From the 2017 Administration

AP CollegeBoard

Physics 2: Algebra-Based

Practice Exam

NOTE: This is a modified version of the 2017 AP Physics 2: Algebra-Based Exam.

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Note: This publication shows the page numbers that appeared in the *2016–17 AP Exam Instructions* book and in the actual exam. This publication was not repaginated to begin with page 1.

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Exam Instructions

The following contains instructions taken from the *2016–17 AP Exam Instructions* book.

AP® Physics 1: Algebra-Based Exam

Regularly Scheduled Exam Date: Tuesday afternoon, May 2, 2017

Late-Testing Exam Date: Thursday afernoon, May 18, 2017

AP® Physics 2: Algebra-Based Exam

Regularly Scheduled Exam Date: Wednesday afternoon, May 3, 2017

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

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
- *2016-17 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Container for students' electronic devices (if needed)
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Extra paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited in the testing room"

Before Distributing Exams: Check that the title on all exam covers is **Physics 1: Algebra-Based** or **Physics 2: Algebra-Based**. If there are any exam booklets with a different title, contact the AP coordinator immediately.

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for 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 49 of the *2016-17 AP Coordinator's Manual*. See pages 46–49 of the *AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 47 of the *AP Coordinator's Manual*.

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 325–326 for a seating chart template and instructions. See the *2016-17 AP Coordinator's Manual* for exam seating requirements (pages 51–54).

Physics 1: Algebra-Based

If you are giving the regularly scheduled exam, say:

It is Tuesday afternoon, May 2, 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 afternoon, May 18, 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 Wednesday afternoon, May 3, 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 19, 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 *2016-17 Bulletin for AP Students and Parents*.

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

Look at your exam packet and confirm that the exam title is "AP Physics 1: Algebra-Based." Raise your hand if your exam packet contains any title other than "AP Physics 1: Algebra-Based" and I will help you.

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

Look at your exam packet and confirm that the exam title is "AP Physics 2: Algebra-Based." Raise your hand if your exam packet contains any title other than "AP Physics 2: Algebra-Based" and I will help you.

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

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

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

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

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

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

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

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

Are there any questions? . . .

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

Open your answer sheet to page 2. You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses 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. The answer sheet has circles marked A–E for each of these questions. For this exam, you will use only the circles marked A–D. 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 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, 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. Remember, you may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled. 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 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. 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. . . .

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 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 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 a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report. A single Incident Report may be completed for multiple students per exam subject per administration (regular or late testing) as long as all of the required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 62 of the *2016-17 AP Coordinator's Manual* for complete details). Then say:

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

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

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

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

If you are giving the regularly scheduled exam, say:

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

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

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

If any students completed the AP number card at the beginning of this exam, 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.

Post-Exam Tasks

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

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

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 *2016-17 AP Coordinator's Manual*.
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2017

AP Number Label
(from Student Pack)

123456789

AP Exam Label
(from Section I Booklet)

CollegeBoard

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

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

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

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

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

C. YOUR AP NUMBER

D. EXAM DATE Month Day

E. EXAM START TIME AM PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

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 (Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec) Day Year

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.

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

792107

SCHOOL USE ONLY

Section Number (1 2 3 4 5 6 7 8 9)

Fee Reduction Granted (1) Option 1 (2) Option 2

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Q4298/1-4

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

1	A B C D E F G H I	4	A B C D E F G H I	7	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	8	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	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

QUESTIONS 131–142

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

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

131	A B C D	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

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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	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	

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	Grade school
Some high school	Some high school
High school diploma or equivalent	High school diploma or equivalent
Vocational or trade school	Vocational or trade school
Some college	Some college
Associate or two-year degree	Associate or two-year degree
Bachelor's or four-year degree	Bachelor's or four-year degree
Some graduate or professional school	Some graduate or professional school
Graduate or professional degree	Graduate or professional degree

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

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

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2017 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

For purposes of test security and/or statistical analysis, some questions
have been removed from the version of the exam that was administered
in 2017. Therefore, the timing indicated here may not be appropriate
for a practice exam.

AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice

2017

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.

Form I
Form Code 4NBP4-S

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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, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ 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,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/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,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^{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

AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

$\Delta L = \tau\,\Delta t$

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

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

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

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

$\Delta U_g = mg\,\Delta y$

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

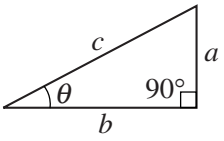
Rectangular solid
$V = \ell wh$

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



PHYSICS 2

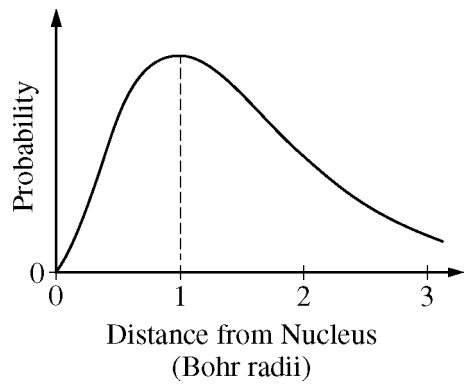
Section I

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. The graph above describes the location of an electron in a hydrogen atom that is in the ground state. What conclusion can be drawn from the graph?

   (A) The distance of the electron from the nucleus is exactly equal to one Bohr radius.
   (B) The electron will probably slide down either the left slope or the right slope, depending on its initial location.
   (C) The electron must always be located within three Bohr radii of the nucleus.
   (D) The greatest probability of locating the electron is at a distance of one Bohr radius from the nucleus.

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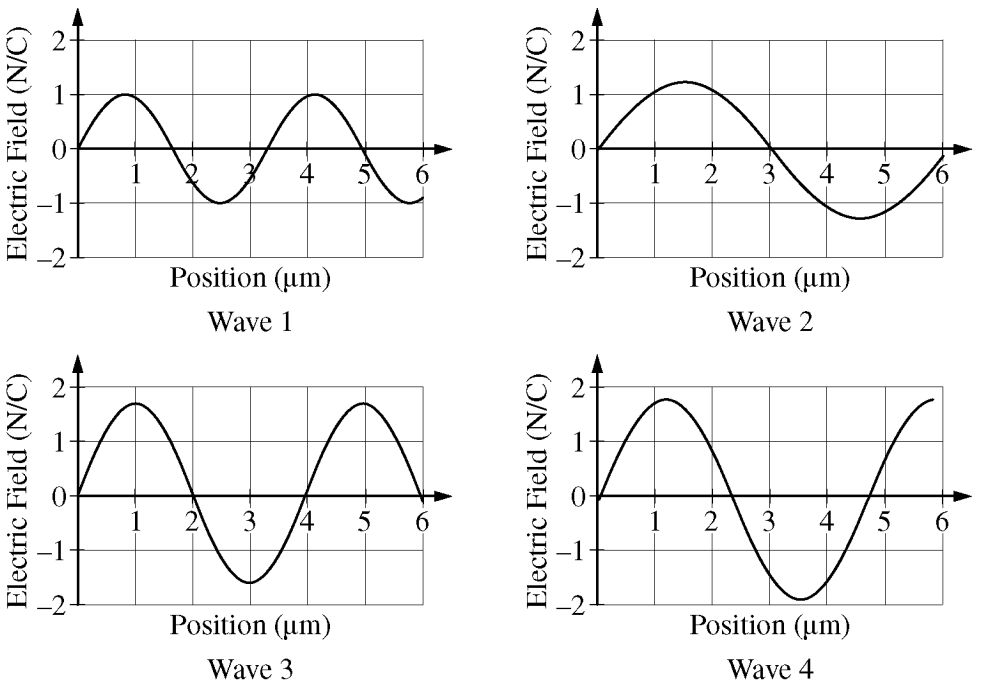

2. The graphs above show the electric field as a function of position at some instant of time for four different electromagnetic plane waves. Which of the following correctly ranks the frequency f of the waves?

   (A) $f_1 > f_2 > f_3 > f_4$

   (B) $f_1 > f_3 > f_4 > f_2$

   (C) $f_2 > f_4 > f_3 > f_1$

   (D) $f_4 > f_3 > f_2 > f_1$

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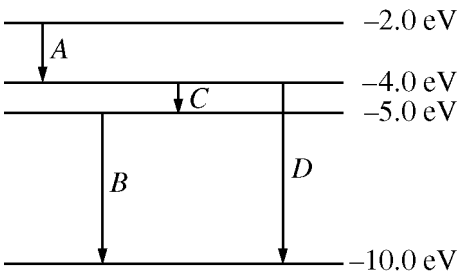
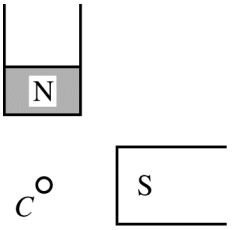
3. When two bowling balls are held with their centers 30 centimeters apart, they exert a gravitational force of magnitude F on each other. For two free protons to exert a net force of magnitude F on each other, the protons must be separated by a distance of approximately 1×10^{-10} m. Under these conditions, will the protons attract or repel each other, and why?

(A) They will attract each other, because they both have positive charge.
(B) They will attract each other, because the gravitational force is always attractive.
(C) They will repel each other, because the repulsive electrical force between the protons is much stronger than the attractive gravitational force.
(D) They will repel each other, because the protons only exert a repulsive electrical force on each other and do not exert an attractive gravitational force.

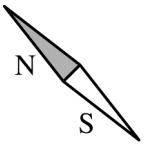


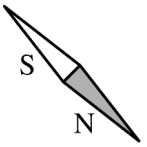
4. The energy level diagram for a hypothetical atom is shown in the figure above. Which of the labeled transitions in the diagram would produce a photon with the shortest wavelength?

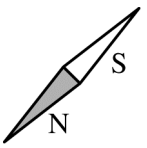
(A) A
(B) B
(C) C
(D) D

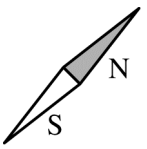


5. The figure above shows a small compass C that is equidistant from the poles of two identical bar magnets. Which of the following best represents the direction that the needle of the compass will point?

