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CollegeBoard

AP® Physics 2: Algebra-Based Exam

From the 2015 Administration

NOTE: This is a modified version of the 2015 AP Physics 2: Algebra-Based Exam.

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

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Exam Instructions

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

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AP® Physics 1: Algebra-Based Exam

Regularly Scheduled Exam Date: Wednesday afternoon, May 6, 2015
Late-Testing Exam Date: Thursday morning, May 21, 2015
Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

AP® Physics 2: Algebra-Based Exam

Regularly Scheduled Exam Date: Thursday afternoon, May 7, 2015
Late-Testing Exam Date: Friday morning, May 22, 2015
Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

Section I
Total Time: 1 hour 30 minutes
Calculator allowed
Number of Questions: 50*
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: 1 hour 30 minutes
Calculator allowed
Number of Questions Physics 1: 5
Number of Questions Physics 2: 4
Percent of Total Score: 50%
Writing Instrument: Pen with black or dark blue ink, or pencil

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2014-15 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template(s)
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Container for students' electronic devices (if needed)
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Extra paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited in the testing room"

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for these entire exams (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 46 of the *2014-15 AP Coordinator's Manual*. See pages 43–46 of the *2014-15 AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 44 of the *2014-15 AP Coordinator's Manual*.

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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.

SECTION I: Multiple Choice

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

Make sure you begin the exam at the designated time. Remember: You must complete a seating chart for this exam. See pages 279–280 for a seating chart template and instructions. See the *2014-15 AP Coordinator's Manual* for exam seating requirements (pages 48–50, 88).

Physics 1: Algebra-Based

If you are giving the regularly scheduled exam, say:

It is Wednesday afternoon, May 6, and you will be taking the AP Physics 1: Algebra-Based Exam.

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

It is Thursday morning, May 21, and you will be taking the AP Physics 1: Algebra-Based Exam.

Physics 2: Algebra-Based

If you are giving the regularly scheduled exam, say:

It is Thursday afternoon, May 7, and you will be taking the AP Physics 2: Algebra-Based Exam.

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

It is Friday morning, May 22, and you will be taking the AP Physics 2: Algebra-Based Exam.

In a moment, you will open the packet that contains your exam materials. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2014-15 Bulletin for AP Students and Parents*. You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

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

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

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

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

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

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

Are there any questions? . . .

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

You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses on pages 2 and 3 of your answer sheet. Remember, for numbers 1 through 45 on answer sheet page 2, mark only the single best answer to each question. For numbers 131 through 135 at the bottom of answer sheet page 3, mark the two best answer choices for each 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 1 hour and 30 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 1 hour and 20 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working. 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

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the back cover. When you have finished, place the booklet on your desk, face up. I will now collect your Section I booklet. . . .

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

There is a 10-minute break between Sections I and II. When all Section I materials have been collected and accounted for and you are ready for the break, say:

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. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic or communication device. Remember, you may never discuss the 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. Are there any questions? . . .



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

SECTION II: Free Response

After the break, say:

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

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

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

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

Read the last statement. . . .

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

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

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

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

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Read Item 4. . . .

I need to collect the Student Pack from anyone who will be taking another AP Exam. You may keep it only if you are not taking any other AP Exams this year. If you have no other AP Exams to take, place your Student Pack under your chair now. . . .

While Student Packs are being collected, read the information on the back cover of the exam booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .

Collect the Student Packs. Then say:

Are there any questions? . . .

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

You have 1 hour and 30 minutes to complete Section II. You are responsible for pacing yourself, and you may proceed freely from one question to the next.

If you are giving the AP Physics 1: Algebra-Based Exam, say:

Section II has 5 questions. It is suggested that you spend approximately 25 minutes each for questions 2 and 3, and 13 minutes each for questions 1, 4, and 5.

If you are giving the AP Physics 2: Algebra-Based Exam, say:

Section II has 4 questions. It is suggested that you spend approximately 25 minutes each for questions 2 and 3, and 20 minutes each for questions 1 and 4.

You must write your answers in the exam booklet using a pen with black or dark blue ink or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read. If you need more paper during the exam, raise your hand. At the top of each extra sheet of paper you use, be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .

You may begin.

Note Start Time here _____. Note Stop Time here _____. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators. After 1 hour and 20 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

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

If any students used extra paper for the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an

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Incident Report and include any exam booklets with extra sheets of paper in an Incident Report return envelope (see page 57 of the *AP Coordinator's Manual* for details). Then say:

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

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

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

When all exam materials have been collected and accounted for, return to students 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, 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.**

Then say:

> **You are now dismissed.**

All exam materials must be placed in secure storage until they are returned to the AP Program after your school's last administration. Before storing materials, check the "School Use Only" section on page 1 of the answer sheet and:

- Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2014-15 AP Coordinator's Manual.*
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

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

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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 2015

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

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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 *2014-15 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

C. YOUR AP NUMBER

D. EXAM DATE Month | Day

E. EXAM START TIME AM | PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PRACTICE CODE

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

L. SOCIAL SECURITY NUMBER (Optional)

COMPLETE THIS AREA ONLY ONCE.

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

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

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET

Exam Name: | Form: | Form Code:

779934

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 2 Option 2

104246-00657• UNLWEB315

Q3914/1-4

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COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

P. 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

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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.

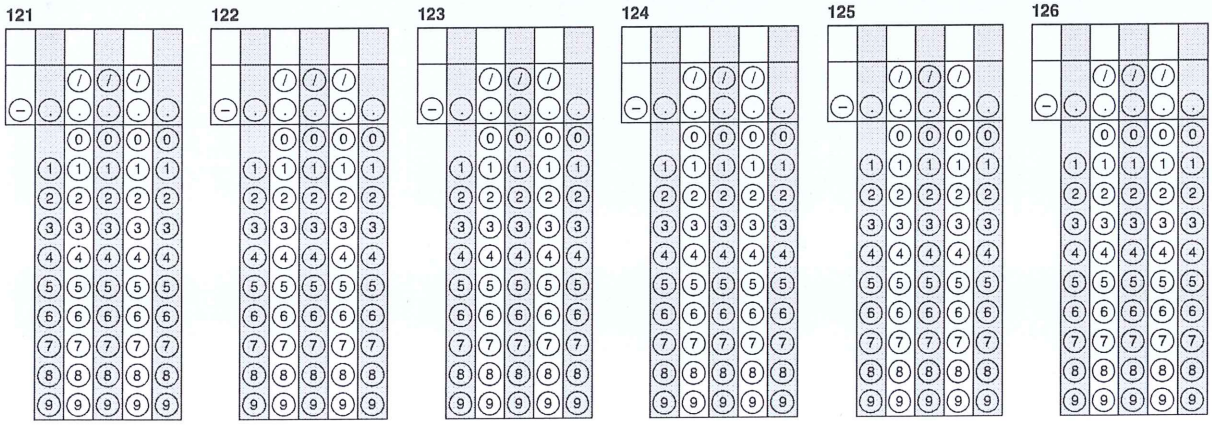
76	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	91	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	106	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
77	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	92	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	107	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
78	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	93	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	108	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
79	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	94	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	109	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
80	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	95	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	110	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
81	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	96	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	111	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
82	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	97	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	112	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
83	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	98	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	113	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
84	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	99	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	114	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
85	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	100	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	115	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
86	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	101	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	116	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
87	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	102	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	117	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
88	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	103	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	118	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
89	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	104	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	119	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
90	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	105	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	120	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

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



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	Ⓐ Ⓑ Ⓒ Ⓓ	135	Ⓐ Ⓑ Ⓒ Ⓓ	139	Ⓐ Ⓑ Ⓒ Ⓓ
132	Ⓐ Ⓑ Ⓒ Ⓓ	136	Ⓐ Ⓑ Ⓒ Ⓓ	140	Ⓐ Ⓑ Ⓒ Ⓓ
133	Ⓐ Ⓑ Ⓒ Ⓓ	137	Ⓐ Ⓑ Ⓒ Ⓓ	141	Ⓐ Ⓑ Ⓒ Ⓓ
134	Ⓐ Ⓑ Ⓒ Ⓓ	138	Ⓐ Ⓑ Ⓒ Ⓓ	142	Ⓐ Ⓑ Ⓒ Ⓓ

