From the 2017 Administration

AP® CollegeBoard

Physics C: Mechanics

Practice Exam

Contents

Note: This publication shows the page numbers that appeared in the ***2016–17 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 *2016–17 AP Exam Instructions* book.

AP® Physics C: Mechanics Exam

Regularly Scheduled Exam Date: Monday afternoon, May 8, 2017

Late-Testing Exam Date: Friday afernoon, May 19, 2017

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
- *2016-17 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template
- 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"

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.

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 49 of the *2016-17 AP Coordinator's Manual*. See pages 46–49 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, he or she must hand copy, date, and sign the release statement on page 47 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 325–326 for a seating chart template and instructions. See the *2016-17 AP Coordinator's Manual* for exam seating requirements (pages 51–54).

If you are giving the regularly scheduled exam, say:

> **It is Monday afternoon, May 8, 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 19, 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 *2016-17 Bulletin for AP Students and Parents*.**

> **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:

> **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 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.

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 of your exam booklet 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 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 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 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 a pen with black or dark blue ink, 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, be sure to 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 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 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. A single Incident Report may be completed for multiple students per exam subject per administration (regular or late testing) as long as all of the required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 62 of the *2016-17 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 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 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 245 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.

Post-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.

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.

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 *2016-17 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.)

AP® Answer Sheet 2017

AP Number Label (from Student Pack)

123456789

AP Exam Label (from Section I Booklet)

CollegeBoard

COMPLETE THIS AREA AT EVERY EXAM. **USE NO. 2 PENCIL ONLY**

To maintain the security of the exam and the validity of my AP score, I will allow no one else to see the multiple-choice exam content. I will seal the multiple-choice booklet when asked to do so, and I will not discuss the exam content with anyone at any time after completing the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the *2016-17 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

A. SIGNATURE — Sign your legal name as it will appear on your college applications. — Date

B. LEGAL NAME — Omit apostrophes, Jr., II.

Legal Last Name — First 15 Letters | Legal First Name — First 12 Letters | MI

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z –

C. YOUR AP NUMBER

0 1 2 3 4 5 6 7 8 9

D. EXAM DATE

Month | Day

E. EXAM START TIME

AM	PM
6	12
7	1
8	2
9	3
10	4
11	5

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER

S

0 1 2 3 4 5 6 7 8 9

G. ONLINE PROVIDER CODE

0 1 2 3 4 5 6 7 8 9

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET

Exam Name: | Form: | Form Code:

792107

SCHOOL USE ONLY

Section Number: 1 2 3 4 5 6 7 8 9

Fee Reduction Granted: 1 Option 1 2 Option 2

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

0 1 2 3 4 5 6 7 8 9

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE

0 1 2 3 4 5 6 7 8 9

School Name

City

State

Country

K. DATE OF BIRTH

Month | Day | Year

Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

L. SOCIAL SECURITY NUMBER (Optional)

0 1 2 3 4 5 6 7 8 9

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE

Using the college code listed in the AP Student Pack, indicate the **ONE** college that you want to receive your AP score report.

College Name

City

State

Country

N. CURRENT GRADE LEVEL

- Not yet in 9th grade
- 9th
- 10th
- 11th
- 12th
- No longer in high school

O. STUDENT SEARCH SERVICE®

Colleges and scholarship programs may request your information to inform you of educational opportunities and financial aid.

Would you like us to supply your information?

Yes No

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

113913-00657 • UNLWEB1116

Q4298/1-4

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

P. SURVEY QUESTIONS — Answer the survey questions in the AP Student Pack. Do not put responses to exam questions in this section.

1	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ	4	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ
2	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ	5	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ
3	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ	6	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ
7	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ		
8	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ		
9	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ Ⓕ Ⓖ Ⓗ Ⓘ		

Q. LANGUAGE — Do not complete this section unless instructed to do so.

If this answer sheet is for the French Language and Culture, German Language and Culture, Italian Language and Culture, Spanish Language and Culture, or Spanish Literature and Culture Exam, please answer the following questions. Your responses will not affect your score.

1. Have you lived or studied for one month or more in a country where the language of the exam you are now taking is spoken?