(A)


(B)


(C)


(D)


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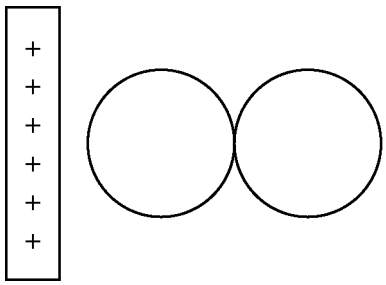
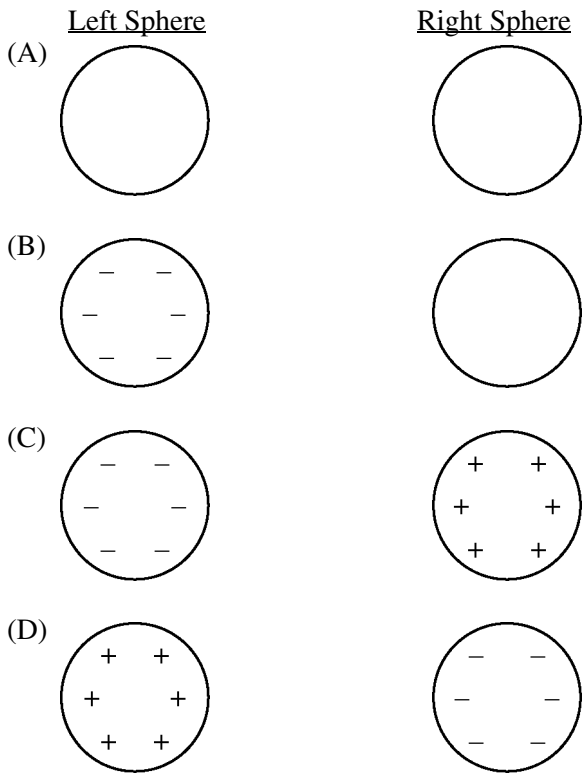
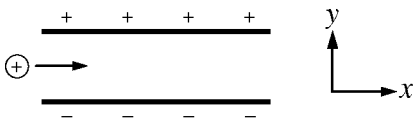
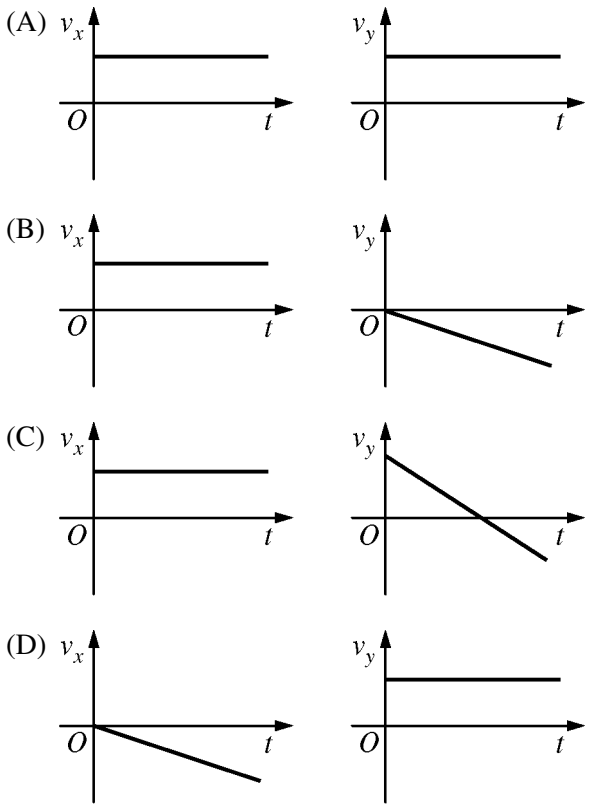


6. Two uncharged conducting spheres on insulating stands are in contact when a positively charged rod is brought near but does not touch them, as shown in the figure above. The right sphere is then moved far to the right, and finally the rod is removed. Which of the following best shows the final distribution of excess charges, if any, on the spheres?





7. A positively charged particle is moving horizontally when it enters the uniform electric field between two parallel charged plates, as shown in the figure above. Which of the following correctly shows the x- and y-components of the velocity v as a function of time t ?



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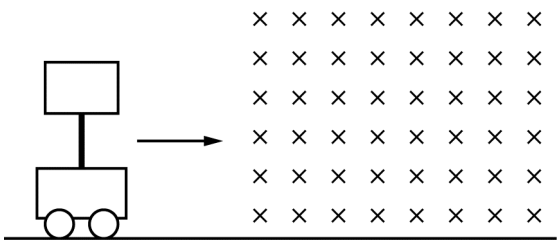
8. A simple circuit has a 24.0 V battery and resistors of resistance 3.0 Ω, 6.0 Ω, and R all connected in parallel. If the current through the battery is 15.0 A, what is the value of R ?

(A) 0.9 Ω
(B) 1.1 Ω
(C) 7.4 Ω
(D) 8.0 Ω



9. A rectangular loop of copper wire is attached to a cart by an insulating rod. The cart is moving at constant speed when it enters a region containing a uniform magnetic field that is perpendicular to the plane of the loop and directed into the page, as shown above. Frictional losses are negligible. Which of the following correctly describes the speed of the cart as it moves into, through, and out of the field?

(A) The speed remains constant.
(B) The speed continually decreases.
(C) The speed decreases as the cart enters the field and increases as it leaves the field but is constant while it is completely inside the field.
(D) The speed decreases as the cart enters and leaves the field but is constant while it is completely inside the field.

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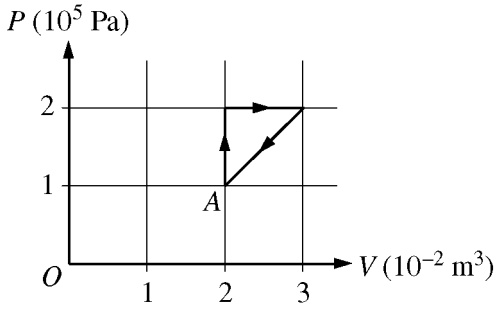

10. A sample of ideal gas that is initially in state *A* shown on the graph above is taken through the cycle shown. What is the net work done on the gas during one cycle?

(A) −500 J
(B) −1000 J
(C) −2000 J
(D) −3500 J

11. A small, well-insulated building is kept cool on a hot day. A person in the building holds a hand close to, but not touching, a solid metal door to the outside and feels warmth coming from the metal door. Which statement best describes how most of the energy is transferred from the outside to the person's hand?

(A) Thermal energy from the outside is convected through the metal door. Thermal energy from the door is conducted by the air and is detected by the person's hand.
(B) Thermal energy from the outside is convected through the metal door. The door radiates energy that is detected by the person's hand.
(C) Thermal energy from the outside is conducted through the metal door. The door radiates energy that is detected by the person's hand.
(D) Thermal energy from the outside is radiated through the metal door. The door radiates energy that is detected by the person's hand.

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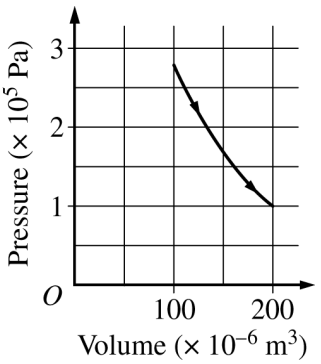
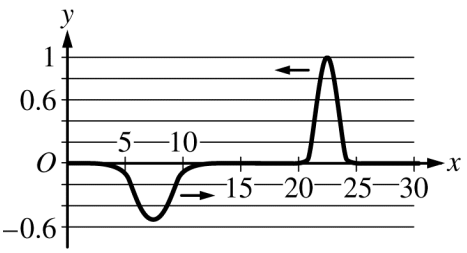
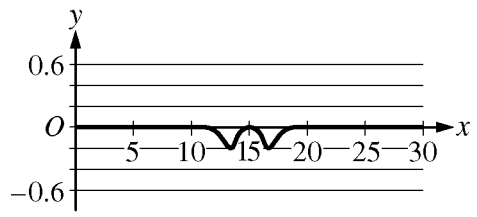


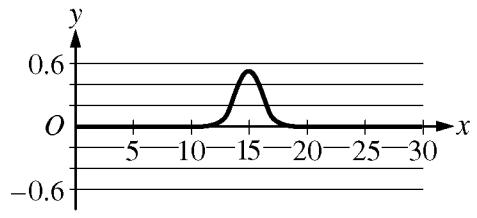
12. The graph above of pressure as a function of volume illustrates a thermodynamic process for an ideal gas in an engine. Which of the following best describes the change in the internal energy of the gas and the work done during the process?

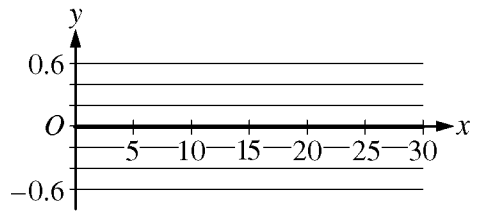
(A) The internal energy increases, and positive work is done by the gas.
(B) The internal energy decreases, and positive work is done on the gas.
(C) The internal energy decreases, and positive work is done by the gas.
(D) The internal energy increases, and positive work is done on the gas.

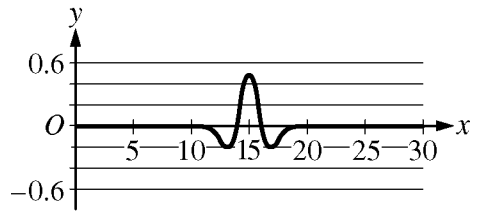


13. Two wave pulses approach each other, as shown in the figure above. The pulse traveling to the right is half the height and twice the width of the pulse traveling to the left. Which of the following best represents the resulting shape when the peaks of the two pulses are at the same location?

(A)


(B)


(C)


(D)


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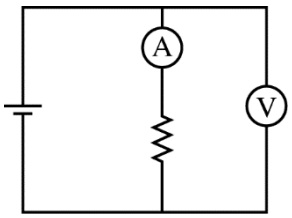
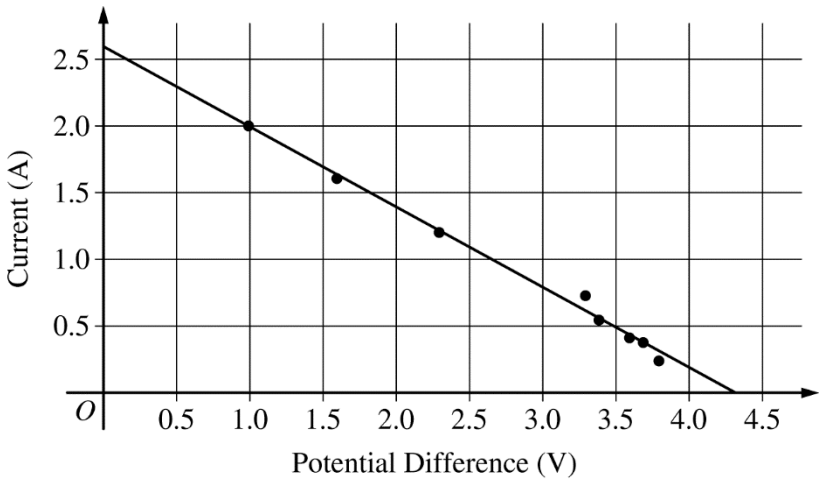
Questions 14-15 refer to the following material.



A student performs an experiment using the circuit shown above, with the goal of determining the characteristics of the battery, which has nonnegligible internal resistance. The student has many resistors with resistances ranging from $0.5\ \Omega$ to $15\ \Omega$. The student puts different resistors in the circuit and records the current and the potential difference measured by the ammeter A and voltmeter V. The student's data table and graph of current as a function of potential difference are shown below.