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DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

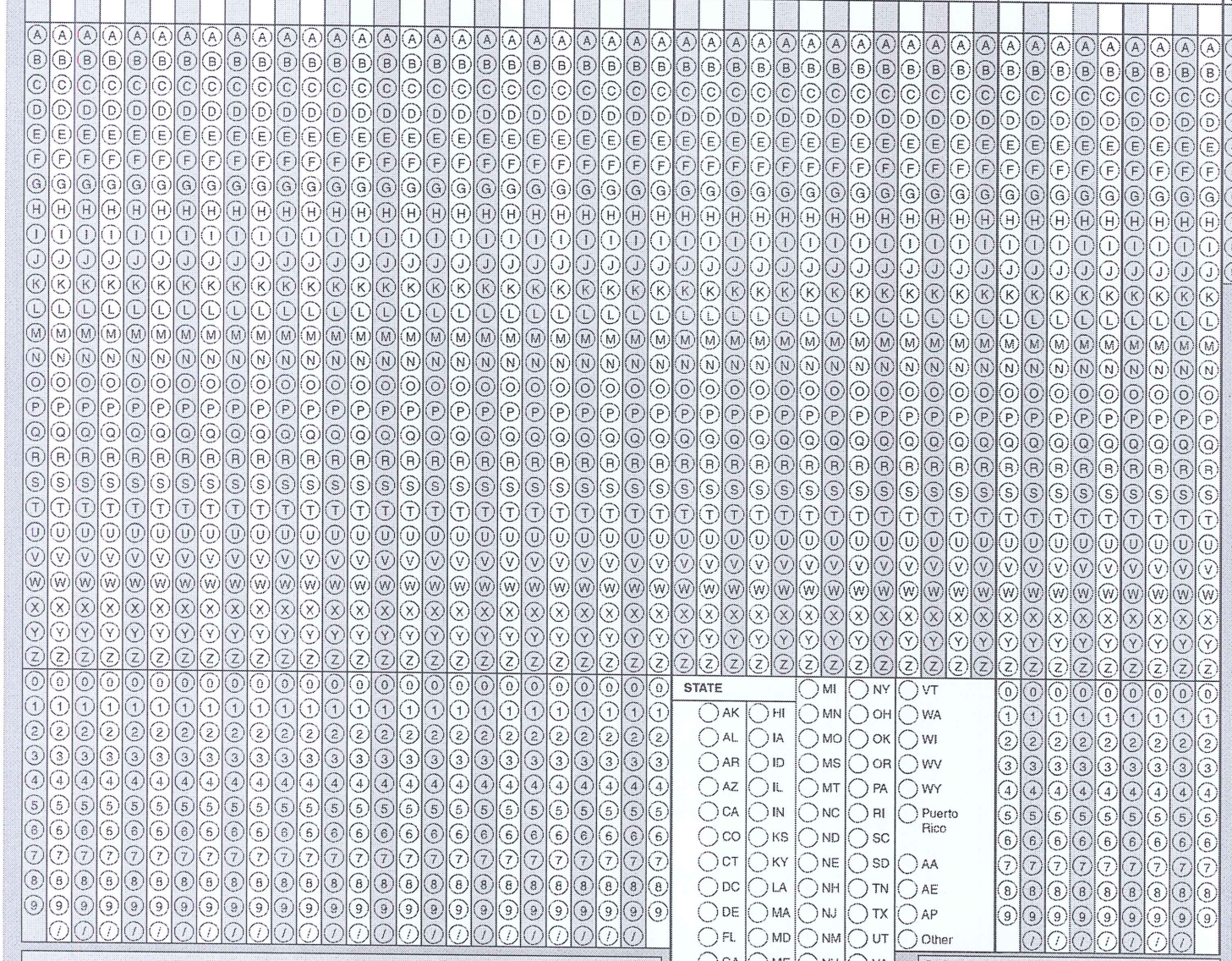
Q. YOUR MAILING ADDRESS Use the address abbreviations from your AP Student Pack. Fill in only one circle per column. Indicate a space in your address by leaving a blank box; do not grid that column.

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE



STATE

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

U. 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.

V. SEX

◯ Female ◯ Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. ETHNICITY/RACE

◯ American Indian or Alaska Native
◯ Asian, Asian American or Pacific Islander
◯ Black or African American
◯ Mexican or Mexican American
◯ Puerto Rican
◯ Other Hispanic, Latino or Latin American
◯ White
◯ Other

Y. PARENTAL EDUCATION LEVEL

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

◯	◯	Grade school
◯	◯	Some high school
◯	◯	High school diploma or equivalent
◯	◯	Vocational or trade school
◯	◯	Some college
◯	◯	Associate or two-year degree
◯	◯	Bachelor's or four-year degree
◯	◯	Some graduate or professional school
◯	◯	Graduate or professional degree
◯	◯	Mother or female guardian
◯	◯	Father or male guardian

R. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

S. STUDENT IDENTIFIER (Student ID Number)

Address	City	State or Province	Country	ZIP or Postal Code

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

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Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2015 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

For purposes of test security and/or statistical analysis, some questions
have been removed from the version of the exam that was administered
in 2015. Therefore, the timing indicated here may not be appropriate
for a practice exam.

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AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2015

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
40
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 40 multiple-choice questions. Pages containing equations and other information are also printed in this 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.

Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question. If you change an answer, be sure that the previous mark is erased completely.

For questions 1 through 36, select the single best answer choice for each question. After you have decided which of the choices is best, completely fill in the corresponding circle on the answer sheet. Here is a sample question and answer.

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

For questions 131 through 134, select the two best answer choices for each question. After you have decided which two choices are best, completely fill in the two corresponding circles on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
New York is a (A) state (B) city (C) country (D) continent	● ● Ⓒ Ⓓ

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 Section I is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

PLACE SEAL HERE

PLACE SEAL HERE
DO NOT seal answer sheet inside

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AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

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

UNIT SYMBOLS							
meter,	m	mole,	mol	watt,	W	farad,	F
kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
second,	s	newton,	N	volt,	V	degree Celsius,	°C
ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. In all situations, positive work is defined as work done on a system.
III. The direction of current is conventional current: the direction in which positive charge would drift.
IV. Assume all batteries and meters are ideal unless otherwise stated.
V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.
VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object

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AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

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

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

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

$L = I\omega$

$\Delta L = \tau \Delta t$

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

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

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

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

$\Delta U_g = mg\Delta y$

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$|\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$|\vec{E}| = \left|\frac{\Delta V}{\Delta r}\right|$

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

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

$E = \frac{Q}{\varepsilon_0 A}$

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

$I = \frac{\Delta Q}{\Delta t}$

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

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

$|\vec{F}_M| = |q\vec{v}||\sin\theta||\vec{B}|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$|\vec{F}_M| = |I\vec{\ell}||\sin\theta||\vec{B}|$

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

$\Phi_B = |\vec{B}|\cos\theta|\vec{A}|$

$\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}$

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

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AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho gh$

$F_b = \rho Vg$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

MODERN PHYSICS

$E = hf$

$K_{max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\lambda = \frac{v}{f}$

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

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

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

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

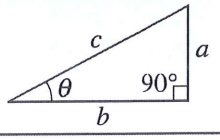
Rectangular solid
$V = \ell wh$

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

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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



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PHYSICS 2
Section I
40 Questions
Time—90 minutes

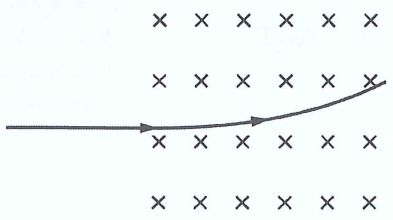
Note: To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

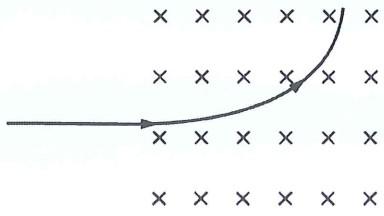
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

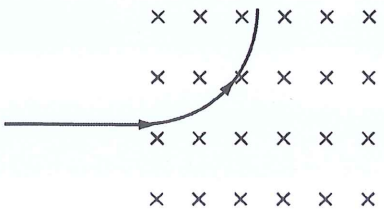
1. Three objects—*X*, *Y*, and *Z*—are each given an excess electric charge. The objects are then brought near each other in pairs but do not touch. It is found that *X* and *Y* attract each other, *Y* and *Z* repel, and *X* and *Z* attract. Which of the following is a correct conclusion about the signs of the charges that can be drawn from these observations?

