CollegeBoard

AP® Physics 2: Algebra-Based Practice Exam

From the 2016 Administration

NOTE: This is a modified version of the 2016 AP Physics 2: Algebra-Based Exam.

Contents

Note: This publication shows the page numbers that appeared in the ***2015–16 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

Exam Instructions

The following contains instructions taken from the *2015–16 AP Exam Instructions* book.

AP® Physics 1: Algebra-Based Exam

Regularly Scheduled Exam Date: Tuesday afternoon, May 3, 2016

Late-Testing Exam Date: Thursday afternoon, May 19, 2016

Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

AP® Physics 2: Algebra-Based Exam

Regularly Scheduled Exam Date: Wednesday afternoon, May 4, 2016

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

Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

Section I **Total Time:** 1 hour 30 minutes
Calculator allowed
Number of Questions: 50*
Percent of Total Score: 50%
Writing Instrument: Pencil required

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

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

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2015-16 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template(s)
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Container for students' electronic devices (if needed)
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Extra paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited in the testing room"

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for 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 47 of the *2015-16 AP Coordinator's Manual*. See pages 44–47 of the *AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 45 of the *AP Coordinator's Manual*.

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

Physics 1: Algebra-Based

If you are giving the regularly scheduled exam, say:

It is Tuesday afternoon, May 3, 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 19, 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 4, 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 20, 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 *2015-16 Bulletin for AP Students and Parents*. You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

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

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

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

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

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

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

Are there any questions? . . .

You will now take the multiple-choice portion of the exam. You should have in front of you the multiple-choice booklet and your answer sheet. Open your answer sheet to page 2. You may never discuss these specific multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled.

You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses 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 <u>two</u> 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 questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .

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

SECTION II: Free Response

After the break, say:

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

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

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

Now 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 60 of the *2015-16 AP Coordinator's Manual* for complete details). Then say:

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

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

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

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

If you are giving the regularly scheduled exam, say:

> **You may not discuss or share these specific free-response questions with anyone unless they are released on the College Board website in about two days. Your AP Exam score results will be available online in July.**

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

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

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

> **Please remember to take your AP number card with you. You will need the information on this card to view your scores and order AP score reporting services online.**

Then say:

> **You are now dismissed.**

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

- Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2015-16 AP Coordinator's Manual*.
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

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

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2016

CollegeBoard

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

COMPLETE THIS AREA AT EVERY EXAM.

USE NO. 2 PENCIL ONLY

To maintain the security of the exam and the validity of my AP score, I will allow no one else to see the multiple-choice questions. I will seal the multiple-choice booklet when asked to do so, and I will not discuss these questions with anyone at any time after completing the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the *2015-16 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

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

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

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

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

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

785208

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 — 2 Option 2

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE | School Name | City | State | Country

K. DATE OF BIRTH

Month | Day | Year

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

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

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

College Name | City | State | Country

N. CURRENT GRADE LEVEL

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

O. STUDENT SEARCH SERVICE®

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

Would you like us to supply your information?

- Yes
- No

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

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COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

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

QUESTIONS 131–142

For Students Taking AP Physics 1 or AP Physics 2

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

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

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

R. YOUR MAILING ADDRESS

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

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

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

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address | City | State or Province | Country | ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email in accordance with the policies in the *2015-16 Bulletin for AP Students and Parents.*

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. RACIAL/ETHNIC GROUP

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

(You may mark all that apply.)

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

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

b. What is your race?

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

Y. PARENTAL EDUCATION LEVEL

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

- **Mother or female guardian**
- **Father or male guardian**

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

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2016 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

For purposes of test security and/or statistical analysis, some questions
have been removed from the version of the exam that was administered
in 2016. Therefore, the timing indicated here may not be appropriate
for a practice exam.