Resistance (Ω)	0.5	1.0	2.0	4.0	6.0	8.0	10	15
Potential Difference (V)	1.0	1.6	2.3	3.3	3.4	3.6	3.7	3.8
Current (A)	2.0	1.6	1.2	0.72	0.55	0.41	0.35	0.23



14. Which of the following is most nearly the battery's internal resistance?

    (A) 0.4 ohm
    (B) 0.6 ohm
    (C) 1.6 ohm
    (D) 2.6 ohm

15. The student now replaces the battery with a different one that has the same emf but a significantly smaller internal resistance. The student runs the experiment again and graphs the new data. Which of the following correctly describes how the new graph compares to the plot shown above?

    (A) The new graph will be the same as the original graph.
    (B) The vertical intercept will have a greater value, but the slope will be the same.
    (C) The vertical intercept will be the same, but the magnitude of the slope will be greater.
    (D) Both the vertical intercept and the magnitude of the slope will be greater.

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16. A sample of gas has a temperature of 200 K. If the speed of every gas molecule in the sample is doubled, what is the new temperature of the gas?

(A) 800 K
(B) 400 K
(C) 200 K
(D) 100 K

Questions 17-19 refer to the following material.

An atom of polonium (Po-216) is moving slowly enough that it can be considered to be at rest. The Po-216 undergoes alpha decay and becomes lead (Pb-212), via the reaction ${}^{216}_{84}\text{Po} \rightarrow {}^{212}_{82}\text{Pb} + {}^{4}_{2}\alpha$. After the decay, the lead atom is moving to the left with speed v_{Pb}, and the alpha particle is moving to the right with speed v_{α}. The masses of the three isotopes involved in the decay are given below.

$$M_{\text{Po-216}} = 216.001915 \text{ u}$$

$$M_{\alpha} = 4.002603 \text{ u}$$

$$M_{\text{Pb-212}} = 211.991898 \text{ u}$$

17. How do the momentum and kinetic energy of the polonium atom compare with the total momentum and kinetic energy of the decay products?

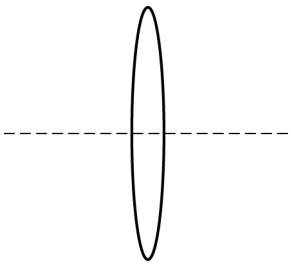
	Polonium Momentum	Polonium Kinetic Energy
(A)	Different	Different
(B)	Different	The same
(C)	The same	Different
(D)	The same	The same

18. How much energy is released in the decay?

(A) None
(B) 0.00741 MeV
(C) 6.90 MeV
(D) 9.31 MeV

19. The half-life of Po-216 is $1/7$ s . What is the probability that any particular Po-216 atom will decay within one second?

(A) 0 %
(B) 7 %
(C) 99 %
(D) 100 %



20. The figure above shows a lens with a focal length of magnitude 30 cm when in air. An object is located 200 cm to the left of the lens. What is the approximate location of the object's image?

(A) 26 cm to the left of the lens
(B) 26 cm to the right of the lens
(C) 35 cm to the left of the lens
(D) 35 cm to the right of the lens

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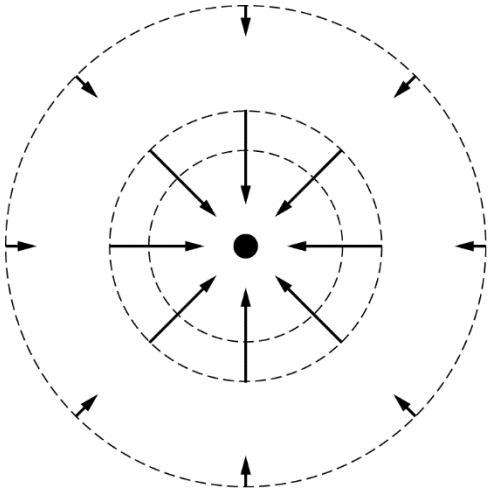
Questions 21-23 refer to the following material.

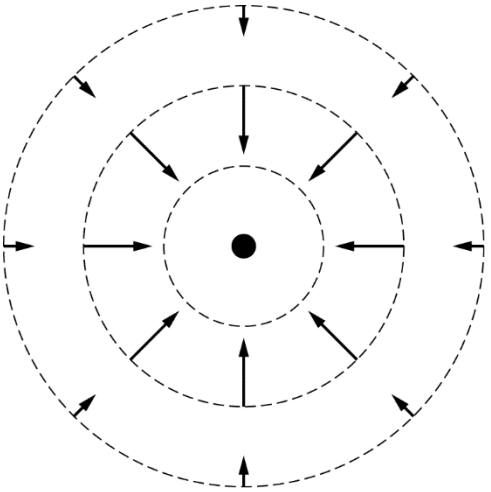
A very small, isolated sphere with charge $+Q$ exists in an empty region of space. A second very small sphere is moved from far away to a short distance from the first sphere.

21. In the figures below, the central dot represents the first sphere. The dashed circles are isolines with the same potential difference between adjacent circles. Which of the figures best represents the isolines and electric field vectors around the first sphere while the second sphere is still far away?

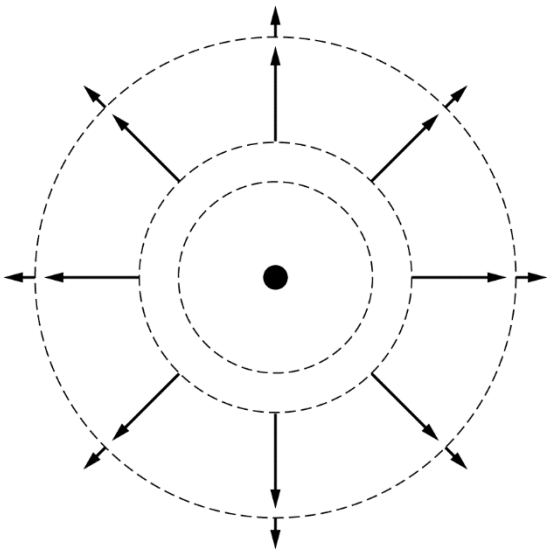
(A)



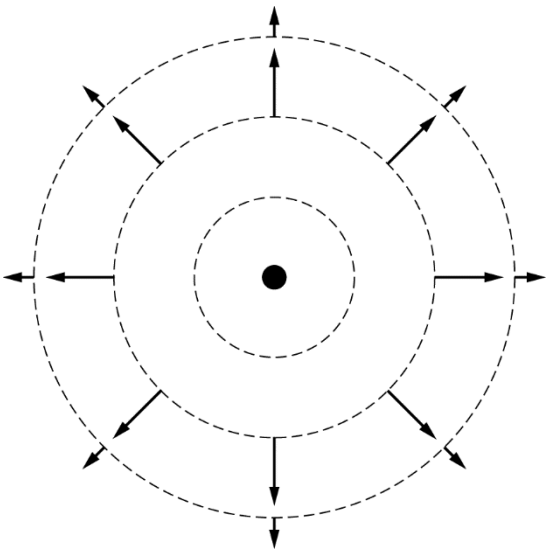
(B)



(C)



(D)



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22. The second sphere has a charge of $+2.0 \times 10^{-9}$ C. As it is moved closer to the first sphere at a constant speed, the second sphere passes through the circular equipotential lines due to the first sphere. Two of these lines are separated by a distance of 0.020 m and have potentials of 100 V and 150 V. What is the magnitude of the average force needed to move the second sphere between the two equipotential lines?

(A) 1.5×10^{-5} N

(B) 5.0×10^{-6} N

(C) 1.0×10^{-7} N

(D) 2.0×10^{-9} N

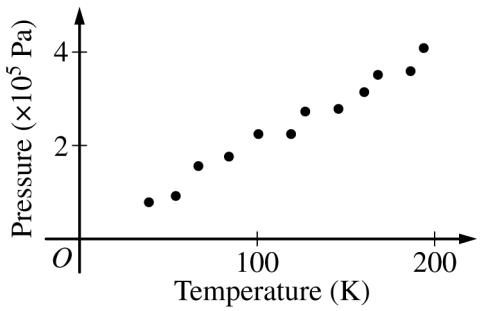
23. As the second sphere is moved at a constant velocity closer to the first sphere, data is taken for the force F exerted on the second sphere by the first sphere as a function of the separation d of the spheres. Which of the following should be graphed to yield a straight line from the data?

(A) F as a function of d

(B) F as a function of d^2

(C) F as a function of $1/d$

(D) F as a function of $1/d^2$



24. A sample of gas is in a sealed container whose volume is held fixed. 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 is expected if the sealed container's volume is increased to three times the original value and the experiment is repeated?

(A) The graph will show a linear relationship that still extrapolates to the origin, but with a smaller slope.

(B) The graph will show a linear relationship that still extrapolates to the origin, but with a larger slope.

(C) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the horizontal axis to the right of the origin.

(D) The graph will show a linear relationship with the same slope, but it will extrapolate to a point on the vertical axis above the origin.

25. Which of the following describes a difference in the behavior of an electrically conducting sphere and that of an insulating sphere?

(A) A conducting sphere can be charged by friction, but an insulating sphere cannot.

(B) An uncharged object can be charged by touching it to a charged conducting sphere, but not by touching it to a charged insulating sphere.

(C) When a conducting sphere is brought near a positively charged object, some of the sphere's electrons move closer to that object. No polarization occurs in the atoms of an insulating sphere.

(D) Excess charge placed on a conducting sphere becomes distributed over the entire surface of the sphere. Excess charge placed on an insulating sphere can remain where it is placed.

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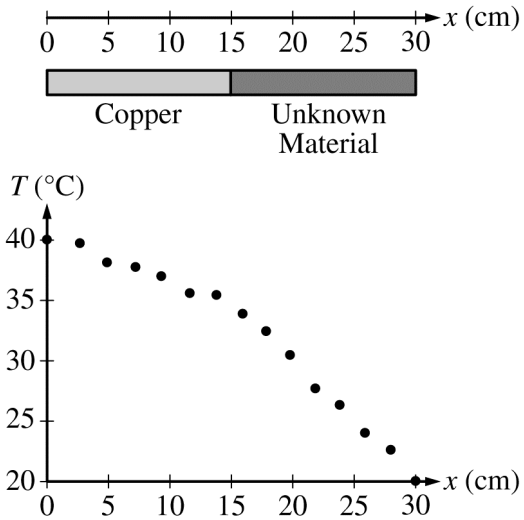

26. A student designs an experiment intended to determine the thermal conductivity of an unknown material. Two 15 cm long bars with the same cross-sectional area are joined together, as shown in the figure above. The bar on the left is made of copper, and the bar on the right is made of the unknown material. The left and right ends of the two-bar combination are maintained at $40°C$ and $20°C$, respectively, and the bars reach equilibrium. The student then measures the temperature T along the bars and produces the data shown in the graph, where $x = 0$ is the left end and 30 cm is the right end. The experimental uncertainty in the data is negligible. Which of the following can the student conclude about k_c, the thermal conductivity of copper, compared with k_u, the thermal conductivity of the unknown material?

