will be taking the AP Physics C: Mechanics Exam.

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

It is Friday afternoon, May 22, and you will be taking the AP Physics C: Mechanics Exam.

In a moment, you will open the packet that contains your exam materials. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2014-15 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. Now place it on page 1 of your answer sheet on the light blue box near the top right-hand 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 will be processed correctly.

Read the statements on the front cover of Section I and look up when you have finished. . . .

Sign your name and write today’s date. Look up when you have finished. . . .

Now print your full legal name where indicated. Are there any questions? . . .

Turn to the back cover and read it completely. Look up when you have finished. . . .

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 these specific multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. . . .

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 here _____. Note Stop Time here _____. 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. 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, face up. 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, face up. I will now collect your Section I booklet. . . .

SECTION II: Free Response

Check that each student has signed the front cover of the sealed Section I booklet. 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 place an AP number label 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 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. . . .

While Student Packs are being collected, 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, be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .

You may begin.



Note Start Time here _____. Note Stop Time here _____. 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, face up. . . .

If any students used extra paper for 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 and include any exam booklets with extra sheets of paper in an Incident Report return envelope (see page 57 of the *AP Coordinator's Manual* for 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 his or her 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 these specific free-response questions with anyone unless they are 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 questions 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, 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 could 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 208 and begin the exam administration for Physics C: Electricity and Magnetism.

If you have no students taking Physics C: Electricity and Magnetism, all exam materials must be placed in secure storage until they are returned to the AP Program after your school's last administration. 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 *2014-15 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.

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.

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.)

76	(A)	(B)	(C)	(D)	(E)
77	(A)	(B)	(C)	(D)	(E)
78	(A)	(B)	(C)	(D)	(E)
79	(A)	(B)	(C)	(D)	(E)
80	(A)	(B)	(C)	(D)	(E)
81	(A)	(B)	(C)	(D)	(E)
82	(A)	(B)	(C)	(D)	(E)
83	(A)	(B)	(C)	(D)	(E)
84	(A)	(B)	(C)	(D)	(E)
85	(A)	(B)	(C)	(D)	(E)
86	(A)	(B)	(C)	(D)	(E)
87	(A)	(B)	(C)	(D)	(E)
88	(A)	(B)	(C)	(D)	(E)
89	(A)	(B)	(C)	(D)	(E)
90	(A)	(B)	(C)	(D)	(E)

91	A	B	C	D	E
92	A	B	C	D	E
93	A	B	C	D	E
94	A	B	C	D	E
95	A	B	C	D	E
96	A	B	C	D	E
97	A	B	C	D	E
98	A	B	C	D	E
99	A	B	C	D	E
100	A	B	C	D	E
101	A	B	C	D	E
102	A	B	C	D	E
103	A	B	C	D	E
104	A	B	C	D	E
105	A	B	C	D	E

106	(A)	(B)	(C)	(D)	(E)
107	(A)	(B)	(C)	(D)	(E)
108	(A)	(B)	(C)	(D)	(E)
109	(A)	(B)	(C)	(D)	(E)
110	(A)	(B)	(C)	(D)	(E)
111	(A)	(B)	(C)	(D)	(E)
112	(A)	(B)	(C)	(D)	(E)
113	(A)	(B)	(C)	(D)	(E)
114	(A)	(B)	(C)	(D)	(E)
115	(A)	(B)	(C)	(D)	(E)
116	(A)	(B)	(C)	(D)	(E)
117	(A)	(B)	(C)	(D)	(E)
118	(A)	(B)	(C)	(D)	(E)
119	(A)	(B)	(C)	(D)	(E)
120	(A)	(B)	(C)	(D)	(E)

For Students Taking AP Biology

121

		/	/	/	
—	•	•	•	•	•
1	0	0	0	0	0
2	1	1	1	1	1
3	2	2	2	2	2
4	3	3	3	3	3
5	4	4	4	4	4
6	5	5	5	5	5
7	6	6	6	6	6
8	7	7	7	7	7
9	8	8	8	8	8

122

—	•	•	•	•	•
	1	0	0	0	0
	2	1	0	1	1
	3	2	1	2	2
	4	3	2	3	3
	5	4	3	4	4
	6	5	4	5	5
	7	6	5	6	6
	8	7	6	7	7
	9	8	7	8	8
	9	9	9	9	9

123

○	○	○	○	○	○
1	0	0	0	0	0
2	1	1	1	1	1
3	2	2	2	2	2
4	3	3	3	3	3
5	4	4	4	4	4
6	5	5	5	5	5
7	6	6	6	6	6
8	7	7	7	7	7
9	8	8	8	8	8