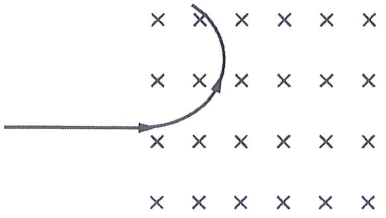
   (A) *X* and *Y* have charges of the same sign, and *Z* has a charge of the opposite sign.
   (B) *X* and *Z* have charges of the same sign, and *Y* has a charge of the opposite sign.
   (C) *Y* and *Z* have charges of the same sign, and *X* has a charge of the opposite sign.
   (D) *X*, *Y*, and *Z* all have charges of the same sign.

2. Each of the figures below shows the path of a charged particle moving in the plane of the page in a magnetic field that is perpendicular to the page. If the mass, speed, and charge of the particles are the same, in which case does the field have the greatest magnitude?

   (A)
   

   (B)
   

   (C)
   

   (D)
   

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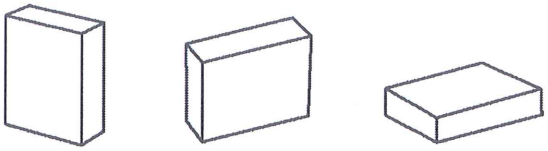
3. The figure above shows pipe 1 of cross-sectional area A_1 and pipe 2 of cross-sectional area A_2, which merge into pipe 3 of cross-sectional area A_3. The water in pipes 1 and 2 flows with speeds v_1 and v_2, respectively. What is the speed of the water in pipe 3 ?

(A) $\dfrac{A_1v_1 + A_2v_2}{A_3}$

(B) $\dfrac{A_1v_1 - A_2v_2}{A_3}$

(C) $\dfrac{(A_1 + A_2)(v_1 + v_2)}{A_3}$

(D) $A_3\left(\dfrac{v_1}{A_1} + \dfrac{v_2}{A_2}\right)$



4. A hollow rectangular box is filled with a liquid and can be placed in any of the three orientations shown above. In which orientation will the fluid pressure at the bottom of the box be greatest, and why?

(A) Orientation X, because pressure at the bottom of a fluid is greater when the vertical height of the fluid is greater

(B) Orientation Y, because pressure at the bottom of a fluid is greater when the width times the height of the fluid is greater

(C) Orientation Z, because pressure at the bottom of a fluid is greater when the area of the bottom surface is greater

(D) All three orientations have the same pressure, because the weight of the fluid is the same in each case.

5. An engineer has four wires made of the same material and wants to determine the material's resistivity. The engineer measures the length L and cross-sectional area A of each wire. The engineer then applies a potential difference V across each wire and measures the resulting current I. To estimate the resistivity of the material using only the slope of a graph of the data, which of the following should be graphed as a function of L/A ?

(A) V
(B) I
(C) V/I
(D) I/V

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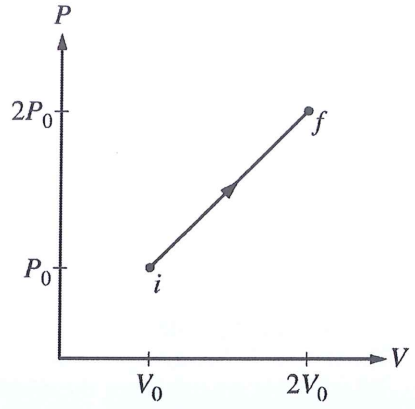
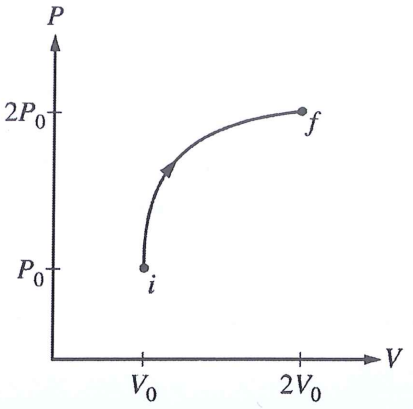
6. An ideal gas is taken from initial state i at pressure P_0 and volume V_0 to final state f at pressure $2P_0$ and volume $2V_0$. The figures below represent four possible processes by which the gas can be taken from state i to state f. For which process is the work done by the gas greatest?

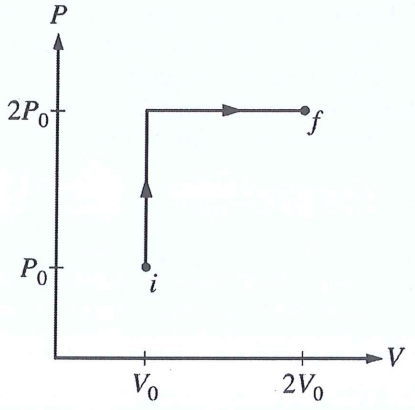
(A)



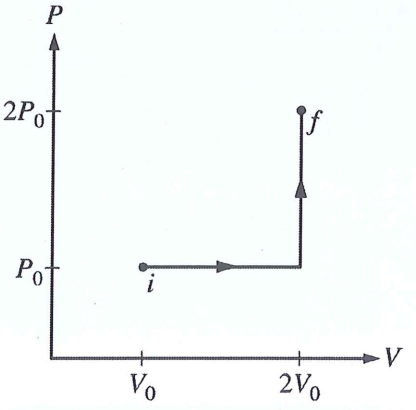
(B)



(C)



(D)



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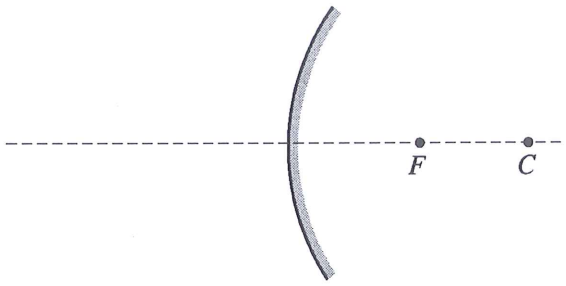
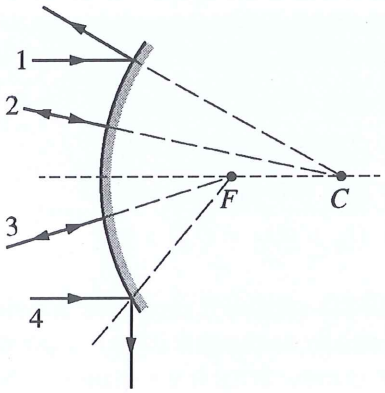
Questions 7-8 refer to the following material.



The figure above shows a convex mirror, its focal point F, and its center of curvature C.

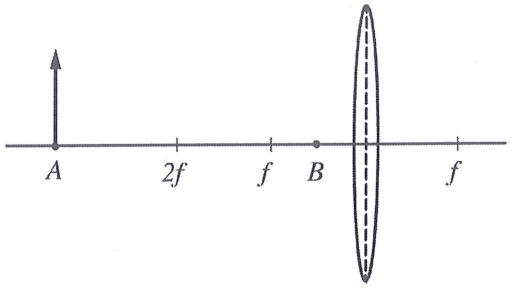


7. Which of the rays shown above is correct for this mirror?

   (A) 1
   (B) 2
   (C) 3
   (D) 4

8. An object is located 2 m to the left of the mirror. If point C is 30 cm from the mirror, what is the approximate location of the object's image?