(A) $k_c < k_u$
(B) $k_c = k_u$
(C) $k_c > k_u$
(D) The relationship cannot be determined from the data given.

27. A sealed container with a lid of area $0.004\ \text{m}^2$ is filled with an ideal gas. The container and gas are allowed to reach thermal equilibrium with the surrounding air. If a 2000 N block is needed to keep the lid from being pushed off the container, what is the absolute pressure inside the container (the pressure compared to vacuum) ?

(A) 1×10^5 Pa
(B) 2×10^5 Pa
(C) 4×10^5 Pa
(D) 6×10^5 Pa

28. Water initially moving through a small horizontal cylindrical pipe enters a new section of pipe with twice the radius of the initial pipe. What is the ratio of the speed of the water in the new section of pipe to the initial speed of the water?

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

29. A block floating in water is supported by the buoyant force exerted on the block by the water. The buoyant force is created on the atomic scale primarily by which of the following electrostatic forces?

(A) A force of attraction between neutral atoms of the block and neutral atoms of the water
(B) A force of attraction between charged atoms of the block and charged atoms of the water
(C) A force of repulsion between nuclei in the neutral atoms of the block and nuclei in the neutral atoms of the water
(D) A force of repulsion between electrons in the neutral atoms of the block and electrons in the neutral atoms of the water

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30. A supernova explosion occurs at a distance of 2×10^{20} m from Earth. The supernova simultaneously emits radiation at both visible and x-ray wavelengths. Which of the following statements best describes the time it takes for the two types of radiation from the supernova to reach Earth?

(A) The two types of radiation reach Earth at the same time, within a few seconds of the supernova explosion.
(B) The two types of radiation reach Earth at the same time, many years after the supernova explosion.
(C) The two types of radiation reach Earth many years after the supernova explosion, but the visible radiation arrives first due to its shorter wavelength.
(D) The two types of radiation reach Earth many years after the supernova explosion, but the x-ray radiation arrives first due to its shorter wavelength.

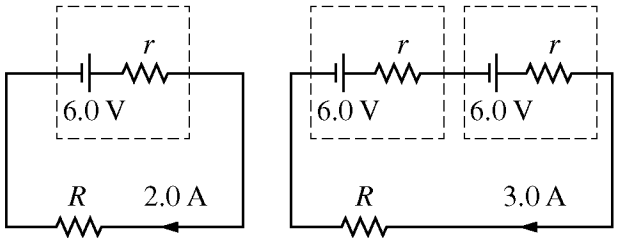
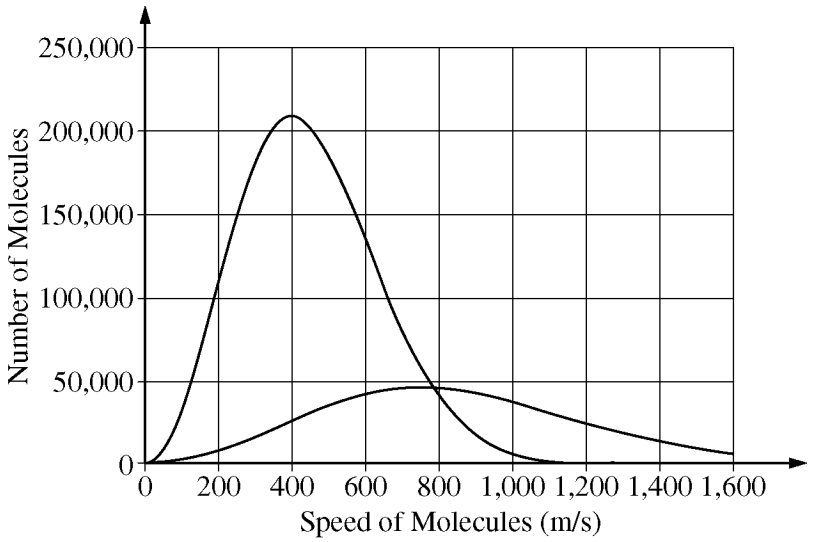


Figure 1 Figure 2

31. A battery with emf 6.0 V and an internal resistance r is connected to a resistor of resistance R, as shown in Figure 1 above. The current in the circuit is 2.0 A. When an identical battery is added to the circuit in series, as shown in Figure 2, the current in the circuit is 3.0 A. Which of the following statements about the resistances in the circuit is true?

(A) r is very small compared to R.
(B) r is very large compared to R.
(C) r is equal to R.
(D) r and R are comparable in magnitude, but they are not equal.



32. Two samples of the same type of gas molecules are placed in different closed containers and are thermally isolated from each other and the environment. The figure above shows the distribution of speeds for the molecules in each of the samples. The two samples are now mixed together and allowed to reach thermal equilibrium. Which of the following is true of the peak of the distribution for the mixed sample?

(A) It is closer to 400 m/s than it is to 800 m/s.
(B) It is closer to 800 m/s than it is to 400 m/s.
(C) It is midway between the peaks of the distributions shown.
(D) There is not just one peak but two, at the same locations as the peaks of the distributions shown.

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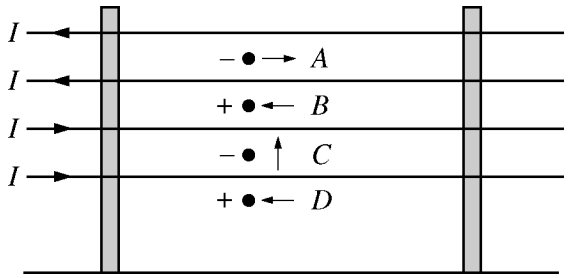

33. Four horizontal wires are arranged on vertical wooden poles, as shown in the figure above. The wires are equally spaced and have equal currents I in the directions indicated in the figure. The dots represent four charged dust particles moving in the plane of the wires. The sign of the charge on each particle and its direction of motion at a particular instant are shown. Which of the dust particles has a magnetic force exerted on it in the downward direction at this instant?

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

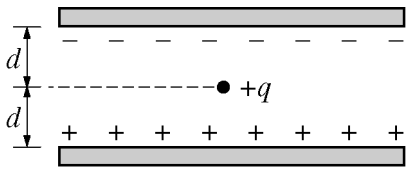

Figure 1

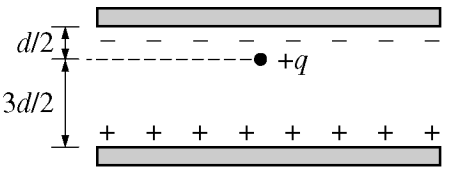

Figure 2

34. A parallel-plate capacitor is charged so that an electric field E is created between the plates. A small oil drop with charge $+q$ is placed halfway between the plates, as shown in Figure 1 above. The force exerted on the oil drop by the electric field is determined to have a magnitude of F. The oil drop is now moved half the distance toward the negatively charged plate, as shown in Figure 2 above. What is the magnitude of the force exerted by the electric field on the oil drop at the position shown in Figure 2 ?

(A) $F/2$
(B) F
(C) $2F$
(D) $4F$

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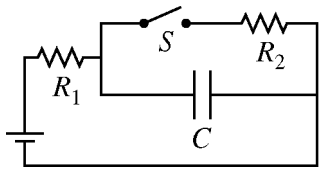

35. In the circuit represented above, resistors R_1 and R_2, capacitor C, and open switch S are connected to a battery. The circuit reaches equilibrium. The switch is then closed, and the circuit is allowed to come to a new equilibrium. Which of the following is a true statement about the charge q_f stored on the capacitor after the switch is closed compared with the charge q_i stored on the capacitor before the switch is closed?

(A) $q_f > q_i$

(B) $q_f = q_i$

(C) $q_f < q_i$

(D) The relationship between the charges cannot be determined unless the resistances of the resistors are known.

36. Louis de Broglie proposed that all forms of matter have both wave properties and particle properties. Which of the following explains why diffraction effects are observable only for small-scale objects?

(A) Wavelengths of large-scale objects are much smaller than any aperture through which the objects could pass.

(B) Wavelengths of large-scale objects are much larger than any aperture through which the objects could pass.

(C) Large-scale objects have too much energy to allow observation of their wave properties.

(D) Large-scale objects move too slowly to allow observation of their wave properties.

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GO ON TO THE NEXT PAGE.

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.

131. A student is given a sample of gas that is at room temperature and is sealed in a container by a movable piston. Which of the following adjustments would allow the student to increase the pressure of the gas? Select two answers.

(A) Put the container in a tank of room-temperature water and pull the piston outward.
(B) Put the container in a tank of room-temperature water and push the piston inward.
(C) Put the container in a tank of hot water and hold the piston in place.
(D) Put the container in a tank of cold water and hold the piston in place.

132. A student is given two different convex spherical mirrors and asked to determine which of the mirrors has the shorter focal length. Answering which of the following questions would allow the student to make this determination? Select two answers.

(A) Which mirror has a larger magnification for a given object distance?
(B) Which mirror has the greater change in magnification when submerged in water?
(C) Which mirror produces an upright image?
(D) Which mirror has a smaller radius of curvature?

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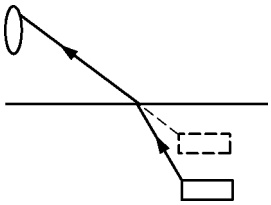
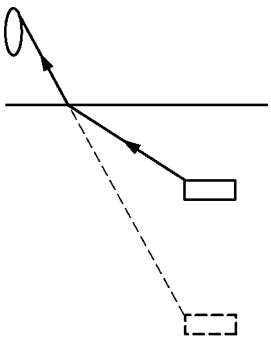
133. On a calm day, student 1 looks down into a pool and sees student 2 swimming underwater. At the same time, student 2 looks up from under the water and sees student 1. In the following diagrams, the oval represents student 1 and the rectangle represents student 2. Diagrams that correctly illustrate the apparent positions seen by student 1 and student 2 include which of the following? Select two answers.

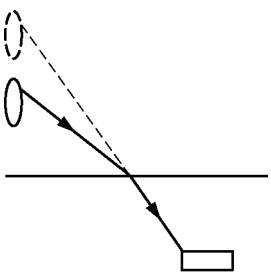
(A)



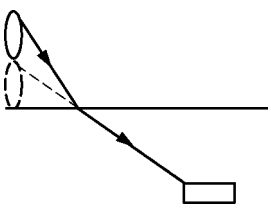
(B)

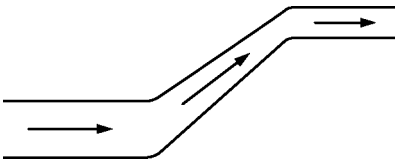


(C)



(D)





134. An ideal fluid is moving from left to right through a pipe, as shown in the figure above. The diameter of the pipe decreases and the height increases from left to right. True statements about the pressure of the fluid as it moves through the pipe include which of the following? Select two answers.