AP® Physics 2: Algebra-Based Exam

SECTION I: Multiple Choice **2016**

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 <u>two</u> 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 4MBP4-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, $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

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

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

PREFIXES		
Factor	Prefix	Symbol
10^{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 <u>on</u> 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

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

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

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

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

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

$\Delta U_g = m g\,\Delta y$

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

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

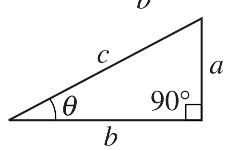
Rectangular solid
$$V = \ell w h$$

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 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. An insulated container with a divider in the middle contains two separated gases. Gas 1 is initially at a higher temperature than gas 2. The divider is then removed. Which of the following observations might be made over a period of time as the two gases mix together, and why?

   (A) Gas 1 remains at a higher temperature than gas 2 because gas 1 started at a higher temperature.
   (B) Gas 1 remains at a higher temperature than gas 2 because gas 1 started with a higher kinetic energy.
   (C) On average, the molecules of gas 1 lose all of their kinetic energy to the molecules of gas 2 through collisions, resulting in gas 2 eventually having a higher temperature than gas 1.
   (D) On average, the molecules of gas 1 lose some of their kinetic energy to the molecules of gas 2 through collisions, resulting in the two gases eventually having the same temperature.

2. A small amount of charge is placed on both an isolated conducting sphere and an isolated insulating sphere. For both spheres, the charge is added at a small area at the top of the sphere. After a few seconds, where on each of the spheres is the charge that was added?

	Conducting	Insulating
(A)	At the top	At the top
(B)	At the top	Spread over the surface
(C)	Spread over the surface	At the top
(D)	Spread over the surface	Spread over the surface

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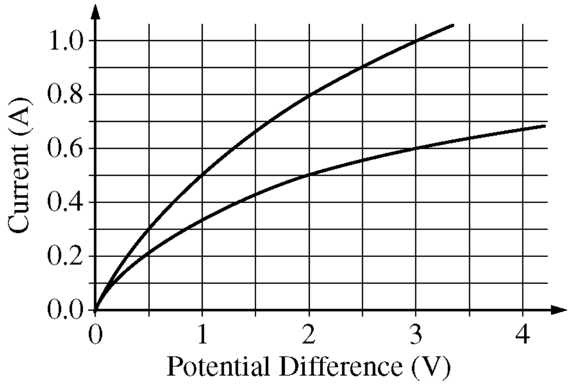
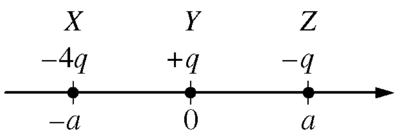
Item 3 was not scored.



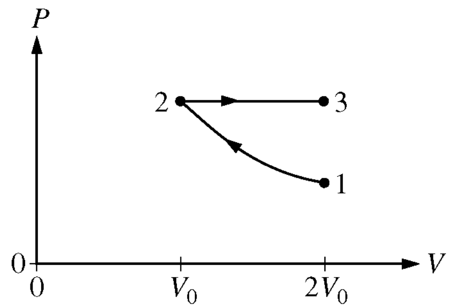
5. The above graph shows current as a function of potential difference for two different filament lamps. If the two lamps are connected in parallel to a 3.0 V battery, what is the total current supplied by the battery?

(A) 0.5 A
(B) 0.8 A
(C) 1.0 A
(D) 1.6 A



4. The figure above shows three objects (X, Y, and Z) that have charges $-4q$, $+q$, and $-q$, respectively. The objects are held fixed on an axis at the positions shown. The magnitude of the electrostatic force exerted by object Y on object Z is F. What is the magnitude of the net electrostatic force exerted on object Y due to the other two objects?

(A) Zero
(B) $2F$
(C) $3F$
(D) $5F$



6. An ideal gas is initially in state 1 at a temperature of 200 K. The gas is taken through the two reversible thermodynamic processes shown in the PV diagram above. The process from state 1 to state 2 is isothermal. The process from state 2 to state 3 is isobaric. What is the temperature of the gas when it is in state 3 ?