   (A) 26 cm to the right of the mirror
   (B) 14 cm to the right of the mirror
   (C) 16 cm to the left of the mirror
   (D) 35 cm to the left of the mirror



9. In the figure above, an object is moved from position A to position B. How does the image formed by the lens change during the move?

   (A) From real, reduced, and inverted to virtual, reduced, and upright
   (B) From real, reduced, and inverted to virtual, enlarged, and upright
   (C) From virtual, enlarged, and upright to real, reduced, and inverted
   (D) From virtual, enlarged, and inverted to real, enlarged, and inverted

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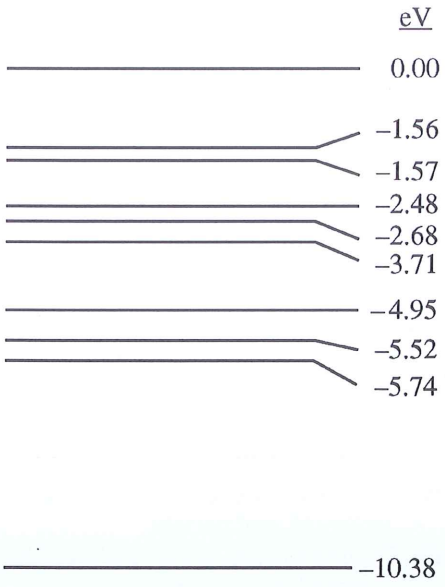


10. The figure above shows energy levels for a mercury atom. A photon with energy 2.03 eV is incident on a mercury atom that is in its first excited state. The atom absorbs the photon and subsequently makes a transition to its ground state. Which of the following correctly describes the process the atom goes through?

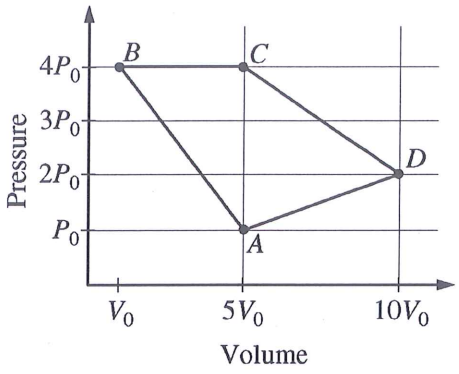
(A) It starts at −10.38 eV, transitions to −3.71 eV, and ends at −5.74 eV.
(B) It starts at −5.74 eV, transitions to −3.71 eV, and ends at −5.74 eV.
(C) It starts at −5.74 eV, transitions to −3.71 eV, and ends at −10.38 eV.
(D) It starts at −10.38 eV, transitions to −8.35 eV, and returns to −10.38 eV.

11. The following equation represents positron-electron annihilation, in which a positron and an electron become two photons.

$$e^+ + e^- \rightarrow \gamma_1 + \gamma_2$$

Which of the following correctly explains a reason why the interaction is possible?

(A) The photons have no charge, so total charge is conserved.
(B) Two particles become two particles, so the number of particles is conserved.
(C) Each side of the equation has only one type of particle.
(D) Each particle has the same kinetic energy.



12. In a laboratory experiment, students recorded the pressure and volume of a sample of ideal gas as its temperature was varied. Their results are represented in the figure above. Which of the following ranks the internal energy U of the gas at the labeled points from greatest to least?

(A) $(U_B = U_C) > U_D > U_A$
(B) $(U_C = U_D) > U_B > U_A$
(C) $(U_C = U_D) > U_A > U_B$
(D) $U_D > (U_C = U_A) > U_B$

13. A 20 kΩ resistor is connected in series with an initially uncharged 100 μF capacitor and a 5 V battery. What is the charge on the capacitor when the circuit has reached steady state?

(A) 5×10^4 C
(B) 2.5×10^{-1} C
(C) 2.5×10^{-4} C
(D) 5×10^{-4} C

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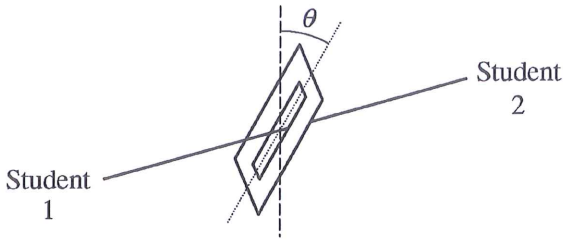
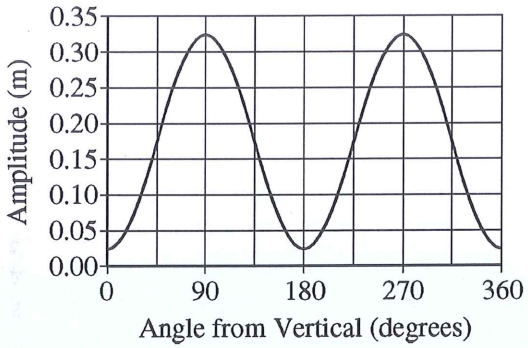




14. Student 1 and student 2 pull on opposite ends of a horizontal string that passes through a long, thin slit in a piece of cardboard, as shown in the top figure above. The plane of the cardboard is kept vertical, and the slit can be rotated so its angle θ relative to the dashed vertical line changes. Student 1 shakes the string, creating a transverse periodic wave of constant amplitude. At his end of the string, student 2 measures the amplitude of the wave that comes through the slit as a function of the angle of the slit relative to vertical. Student 2's data is shown in the graph. In what direction is student 1 shaking the string?

(A) Horizontally
(B) Vertically
(C) At 45° to vertical
(D) Toward and away from the slit

15. A particle with charge Q and mass M has instantaneous speed u_1 when it is at a position where the electric potential is V_1. At a later time, the particle has moved a distance R away to a position where the electric potential is V_2. Which of the following equations can be used to find the speed u_2 of the particle at the new position?

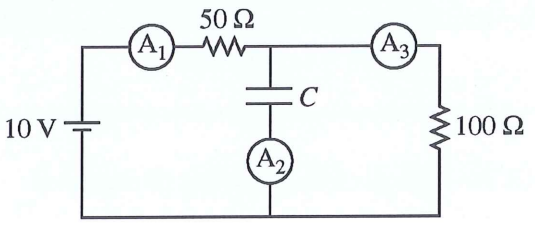
(A) $\frac{1}{2}M\left(u_2^2 - u_1^2\right) = Q(V_1 - V_2)$

(B) $\frac{1}{2}M(u_2 - u_1)^2 = Q(V_1 - V_2)$

(C) $\frac{1}{2}Mu_2^2 = QV_1$

(D) $\frac{1}{2}Mu_2^2 = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{R}$

Questions 16-18 refer to the following material.



The figure above shows a 10 V battery connected in a circuit with two resistors, a parallel-plate capacitor of capacitance C, and three ammeters. The circuit has been connected for a long time.

16. Let I_i be the current in ammeter A_i. Which of the following correctly ranks the currents in the three ammeters?

(A) $(I_1 = I_3) > I_2$
(B) $I_1 > (I_3 = I_2)$
(C) $I_1 > I_3 > I_2$
(D) $I_3 > (I_1 = I_2)$

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17. Which of the following is correct about the voltage V_C across the capacitor?

(A) $V_C = 0$
(B) $0 < V_C < 10$ V
(C) $V_C = 10$ V
(D) $V_C > 10$ V

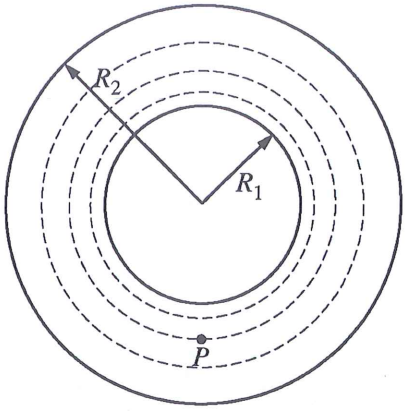
18. Assume the capacitance C of the capacitor is known. The gap between the capacitor's plates is now filled with an unknown insulating material, and the circuit is again left connected for a long time. Measuring which of the following provides enough information to determine the unknown material's dielectric constant κ?

