CollegeBoard

AP® Physics C: Mechanics Practice Exam

From the 2016 Administration

Contents

Note: This publication shows the page numbers that appeared in the ***2015–16 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 *2015–16 AP Exam Instructions* book.

AP® Physics C: Mechanics Exam

Regularly Scheduled Exam Date: Monday afternoon, May 9, 2016

Late-Testing Exam Date: Friday afternoon, May 20, 2016

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
- *2015-16 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 47 of the *2015-16 AP Coordinator's Manual*. See pages 44–47 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 45 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 305–306 for a seating chart template and instructions. See the *2015-16 AP Coordinator's Manual* for exam seating requirements (pages 49–52).

If you are giving the regularly scheduled exam, say:

> **It is Monday afternoon, May 9, 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 20, 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 *2015-16 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 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. Open your answer sheet to page 2. 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 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 60 of the *2015-16 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 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, 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 228 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 *2015-16 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.)

AP Answer Sheet 2016

AP Number Label (from Student Pack)

B123456789T

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 questions. I will seal the multiple-choice booklet when asked to do so, and I will not discuss these questions 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 *2015-16 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: 6 7 8 9 10 11 | PM: 12 1 2 3 4 5

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER — S

G. ONLINE PROVIDER CODE

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET — Exam Name: | Form: | Form Code:

785208

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

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND — SCHOOL CODE — 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)

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.

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

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

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	91	A B C D E	106	A B C D E
77	A B C D E	92	A B C D E	107	A B C D E
78	A B C D E	93	A B C D E	108	A B C D E
79	A B C D E	94	A B C D E	109	A B C D E
80	A B C D E	95	A B C D E	110	A B C D E
81	A B C D E	96	A B C D E	111	A B C D E
82	A B C D E	97	A B C D E	112	A B C D E
83	A B C D E	98	A B C D E	113	A B C D E
84	A B C D E	99	A B C D E	114	A B C D E
85	A B C D E	100	A B C D E	115	A B C D E
86	A B C D E	101	A B C D E	116	A B C D E
87	A B C D E	102	A B C D E	117	A B C D E
88	A B C D E	103	A B C D E	118	A B C D E
89	A B C D E	104	A B C D E	119	A B C D E
90	A B C D E	105	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 | 122 | 123 | 124 | 125 | 126

(Each grid: – . / / / . . . . ; columns 0 1 2 3 4 5 6 7 8 9)

QUESTIONS 131–142

For Students Taking 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	135	A B C D	139	A B C D
132	A B C D	136	A B C D	140	A B C D
133	A B C D	137	A B C D	141	A B C D
134	A B C D	138	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

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

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 in accordance with the policies in the *2015-16 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 2016 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

2016

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

At a Glance

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

Instructions

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

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

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

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

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

Form I
Form Code 4MBP4-S

80

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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\mathrm{D}U_g = mg\mathrm{D}h$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

$\vec{F}_s = -k\mathrm{D}\vec{x}$

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = N e v_d A$

$I = \frac{\mathrm{D}V}{R}$

$R_s = \sum_i R_i$

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

$P = I\mathrm{D}V$

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

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

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

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

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

$B_s = \mu_0 n I$

$\mathrm{F}_B = \int \vec{B} \circ d\vec{A}$

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\mathrm{F}_B}{dt}$

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

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

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

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

$S = 4\pi r^2$

Right Triangle

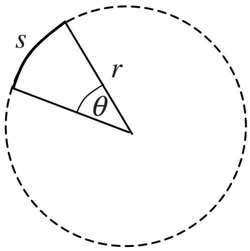
$a^2 + b^2 = c^2$

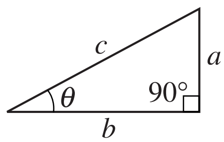
$\sin\theta = \frac{a}{c}$

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

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

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

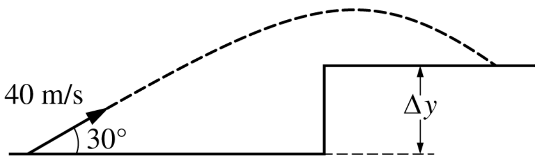
SECTION I

Time—45 minutes

35 Questions

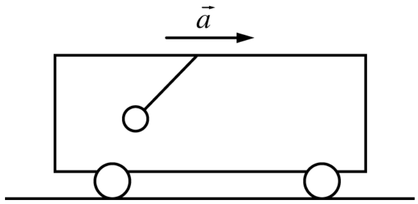
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

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



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

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



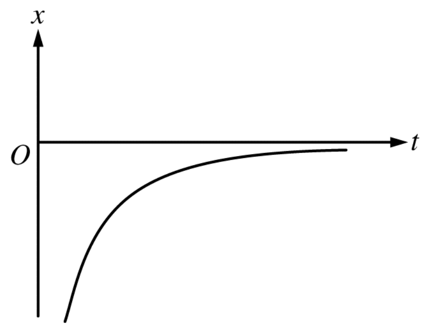
2. A small sphere hangs from a string attached to the ceiling of a uniformly accelerating train car. It is observed that the string makes an angle of $37°$ with respect to the vertical. The magnitude of the acceleration a of the train car is most nearly

   (A) 6.0 m/s^2
   (B) 7.5 m/s^2
   (C) 8.0 m/s^2
   (D) 10 m/s^2
   (E) 13 m/s^2

GO ON TO THE NEXT PAGE.