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

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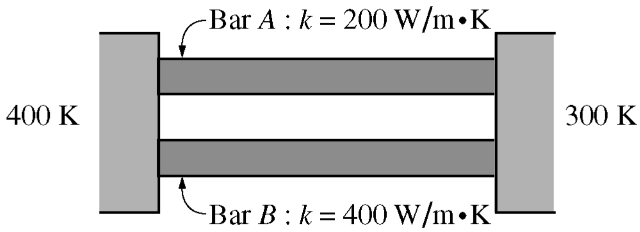
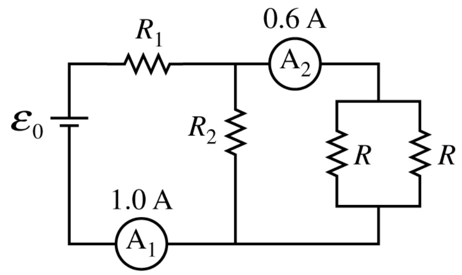


7. Two metal bars with the same length and same cross-sectional area are placed between two tanks with temperatures of 400 K and 300 K, as shown above. The thermal conductivity of the top bar is 200 W/m•K, and that of the bottom bar is 400 W/m•K. If the net energy transferred through the top bar in a given time interval is Q, what is the net energy transferred through the bottom bar during the same time interval?

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

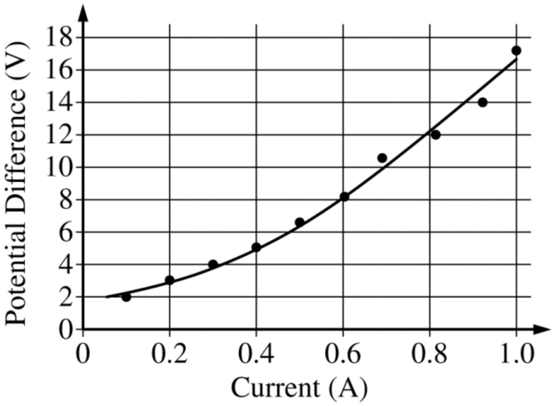
8. A ray of light in air ($n = 1.0$) is incident on glass ($n = 1.5$) at a small angle θ_a to the normal. The angle of the ray to the normal in the glass is θ_g. The speeds of light in air and the glass are v_a and v_g, respectively. How do the values of the speed of light and the angle of the ray of light to the normal in air compare to those in the glass?

	Speed of Light	Angle to Normal
(A)	$v_a > v_g$	$\theta_a > \theta_g$
(B)	$v_a > v_g$	$\theta_a < \theta_g$
(C)	$v_a < v_g$	$\theta_a > \theta_g$
(D)	$v_a < v_g$	$\theta_a < \theta_g$



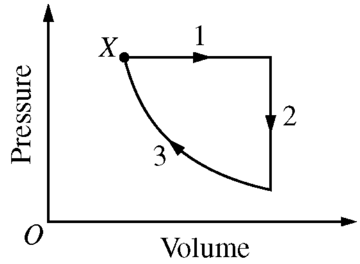
9. The figure above shows a circuit containing four resistors, a battery, and two ammeters. The current in ammeter A_1 is 1.0 A, and the current in ammeter A_2 is 0.6 A. The two resistors labeled R are identical. What are the currents in R_2 and in each of the two resistors labeled R ?

	R_2	Each R
(A)	1.6 A	0.3 A
(B)	1.6 A	0.6 A
(C)	0.4 A	0.3 A
(D)	0.4 A	0.6 A



10. The graph above shows experimental data for the potential difference across a lightbulb as a function of the current through the lightbulb. The power dissipated by the lightbulb when the potential difference across the bulb is 12 V is most nearly