(A) The pressure tends to decrease due to the increase in the fluid's speed as the pipe gets narrower.
(B) The pressure tends to increase due to the decrease in the fluid's speed as the pipe gets narrower.
(C) The pressure tends to decrease due to the increase in the potential energy of the fluid-Earth system as the pipe gets higher.
(D) The pressure tends to increase due to the increase in the potential energy of the fluid-Earth system as the pipe gets higher.

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GO ON TO THE NEXT PAGE.

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.**

Section II: Free-Response Questions

This is the free-response section of the 2017 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics 2: Algebra-Based Exam

SECTION II: Free Response

2017

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.

Form I
Form Code 4NBP4-S

84

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, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ 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,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/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,	$1 \text{ atm} = 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^{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

AP® PHYSICS 2 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

$\Delta L = \tau\,\Delta t$

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

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

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

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

$\Delta U_g = mg\,\Delta y$

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

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

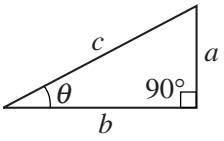
Rectangular solid
$V = \ell w h$

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



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)

   A team of engineering students is testing their newly designed 200 kg raft in the pool where the diving team practices. The raft must hold a 730 kg steel cube with edges of length 45.0 cm without sinking. Assume the density of water in the pool is $1000\ \text{kg}/\text{m}^3$.

   (a) The students use a crane to gently place the cube on the raft but accidentally place it off center. The cube remains on the raft for a few moments and then the raft tilts, causing the cube to slide off and sink to the bottom of the pool. The raft remains floating in the pool. In a coherent paragraph-length response, indicate whether the water level in the pool when the cube is on the bottom of the pool is higher than, lower than, or the same as when the cube is on the raft, and explain your reasoning. For both cases, assume that there is no motion of the water.

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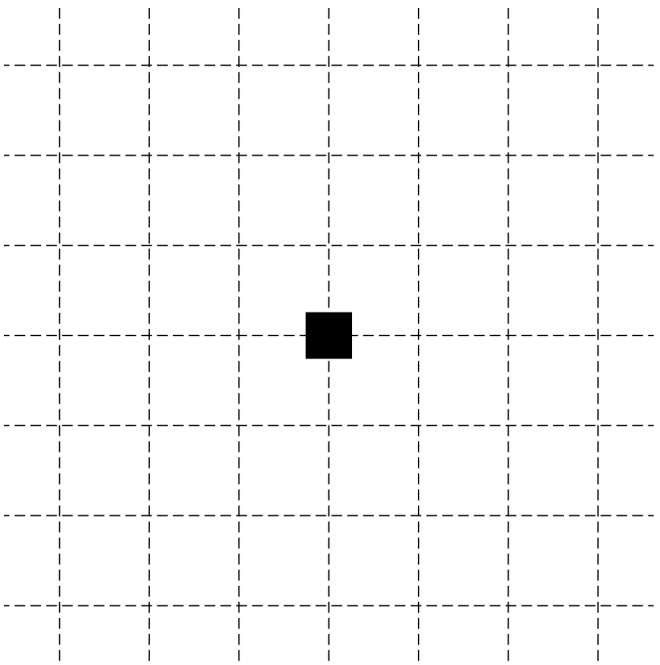
GO ON TO THE NEXT PAGE.

(b) The bottom of the pool is 5 m below the surface of the water. The crane is now used to lift the cube out of the pool. The cube is lifted upward at a slow and constant speed, so all drag forces are negligible.

i. Predict how the force exerted by the crane on the cube when the bottom of the cube is at a depth of 2.0 m compares to the force exerted by the crane on the cube when the bottom of the cube is at a depth of 4.0 m. Explain your reasoning.

ii. On the black square below, which represents the cube, draw and label the forces (not components) that are exerted on the cube while the crane is lifting it and the bottom of the cube is 4 m below the surface of the water. Each force must be represented by a distinct arrow starting on, and pointing away from, the black square. The lengths of the arrows should approximately demonstrate the net force on the cube.



iii. Calculate the force exerted by the crane on the cube when the bottom of the cube is 4 m below the surface of the water.

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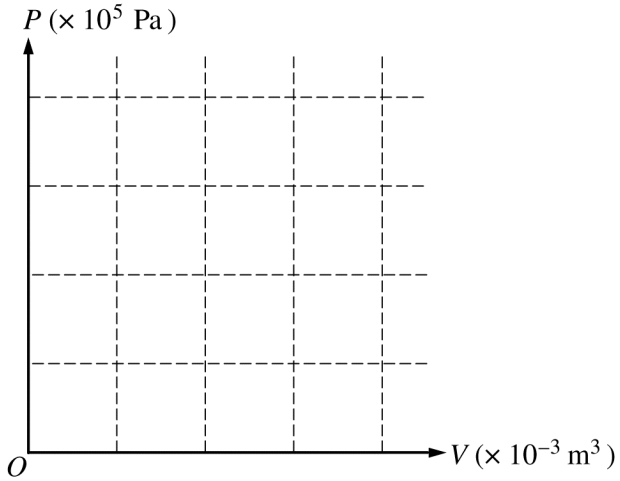
2. (12 points, suggested time 25 minutes)

A student gives the following description of a thermodynamic cycle through which a sample of an ideal monatomic gas is taken.

"Initially, the gas has a volume of 1×10^{-3} m^3 and a pressure of 1×10^5 Pa . The gas is in a closed cylinder that has a movable piston on one end. Call the initial state of the gas state *A*. Process *AB* takes the gas at constant pressure from state *A* to state *B*, where *B* has three times the volume of state *A*. The gas is then compressed isothermally until it is back to its initial volume, reaching state *C*. Finally, a single process *CA* returns the gas to its initial state *A*."

(a)

i. On the axes below, plot states *A*, *B*, and *C*, and sketch a graph of pressure *P* as a function of volume *V* for cycle *ABCA*. Label states *A*, *B*, and *C*, and label the axes with numerical values.



ii. Let the temperature for state *A* be T_0 . In terms of T_0 , determine the temperature for state *B*.

iii. Compare the temperature at state *C* to the temperature at state *A*. Explain how your comparison is consistent with your graph above.

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GO ON TO THE NEXT PAGE.

(b)

i. Briefly describe an experimental procedure that would take the gas from state *C* to state *A*.

ii. Relate the temperature of the gas to the microscopic processes involved in the energy transfer as the gas goes from state *C* to state *A* for the procedure you described in part (b)(i).

(c)

i. Use the student's verbal description or your graph in part (a)(i) to calculate a numerical value for the work done on the gas in process *AB*.

ii. The magnitude of the change in internal energy for process *AB* is $|\Delta U| = 300$ J . Calculate a numerical value for the energy added to or removed from the gas by heating in process *AB*.

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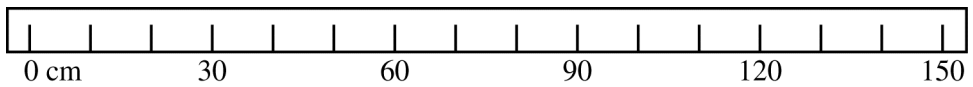
3. (12 points, suggested time 25 minutes)

Students are asked to perform an experiment to determine the focal length of a converging lens. They are given an optical bench that includes a lamp, a converging lens in a holder, and a screen. All three of these can be positioned anywhere along the optical bench. The students decide to form real images by placing the lamp at various specific distances from the lens and moving the screen until a focused image of the lamp filament is formed on the screen. They keep the lens at the 60 cm mark on the optical bench. The table below shows their data for the object and image distances.

Trial	1	2	3	4	5
Object Distance s_o (cm)	55	45	35	30	25
Image Distance s_i (cm)	21.3	23.8	28.5	32.5	43

(a) On the figure below, representing the optical bench, draw and label the screen, lens, and lamp in correct positions for trial 1.



(b) What quantities could be plotted to create a linear graph that could be used to calculate the focal length of the lens? Justify your answer.

Use the empty rows of the table above to record any values you need to calculate.

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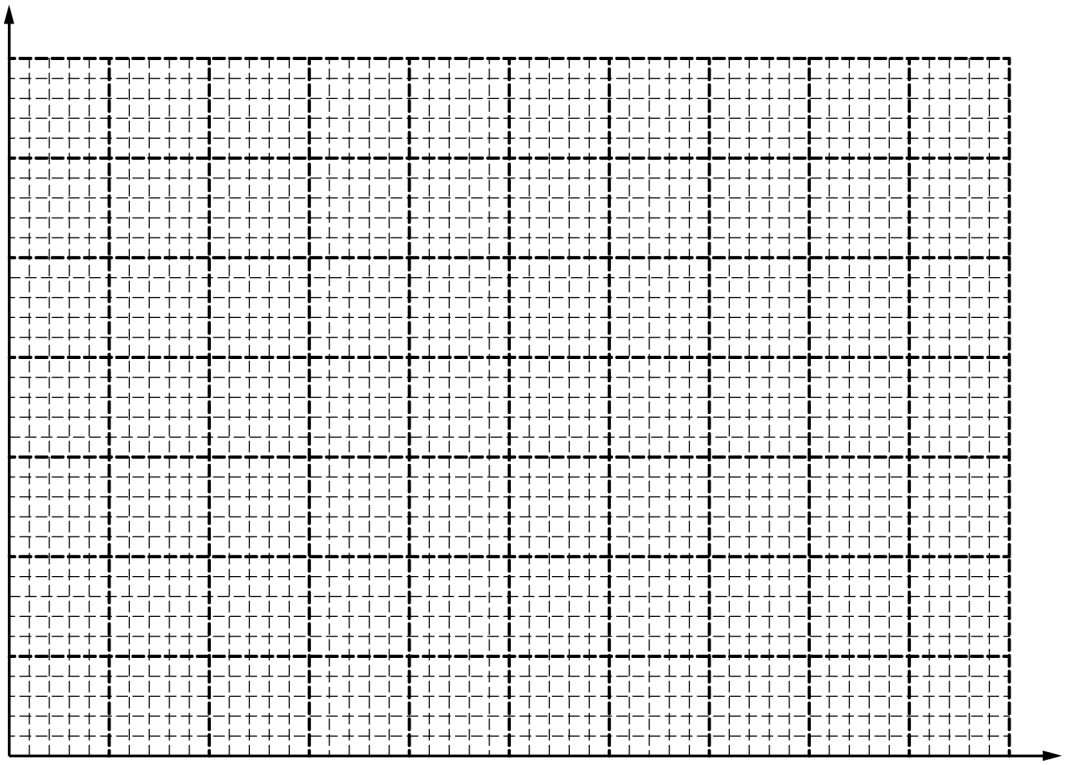
(c)

i. On the axes below, plot data for the quantities you indicated in part (b). Label and scale the axes.



ii. Use your graph to calculate the focal length of the lens. Show your calculations.