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

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

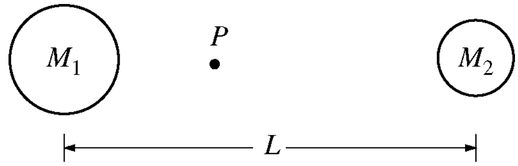


4. The position x as a function of time t for an object moving in a straight line is shown in the graph above. Which of the following best describes the object's speed and direction of motion during the time interval shown?

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

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

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



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

(A) $\frac{M_1}{M_2}L$

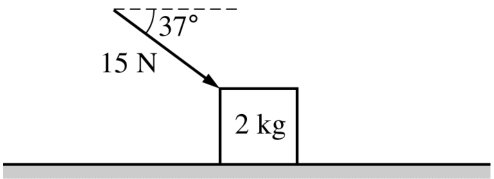
(B) $\frac{(M_1 + M_2)}{M_1}L$

(C) $\frac{(M_1 + M_2)}{M_2}L$

(D) $\frac{M_2}{(M_1 + M_2)}L$

(E) $\frac{M_1}{(M_1 + M_2)}L$

Questions 7-8



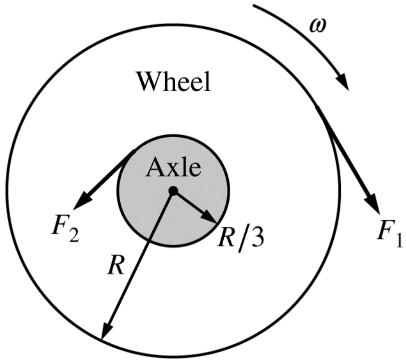
A 2 kg block is initially at rest on a horizontal frictionless table. A force of 15 N is then exerted on the block at an angle of 37° to the horizontal, as shown above.

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

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

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

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

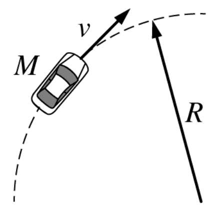


Note: Vectors not drawn to scale.

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

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

Questions 10-11



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

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

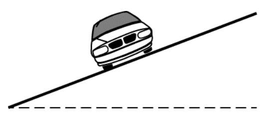
(A) $\frac{Rg}{v^2}$

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

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

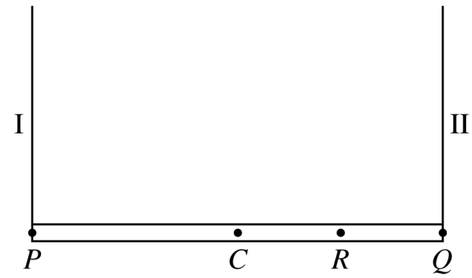
(D) $\frac{v^2}{Rg}$

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



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

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



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

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

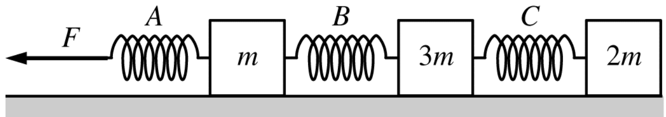
13. The potential energy U as a function of the position x of an object is given by $U(x) = -400/x$, where U is in joules and x is in meters. The object is released from rest at position $x = 30$ m and is free to move along the x-axis. When the object has moved a distance of 10 m from its initial position,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

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

GO ON TO THE NEXT PAGE.

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

Questions 20-21

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

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

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

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

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

(D) $I\omega$

(E) ωr

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

(A) Fr

(B) $I\omega^2$

(C) $\omega^2 r$

(D) Fr^2

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

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

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

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

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

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

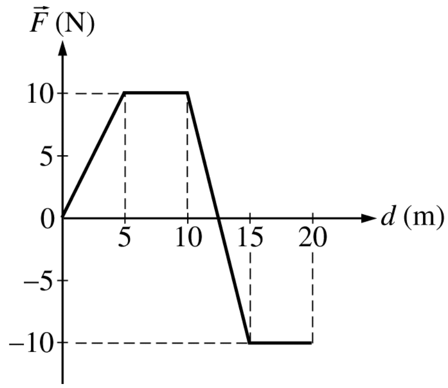
(C) $-\vec{v}_{BR} + \vec{v}_{RL}$

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

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

Questions 24-25

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



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

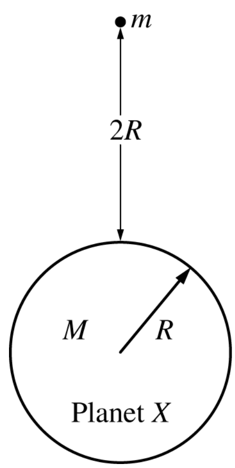
(A) 7.5 J
(B) 10 J
(C) 50 J
(D) 75 J
(E) 100 J

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

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

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

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



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

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

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

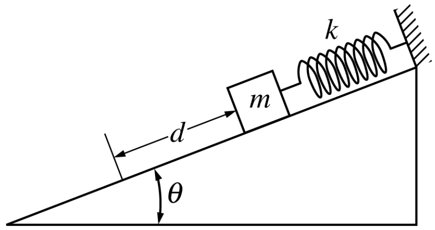
(C) $\sqrt{\frac{8GM}{3R}}$

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

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

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

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



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

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

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

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

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

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

GO ON TO THE NEXT PAGE.