124

-	.	/	/	/	.
1	0	0	0	0	0
2	1	1	1	1	1
3	2	2	2	2	2
4	3	3	3	3	3
5	4	4	4	4	4
6	5	5	5	5	5
7	6	6	6	6	6
8	7	7	7	7	7
9	8	8	8	8	8

125

−	⊙	⊙	⊙	⊙	⊙
	1	0	0	0	0
	2	1	1	1	1
	3	2	2	2	2
	4	3	3	3	3
	5	4	4	4	4
	6	5	5	5	5
	7	6	6	6	6
	8	7	7	7	7
	9	8	8	8	8
		9	9	9	9

126

○	○	/	/	/	
		○	○	○	
	①	0	0	0	0
	②	1	1	1	1
	③	2	2	2	2
	④	3	3	3	3
	⑤	4	4	4	4
	⑥	5	5	5	5
	⑦	6	6	6	6
	⑧	7	7	7	7
	⑨	8	8	8	8
		9	9	9	9

For Students Taking AP Physics 1 or AP Physics 2

131 (A) (B) (C) (D)

132 (A) (B) (C) (D)

133 (A) (B) (C) (D)

134 (A) (B) (C) (D)

135 (A) (B) (C) (D)

136 (A) (B) (C) (D)

137 (A) (B) (C) (D)

138 (A) (B) (C) (D)

139 (A) (B) (C) (D)

140 (A) (B) (C) (D)

141 (A) (B) (C) (D)

142 (A) (B) (C) (D)

[illegible]

DO NOT WRITE IN THIS AREA

Use the address abbreviations from your AP Student Pack. Fill in only one circle per column. Indicate a space in your address by leaving a blank box; do not grid that column.

U. STUDENT SEARCH SERVICE®

☐ Yes ☐ No

If you don't answer and previously chose to participate in this service, we will continue providing your information.

V. SEX

☐ Female

W. WHICH LANGUAGE DO YOU KNOW BEST?

English

☐ English and another language

☐ Another language

X. ETHNICITY/RACE

☐ American Indian or Alaska Native

☐ Asian, Asian American or Pacific Islander

Black or African American

Mexican or Mexican American

Puerto Rican

Other Hispanic, Latino or Latin American

White

Other

Y. PARENTAL EDUCATION I LEVEL

In the first column, indicate the highest level of education of your parent/guardian. If you have two parents/guardians, indicate the level of education for your other parent/guardian in the second column. In the appropriate column for each parent/guardian, indicate whether this is your mother or female guardian or your father or male guardian.

☐ Grade school

☐ Some high school

☐ High school diploma or equivalent

☐ Vocational or trade school

Some college

☐ Associate or two-year degree

☐ Bachelor's or four-year degree

☐ Some graduate or professional school☐ Graduate or professional degree

☐ Mother or female guardian

☐ Father or male guardian

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3. STUDENT IDENTIFIER (Student ID Number)

R. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

☐ If your address does not fit in the spaces provided in Item Q, fill in as many circles as you can, then fill in the circle in Item R and print the remainder of your address in the spaces provided.

Address

City

State or Province

ZIP or Postal Code

T. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email in accordance with the policies in the 2014-15 Bulletin for AP Students and Parents.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2015 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

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) ● (C) (D) (E)