Question 3 continues on the next page.

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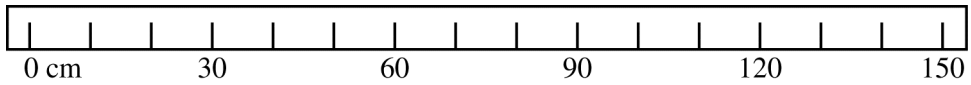
(d) The students are now given a converging mirror of focal length 15 cm to replace the lens and asked to make measurements that would allow them to verify the focal length of the mirror. Describe a procedure that would result in creation of a real image from which the focal length could be determined. On the figure below, representing the optical bench, draw and label the screen, lamp, and mirror in appropriate positions. Indicate what measurements should be made and how they could be used to calculate the focal length.



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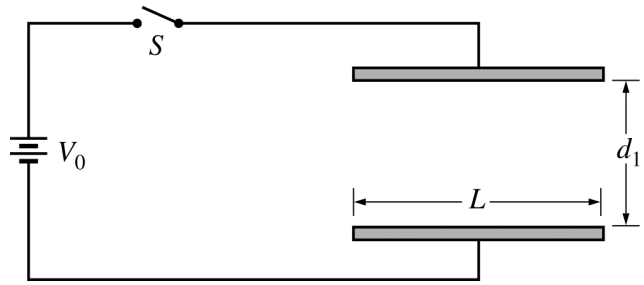
THIS PAGE MAY BE USED FOR SCRATCH WORK.

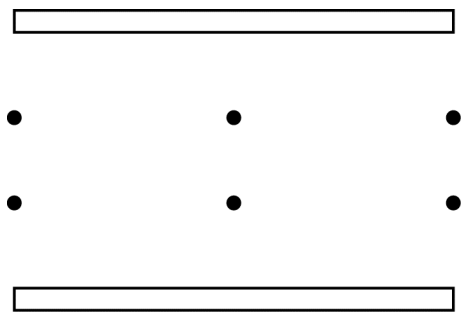


4. (10 points, suggested time 20 minutes)

An uncharged air-filled capacitor has square plates of side L whose separation can be varied. The initial plate separation is d_1, which is comparable to L. The capacitor is connected to a battery with potential difference V_0 and a switch S, as shown above. Assume the dielectric constant of the air is 1.0.

(a) The switch is closed and remains closed for a long time.

i. On the diagram below, draw a vector at each dot to represent the electric field created by the charge on the capacitor plates.



ii. The plates are now moved to a new separation $d_2 << d_1$ and allowed to reach equilibrium. Calculate the magnitude of the charge on each plate of the capacitor in terms of V_0, L, d_2, and physical constants, as appropriate.

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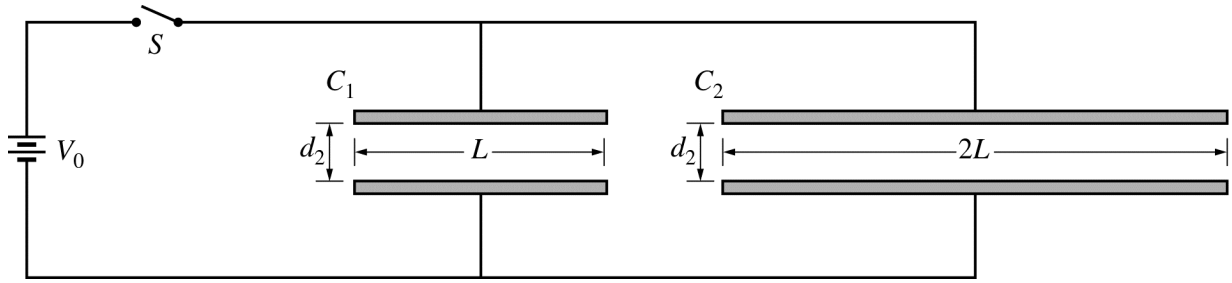
GO ON TO THE NEXT PAGE.

(b) The plates are pulled apart to a separation of $2d_2$, where $2d_2 << d_1$.

i. Suppose the switch remains closed while the plates are pulled apart. Compare the magnitude of the new electric field between the plates when their separation is $2d_2$ to the magnitude of the field for plate separation d_2. Support your comparison using appropriate physics principles.

ii. Suppose the switch is opened before the plates are pulled apart. Compare the magnitude of the new electric field between the plates when their separation is $2d_2$ to the magnitude of the field for plate separation d_2. Support your claim using appropriate physics principles.

(c) The new circuit shown below is now assembled. The plates of the original capacitor, C_1, are at separation d_2. A second capacitor, C_2, with square plates of side 2*L* and plate separation d_2, is connected in parallel with the original capacitor. Both capacitors are initially uncharged. The switch is closed and the circuit reaches equilibrium. Let Q_0 be the magnitude of the charge on each plate of capacitor C_1 in the previous circuit, as determined in part (a)(ii). In terms of Q_0, calculate the magnitude of the charge on each plate of the two capacitors in the new circuit.



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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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

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 FRONT 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 2 Practice Exam, Section I

Question 1: D

Question 2: B

Question 3: C

Question 4: D

Question 5: B

Question 6: C

Question 7: B

Question 8: D

Question 9: D

Question 10: A

Question 11: C

Question 12: C

Question 13: D

Question 14: C

Question 15: D

Question 16: A

Question 17: C

Question 18: C

Question 19: C

Question 20: D

Question 21: C

Question 22: B

Question 23: D

Question 24: A

Question 25: D

Question 26: C

Question 27: D

Question 28: D

Question 29: D

Question 30: B

Question 31: D

Question 32: A

Question 33: D

Question 34: B

Question 35: C

Question 36: A

Question 131: B, C

Question 132: A, D

Question 133: A, C

Question 134: A, C

Free-Response Scoring Guidelines

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

AP® PHYSICS 2
2017 SCORING GUIDELINES

Question 1

10 points total | **Distribution of points**

(a) 5 points

For indicating that a floating object displaces its weight in water	1 point
For indicating that a submerged object displaces its volume in water	1 point
For justifying with correct reasoning that the volume of displaced water required to make the cube float is much greater than the cube's volume Examples: Noting that the density of the block is much greater than that of water; noting that when the cube is on the bottom the buoyant force is less than the weight because of the normal force	1 point
For predicting that the water level is lower when the block is submerged (or higher when the block is floating) given some attempt to explain the concepts listed above	1 point
For a logical, relevant, and internally consistent response that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response	1 point

(b)

i) 1 point

For indicating that the tension is the same at any depth with a correct reference to the buoyant force Example: The volume of water displaced remains the same so the buoyant force remains the same. The weight of the cube does not change, so the force exerted by the crane is unchanged.	1 point

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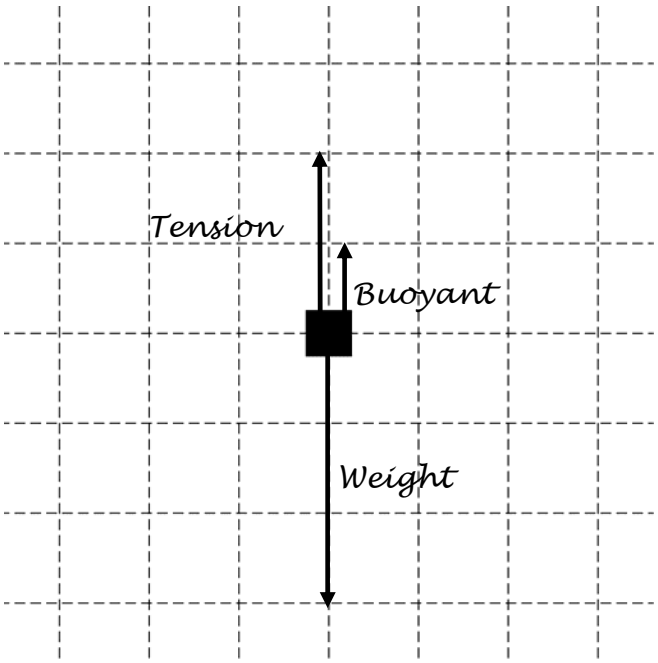
Question 1 (continued)

Distribution of points

ii) 2 points



For a labeled buoyant force directed upward and a labeled gravitational force directed downward, with the buoyant force drawn shorter than the gravitational force — 1 point

For a labeled tension force directed upward and the sum of the drawn vectors approximately indicating equilibrium — 1 point

Figure can have a single buoyant force, or a set of pressure forces that reasonably equals an appropriate net buoyant force, but not both.

Only force vectors that clearly originate on the block earn credit.

iii) 2 points

For an expression obtained by using Newton's 2nd law for equilibrium and the free body diagram in part (b)(ii) — 1 point

$F_{Tension} = F_g - F_b$

$F_{Tension} = m_{cube}g - \rho g V_{cube}$

For correct substitutions into the buoyant force and the gravitational force expressions or a numerical answer implying correct substitutions of the given quantities — 1 point

$F_{Tension} = (730\ \text{kg})\left(9.8\ \text{m/s}^2\right) - \left(1000\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)(0.45\ \text{m})^3$

$F_{Tension} = 6300\ \text{N}$ (or 6400 N using $g = 10\ \text{m/s}^2$)

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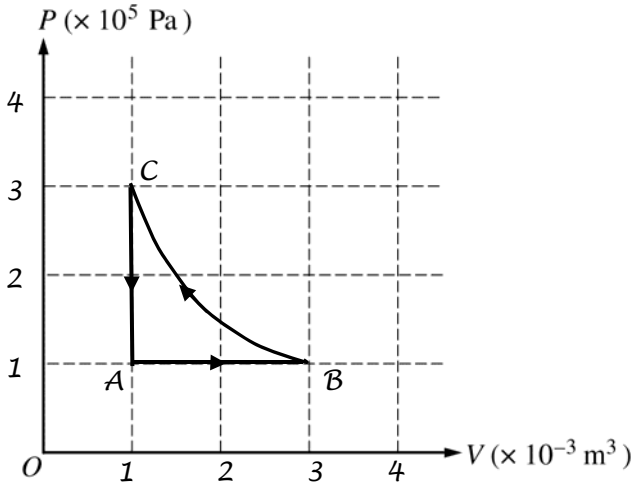
AP® PHYSICS 2
2017 SCORING GUIDELINES

Question 2

12 points total **Distribution of points**

(a)

i) 3 points



For a straight line at constant pressure from A to B to the correct final volume, which must be labeled 3 — 1 point

For an isotherm from B to C ending at the right final pressure, which must be labeled 3; curve must be obviously concave up — 1 point

For a straight line from C to A at constant volume, with state A labeled (1, 1) — 1 point

ii) 1 point

Using the ideal gas law:

$P_A V_A = nRT_0$

$P_B V_B = P_A 3V_A$

$nRT_B = 3nRT_0$

For the correct answer — 1 point

$T_B = 3T_0$

iii) 1 point

For a correct comparison of the temperatures <u>or</u> correctly indicating — 1 point

$T_B = T_C = 3T_A$ or $3T_0$ or a value consistent with the answer to part (a)(i) or (ii)

<u>AND</u> making a reference to the isotherm <u>or</u> the values of P and V at points C and A

Examples:

$T_C = 3T_0$ since it is on an isotherm with point B, as shown by the graph.