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

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

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

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

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

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

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

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

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

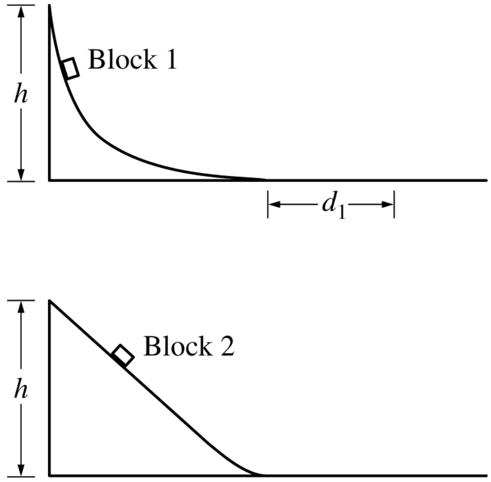
(A) zero

(B) $v_e/2$

(C) v_e

(D) $\sqrt{2}v_e$

(E) $\sqrt{3}v_e$



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

(A) $d_2 < d_1$, because block 2 reaches its maximum speed later than block 1

(B) $d_2 < d_1$, because block 2 has a lower maximum speed than block 1

(C) $d_2 = d_1$, because the blocks have the same mass

(D) $d_2 = d_1$, because the blocks start at the same height

(E) $d_2 > d_1$, because the track for block 2 is shorter

GO ON TO THE NEXT PAGE.

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

34. In an experiment, two blocks of different roughness are placed on the same rough wooden board. The table above shows three values for each block: the mass, the area of the block in contact with the board, and the coefficient of static friction μ_s between the block and the board. The experiment begins with the board horizontal. One end of the board is then slowly raised. Which of the following correctly identifies the block that will start sliding down the board first and why?

(A) Block 1, because it has less mass per unit area
(B) Block 1, because the coefficient of friction is smaller
(C) Block 2, because it has greater mass
(D) Block 2, because it has a smaller surface area
(E) Block 2, because the coefficient of friction is larger

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

(A) s
(B) m/s
(C) m/s^2
(D) m^2/s
(E) m^2/s^2

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 2016 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

2016

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

At a Glance

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

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐

   First letter of your first name ☐

2. Date of birth

   ☐☐ ☐☐ ☐☐☐☐
   Month Day Year

3. Six-digit school code

   ☐☐☐☐☐☐

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 4MBP4-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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\mathrm{D}U_g = mg\mathrm{D}h$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

$\vec{F}_s = -k\mathrm{D}\vec{x}$

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Nev_d A$

$I = \frac{\mathrm{D}V}{R}$

$R_s = \sum_i R_i$

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

$P = I\mathrm{D}V$

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
F = flux
κ = dielectric constant

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

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

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

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

$B_s = \mu_0 n I$

$\mathrm{F}_B = \int \vec{B} \cdot d\vec{A}$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\mathrm{F}_B}{dt}$

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

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

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

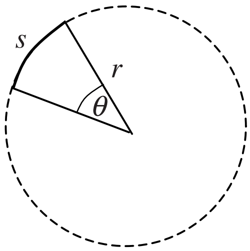
Rectangular Solid
$V = \ell wh$

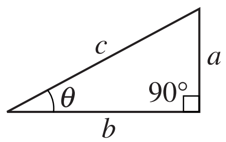
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

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

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

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

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

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

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

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

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

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

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

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

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

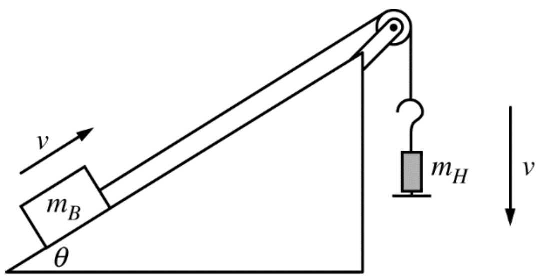
VECTOR PRODUCTS

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

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

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

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



Mech.1.

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

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

(b) Derive an expression for the mass m_H of the hanging object. Express your answer in terms of m_B, θ, μ_k, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

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

(c)

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

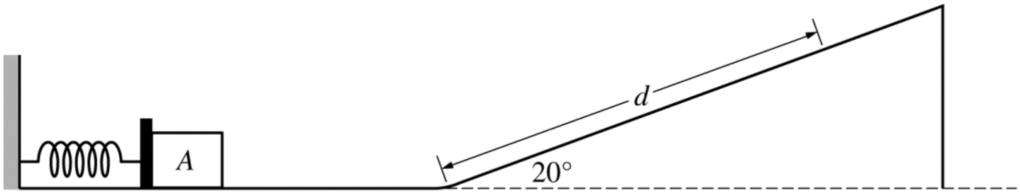
ii. What is the direction of the acceleration of the block immediately after the string is cut?