◯ Yes ◯ No

2. Do you regularly speak or hear the language at home?

◯ Yes ◯ No

QUESTIONS 1–75

Indicate your answers to the exam questions in this section (pages 2 and 3). Mark only one response per question for Questions 1 through 120. If a question has only four answer options, do not mark option E. Answers written in the multiple-choice booklet will not be scored.

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS

You must use a No. 2 pencil and marks must be complete. Do not use a mechanical pencil. It is very important that you fill in the entire circle darkly and completely. If you change your response, erase as completely as possible. Incomplete marks or erasures may affect your score.

1	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	26	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	51	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
2	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	27	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	52	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
3	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	28	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	53	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
4	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	29	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	54	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
5	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	30	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	55	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
6	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	31	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	56	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
7	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	32	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	57	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
8	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	33	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	58	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
9	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	34	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	59	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
10	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	35	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	60	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
11	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	36	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	61	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
12	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	37	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	62	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
13	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	38	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	63	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
14	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	39	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	64	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
15	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	40	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	65	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
16	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	41	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	66	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
17	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	42	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	67	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
18	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	43	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	68	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
19	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	44	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	69	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
20	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	45	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	70	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
21	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	46	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	71	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
22	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	47	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	72	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
23	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	48	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	73	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
24	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	49	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	74	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
25	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	50	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	75	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

ETS USE ONLY

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

SELECTED MEDIA EXAMS	R	W	O	OTHER EXAMS	R	W	O
PT02				TOTAL			
PT03				Subscore (if applicable)			
PT04				Subscore (if applicable)			

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

Be sure each mark is dark and completely fills the circle. If a question has only four answer options, do not mark option E.

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

QUESTIONS 121–126

For Students Taking AP Biology

Write your answer in the boxes at the top of the griddable area and fill in the corresponding circles. Mark only one circle in any column. You will receive credit only if the circles are filled in correctly.

121
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

122
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

123
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

124
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

125
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

126
/ / /
– . . . . .
0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

QUESTIONS 131–142

For Students Taking AP Computer Science Principles, AP Physics 1, or AP Physics 2

Mark two responses per question. You will receive credit only if both correct responses are selected.

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

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

R. YOUR MAILING ADDRESS

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.

STREET ADDRESS (include street number, street name, apartment number, etc.)

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

		MI	NY	VT
AK	HI	MN	OH	WA
AL	IA	MO	OK	WI
AR	ID	MS	OR	WV
AZ	IL	MT	PA	WY
CA	IN	NC	RI	Puerto Rico
CO	KS	ND	SC	
CT	KY	NE	SD	AA
DC	LA	NH	TN	AE
DE	MA	NJ	TX	AP
FL	MD	NM	UT	Other
GA	ME	NV	VA	

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email address in accordance with the policies in the *2016-17 Bulletin for AP Students and Parents.*

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

- English
- English and another language about the same
- Another language

X. RACIAL/ETHNIC GROUP

Please answer both questions about Hispanic origin and about race. For the following questions about your identity, Hispanic origins are not races.

(You may mark all that apply.)

a. Are you of Hispanic, Latino, or Spanish origin?

- No, not of Hispanic, Latino, or Spanish origin
- Yes, Cuban
- Yes, Mexican
- Yes, Puerto Rican
- Yes, another Hispanic, Latino, or Spanish origin

b. What is your race?

- American Indian or Alaska Native
- Asian (including Indian subcontinent and Philippines origin)
- Black or African American (including Africa and Afro-Caribbean origin)
- Native Hawaiian or other Pacific Islander
- White (including Middle Eastern origin)

Y. PARENTAL EDUCATION LEVEL

In the first column, indicate the highest level of education of one parent/guardian, and indicate whether this is your mother/female guardian or father/male guardian. Then, if applicable, indicate the highest level of education of your other parent/guardian in the second column, and indicate whether this is your mother/female guardian or father/male guardian.