(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

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

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

$$v_x = v_{x0} + a_x t$$

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

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

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mg\Delta h$$

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

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

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

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

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

$$v = r\omega$$

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

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

$$\omega = \omega_0 + \alpha t$$

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

$$a = \text{acceleration}$$

$$E = \text{energy}$$

$$F = \text{force}$$

$$f = \text{frequency}$$

$$h = \text{height}$$

$$I = \text{rotational inertia}$$

$$J = \text{impulse}$$

$$K = \text{kinetic energy}$$

$$k = \text{spring constant}$$

$$\ell = \text{length}$$

$$L = \text{angular momentum}$$

$$m = \text{mass}$$

$$P = \text{power}$$

$$p = \text{momentum}$$

$$r = \text{radius or distance}$$

$$T = \text{period}$$

$$t = \text{time}$$

$$U = \text{potential energy}$$

$$v = \text{velocity or speed}$$

$$W = \text{work done on a system}$$

$$x = \text{position}$$

$$\mu = \text{coefficient of friction}$$

$$\theta = \text{angle}$$

$$\tau = \text{torque}$$

$$\omega = \text{angular speed}$$

$$\alpha = \text{angular acceleration}$$

$$\phi = \text{phase angle}$$

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

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

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

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

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

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

$$|\vec{F}_G| = \frac{Gm_1 m_2}{r^2}$$

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

ELECTRICITY AND MAGNETISM

$$|\vec{F}_E| = \frac{1}{4\pi\epsilon_0} \left| \frac{q_1 q_2}{r^2} \right|$$

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

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$$

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

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

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Nev_d A$$

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

$$R_s = \sum_i R_i$$

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

$$P = I\Delta V$$

$$A = \text{area}$$

$$B = \text{magnetic field}$$

$$C = \text{capacitance}$$

$$d = \text{distance}$$

$$E = \text{electric field}$$

$$\mathcal{E} = \text{emf}$$

$$F = \text{force}$$

$$I = \text{current}$$

$$J = \text{current density}$$

$$L = \text{inductance}$$

$$\ell = \text{length}$$

$$n = \text{number of loops of wire per unit length}$$

$$N = \text{number of charge carriers per unit volume}$$

$$P = \text{power}$$

$$Q = \text{charge}$$

$$q = \text{point charge}$$

$$R = \text{resistance}$$

$$r = \text{radius or distance}$$

$$t = \text{time}$$

$$U = \text{potential or stored energy}$$

$$V = \text{electric potential}$$

$$v = \text{velocity or speed}$$

$$\rho = \text{resistivity}$$

$$\Phi = \text{flux}$$

$$\kappa = \text{dielectric constant}$$

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

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

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

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

$$B_s = \mu_0 nI$$

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

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$

$$\mathcal{E} = -L \frac{dI}{dt}$$

$$U_L = \frac{1}{2} LI^2$$

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

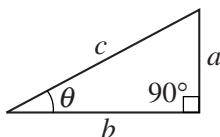
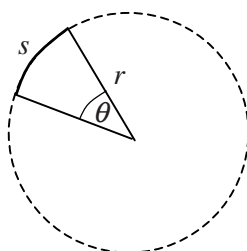
ℓ = length

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

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

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

PHYSICS C: MECHANICS

SECTION I

Time—45 minutes

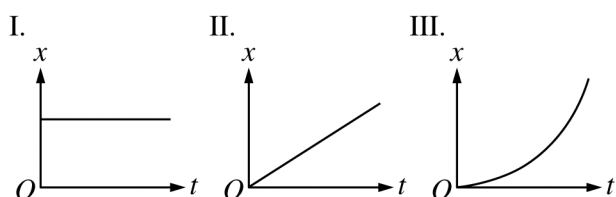
35 Questions

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.

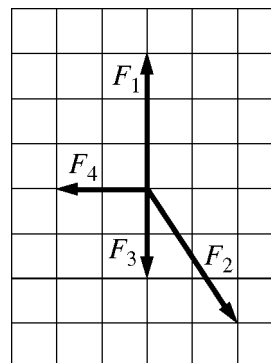
Note: To simplify calculations, you may use $g = 10\text{ m/s}^2$ in all problems.

Questions 1-3

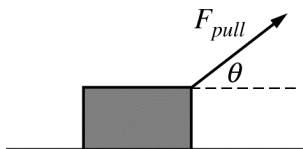
The graphs below show position x plotted as a function of time t for each of three objects constrained to move along a straight, level path.



- In which of the graphs is the magnitude of the momentum of the object increasing?
 - II only
 - III only
 - I and II
 - I and III
 - II and III
- In which of the graphs does the object have a constant nonzero kinetic energy?
 - I only
 - II only
 - III only
 - I and II
 - I and III
- In which of the graphs is the net force on the object zero?
 - I only
 - III only
 - I and II only
 - II and III only
 - I, II, and III



- 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?
 - F_1 and F_3 only
 - F_1 , F_2 , and F_4 only
 - F_2 , F_3 , and F_4 only
 - All four forces
 - No combination of the forces would result in equilibrium.



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?

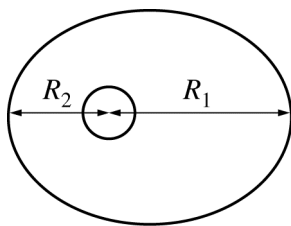
(A) $\frac{1}{2}L$
 (B) L
 (C) $\sqrt{2}L$
 (D) $2L$
 (E) $4L$

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.

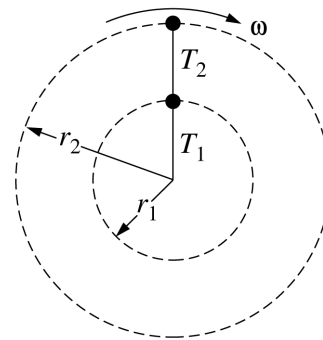
11. A newly discovered planet has three times the mass and five times the radius of Earth. What is the ratio of the acceleration due to gravity at the surface of the new planet to the acceleration due to gravity at the surface of Earth?