(A) The potential difference across the capacitor and the current in each branch of the circuit
(B) The potential difference across the capacitor and the charge on one of its plates
(C) The potential difference across the capacitor and the charge on the dielectric material
(D) The separation between the capacitor plates and the area of the plates

---

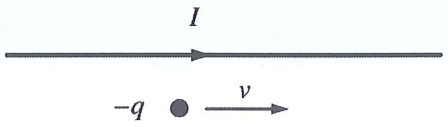
19. An ideal gas with molecules of mass m is contained in a cube with sides of area A. The average vertical component of the velocity of the gas molecules is v, and N molecules hit the side of the cube in a time Δt. What is the pressure exerted by the gas on the bottom of the cube?

(A) $mv/A\,\Delta t$
(B) $2mv/A\,\Delta t$
(C) $Nmv/A\,\Delta t$
(D) $2Nmv/A\,\Delta t$



20. The figure above represents two charged, concentric conducting shells with radii R_1 and R_2. The space between the shells is filled with air. The dashed lines represent equipotentials. The electric field just outside the inner shell has magnitude E_1, and the electric field just inside the outer shell has magnitude E_2. Which of the following statements is true of the magnitude E of the electric field at point P?

(A) $E = 0$
(B) $E_1 > E > E_2$
(C) $E = E_1$
(D) $E_1 < E < E_2$



21. An object with charge $-q$ is in motion near a wire that has a current I to the right. At the instant shown in the figure above, the object is traveling to the right with speed v. Both the wire and the motion of the object are in the plane of the page. Which of the following statements is true about the force on the object due to the current I at the instant shown?

(A) The force is directed toward the top of the page.
(B) The force is directed toward the bottom of the page.
(C) The force is directed toward the right.
(D) There is no force on the object due to the current.

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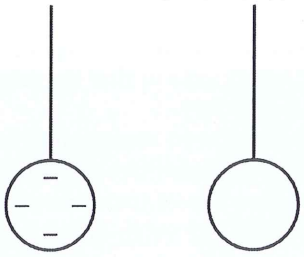
Metal

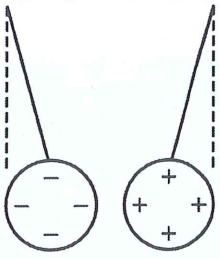
22. A metal sphere with a small negative charge hangs vertically from a light thread, as shown in the figure above. The metal sphere is then brought near but does not touch an uncharged plastic sphere of the same size that is also hanging vertically on a light thread. Which of the following best shows the two spheres after they have reached equilibrium?

(A)



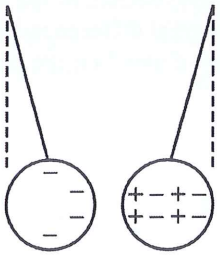
Metal Plastic

(B)



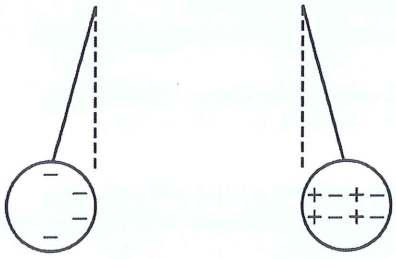
Metal Plastic

(C)



Metal Plastic

(D)



Metal Plastic

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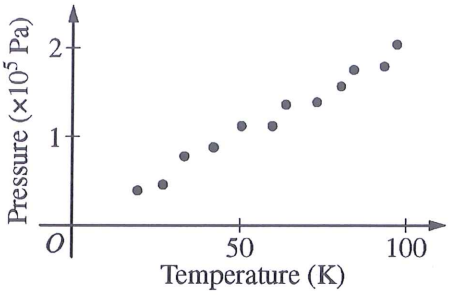

23. A sample of gas is in a container of fixed volume. The pressure of the gas is measured as its absolute temperature is increased. A graph of pressure measurements as a function of temperature is shown above. According to the ideal gas law, which of the following will be true if the container volume is reduced to half the original value and the experiment is repeated?

(A) The graph will still show a linear relationship that extrapolates to the origin, but with a smaller slope.
(B) The graph will still show a linear relationship that extrapolates to the origin, but with a larger slope.
(C) The graph will still show a linear relationship, but it will not extrapolate to the origin.
(D) The graph will not show a linear relationship, but it will still extrapolate to the origin.

24. Two containers, each holding a different gas, are brought into thermal contact. The gas atoms in container *X* have twice the mass and half the average speed of the gas atoms in container *Y*. Which of the following best describes the energy transfer by thermal conduction, if any, between the two containers?

(A) There is a net energy transfer from container *X* to container *Y*.
(B) There is a net energy transfer from container *Y* to container *X*.
(C) There is no net energy transfer between the containers, because no atoms move between them.
(D) There is no net energy transfer between the containers, because energy is transferred at approximately equal rates in each direction.

25. A group of students wants to determine the internal resistance of a battery. They connect the battery to a variable resistor. The students measure the potential difference across the battery as a function of the current through the battery as they vary the resistance. Which of the following analyses of the data could be used to determine the internal resistance of the battery?

(A) Divide the potential difference across the battery by the current through it for each data point. The average of these calculations gives the internal resistance of the battery.
(B) Graph the potential difference across the battery as a function of the current through it. Extrapolate to find the *y*-intercept and divide this by the average of the current measurements to find the internal resistance of the battery.
(C) Find the best-fit straight line for a graph of potential difference across the battery as a function of the current through it. The absolute value of the slope represents the internal resistance of the battery.
(D) This data cannot be analyzed to give the internal resistance of the battery, because the potential difference across the battery does not depend on the current.

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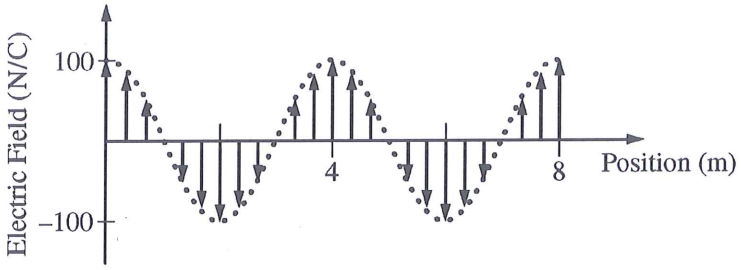


26. The figure above represents the electric field E as a function of position x due to a particular radio wave at time $t = 0$ s. Which of the following equations correctly describes the electric field?

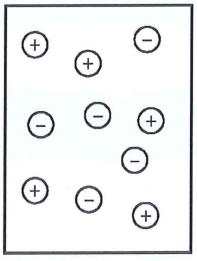
(A) $E = (100\ \text{N/C})\ \cos\left(\frac{\pi x}{1\ \text{m}}\right)$

(B) $E = (100\ \text{N/C})\ \cos\left(\frac{\pi x}{2\ \text{m}}\right)$

(C) $E = (100\ \text{N/C})\ \cos\left(\frac{\pi x}{4\ \text{m}}\right)$

(D) $E = (100\ \text{N/C})\ \sin\left(\frac{\pi x}{4\ \text{m}}\right)$

Questions 27-28 refer to the following material.



A very hot gas composed of equal numbers of positive and negative ions is in a closed, thermally insulated container and is in thermal equilibrium at temperature T_0. The figure above represents the initial distribution of the ions. A strong uniform electric field directed toward the bottom of the page is now created in and around the container, and the gas is allowed to reach a new thermal equilibrium at temperature T_1.

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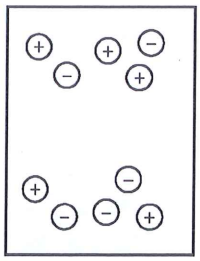
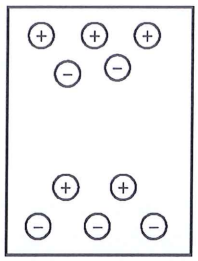
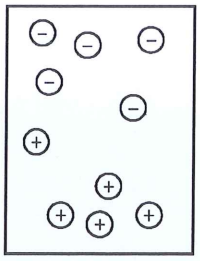
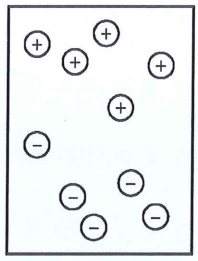
27. Which of the following best represents a possible distribution of the ions at temperature T_1 ?