On the graph, C has the same volume and 3 times the pressure as A. By the ideal gas law it thus has a temperature 3 times that of A.

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Question 2 (continued)

Distribution of points

(b)

i) 2 points

For recognizing that the volume remains constant and describing a valid way to accomplish this in the procedure — 1 point

For recognizing that the temperature must decrease and describing a valid way to accomplish this in the procedure — 1 point

Example: Lock the piston in place and put the cylinder in a cool water bath.

ii) 2 points

For some reasonable description of microscopic processes in which collision of molecules is the process by which energy is transferred — 1 point

For correctly stating the direction of energy flow (e.g. hot (fast) to cold (slow)) and linking the direction of energy flow to the final temperature of the gas — 1 point

Example: The warmer gas (faster molecules) collide with the cooler surroundings (slower molecules). The net energy flow is from the gas to the surroundings which results in cooler gas (slower molecules).

(c)

i) 2 points

For numerically calculating the amount of work done $\left(W = \left|P\Delta V\right|\right)$ — 1 point

$W = -P\Delta V = -\left(1 \times 10^{5}\ \text{Pa}\right)\left(2 \times 10^{-3}\ \text{m}^{3}\right)$

For the correct answer with negative sign (no units required) — 1 point

$W = -200\ \text{J}$

ii) 1 point

For applying conservation of energy using the value from part (c)(i) — 1 point

$\Delta U = Q + W$

$300\ \text{J} = Q - 200\ \text{J}$

$Q = 500\ \text{J}$

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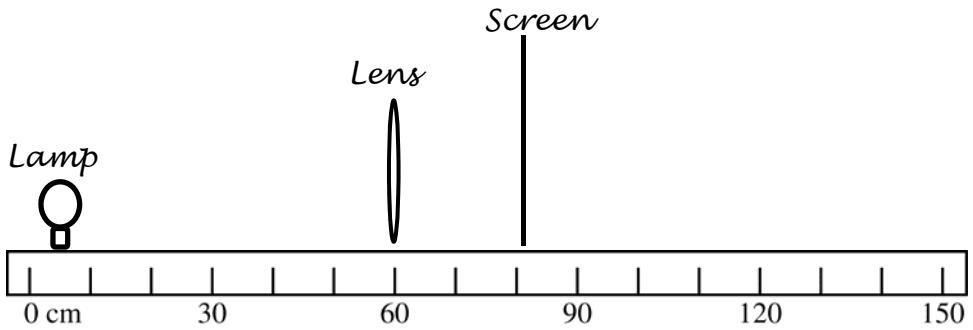
Question 3

12 points total **Distribution of points**

(a) 2 points



For the lamp correctly positioned 55 cm from the converging lens 1 point
For the screen correctly positioned 21.3 cm from the lens, on the opposite side from the lamp 1 point

(b) 3 points

For indicating a valid pair of quantities that would lead to a linear graph from which the focal length could be determined 1 point
For justifying the choice of quantities, either by indicating how to use the slope or intercept of the line to determine the focal length or by indicating how the lens equation yields a linear function 1 point
For calculating data for the table, with at least three correct pairs of numbers 1 point
Table below shows data for two possibilities: $1/s_0$ and $1/s_i$; $s_0 s_i$ and $s_0 + s_i$

Trial	1	2	3	4	5
Object Distance s_o (cm)	55	45	35	30	25
Image Distance s_i (cm)	21.3	23.8	28.5	32.5	43
$1/s_O$	0.018	0.022	0.029	0.033	0.04
$1/s_i$	0.047	0.042	0.035	0.031	0.023
$s_O s_i$	1172	1071	998	975	1075
$s_O + s_i$	76	69	64	63	68

(c)

i) 2 points

For the axes scaled linearly and labeled with units for plotted quantities (even if the wrong quantities are plotted), such that the plot uses at least half of the axes 1 point
For correctly plotting the data listed in the part (b) table 1 point
The following graphs show the two possibilities noted above.

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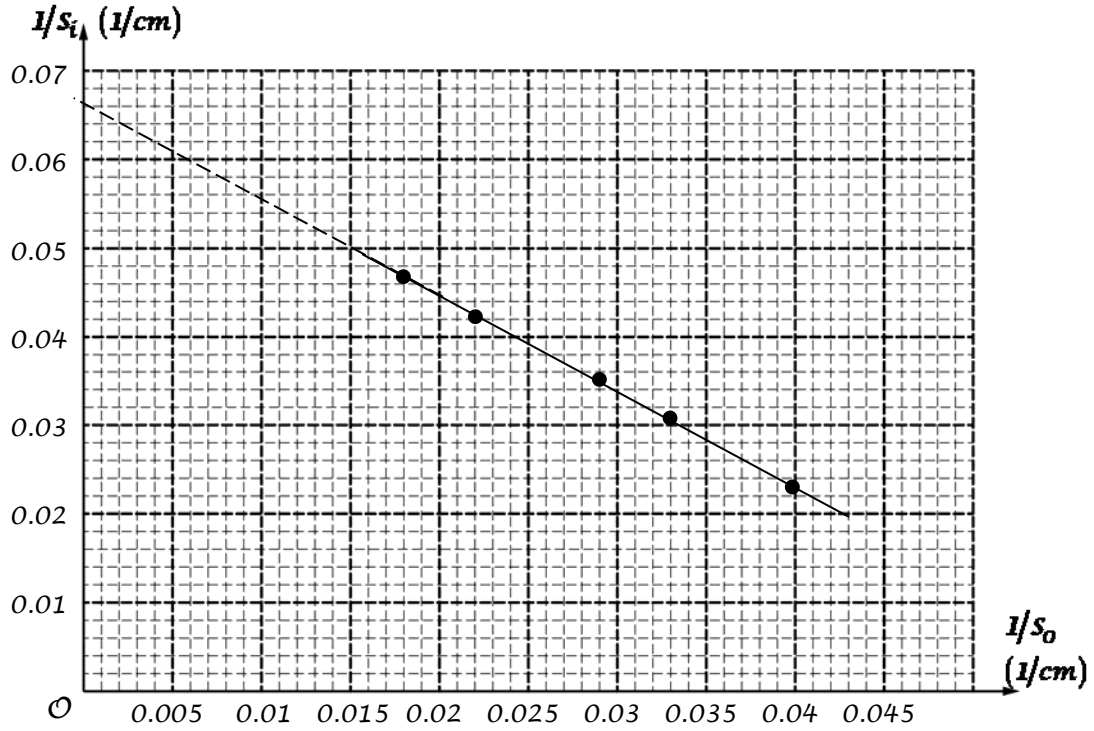
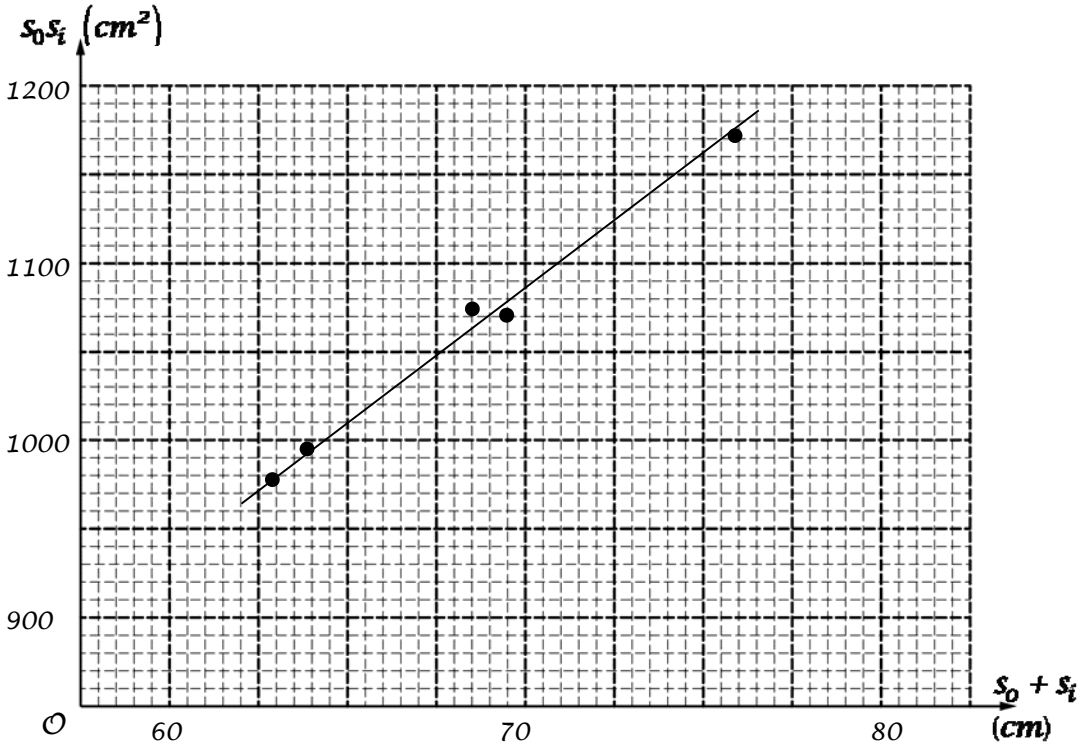
Question 3 (continued)

Distribution of points

(c) i) (continued)





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Question 3 (continued)

Distribution of points

(c) (continued)

ii) 2 points

For drawing a straight best-fit line accurately through the data (data points evenly distributed about the line and representing the trend of the data) — 1 point

For accurately calculating the slope or intercept using the graph (depending on quantities plotted) and relating it to the focal length — 1 point

For the first graph ($1/s_i$ as a function of $1/s_0$):

From the lens equation $\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_0}$, so $\frac{1}{f}$ equals the intercept on the $1/s_i$ axis