- **Mother or female guardian**
- **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

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2017 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

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

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,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ (\text{N}\cdot\text{m}^2)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\Delta U_g = mg\Delta h$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

a = 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

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

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

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

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

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

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

$\left|\vec{F}_G\right| = \frac{Gm_1m_2}{r^2}$

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

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0}\left|\frac{q_1q_2}{r^2}\right|$

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

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

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

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

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

$U_E = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

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

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

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

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

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

$B_s = \mu_0 nI$

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

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

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

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

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

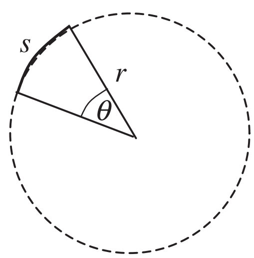
$a^2 + b^2 = c^2$

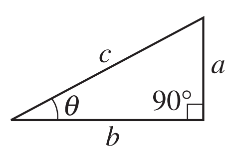
$\sin\theta = \frac{a}{c}$

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

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

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

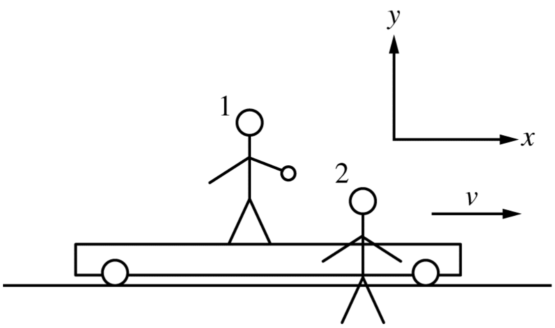
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

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

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.

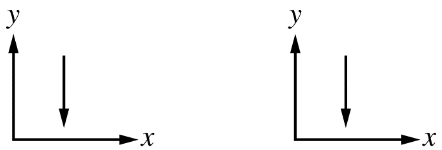
   What is the plane's speed at *t* = 30 s ?

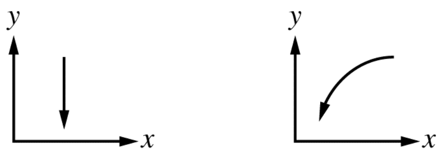
   (A) 10 m/s
   (B) 30 m/s
   (C) 100 m/s
   (D) 150 m/s
   (E) 300 m/s

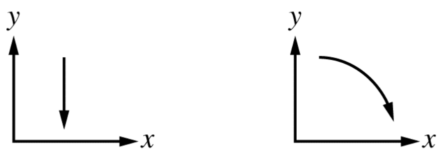


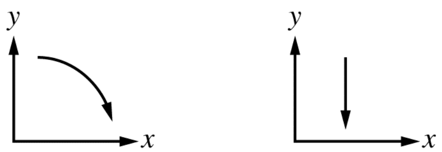
2. Student 1 is standing on a cart holding a small stone, while student 2 is standing at rest on the ground, as shown in the figure above. The cart is moving at a constant speed v in the $+x$-direction, as indicated by the coordinate system shown. Student 1 drops the stone precisely when passing student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

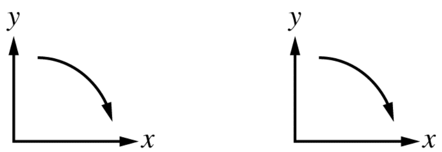
<u>Student 1</u> <u>Student 2</u>

(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

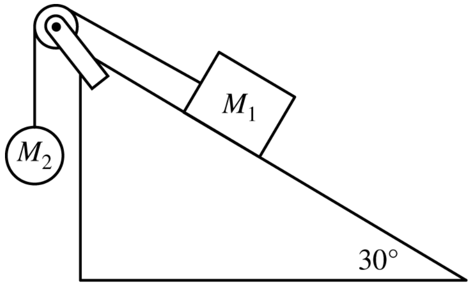
(A) not constant
(B) 0
(C) $4.8 \text{ kg}\bullet\text{m}^2/\text{s}$
(D) $6.4 \text{ kg}\bullet\text{m}^2/\text{s}$
(E) $8.0 \text{ kg}\bullet\text{m}^2/\text{s}$

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.



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) $M_1 < M_2\left(\sin 30^\circ\right)$
(D) $M_1\left(\sin 30^\circ\right) < M_2$
(E) $M_1\left(\sin 30^\circ\right) > M_2$

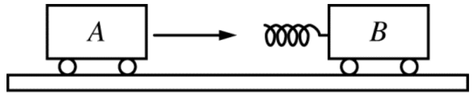


Figure 1

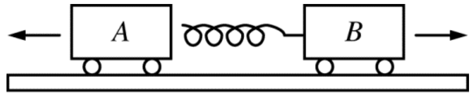


Figure 2

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?