(A) 

(B) 

(C) 

(D) 

28. The electric field is now turned off, and the gas is allowed to reach a final equilibrium temperature T_2 . How does T_2 compare to T_1 , and why?

(A) T_2 is less, because the electric potential energy added by the field to separate the ions is gone once the field is turned off.

(B) T_2 is less, because pairs of positive and negative ions bond to become molecules once the field is turned off, and energy is required to create the bonds.

(C) T_2 is greater, because work is done on the ions in the process of turning off the field.

(D) T_2 is greater, because the electric potential energy of the separated ions is converted to kinetic energy as they mix and collide.

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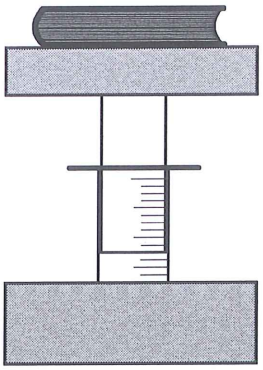
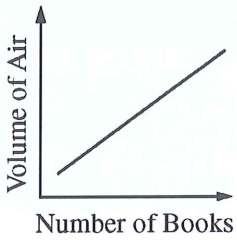
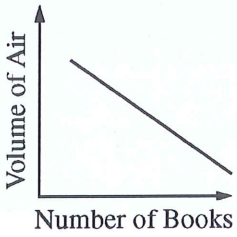


29. Students in a lab are given the plunger-syringe system represented above, which contains air at room temperature. The students take their physics textbooks and place them on top of the plunger one at a time. Each time a book is added, they allow the system to come to room temperature and then record the volume of the air in the syringe. Assume that air may be treated as an ideal gas. Which of the following best represents the expected graph of the volume of the air as a function of the number of books?

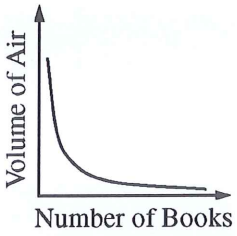
(A)



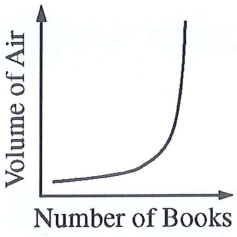
(B)



(C)



(D)



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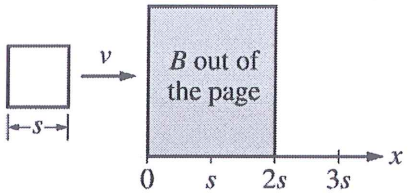
30. A hydrogen atom is isolated in a vacuum chamber. The electron is now separated from the proton and moved to a distance 1 cm away. Let F_G be the magnitude of the gravitational force between the proton and electron, and let F_E be the magnitude of the electric force between the proton and electron. How does the ratio F_G/F_E change as the particles are separated?

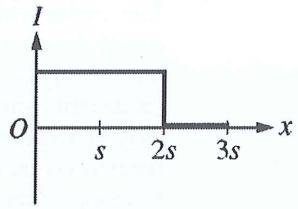
(A) F_G/F_E does not change; it is the same nonzero value for all separations.
(B) F_G/F_E becomes larger as the particles are moved apart.
(C) F_G/F_E becomes smaller as the particles are moved apart.
(D) F_G/F_E cannot be evaluated; it is undefined for all separations.

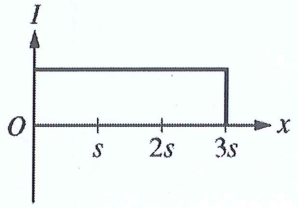
31. When the average speed of the molecules in a certain sample of gas is v, the absolute temperature of the gas is T. If the average speed of the molecules is doubled to $2v$, what is the new absolute temperature?

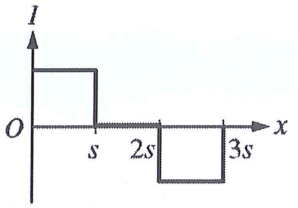
(A) $4T$
(B) $2T$
(C) T
(D) $\sqrt{2}T$

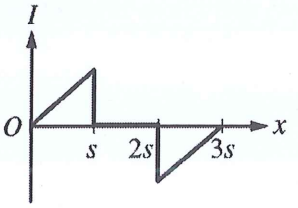


32. The gray rectangle in the figure above represents a region of uniform magnetic field directed out of the page. A square loop of wire of side s is in the plane of the page and is pulled at constant speed v through the field. Which of the following could show the current I in the loop as a function of the position of the right edge of the loop?

(A)


(B)


(C)


(D)


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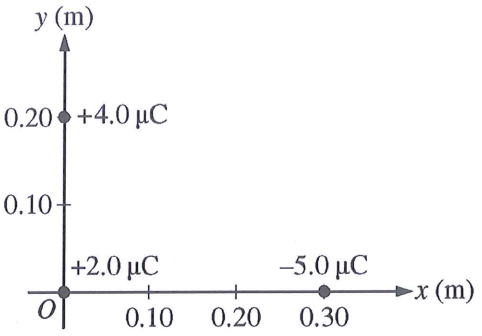
33. The mass of a proton is 1.673×10^{-27} kg, and the mass of a neutron is 1.675×10^{-27} kg. A proton and neutron combine to form a deuteron, releasing 3.520×10^{-13} J. What is the mass of the deuteron?

(A) 3.344×10^{-27} kg
(B) 3.348×10^{-27} kg
(C) 3.352×10^{-27} kg
(D) 3.911×10^{-30} kg



34. The figure above shows the locations and charges of three objects. The magnitude of the electric force exerted on the object located at the origin is most nearly

(A) 0.47 N
(B) 0.80 N
(C) 2.1 N
(D) 2.8 N

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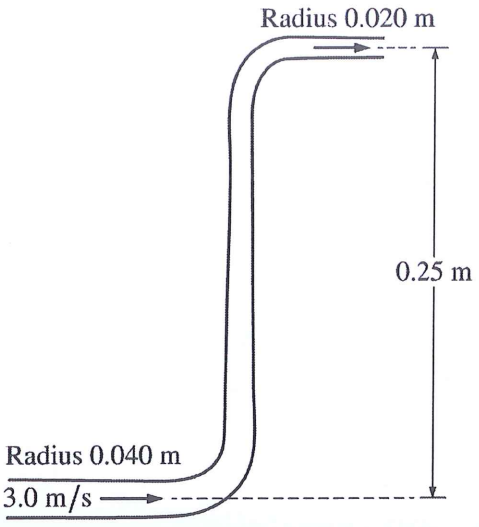
$$^{214}_{83}\text{Bi} \rightarrow \text{X} + \beta^{+}$$

35. In the decay represented above, what is the nucleon number of particle X?

(A) 82
(B) 83
(C) 213
(D) 214



36. Water of density 1000 kg/m^3 flows at a speed of 3.0 m/s through a section of pipe of radius 0.040 m . The pipe bends upward to 0.25 m above its original height and tapers to a radius of 0.020 m , as shown in the figure above.

If the water pressure is 1.50×10^5 Pa in the lower part of the pipe, the water pressure in the upper part of the pipe is most nearly

(A) 0.80×10^5 Pa
(B) 1.48×10^5 Pa
(C) 1.53×10^5 Pa
(D) 2.29×10^5 Pa

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Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then fill in the corresponding circles that begin with number 131 on page 3 of the answer sheet.

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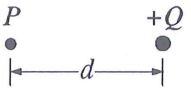
131. For which of the following phenomena is an explanation that treats light as a wave most appropriate? Select two answers.

(A) Visible light shining on a metal must have a minimum frequency to cause electrons to be emitted.
(B) Visible light shining on a multislit grating causes an interference pattern.
(C) X-rays impart some of their momentum to an electron, causing the x-rays to be scattered.
(D) X-rays incident on a crystalline solid create a diffraction pattern.