____ Up the ramp ______ Down the ramp

____ No direction, because the acceleration is zero

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

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



Note: Figure not drawn to scale.

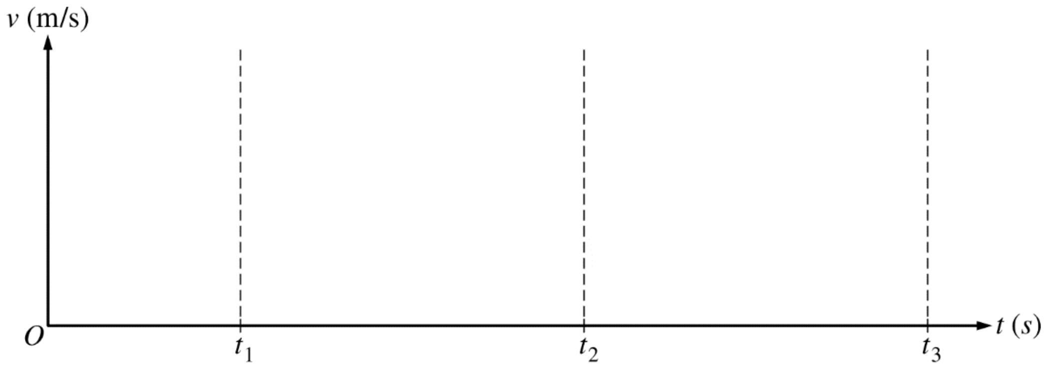
Mech.2.

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

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

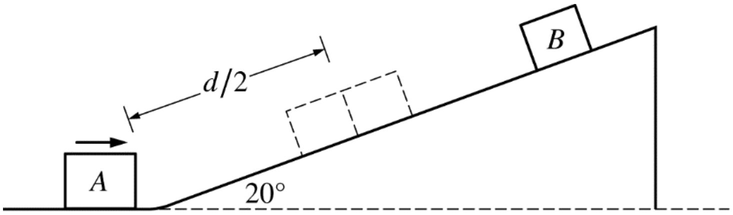
(b) Calculate the maximum distance *d* block *A* travels up the ramp.

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



Note: Time intervals not to scale.

GO ON TO THE NEXT PAGE.



Note: Figure not drawn to scale.

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

(d)

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

ii. In what direction, if any, are the two blocks moving immediately after the collision?

____ Up the ramp ____ Down the ramp

____ Undefined, because the blocks momentarily come to rest after the collision

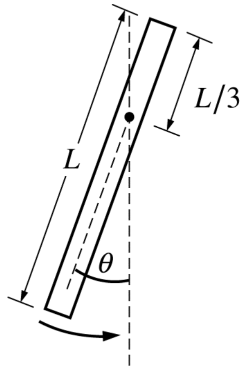
(e)

i. Calculate the magnitude of the impulse exerted on block *A* by block *B*.

ii. In what direction, if any, is the impulse exerted on block *A* by block *B* ?

____ Up the ramp ____ Down the ramp

____ Undefined, because the impulse is zero



Mech.3.

A uniform rod of mass M and length L is pivoted at a point a distance $L/3$ from the top end, as shown above. The rod is pulled back so that it makes a small angle with the vertical and is then released.

(a) Using integral calculus, show that the rotational inertia for the rod around its pivot is $ML^2/9$.

(b)

i. Using Newton's 2nd law in rotational form, write but do NOT solve a differential equation in terms of M, L, and physical constants, as appropriate, that can be used to determine the angular displacement theta as a function of time t.

ii. Using the differential equation from part (b)i, show that the period of oscillation for the rod is given by the expression $T = 2\pi\sqrt{\dfrac{2L}{3g}}$.

An experiment is performed with thin, uniform metal rods of different lengths, each pivoted around a point one third the length of the rod from the top end and used as a physical pendulum, as shown in the figure on the previous page. Each rod is pulled back so that it makes a small angle with the vertical and is then released, and the period of oscillation is measured. The data are recorded in the table below.