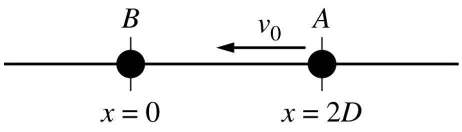
	Kinetic energy	Magnitude of Momentum
(A)	Increases	Decreases
(B)	Increases	Stays the same
(C)	Increases	Increases
(D)	Stays the same	Increases
(E)	Stays the same	Stays the same

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.

GO ON TO THE NEXT PAGE.

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

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

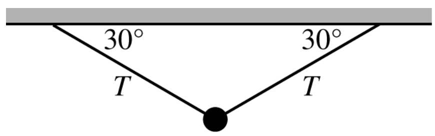
(C) $\dfrac{\beta}{4D^2} + \dfrac{1}{2}Mv_0^2 = \dfrac{\beta}{r_{MIN}^2} + \dfrac{1}{2}Mv_0^2$

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

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

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 $4.0\ \text{m/s}^2$.
(C) It is about $9.0\ \text{m/s}^2$.
(D) It is about $10\ \text{m/s}^2$.
(E) It cannot be determined without knowing the mass of the skier.

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 $R = 5\ \text{m/s}$ and $S = 10\ \text{m/s}^2$. The positive direction is upward.

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

(A) $-10\ \text{m/s}^2$
(B) $-5\ \text{m/s}^2$
(C) 0
(D) $5\ \text{m/s}^2$
(E) $10\ \text{m/s}^2$

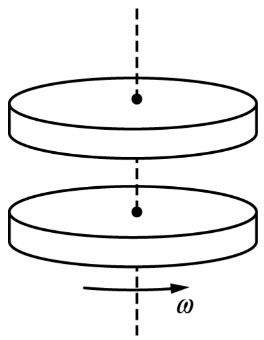
15. At what time does the ball reach its maximum height above the building?

(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

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) $\dfrac{MR^2\omega_f}{\Delta t}$

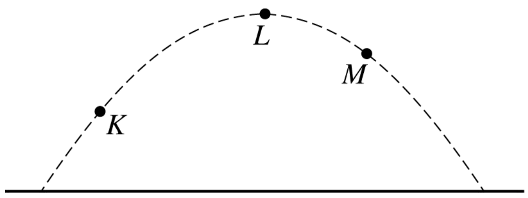
(C) $\dfrac{MR^2\omega_f}{2\Delta t}$

(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) $10MR^2$



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?

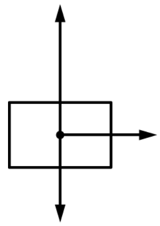
(A) $a_K = a_L = a_M$
(B) $a_K = a_L > a_M$
(C) $a_K = a_M > a_L$
(D) $a_K > a_L = a_M$
(E) $a_K > a_M > a_L$

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) 

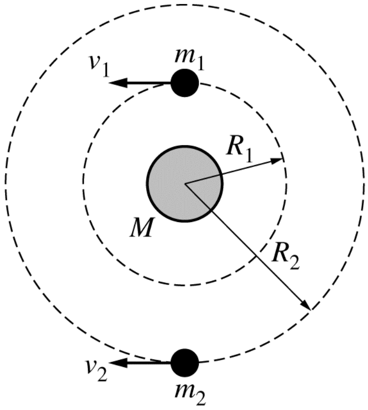
(C) 

(D) 

(E)

GO ON TO THE NEXT PAGE.