(A) 0.067 W
(B) 7.7 W
(C) 9.6 W
(D) 15 W



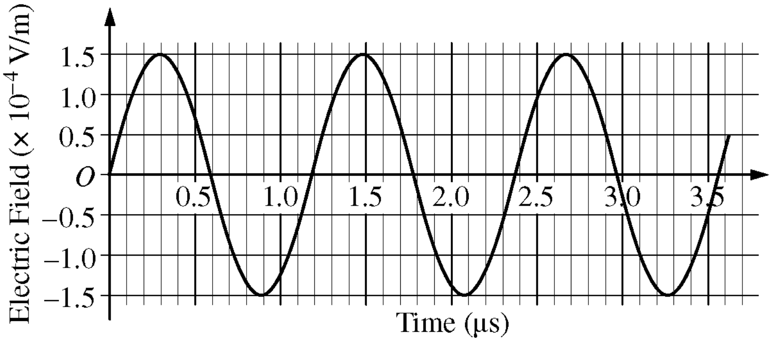
11. The graph above shows pressure as a function of volume for a sample of an ideal gas. The gas has an internal energy of 1000 J at state X and is taken through the cycle shown. Process 3 is isothermal. The work that the gas does on the environment is 400 J during process 1 and 250 J during one complete cycle. What is the net thermal energy transferred into the gas during one complete cycle?

(A) 0 J
(B) 250 J
(C) 400 J
(D) 650 J

GO ON TO THE NEXT PAGE.

Questions 12-13 refer to the following material.

You and a friend are traveling in a car. You tune the car radio to a station of frequency 850 kHz. The graph below represents the electric field strength of the radio wave at a given position as a function of time.

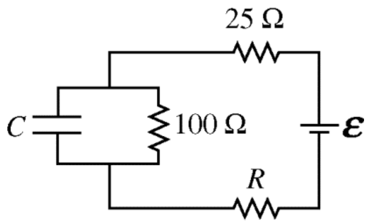


12. Both the sound and radio waves are present inside the car. Which of the following is true about these waves?

    (A) Both waves are longitudinal.
    (B) Both waves can be polarized.
    (C) Both waves travel at the speed of light.
    (D) Sound waves require a medium in which to propagate and radio waves do not.

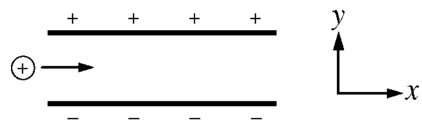
13. Which of the following best represents the electric field strength E measured in V/m as a function of time t measured in μs ?

    (A) $E = \left(3.0 \times 10^{-4}\right)\sin(10.6t)$
    (B) $E = \left(3.0 \times 10^{-4}\right)\sin(5.32t)$
    (C) $E = \left(1.5 \times 10^{-4}\right)\sin(10.6t)$
    (D) $E = \left(1.5 \times 10^{-4}\right)\sin(5.32t)$

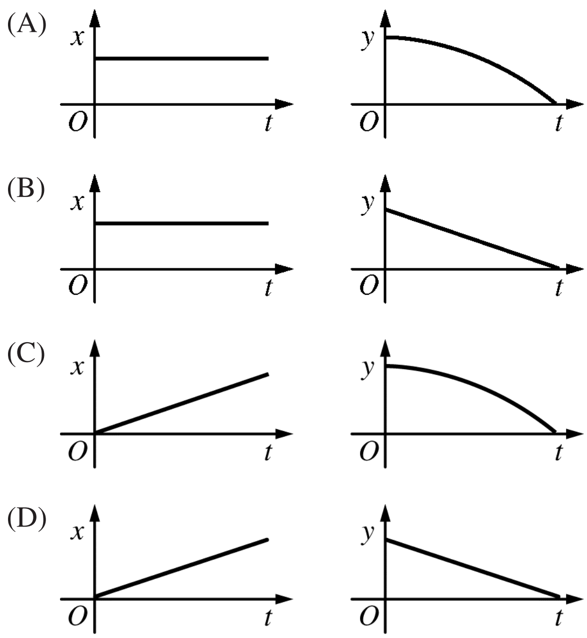


14. A 25 Ω resistor and a 100 Ω resistor are connected in a circuit with a third resistor of unknown resistance R, a capacitor of unknown capacitance C, and a battery of unknown emf $\mathcal{E}$, as shown above. After a long time, the potential difference across the 25 Ω resistor is measured to be 4 V. What is the emf of the battery?