- (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

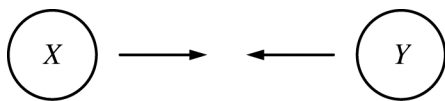


13. Two objects of equal mass m are tied to a string and placed on a horizontal frictionless tabletop. The string and objects spin with angular velocity ω so that the objects move in circles of radius r_1 and r_2 , as shown above. The tensions T_1 and T_2 must satisfy which of the following relations?

- (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

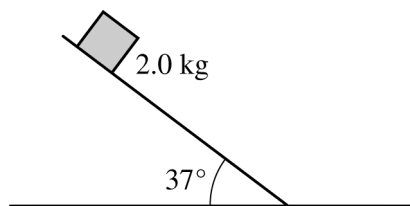


15. Two 1.0 kg balls have a perfectly elastic head-on collision, as shown in the figure above. Before the collision, ball X has a velocity of 2.0 m/s to the right and ball Y has a velocity of 4.0 m/s to the left. After the collision, ball X has a velocity of

(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

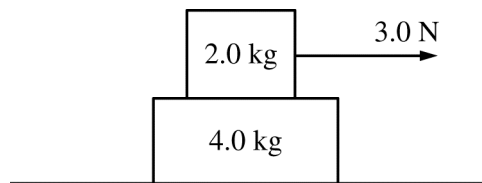
16. An object of mass m and velocity $3v$ toward the east has a completely inelastic collision with an object of mass $2m$ and velocity $2v$ toward the north. After the collision, the momentum of the combined object has a magnitude of

(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?

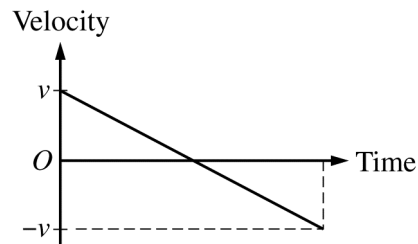
(A) zero
 (B) $g/6$
 (C) $g/3$
 (D) $g/2$
 (E) g

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) $\vec{v}/2$

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?

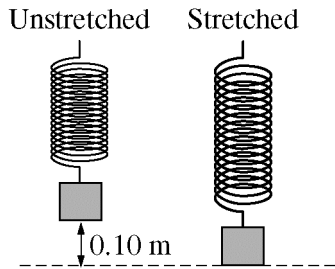
- (A) The coin hits the bottom of the tube first because it weighs more.
- (B) The coin hits the bottom of the tube first because it is more dense.
- (C) The feather hits the bottom of the tube first because it weighs less.
- (D) The coin and feather hit the bottom of the tube at the same time because 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.

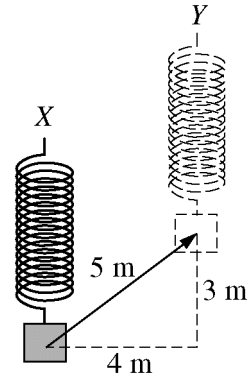
Questions 23-24



Note: Figure not drawn to scale.

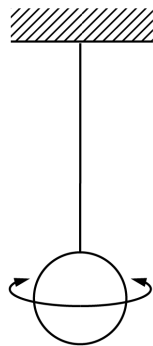
A block is hung vertically from a spring of force constant 50 N/m and slowly lowered to equilibrium, stretching the spring by 0.10 m , as shown in the figure above.

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.



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 $10 \text{ kg}\cdot\text{m}^2$, then the torsion constant of the wire is most nearly

- (A) $7 \text{ kg}\cdot\text{m}^2/\text{s}^2$
- (B) $20 \text{ kg}\cdot\text{m}^2/\text{s}^2$
- (C) $30 \text{ kg}\cdot\text{m}^2/\text{s}^2$
- (D) $40 \text{ kg}\cdot\text{m}^2/\text{s}^2$
- (E) $50 \text{ kg}\cdot\text{m}^2/\text{s}^2$

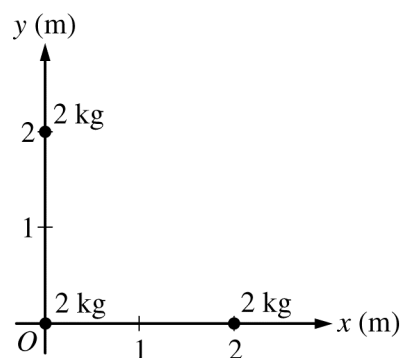
26. Assuming air resistance is negligible, how does a diver doing flips off a diving board change rotational speed in midair?