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) $\dfrac{m_1R_1}{m_2R_2}$

(B) $\dfrac{m_2R_2}{m_1R_1}$

(C) $\dfrac{m_1R_2}{m_2R_1}$

(D) $\dfrac{m_2R_1}{m_1R_2}$

(E) $\dfrac{m_1R_2^2}{m_2R_1^2}$

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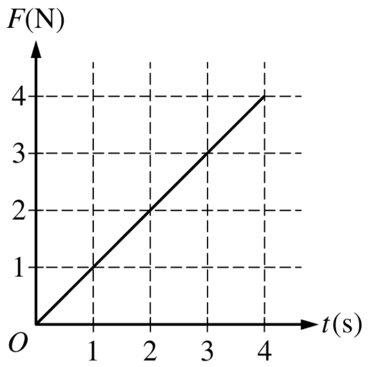
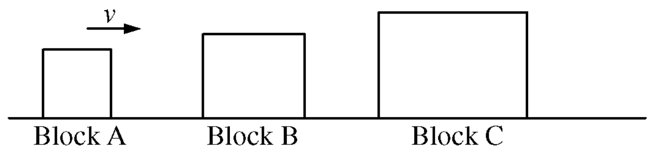


27. The graph above shows a variable force F that acts on an object as it moves along a straight line as a function of time t. What is the change in momentum of the object from $t = 2$ s to $t = 4$ s ?

(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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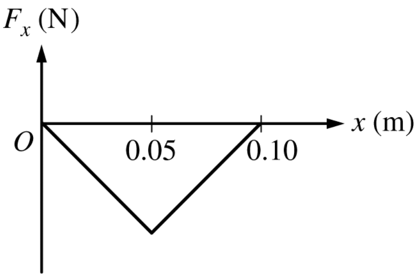


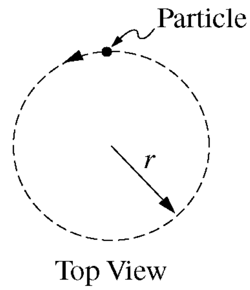
29. The graph above shows a conservative force F_x as a function of position x acting on an object in a closed system. If this is the only force acting on the object, what happens to the potential energy of the system as the object moves from 0 m to 0.10 m?

(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



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 $t \geq 0$.

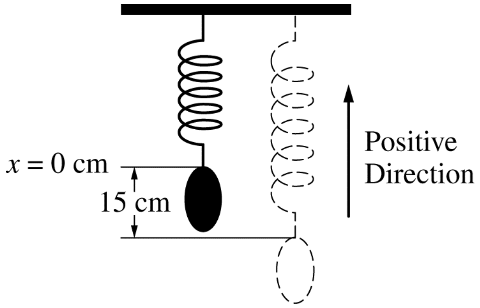
31. Which of the following best describes the acceleration vector for the particle at the moment shown in the diagram?

(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) $mb^2r^2t^2$

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.

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 2017 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

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

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 4NBP4-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, $N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	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, $g = 9.8 \text{ m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} = 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25} \text{ J}\cdot\text{m} = 1.24 \times 10^{3} \text{ eV}\cdot\text{nm}$
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\left(\text{N}\cdot\text{m}^2\right)$
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,	$1 \text{ atm} = 1.0 \times 10^{5} \text{ N/m}^2 = 1.0 \times 10^{5}$ 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

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

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

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

$V = \pi r^2 \ell$

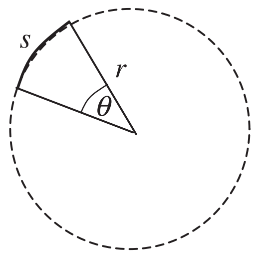
$S = 2\pi r\ell + 2\pi r^2$

Sphere

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

$S = 4\pi r^2$

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



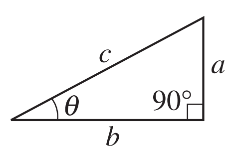
Right Triangle

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

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

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

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



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

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

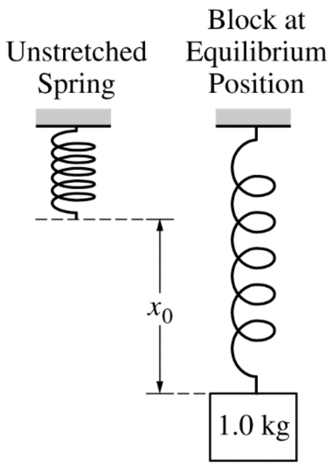
$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

THIS PAGE MAY BE USED FOR SCRATCH WORK.

GO ON TO THE NEXT PAGE.

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.