$\frac{1}{f} = 0.066 \text{ cm}^{-1}$

$f = 15.2 \text{ cm}$

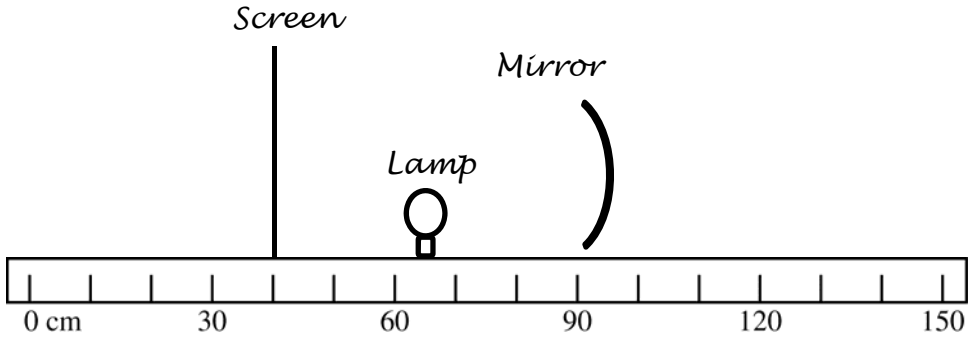
For the second graph ($s_0 s_i$ as a function of $s_0 + s_i$):

The lens equation can be rearranged as $s_0 s_i = f(s_0 + s_i)$, so f equals the slope

$f = \frac{(1170 - 970) \text{ cm}^2}{(75.5 - 62.5) \text{ cm}} = \frac{200}{13} \text{ cm}$

$f = 15.4 \text{ cm}$

(d) 3 points



For drawing and labeling the lamp, screen, and converging mirror at positions that will create a real image — 1 point

For describing appropriate measurements — 1 point

For describing a calculation of the focal length that correctly uses the measurements — 1 point

Example: Place the lamp between 15 and 30 cm from the mirror. Place the screen on the other side of the lamp from the mirror, adjusting its position until the clearest image is formed. Measure the distance of the lamp and screen from the mirror. Use the equation $\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$ to calculate the focal length.

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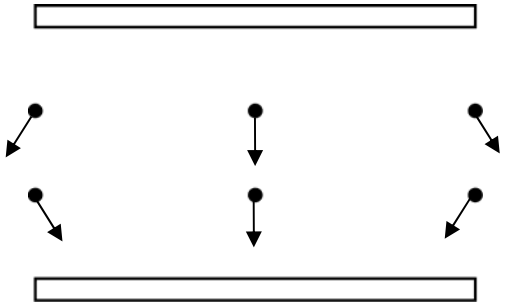
Question 4

10 points total **Distribution of points**

(a)

i) 2 points



For a representation of the electric field using vectors (not curved lines) that each have a component downward — 1 point

For accurately representing fringing near the edges and a uniform field near the middle (even if field lines are drawn instead of vectors, or the field has components upward instead of downward) — 1 point

ii) 1 point

For a correct calculation of the charge — 1 point

$Q = C\,\Delta V = \left(\varepsilon_0 L^2 / d_2\right) V_0$

$Q = \varepsilon_0 L^2 V_0 / d_2$

(b)

i) 2 points

For indicating that since the battery remains connected, the potential difference across the capacitor remains the same — 1 point

For indicating that the electric field must decrease since $E = \Delta V / d$ and d has increased — 1 point

Alternate Solution — *Alternate points*

$C = \kappa \varepsilon_0 A / d$

For reasoning that capacitance decreases as d increases — *1 point*

$Q = C\,\Delta V$

For reasoning that the potential difference across the capacitor remains the same and therefore the charge decreases — *1 point*

$E = Q / \varepsilon_0 A$, so E decreases because Q decreases

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Question 4 (continued)

Distribution of points

(b) (continued)

ii) 2 points

For indicating that the charge on each plate is the same as in part (a)(ii) — 1 point
For reasoning that the electric field depends only on the magnitude of the charge, and therefore does not change (or has a change consistent with the change in charge indicated) — 1 point

Examples:

The charge on the plates does not change, so E remains the same.

$E = \Delta V/d = Q/Cd$. Since $C \propto 1/d$, E is independent of the plate spacing which is the only thing that changes.

Alternate Solution — *Alternate points*

$C = \kappa\varepsilon_0 A/d$, *so as d increases C decreases*

$\Delta V = Q/C$

For recognizing that since charge is constant, as C decreases ΔV *increases* — *1 point*

$E = \Delta V/d$

For reasoning that E does not change since ΔV *and d increase by the same factor* — *1 point*

(c) 3 points

For indicating that the potential difference is the same across each capacitor — 1 point
For indicating that $C_2 = 4C_1$ — 1 point
For values of the charge on each capacitor consistent with the relationship between capacitances — 1 point

$Q_1 = Q_0$, $Q_2 = 4Q_0$

Example: The conditions for C_1 are the same as in part (a)(ii), so it has a charge Q_0. The area of C_2 is four times that of C_1, so it has four times the capacitance. In order to have the same potential difference as C_1, it must therefore have four times the charge.

Alternate solution — *Alternate Points*

For indicating the potential difference is the same across each capacitor — *1 point*

For indicating $A_2 = 4A_1$ — *1 point*

For values of the charge on each capacitor consistent with the relationship between areas — *1 point*

$Q_1 = \varepsilon_0 V_0 L^2/d_2$

$Q_2 = \varepsilon_0 V_0 (2L)^2/d_2$

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Scoring Worksheet

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

2017 AP Physics 2 Scoring Worksheet

Section I: Multiple Choice

_____	× 1.0000 =	_____
Number Correct (out of 40)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 10)	× 0.9090 =	_____ (Do not round)
Question 2	_____ (out of 12)	× 0.9090 =	_____ (Do not round)
Question 3	_____ (out of 12)	× 0.9090 =	_____ (Do not round)
Question 4	_____ (out of 10)	× 0.9090 =	_____ (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 2

Composite Score Range	AP Score
57-80	5
48-56	4
34-47	3
20-33	2
0-19	1

Question Descriptors and Performance Data

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

2017 AP Physics 2: Algebra-Based
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practices	Key	% Correct
1	2-7.C.1.1	7.C.1	1.4	D	94
2	2-6.A.1.2	6.A.1	1.2	B	84
3	2-3.C.2.2|2-3.G.1.2	3.C.2|3.G.1	7.2|7.1	C	82
4	2-1.A.4.1|2-5.B.8.1|2-7.C.4.1	1.A.4|5.B.8|7.C.4	1.1|1.2|1.1|1.2	D	65
5	2-2.D.3.1	2.D.3	1.2	B	75
6	2-4.E.3.4	4.E.3	1.1|1.4|6.4	C	75
7	2-2.C.5.3	2.C.5	1.1|7.1	B	74
8	2-5.B.9.5|2-5.B.9.6	5.B.9	6.4|2.2	D	70
9	2-3.B.1.4|2-3.C.3.1|2-4.E.2.1	3.B.1|3.C.3|4.E.2	6.4|7.2|1.4|6.4	D	18
10	2-5.B.7.3	5.B.7	1.4|2.2	A	60
11	2-5.B.6.1	5.B.6	1.2	C	52
12	2-5.B.7.1|2-5.B.7.3	5.B.7	6.4|1.4|2.2	C	58
13	2-6.C.1.2|2-6.C.1.1	6.C.1	6.4|1.4	D	69
14	2-4.E.5.3|2-5.B.9.4|2-5.B.9.7	4.E.5|5.B.9	5.1|5.1|5.1	C	38
15	2-4.E.5.2|2-4.E.5.3	4.E.5	6.4|5.1	D	39
16	2-5.B.4.1|2-7.A.2.1	5.B.4|7.A.2	6.4|7.2|7.1	A	55
17	2-5.D.2.6	5.D.2	6.4|7.2	C	45
18	2-4.C.4.1	4.C.4	2.2|7.2	C	58
19	2-7.C.3.1	7.C.3	6.4	C	41
20	2-6.E.5.1	6.E.5	1.4|2.2	D	65
21	2-2.C.2.1|2-2.E.2.1	2.C.2|2.E.2	2.2|6.4|6.4	C	41
22	2-2.C.1.2|2-2.E.3.1|2-2.E.3.2|2-5.B.5.5	2.C.1|2.E.3|5.B.5	2.2|2.2|1.4|6.4|2.2|6.4	B	56
23	2-3.C.2.3	3.C.2	2.2	D	56
24	2-7.A.3.1|2-7.A.3.3	7.A.3	6.4|7.2|5.1	A	59
25	2-4.E.3.3	4.E.3	1.1	D	49
26	2-1.E.3.1	1.E.3	5.1	C	49
27	2-7.A.1.2	7.A.1	1.4|2.2	D	52
28	2-5.F.1.1	5.F.1	2.2	D	71
29	2-3.C.4.2	3.C.4	6.2	D	65
30	2-6.F.1.1|2-6.F.2.1	6.F.1|6.F.2	6.4|7.2|1.1	B	49
31	2-4.E.5.1	4.E.5	2.2|6.4	D	40
32	2-7.A.2.2	7.A.2	7.1	A	54
33	2-3.C.3.1	3.C.3	1.4	D	47
34	2-2.C.1.1	2.C.1	6.4	B	37
35	2-5.B.9.5	5.B.9	6.4	C	36
36	2-6.G.1.1	6.G.1	6.4|7.1	A	31

2017 AP Physics 2: Algebra-Based

Question Descriptors and Performance Data

Question	Learning Objectives	Essential Knowledge	Science Practices	Key	% Correct
131	2-7.A.3.2	7.A.3	4.2	B,C	88
132	2-6.E.2.1|2-6.E.4.1	6.E.2|6.E.4	6.4|4.1|5.1	A,D	70
133	2-6.E.3.3	6.E.3	6.4	A,C	54
134	2-5.B.10.4	5.B.10	6.2	A,C	50

Free-Response Questions

Question	Learning Objectives	Essential Knowledge	Science Practices	Mean Score
1	2-1.E.1.2|2-3.B.1.4|2-3.B.2.1|2-3.C.4.1|2-5.B.10.1|2-5.B.10.2	1.E.1|3.B.1|3.B.2|3.C.4|5.B.10	6.4|6.4|1.1|2.2|6.1|2.2|2.2	4.05
2	2-4.C.3.1|2-5.B.4.1|2-5.B.5.6|2-5.B.6.1|2-5.B.7.1|2-5.B.7.2|2-5.B.7.3|2-7.A.2.2|2-7.A.3.3	4.C.3|5.B.4|5.B.5|5.B.6|5.B.7|7.A.2|7.A.3	6.4|6.4|7.2|5.1|1.2|6.4|1.1|1.4|2.2|7.1|5.1	6.86
3	2-6.E.4.1|2-6.E.5.2	6.E.4|6.E.5	4.1|5.2|4.1|5.1	4.86
4	2-2.C.5.1|2-2.C.5.2|2-4.E.4.1|2-4.E.5.1|2-4.E.5.2	2.C.5|2.C.5|4.E.4|4.E.5	1.1|2.2|2.2|6.4|6.4|6.4	2.43

AP Physics 2: Algebra-Based

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