Length (m)	0.5	1.0	1.5	2.0	2.5
Period (s)	1.2	1.6	2.0	2.3	2.6

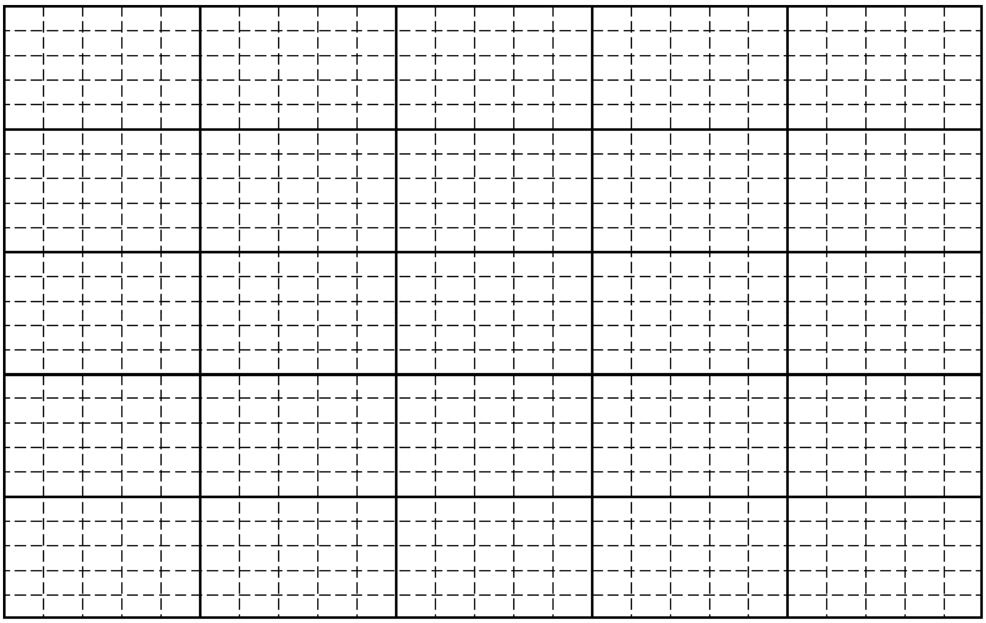
(c) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the acceleration due to gravity *g*.

Horizontal axis: ____________________

Vertical axis: ____________________

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

(d) Plot the straight line data points on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(e) Using your straight line, determine an experimental value for *g*.

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

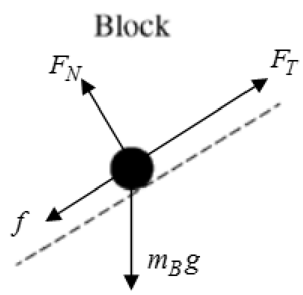
Free-Response Scoring Guidelines

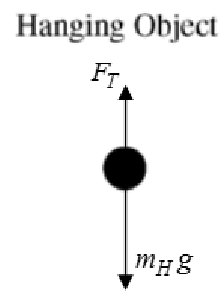
The following contains the scoring guidelines
for the free-response questions in this exam.

Question 1

15 points total | **Distribution of points**

(a) 4 points





For correctly drawing and labeling the force of tension and the force of friction for the Block — 1 point
For correctly drawing and labeling the normal force vector for the Block — 1 point
For correctly drawing and labeling the weight vector for the Block — 1 point
For correctly drawing and labeling both vertical vectors for the Hanging Object — 1 point
Note: a maximum of three points can only be earned if there are any extraneous vectors

(b) 3 points

For a correct Newton's 2nd law equation of the two-block system — 1 point

$$m_H g - F_T = m_H a = 0$$
$$F_T - m_B g\sin\theta - f = m_B a = 0$$
or
$$m_H g - m_B g\sin\theta - f = (m_H + m_B)a = 0$$

For setting the acceleration of the two-block system equal to zero either implicitly or explicitly — 1 point

$$m_H g - m_B g\sin\theta - \mu_k m_B g\cos\theta = 0$$

For a correct answer — 1 point

$$m_H = m_B(\sin\theta + \mu_k\cos\theta)$$

(c)
i. 3 points

For correctly applying Newton's second law to the block — 1 point

$$-m_B g\sin\theta - \mu_k m_B g\cos\theta = m_B a$$
$$-g(\sin\theta + \mu_k\cos\theta) = a$$

For correctly substituting into the above equation — 1 point

$$a = -(9.8\ \text{m/s}^2)((0.10)\cos 30 + \sin 30)$$

For a correct answer — 1 point

$a = 5.75\ \text{m/s}^2$ (Note: $a = 5.87\ \text{m/s}^2$ if $g = 10\ \text{m/s}^2$ is used)

Question 1 (continued)

Distribution of points

ii. 1 point

For selecting "Down the ramp" — 1 point

iii. 1 point

For a correct answer — 1 point

$a = g = 9.81\ \text{m/s}^2$ (Note: $a = g = 10\ \text{m/s}^2$ is also acceptable)

Note: No work needs to be shown for this part

(d) 3 points

For using a correct kinematics equation for calculating the distance traveled by the block — 1 point

$v_2^2 = v_1^2 + 2ad$

For setting the final velocity of the block equal to zero — 1 point

$0 = v_1^2 + 2ad$

$$d = \frac{-v_1^2}{2a} = \frac{-(2.0\ \text{m/s})^2}{(2)\left(-5.75\ \text{m/s}^2\right)}$$

For a correct answer — 1 point

$d = 0.348\ \text{m}$ (Note: $d = 0.341\ \text{m}$ if $g = 10\ \text{m/s}^2$ is used)

Alternate solution

For using a correct statement of conservation of energy — *1 point*

$KE_i + W_f = PE_f$

For converting h to d — *1 point*

$h = d\sin\theta$

For a correct answer — *1 point*

$d = 0.348\ \text{m}$ *(Note:* $d = 0.341\ \text{m}$ *if* $g = 10\ \text{m/s}^2$ *is used)*

Question 2

15 points total — **Distribution of points**

(a) 2 points

For correctly using conservation of energy to determine the speed of block A — 1 point

$U_{S1} = K_2$

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

$v = \sqrt{\frac{k}{m}}x = \sqrt{\frac{(700\ \text{N/m})}{(3.0\ \text{kg})}}(0.15\ \text{m})$