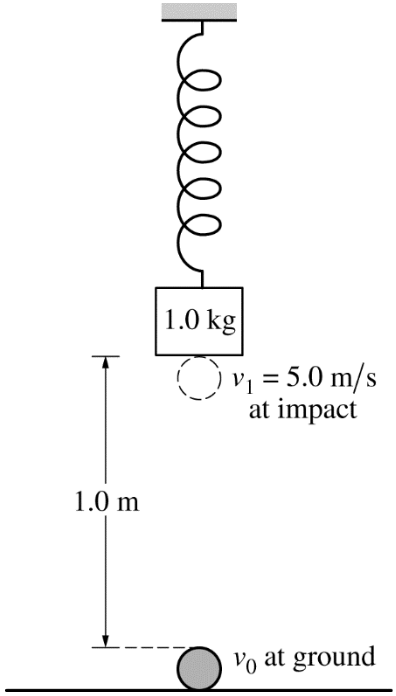


1. A spring of negligible mass and with a spring constant of $50\ \text{N/m}$ is hung vertically, as shown above in the figure on the left. A block of mass 1.0 kg is attached to the spring and slowly lowered a distance x_0 until it hangs at rest at the equilibrium position, as shown above in the figure 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.



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.

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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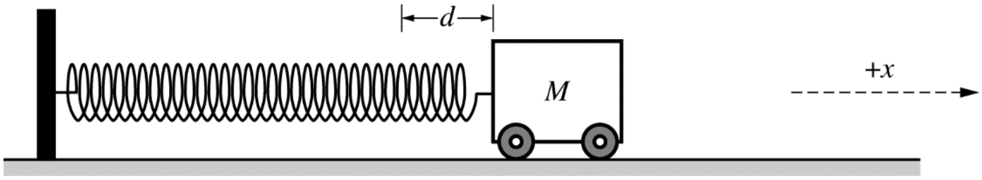
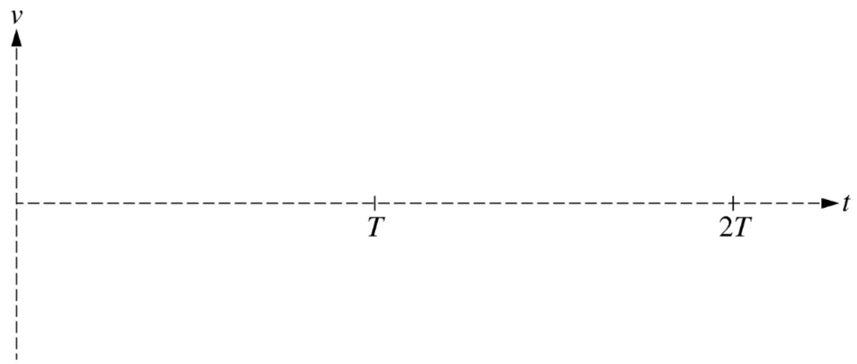
THIS PAGE MAY BE USED FOR SCRATCH WORK.



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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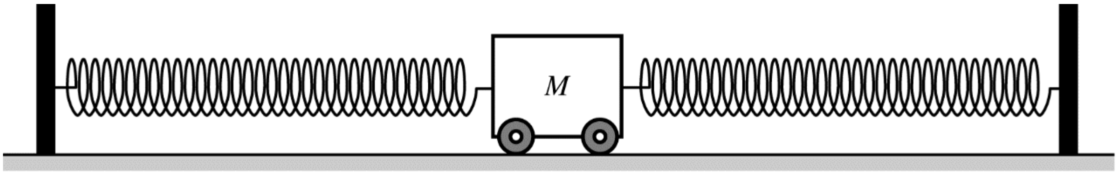