132. An isolated point charge $+Q$ is located a distance d to the right of point P, as shown above. The point charge is then moved a distance less than d. Movement in which of the following directions will result in a change in the direction of the electric field at point P ? Select two answers.

(A) Toward the left
(B) Toward the right
(C) Toward the top of the page
(D) Toward the bottom of the page

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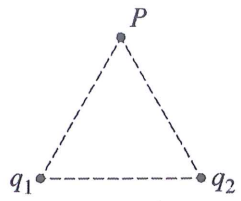
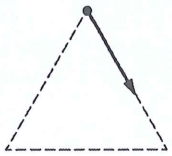
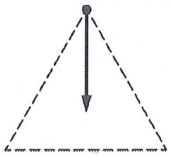
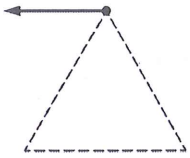


133. Two point charges, q_1 and q_2, of equal magnitude are at the vertices of an equilateral triangle, as shown above. The sign of each of the charges is unknown. A positive point charge is placed at vertex P and released from rest. Which of the following shows a possible direction of the initial acceleration of the positive point charge due to the net force exerted on it by q_1 and q_2? Select two answers.

(A)


(B)


(C)


(D)


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134. Some students performing a double-slit interference experiment with light want to increase the separation of the interference maxima to improve their measurement of the spacing between maxima. Which of the following changes by itself will accomplish this goal? Select two answers.

(A) Decreasing the distance between the light source and the slits
(B) Decreasing the separation between the slits
(C) Increasing the distance between the slits and the screen
(D) Using a light source that has a shorter wavelength

END OF SECTION I

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

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

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Section II: Free-Response Questions

This is the free-response section of the 2015 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

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AP® Physics 2: Algebra-Based Exam

SECTION II: Free Response

2015

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
4
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Suggested Time
Approximately 25 minutes each for questions 2 and 3 and 20 minutes each for questions 1 and 4
Weight
Approximate weights:
Questions 2 and 3: 27% each
Questions 1 and 4: 23% each

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.

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AP® PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg·s^2
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

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

UNIT SYMBOLS							
meter,	m	mole,	mol	watt,	W	farad,	F
kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
second,	s	newton,	N	volt,	V	degree Celsius,	°C
ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. In all situations, positive work is defined as work done on a system.
III. The direction of current is conventional current: the direction in which positive charge would drift.
IV. Assume all batteries and meters are ideal unless otherwise stated.
V. Assume edge effects for the electric field of a parallel plate capacitor unless otherwise stated.
VI. For any isolated electrically charged object, the electric potential is defined as zero at infinite distance from the charged object

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AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

$x = A\cos(\omega t) = A\cos(2\pi f t)$

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

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

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

$L = I\omega$

$\Delta L = \tau \Delta t$

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

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

a = acceleration
A = amplitude
d = distance
E = energy
F = force
f = frequency
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed

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

$\Delta U_g = mg\Delta y$

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

$|\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$

$\Delta U_E = q\Delta V$

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

$|\vec{E}| = \left|\frac{\Delta V}{\Delta r}\right|$

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

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

$E = \frac{Q}{\varepsilon_0 A}$

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

$I = \frac{\Delta Q}{\Delta t}$

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = separation
t = time
U = potential (stored) energy
V = electric potential
v = speed
κ = dielectric constant
ρ = resistivity
θ = angle
Φ = flux

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

$|\vec{F}_M| = |q\vec{v}||\sin\theta||\vec{B}|$

$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$|\vec{F}_M| = |I\vec{\ell}||\sin\theta||\vec{B}|$

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

$\Phi_B = |\vec{B}|\cos\theta|\vec{A}|$

$\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}$

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

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AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho gh$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

$\frac{Q}{\Delta t} = \frac{kA\,\Delta T}{L}$

$PV = nRT = Nk_BT$

$K = \frac{3}{2}k_BT$

$W = -P\Delta V$

$\Delta U = Q + W$

A = area
F = force
h = depth
k = thermal conductivity
K = kinetic energy
L = thickness
m = mass
n = number of moles
N = number of molecules
P = pressure
Q = energy transferred to a system by heating
T = temperature
t = time
U = internal energy
V = volume
v = speed
W = work done on a system
y = height
ρ = density

WAVES AND OPTICS

$\lambda = \frac{v}{f}$

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

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

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

$|M| = \left|\frac{h_i}{h_o}\right| = \left|\frac{s_i}{s_o}\right|$

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
s = distance
v = speed
λ = wavelength
θ = angle

MODERN PHYSICS

$E = hf$

$K_{max} = hf - \phi$

$\lambda = \frac{h}{p}$

$E = mc^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

Rectangular solid
$V = \ell wh$

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

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

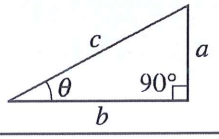
Right triangle

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

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

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

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



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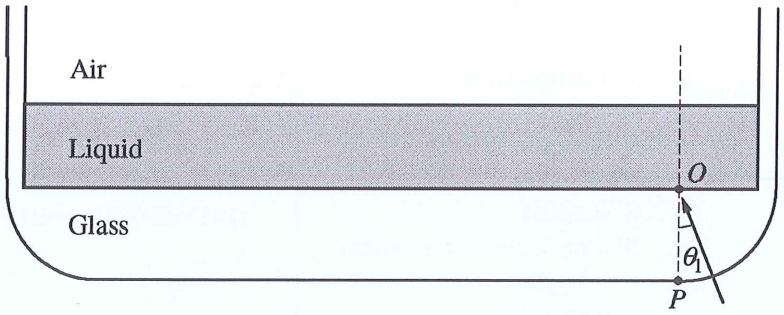
PHYSICS 2
Section II
4 Questions
Time—90 minutes

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (10 points - suggested time 20 minutes)

The figure above shows a cross section of a drinking glass (index of refraction 1.52) filled with a thin layer of liquid (index of refraction 1.33). The bottom corners of the glass are circular arcs, with the bottom right arc centered at point O. A monochromatic light source placed to the right of point P shines a beam aimed at point O at an angle of incidence θ. The flat bottom surface of the glass containing point P is frosted so that bright spots appear where light from the beam strikes the bottom surface and does not reflect. When $\theta = \theta_1$, two bright spots appear on the bottom surface of the glass. The spot closer to point P will be referred to as X; the spot farther from P will be referred to as Y. The location of spot X and that of spot Y both change as θ is increased.

(a) In a coherent paragraph-length answer, describe the processes involved in the formation of spots X and Y when $\theta = \theta_1$. Include an explanation of why spot Y is located farther from point P than spot X is and what factors affect the brightness of the spots.

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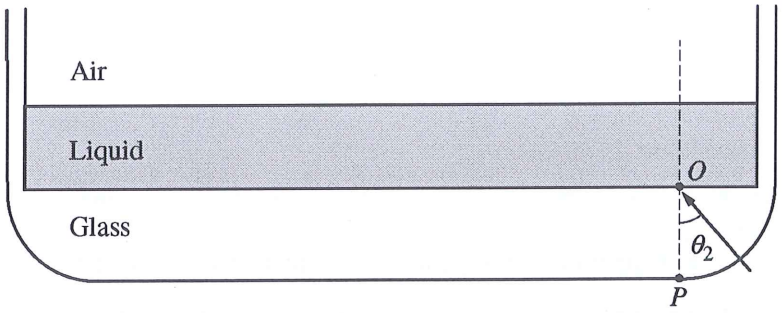
(b) When θ is increased to θ_2, one of the spots becomes brighter than it was before, due to total internal reflection.