    (A) 20 V
    (B) 16 V
    (C) 4 V
    (D) The emf of the battery cannot be determined without knowing the value of R.



15. 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 could show the x and y positions of the particle as a function of time t?



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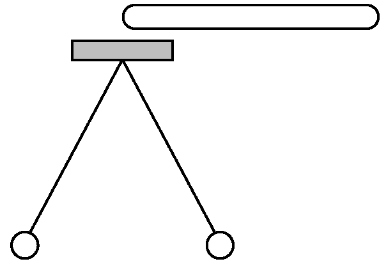
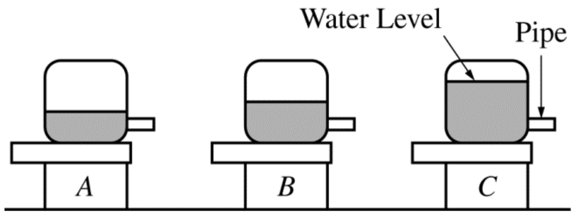
16. A typical iron nucleus contains 30 neutrons and 26 protons. Which of the following explains why the nucleus stays together despite the electric repulsion between the protons?

(A) The neutrons become polarized and exert a net attractive electric force on each proton that is stronger than the net repulsive force.
(B) The net gravitational force exerted on each proton due to all the nucleons is stronger than the net repulsive force.
(C) The net magnetic force exerted on each proton due to all the nucleons is stronger than the net repulsive force.
(D) The net strong force on each proton due to all the nucleons is stronger than the net repulsive force.



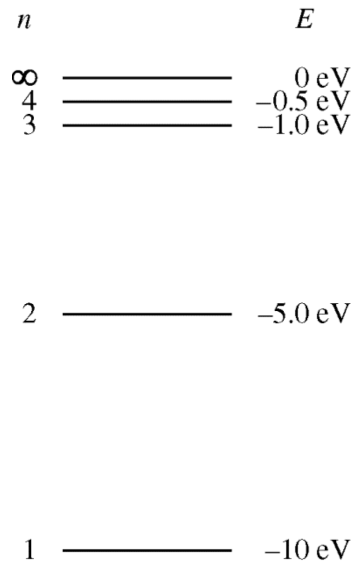
17. An initially uncharged electroscope consists of two thin, 50 cm long conducting wires attached to a cap, with a 25 g conducting sphere attached to the other end of each wire. When a charged rod is brought close to but not touching the cap, as shown above, the spheres separate a distance of 30 cm. What can be determined about the induced charge on each sphere from this information?

(A) The magnitude but not the sign
(B) The sign but not the magnitude
(C) Both the magnitude and the sign
(D) Nothing can be determined about the induced charges.



18. Three identical reservoirs, A, B, and C, are represented above, each with a small pipe where water exits horizontally. The pipes are set at the same height above a pool of water. The water in the reservoirs is kept at the levels shown. Which of the following correctly ranks the horizontal distances d that the streams of water travel before hitting the surface of the pool?

(A) $d_A > d_B > d_C$
(B) $d_A = d_B = d_C$
(C) $(d_A = d_B) > d_C$
(D) $d_C > d_B > d_A$



19. A hypothetical hydrogen-like atom has energy states as represented in the energy-level diagram above. The atom is in the ground state when it absorbs a photon with frequency 2.18×10^{15} Hz. What energy state will the atom be in after it absorbs the photon?

(A) $n = \infty$
(B) $n = 4$
(C) $n = 3$
(D) $n = 2$

GO ON TO THE NEXT PAGE.

20. In each of the nuclear reactions given below, a product is indicated by the letter X. In which of the reactions does the letter X represent a positron? (A positron is a positively charged particle with the same mass and magnitude of charge as an electron.)