Figure 1

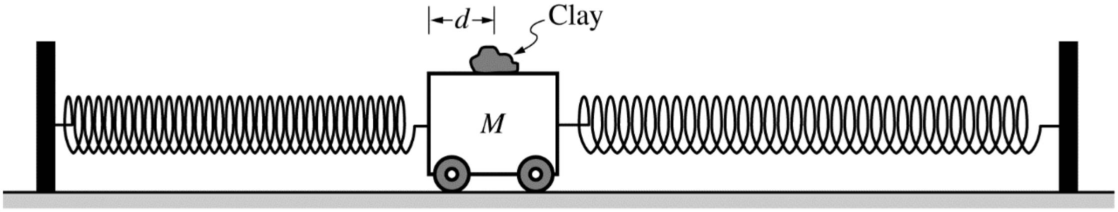
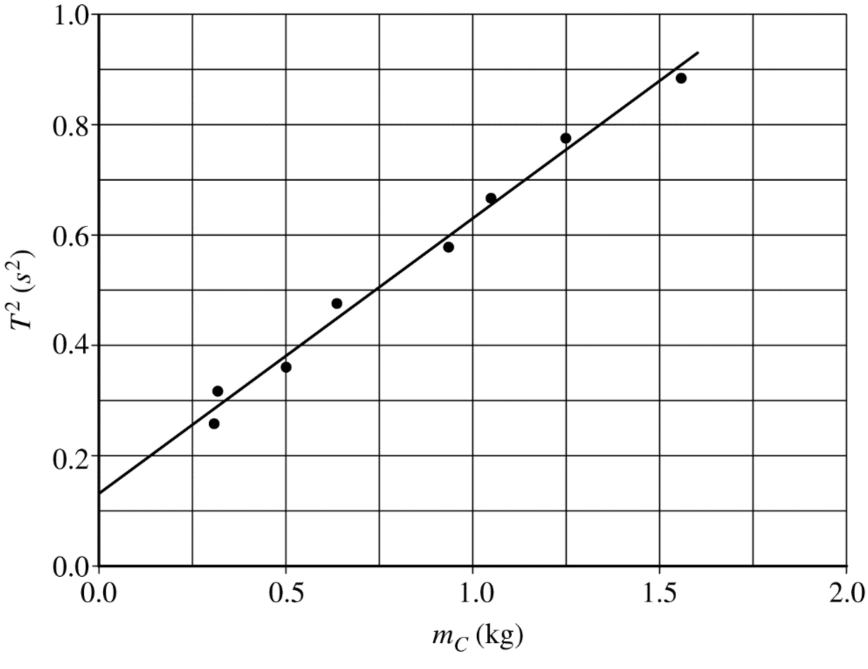


Figure 2

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

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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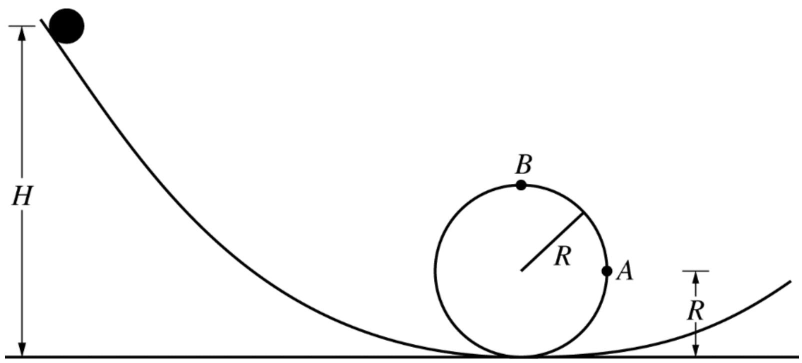
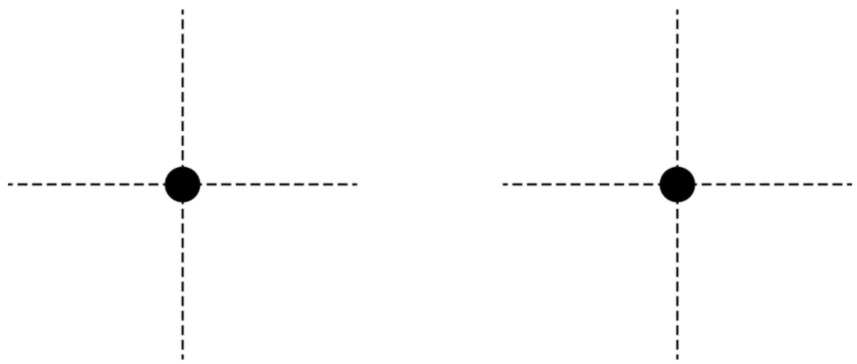


3. A sphere of mass m and radius r is released from rest at the top of a curved track of height H. The sphere travels down the curved track and around a loop of radius R. The sphere rolls without slipping during the entire motion. Point A on the loop is at height R, and point B is at the top of the loop. 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 $r \ll R$.