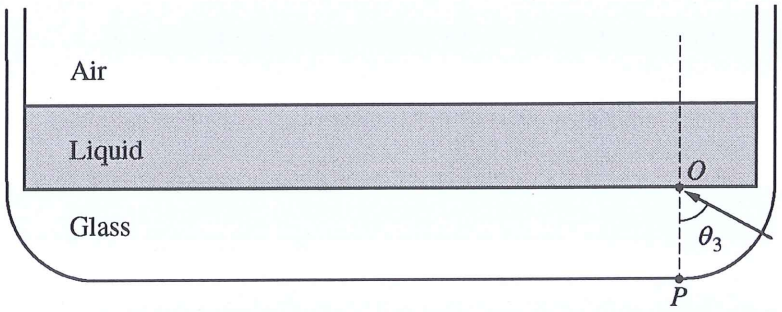
i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of spots X and Y when $\theta = \theta_2$.



ii. Which spot, X or Y, becomes brighter than it was before due to total internal reflection? Explain your reasoning.

(c) When θ is further increased to θ_3, one of the spots disappears entirely.

i. On the figure below, draw a ray diagram that clearly and accurately shows the formation of the remaining spot, X or Y, when $\theta = \theta_3$.



ii. Indicate which spot, X or Y, disappears. Explain your reasoning in terms of total internal reflection.

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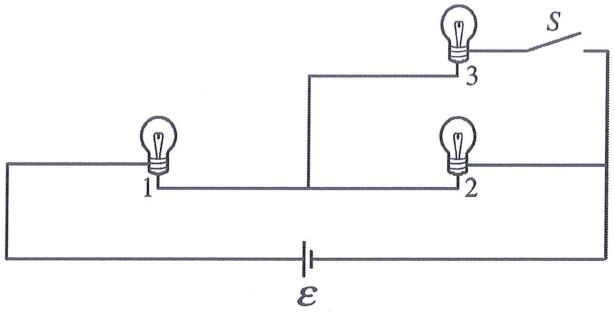

2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

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(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

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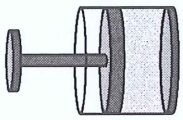
3. (12 points, suggested time 25 minutes)

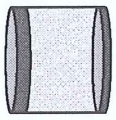
Students are watching a science program about the North Pole. The narrator says that cold air sinking near the North Pole causes high air pressure. Based on the narrator's statement, a student makes the following claim: "Since cold air near the North Pole is at high pressure, temperature and pressure must be inversely related."

(a) Do you agree or disagree with the student's claim about the relationship between pressure and temperature? Justify your answer.

After hearing the student's hypothesis, you want to design an experiment to investigate the relationship between temperature and pressure for a fixed amount of gas. The following equipment is available.



Cylinder with Movable Piston



Cylinder with Fixed Lid

___ A cylinder with a movable piston, shown above on the left
___ A cylinder with a fixed lid, shown above on the right
Note: The two cylinders have gaskets through which measurement instruments can be inserted without gas escaping.
___ A pressure sensor
___ A basin that is large enough to hold either cylinder with a lot of extra room
___ A source of hot water
___ A source of mixed ice and water
___ A meterstick
___ A thermometer
___ A stopwatch

(b) Put a check in the blank next to each of the items above that you would need for your investigation. Outline the experimental procedure you would use to gather the necessary data. Make sure the outline contains sufficient detail so that another student could follow your procedure.

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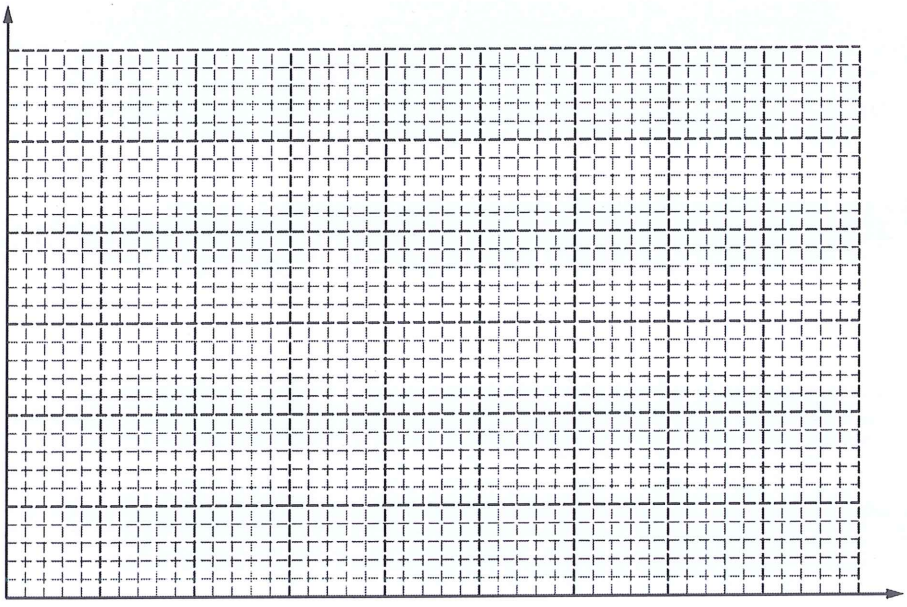
The table below shows data from a different experiment in which the volume, temperature, and pressure of a sample of gas are varied.

Trial Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Volume $\left(cm^3\right)$	10.0	5.0	4.0	3.0	5.0	4.0	10.0	5.0	3.0	4.0	5.0	10.0	3.0	5.0
Pressure (kPa)	100	200	250	330	220	270	110	230	380	290	240	120	420	250
Temperature (°C)	0	0	0	0	20	20	20	40	40	40	60	60	70	70

(c) What subset of the experimental trials would be most useful in creating a graph to determine the relationship between temperature and pressure for a fixed amount of gas? Explain why the trials you selected are most useful.

(d) Plot the subset of data chosen in part (c) on the axes below. Be sure to label the axes appropriately. Draw a curve or line that best represents the relationship between the variables.



(e) What can be concluded from your curve or line about the relationship between temperature and pressure?

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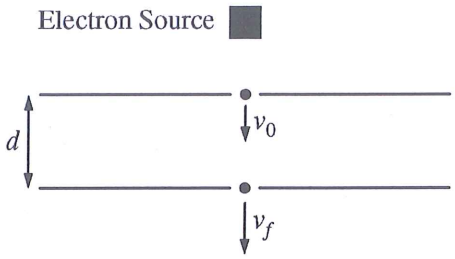

Note: Figure not drawn to scale.

4. (10 points - suggested time 20 minutes)

The apparatus shown in the figure above consists of two oppositely charged parallel conducting plates, each with area $A = 0.25\ \text{m}^2$, separated by a distance $d = 0.010\ \text{m}$. Each plate has a hole at its center through which electrons can pass. High velocity electrons produced by an electron source enter the top plate with speed $v_0 = 5.40 \times 10^6\ \text{m/s}$, take 1.49 ns to travel between the plates, and leave the bottom plate with speed $v_f = 8.02 \times 10^6\ \text{m/s}$.

(a) Which of the plates, top or bottom, is negatively charged? Support your answer with a reference to the direction of the electric field between the plates.

(b) Calculate the magnitude of the electric field between the plates.

(c) Calculate the magnitude of the charge on each plate.

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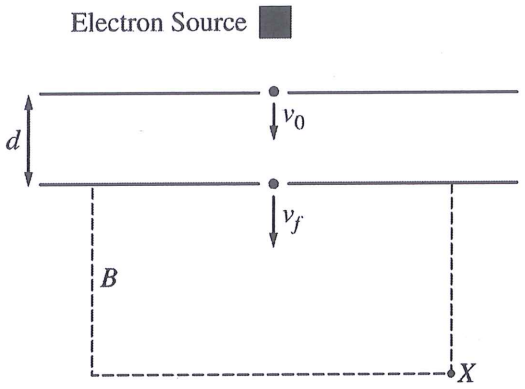
(d) The electrons leave the bottom plate and enter the region inside the dashed box shown below, which contains a uniform magnetic field of magnitude B that is perpendicular to the page. The electrons then leave the magnetic field at point X.



Note: Figure not drawn to scale.

i. On the figure above, sketch the path of the electrons from the bottom plate to point X. Explain why the path has the shape that you sketched.

ii. Indicate whether the magnetic field is directed into the page or out of the page. Briefly explain your choice.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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- **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 FRONT COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**