- (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.

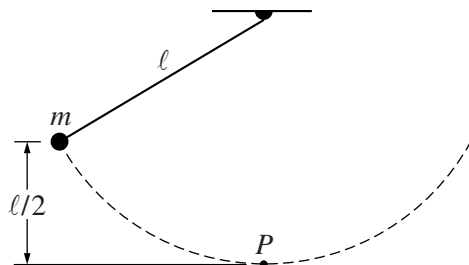
- (A) I only
- (B) III only
- (C) I and II only
- (D) II and III only
- (E) I, II, and III



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) $(1/2 \text{ m}, 1/2 \text{ m})$
- (B) $(2/3 \text{ m}, 2/3 \text{ m})$
- (C) $(3/4 \text{ m}, 3/4 \text{ m})$
- (D) $(1 \text{ m}, 1 \text{ m})$
- (E) $(4/3 \text{ m}, 4/3 \text{ m})$

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.

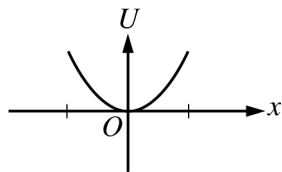
29. The speed of the ball as it swings through point P is

- (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?

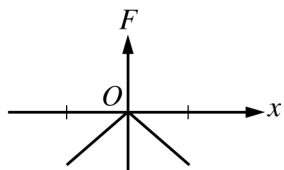
- I. Mechanical energy of the ball-Earth system
- II. Linear momentum of the ball
- III. Angular momentum of the ball about the pivot point

- (A) I only
- (B) II only
- (C) I and III only
- (D) II and III only
- (E) I, II, and III

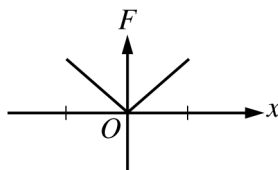


31. The graph above shows potential energy U versus position x for an object. Which of the following graphs shows the force F exerted on the object as a function of position x ?

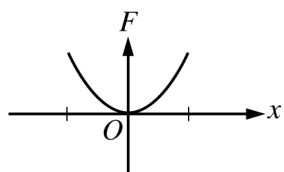
(A)



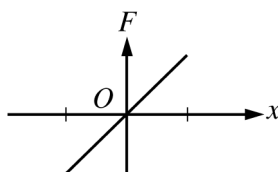
(B)



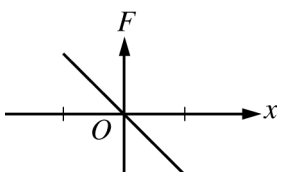
(C)

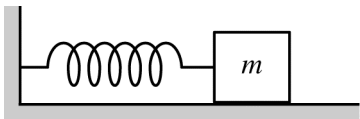


(D)



(E)





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?

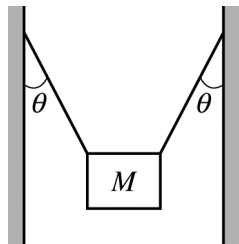
(A) 1 cm
(B) $\sqrt{2}$ cm
(C) 2 cm
(D) $2\sqrt{2}$ cm
(E) 3 cm

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 $F(t) = (4t - t^3)$ 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



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**

Section II: Free-Response Questions

This is the free-response section of the 2015 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