For a correct answer — 1 point

$v = 2.29\ \text{m/s}$

(b) 2 points

For correctly using conservation of energy to determine the distance block A travels up the ramp — 1 point

$K_1 = U_{g2}$

$\frac{1}{2}mv^2 = mgh = mgd\sin\theta$

$d = \frac{mv^2}{2mg\sin\theta} = \frac{(3.0\ \text{kg})(2.29\ \text{m/s})^2}{(2)(3.0\ \text{kg})\left(9.8\ \text{m/s}^2\right)(\sin 20)}$

For a correct answer — 1 point

$d = 0.783\ \text{m}$ (Note: $d = 0.767\ \text{m}$ if $g = 10\ \text{m/s}^2$ is used)

Alternate Solution

For correctly using conservation of energy to determine the distance block A travels up the ramp — *1 point*

$U_{S1} = U_{g2}$

$\frac{1}{2}kx^2 = mgh = mgd\sin\theta$

$d = \frac{kx^2}{2mg\sin\theta} = \frac{(700\ \text{N/m})(0.15\ \text{m})^2}{(2)(3.0\ \text{kg})\left(9.8\ \text{m/s}^2\right)(\sin 20)}$

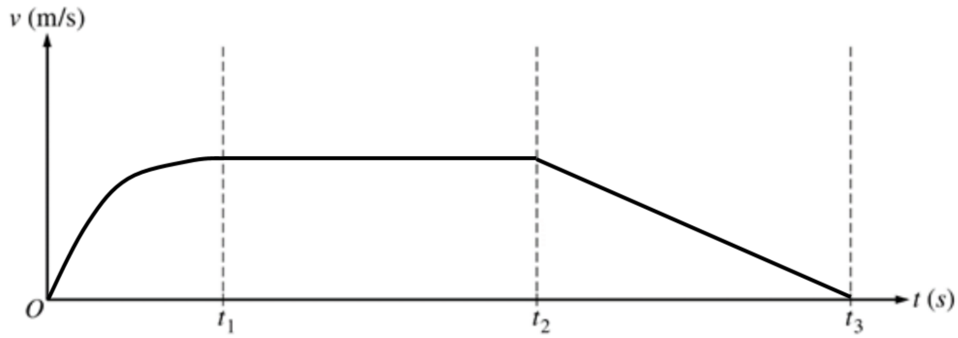
For a correct answer — *1 point*

$d = 0.783\ \text{m}$ (Note: $d = 0.767\ \text{m}$ if $g = 10\ \text{m/s}^2$ is used)

Question 2 (continued)

Distribution of points

(c) 3 points



For a concave down curve that starts at the origin $t = 0$ and becomes horizontal as $t = t_1$	1 point
For a horizontal line from $t = t_1$ to $t = t_2$ that is continuous with first section	1 point
For a straight line with a negative slope from $t = t_2$ to the horizontal axis at $t = t_3$ that is continuous with second section	1 point

Question 2 (continued)

Distribution of points

(d)

i. 5 points

For correctly using conservation of energy to determine speed of block A — 1 point

$K_1 = U_{g2} + K_2$

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

$\frac{1}{2}mv_1^2 = mg\frac{d}{2}\sin\theta + \frac{1}{2}mv_2^2$

For correctly substituting into the equation above — 1 point

$v_1^2 = gd\sin\theta + v_2^2$

$(2.29\ \text{m/s})^2 = \left(9.8\ \text{m/s}^2\right)(0.783\ \text{m})(\sin 20) + v^2$

For a correct answer — 1 point

$v_A = 1.62\ \text{m/s}$ (Note: $v_A = 1.60\ \text{m/s}$ if $g = 10\ \text{m/s}^2$ is used)

For correctly using conservation of energy to determine speed of block B — 1 point

$U_{g1} = K_2$

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

$mg\frac{d}{2}\sin\theta = \frac{1}{2}mv^2$

$v = \sqrt{\left(9.8\ \text{m/s}^2\right)(0.783)(\sin 20)}$

Correct answer

$v_B = 1.62\ \text{m/s}$ (Note: $v_B = 1.64\ \text{m/s}$ if $g = 10\ \text{m/s}^2$ is used)

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

$m_A v_A + m_B v_B = (m_A + m_B)v_f$

$$v_f = \frac{(3.0\ \text{kg})(1.62\ \text{m/s}) + (0.50\ \text{kg})(-1.62\ \text{m/s})}{(3.0\ \text{kg} + 0.50\ \text{kg})}$$

Correct answer

$v_f = 1.16\ \text{m/s}$ (Note: $v_f = 1.14\ \text{m/s}$ if $g = 10\ \text{m/s}^2$ is used)

Alternate solution:

For correctly calculating the acceleration of block A — *1 point*

$F = m_A a = m_A g\sin 20^\circ$

$a = g\sin 20^\circ = 3.35\ \text{m/s}^2$

Question 2 (continued)

Distribution of points

For correctly substituting into a correct kinematic equation — *1 point*

$$v_{fA}^2 = v_{0A}^2 + 2a(d/2)$$
$$v_{fA}^2 = (2.29\ \text{m/s})^2 + 2\left(-3.35\ \text{m/s}^2\right)\left(\frac{0.783\ \text{m}}{2}\right)$$