(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.

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*.

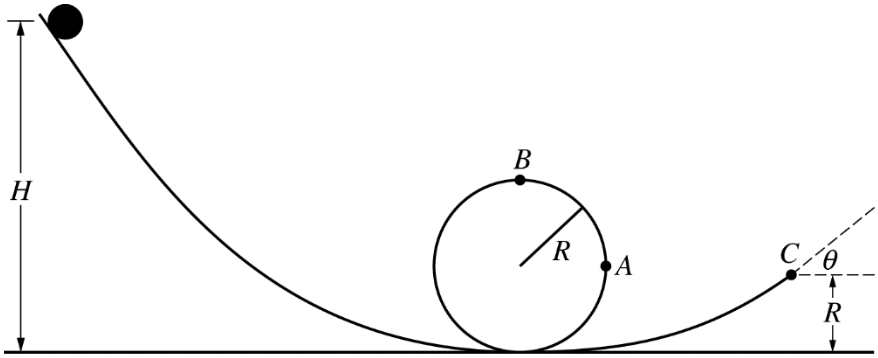
(d) The minimum release height necessary for the sphere to travel around the loop and not lose contact with the loop at point B is H_{MIN} . The sphere is replaced with a hoop of the same mass and radius. Will the value of H_{MIN} increase, decrease, or stay the same?

____ Increase ____ Decrease ____ Stay the same

Justify your answer.

Question 3 continues on the next page.

GO ON TO THE NEXT PAGE.



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.

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.**

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: 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

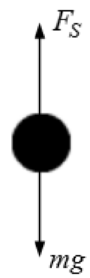
Free-Response Scoring Guidelines

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

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

$F_S = mg$

$kx = mg$

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

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

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

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

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*

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

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

For a correct answer with units — *1 point*

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

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.

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.

Question 2

15 points total | **Distribution of points**

(a) 2 points

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

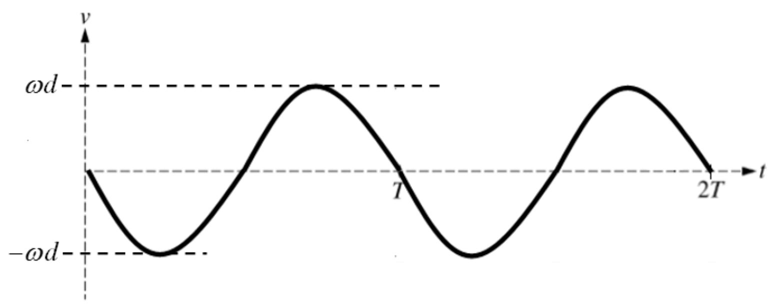
$$v(t) = \frac{dx}{dt}$$

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

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

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

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: $32.5 - 41.5\ \text{N/m}$

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

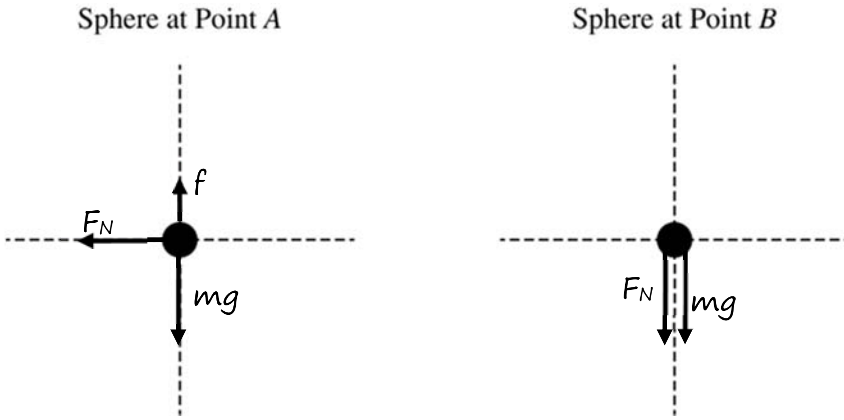
Example: Since the period does not depend on the amplitude of oscillation, the graph would not change.

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

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

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

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

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*

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

Scoring Worksheet

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

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

Question Descriptors and Performance Data

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

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

AP Physics C: Mechanics

The College Board