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

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

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

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

$$v_x = v_{x0} + a_x t$$

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

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

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mg \Delta h$$

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

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

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

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

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

$$v = r \omega$$

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

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

$$\omega = \omega_0 + \alpha t$$

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

$$a = \text{acceleration}$$

$$E = \text{energy}$$

$$F = \text{force}$$

$$f = \text{frequency}$$

$$h = \text{height}$$

$$I = \text{rotational inertia}$$

$$J = \text{impulse}$$

$$K = \text{kinetic energy}$$

$$k = \text{spring constant}$$

$$\ell = \text{length}$$

$$L = \text{angular momentum}$$

$$m = \text{mass}$$

$$P = \text{power}$$

$$p = \text{momentum}$$

$$r = \text{radius or distance}$$

$$T = \text{period}$$

$$t = \text{time}$$

$$U = \text{potential energy}$$

$$v = \text{velocity or speed}$$

$$W = \text{work done on a system}$$

$$x = \text{position}$$

$$\mu = \text{coefficient of friction}$$

$$\theta = \text{angle}$$

$$\tau = \text{torque}$$

$$\omega = \text{angular speed}$$

$$\alpha = \text{angular acceleration}$$

$$\phi = \text{phase angle}$$

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

$$|\vec{F}_E| = \frac{1}{4\pi\epsilon_0} \left| \frac{q_1 q_2}{r^2} \right|$$

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

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$$

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

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

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Ne v_d A$$

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

$$R_s = \sum_i R_i$$

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

$$P = I \Delta V$$

$$A = \text{area}$$

$$B = \text{magnetic field}$$

$$C = \text{capacitance}$$

$$d = \text{distance}$$

$$E = \text{electric field}$$

$$\mathcal{E} = \text{emf}$$

$$F = \text{force}$$

$$I = \text{current}$$

$$J = \text{current density}$$

$$L = \text{inductance}$$

$$\ell = \text{length}$$

$$n = \text{number of loops of wire per unit length}$$

$$N = \text{number of charge carriers per unit volume}$$

$$P = \text{power}$$

$$Q = \text{charge}$$

$$q = \text{point charge}$$

$$R = \text{resistance}$$

$$r = \text{radius or distance}$$

$$t = \text{time}$$

$$U = \text{potential or stored energy}$$

$$V = \text{electric potential}$$

$$v = \text{velocity or speed}$$

$$\rho = \text{resistivity}$$

$$\Phi = \text{flux}$$

$$\kappa = \text{dielectric constant}$$

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

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

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

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

$$B_s = \mu_0 n I$$

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

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$

$$\mathcal{E} = -L \frac{dI}{dt}$$

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

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

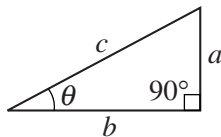
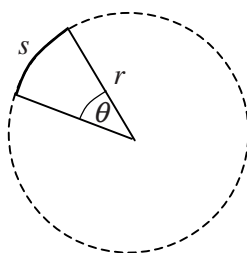
ℓ = length

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

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

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

PHYSICS C: MECHANICS

SECTION II

Time—45 minutes

3 Questions

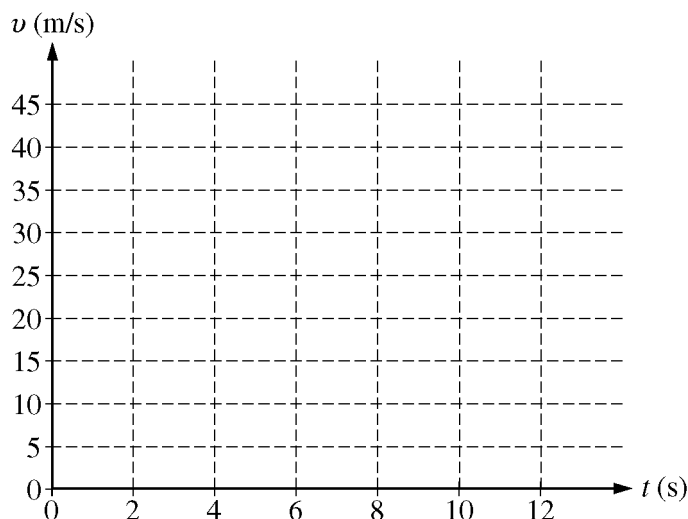
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

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.

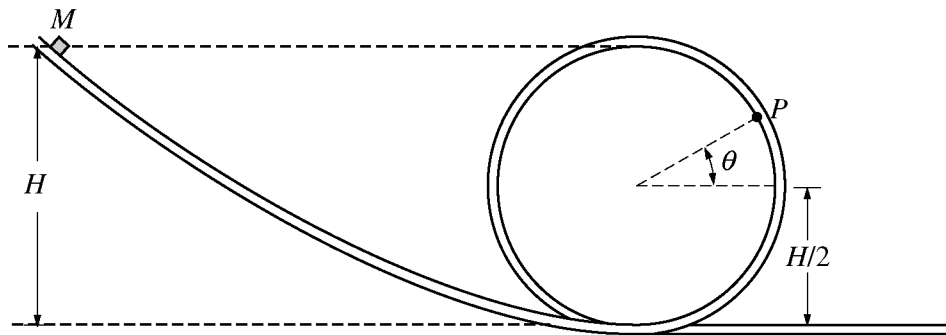
- (c) Explain how you would use your graph in part (a) to find the distance traveled by the car between $t = 2$ s and $t = 8$ s.

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.

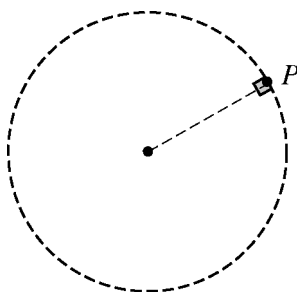


Mech. 2.