For a correct answer — *1 point*

$v_A = 1.62\ \text{m/s}$ *(Note: $v_A = 1.60\ \text{m/s}$ if $g = 10\ \text{m/s}^2$ is used)*

For using a correct kinematic equation to determine the speed of block B — *1 point*

$$v_{fB}^2 = v_{0B}^2 + 2a(d/2)$$
$$v_{fB}^2 = 0 + 2\left(3.35\ \text{m/s}^2\right)\left(\frac{0.783\ \text{m}}{2}\right)$$
$$v_{fB} = 1.62\ \text{m/s}$$

For correctly using conservation of momentum to determine the speed of the blocks after the collision — *1 point*

$$m_A v_A + m_B v_B = (m_A + m_B)v_f$$
$$v_f = \frac{(3.0\ \text{kg})(1.62\ \text{m/s}) + (0.50\ \text{kg})(-1.62\ \text{m/s})}{(3.0\ \text{kg} + 0.50\ \text{kg})}$$

Correct answer

$v_f = 1.16\ \text{m/s}$ *(Note: $v_f = 1.14\ \text{m/s}$ if $g = 10\ \text{m/s}^2$ is used)*

ii. 1 point

For selecting "Up the ramp" — 1 point

(e)

i. 1 point

Correctly using the impulse equation

$$J = m(v_2 - v_1)$$
$$J = (3.0\ \text{kg})(1.16\ \text{m/s} - 1.62\ \text{m/s})$$

For an answer consistent with the speed of the blocks determined in part (d) — 1 point

$J = -1.38\ \text{N•s}$ (Note: $J = -1.38\ \text{N•s}$ if $g = 10\ \text{m/s}^2$ is used)

Note: The negative sign is not needed since the question asks for magnitude

ii. 1 point

For selecting "Down the ramp" — 1 point

Question 3

15 points total | **Distribution of points**

(a) 3 points

For using integral calculus to attempt to calculate the rotational inertia of the rod — 1 point

$I = \int r^2\,dm$ & $\lambda = M/L$ & $dm = \lambda\,dr$

$I = \int \lambda r^2\,dr$

For correctly integrating the formula above — 1 point

$I = \lambda\left[\dfrac{r^3}{3}\right]$

For integrating using the correct limits or correct constant of integration — 1 point

$I = \dfrac{\lambda}{3}\left(\left[r^3\right]_{r=-L/3}^{r=2L/3}\right) = \dfrac{\lambda}{3}\left[\left(\left(\dfrac{2L}{3}\right)^3 - \left(-\dfrac{L}{3}\right)^3\right)\right]$

$I = \dfrac{M}{3L}\left(\dfrac{8L^3}{27} - \left(-\dfrac{L^3}{27}\right)\right) = \left(\dfrac{M}{3L}\right)\left(\dfrac{9L^3}{27}\right)$

Correct answer:

$I = ML^2/9$

Alternate Solution

For using integral calculus to attempt to calculate the rotational inertia of the rod about its center — *1 point*

$I = \int r^2\,dm$ & $\lambda = M/L$ & $dm = \lambda\,dr$

$I = \int \lambda r^2\,dr = \lambda\left[\dfrac{r^3}{3}\right]$

For integrating using the correct limits or correct constant of integration — *1 point*

$I = \dfrac{\lambda}{3}\left(\left[r^3\right]_{r=-L/2}^{r=L/2}\right) = \dfrac{\lambda}{3}\left[\left(\left(\dfrac{L}{2}\right)^3 - \left(-\dfrac{L}{2}\right)^3\right)\right] = \dfrac{M}{3L}\left(\dfrac{L^3}{8} - \left(-\dfrac{L^3}{8}\right)\right) = \left(\dfrac{M}{3L}\right)\left(\dfrac{2L^3}{8}\right)$

$I = \dfrac{1}{12}ML^2$

For correctly using the Parallel-Axis Theorem — *1 point*

$I = I_{CM} + Mh^2 = \dfrac{1}{12}ML^2 + M\left(\dfrac{L}{6}\right)^2 = \left(\dfrac{1}{12} + \dfrac{1}{36}\right)ML^2 = \left(\dfrac{3+1}{36}\right)ML^2$

Correct answer:

$I = ML^2/9$

Question 3 (continued)

Distribution of points

(b)

i. 2 points

For using a correct expression of Newton's 2nd law for the rotation of the rod — 1 point

$\tau = Fr_{\perp} = I\alpha$

$-Mg\left(\frac{L}{6}\right)\sin\theta = \frac{ML^2}{9}\alpha$

For expressing the equation as a differential equation — 1 point

$-\frac{3}{2}\frac{g}{L}\sin\theta = \frac{d^2\theta}{dt^2}$

ii. 2 points

For using the small-angle approximation; where $\sin\theta \approx \theta$ — 1 point

$-\frac{3}{2}\frac{g}{L}\theta = \frac{d^2\theta}{dt^2}$

For comparing above equation to the rotational form of simple harmonic motion or for solving the differential equation — 1 point