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 .



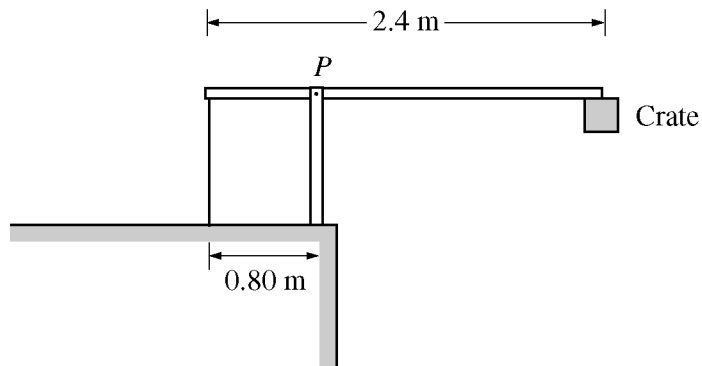
- (c) Derive an expression for the magnitude of the force exerted by the loop on the block when it is at position P . If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

- (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.



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).

(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

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.**

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

Free-Response Scoring Guidelines

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

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 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.

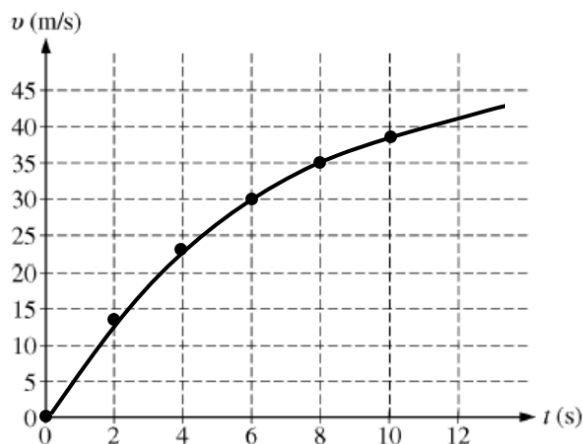
AP[®] PHYSICS C: MECHANICS 2015 SCORING GUIDELINES

Question 1

15 points total

**Distribution
of points**

(a) 3 points



For accurately plotting at least five points
For a smooth curve with a positive slope
For a concave down curve starting at the origin

1 point
1 point
1 point

(b)
i. 1 point

The correct choice is “Increase”
For a correct justification
Example: The speed increases as the magnitude of the velocity increases for each data point

1 point

ii. 1 point

The correct choice is “Decrease”
For a correct justification
Example: Since the slope of the line decreases with time, the acceleration of the car must decrease with time

1 point

(c) 2 points

For mentioning area under the curve
For specifically describing the area between $t = 2$ s and $t = 8$ s
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.

1 point
1 point

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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
$a(t) = \frac{d}{dt}(-0.3t^2 + 7t) = -0.6t + 7$	
(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
$\Delta x = \int_0^t (-0.3t^2 + 7t) dt$	
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
$x(2) = 13.2 \text{ m}$	
$x(8) = 172.8 \text{ m}$	
For the correct answer with units	1 point
$\Delta x = 159.6 \text{ m}$	
<i>Alternate solution</i>	<i>Alternate points</i>
<i>For using the integral of the speed and recognizing that the distance is the change in position</i>	<i>1 point</i>
<i>For using the correct limits or constant of integration</i>	<i>1 point</i>
$\Delta x = \int_2^8 (-0.3t^2 + 7t) dt$	
$\Delta x = \left. \frac{-0.3t^3}{3} + \frac{7t^2}{2} \right _2^8 = -51.2 + 224 - (-0.8 + 14)$	
<i>For the correct answer with units</i>	<i>1 point</i>
$\Delta x = 159.6 \text{ m}$	

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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

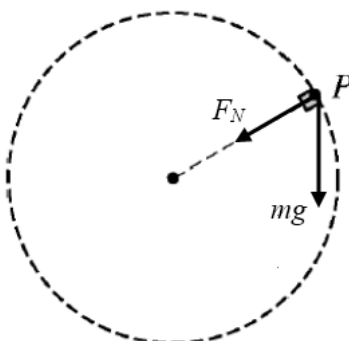
$$y_P = \frac{H}{2} + \frac{H}{2}\sin\theta$$

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

$$F_N + w_{\text{radial}} = \frac{mv^2}{R}$$

For using the correct radial component of the weight

1 point

$$w_{\text{radial}} = mg \sin\theta$$

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)

1 point

$$0 = mg(2 - 3\sin\theta)$$

$$3\sin\theta = 2$$

$$\theta = \sin^{-1}(2/3)$$

For an answer consistent with part (c)

1 point

$$\theta = 41.8^\circ$$

(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.

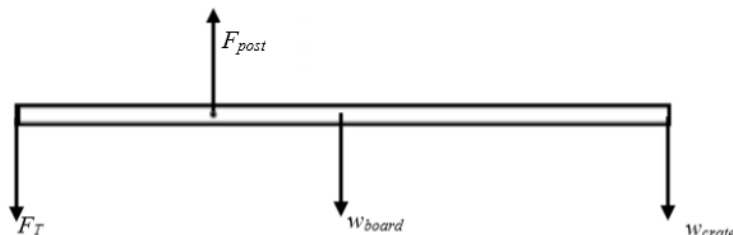
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Question 3

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:

$$\tau_{\text{cw}} - \tau_{\text{ccw}} = 0$$

$$\tau_{w\text{-board}} + \tau_{w\text{-crate}} = \tau_{\text{post}}$$

For substituting correct radii for all torques

1 point

$$(200 \text{ N})(1.2 \text{ m}) + (400 \text{ N})(2.4 \text{ m}) = (F_{\text{post}})(0.8 \text{ m})$$

For correctly calculating either the tension or the post force

1 point

$$F_{\text{post}} = 1500 \text{ N}$$

For a correct method for determining the remaining force and a consistent answer

1 point

$$F_{\text{up}} = F_{\text{down}}$$

$$F_{\text{post}} = w_{\text{board}} + w_{\text{crate}} + F_T$$

$$F_T = 1500 \text{ N} - 200 \text{ N} - 400 \text{ N}$$

$$F_T = 900 \text{ N}$$

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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

$$I_{\text{board}-P} = Md^2 + I_{\text{cm}} = Md^2 + \frac{1}{12}ML^2$$

$$I_{\text{board}-P} = \left(\frac{200 \text{ N}}{9.8 \text{ m/s}^2} \right) (0.4 \text{ m})^2 + \frac{1}{12} \left(\frac{200 \text{ N}}{9.8 \text{ m/s}^2} \right) (2.4 \text{ m})^2 = 13.1 \text{ kg}\cdot\text{m}^2$$

(or $12.8 \text{ kg}\cdot\text{m}^2$ using $g = 10 \text{ m/s}^2$)

For correctly calculating the rotational inertia of the crate about P

1 point

$$I = m_{\text{crate}} r^2 = \left(\frac{400 \text{ N}}{9.8 \text{ m/s}^2} \right) (1.6)^2 = 104.5 \text{ kg}\cdot\text{m}^2$$

(or $102.4 \text{ kg}\cdot\text{m}^2$ 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

$$\Sigma I_P = 117.6 \text{ kg}\cdot\text{m}^2 \quad (\text{or } 115.2 \text{ kg}\cdot\text{m}^2 \text{ using } g = 10 \text{ m/s}^2)$$

(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

$$\alpha = 6.13 \text{ rad/s}^2 \quad (\text{or } 6.25 \text{ rad/s}^2 \text{ using } g = 10 \text{ m/s}^2)$$

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

$$a = 4.9 \text{ m/s}^2 \quad (\text{or } 5.0 \text{ m/s}^2 \text{ using } g = 10 \text{ m/s}^2)$$

Units 1 point

For correct units on all answers

1 point

Scoring Worksheet

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

2015 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

$$\frac{\text{Number Correct}}{\text{(out of 35)}} \times 1.2857 = \frac{\text{Weighted Section I Score}}{\text{(Do not round)}}$$

Section II: Free Response

$$\text{Question 1} \quad \frac{\text{out of 15}}{\text{(out of 15)}} \times 1.0000 = \frac{\text{(Do not round)}}$$

$$\text{Question 2} \quad \frac{\text{out of 15}}{\text{(out of 15)}} \times 1.0000 = \frac{\text{(Do not round)}}$$

$$\text{Question 3} \quad \frac{\text{out of 15}}{\text{(out of 15)}} \times 1.0000 = \frac{\text{(Do not round)}}$$

$$\text{Sum} = \frac{\text{Weighted Section II Score}}{\text{(Do not round)}}$$

Composite Score

$$\frac{\text{Weighted Section I Score}}{\text{Weighted Section I Score}} + \frac{\text{Weighted Section II Score}}{\text{Weighted Section II Score}} = \frac{\text{Composite Score}}{\text{(Round to nearest whole number)}}$$

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

AP Physics C: Mechanics

The College Board

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