$-\frac{3}{2}\frac{g}{L}\theta = \frac{d^2\theta}{dt^2} = \alpha = -\theta\omega^2$

$\omega^2 = \left(\frac{2\pi}{T}\right)^2 = \frac{3}{2}\frac{g}{L}$

Correct answer:

$T = 2\pi\sqrt{\frac{2L}{3g}}$

(c) 1 point

For selecting appropriate variable to create a straight line relationship — 1 point

Example:

Horizontal axis: Length

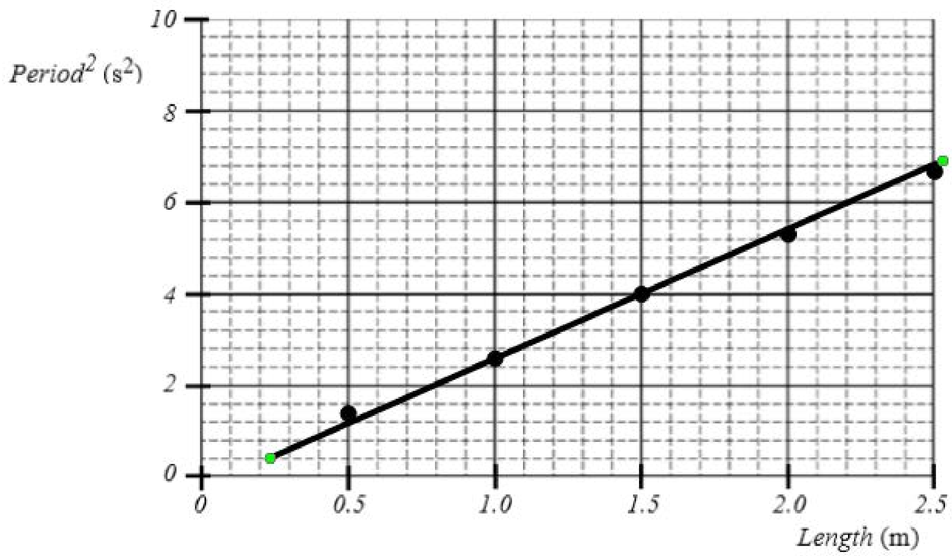
Vertical axis: Period Squared

Note: Square root of Length and Period is also acceptable as is reversing the axes

Question 3 (continued)

Distribution of points

(d) 4 points



For labeling both axes with appropriate variables and units — 1 point
For a correct scale that uses more than half the grid — 1 point
For correctly plotting data indicated in part (c) — 1 point
For drawing a straight line consistent with the given data — 1 point

(e) 3 points

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

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(6.0 - 2.0)}{(2.20 - 0.80)} = 2.86\ \text{s}^2/\text{m}$$

Note: linear regression gives $\text{slope} = 2.67\ \text{s}^2/\text{m}$

For correctly relating g to the slope — 1 point

$$T = 2\pi\sqrt{\frac{2L}{3g}} \quad T^2 = \frac{(4\pi^2)2L}{3g} \quad slope = \frac{(4\pi^2)\times 2}{3g}$$

$$g = \frac{8\pi^2}{3 \times slope} = \frac{8\pi^2}{3 \times (2.86\ \text{s}^2/\text{m})}$$

For a correct answer — 1 point

$g = 9.20\ \text{m/s}^2$

Note: linear regression gives $g = 9.86\ \text{m/s}^2$

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

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

Section II: Free Response

Question 1 __________ (out of 15) × 1.0000 = __________ (Do not round)

Question 2 __________ (out of 15) × 1.0000 = __________ (Do not round)

Question 3 __________ (out of 15) × 1.0000 = __________ (Do not round)

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

Composite Score

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

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
54-90	5
42-53	4
33-41	3
25-32	2
0-24	1

Question Descriptors and Performance Data

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

2016 AP Physics C: Mechanics
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Topic	Key	% Correct
1	Kinematics	A	66
2	Kinematics	B	38
3	Kinematics	E	87
4	Kinematics	A	72
5	System Of Particles & Linear Momentum	B	57
6	System Of Particles & Linear Momentum	D	44
7	Work/Energy/Power	C	77
8	Newton's Laws	C	67
9	Rotation & Circular Motion	D	64
10	Rotation & Circular Motion	D	65
11	Rotation & Circular Motion	C	62
12	Rotation & Circular Motion	B	29
13	Work/Energy/Power	D	14
14	Work/Energy/Power	C	74
15	Oscillations	A	56
16	Kinematics	C	66
17	Kinematics	A	75
18	System Of Particles & Linear Momentum	C	49
19	System Of Particles & Linear Momentum	C	60
20	Rotation & Circular Motion	B	69
21	Rotation & Circular Motion	E	73
22	Kinematics	A	45
23	Kinematics	A	54
24	Work/Energy/Power	D	87
25	Work/Energy/Power	B	63
26	Gravity	D	51
27	Gravity	B	34
28	Kinematics	D	74
29	Oscillations	D	18
30	Oscillations	E	34
31	Gravity	C	24
32	Gravity	E	7
33	Newton's Laws	D	59
34	Newton's Laws	B	59
35	Kinematics	C	77

AP Physics C: Mechanics