(A) ${}^{14}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{15}_{8}\text{O} + \text{X}$

(B) ${}^{15}_{8}\text{O} \rightarrow {}^{15}_{7}\text{N} + \text{X} + \nu$

(C) ${}^{15}_{7}\text{N} + {}^{1}_{1}\text{H} \rightarrow {}^{12}_{6}\text{C} + \text{X}$

(D) ${}^{12}_{6}\text{C} + \text{X} \rightarrow {}^{13}_{7}\text{N} + \gamma$

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21. Which of the following correctly describes the motion of particles when a single transverse mechanical wave passes through a medium?

(A) The particles vibrate back and forth along the same direction as the wave propagates.
(B) The particles vibrate back and forth along a single direction that is perpendicular to the direction of propagation of the wave.
(C) Each particle vibrates back and forth along a single direction that is perpendicular to the direction of propagation of the wave, but each particle's direction is different.
(D) The particles vibrate back and forth without any energy being carried along with the wave as it propagates.

22. A student is given a loudspeaker with a square opening and asked to make a change in the dimensions of the opening so that the sound wave is more spread out vertically and narrowed horizontally. Which of the following is the correct use of the principle of diffraction to accomplish the desired result?

(A) The task is impossible since diffraction affects only electromagnetic radiation and very short wavelengths.
(B) Make the opening into a rectangle with a longer vertical dimension and a shorter horizontal dimension.
(C) Make the opening into a rectangle with a longer horizontal dimension and a shorter vertical dimension.
(D) Keep the opening in the shape of a square, but reduce both the horizontal and vertical dimensions.

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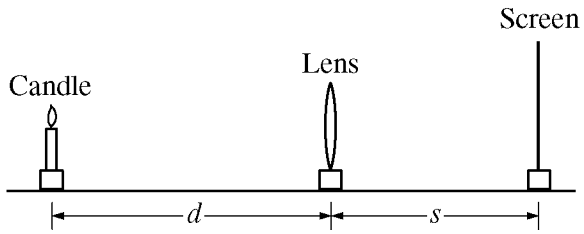


23. In the experimental setup shown in the figure above, a thin lens stands between a candle and a screen. A student moves the candle to several positions relative to the lens and then adjusts the position of the screen until an image is formed. Each time, the student records the distance d from the candle to the lens and the distance s from the lens to the screen. Which of the following procedures will allow the student to determine the focal length of the lens?

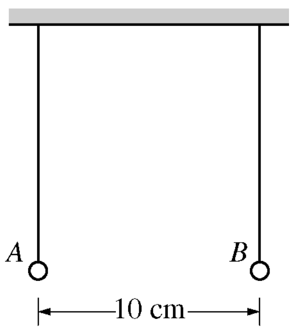
(A) Graph s as a function of d. The focal length will be the vertical intercept.
(B) Graph s as a function of d. The focal length will be the slope of the line.
(C) Graph $1/s$ as a function of $1/d$. The focal length will be the inverse of the vertical intercept.
(D) Graph $1/s$ as a function of $1/d$. The focal length will be the inverse of the slope of the line.

24. A student in an electronics lab is studying the electrical properties of pieces of graphite. The student applies a potential difference of 24 V across the length of a cylindrical piece of graphite with a radius of 0.5 mm. The student has another piece of graphite of the same length but with a radius of 0.7 mm. The student wants the same current in both pieces of graphite. What potential difference should the student apply across the 0.7 mm piece?

(A) 6 V
(B) 12 V
(C) 17 V
(D) 24 V

GO ON TO THE NEXT PAGE.

Questions 25-28 refer to the following material.



Two identical, uncharged, nonconducting spheres hang vertically from insulating strings and are a distance of 10 cm apart, as shown in the figure above. The spheres are then each given a net charge; sphere A gets $-10\ \mu C$ and sphere B gets $-20\ \mu C$. The spheres are allowed to come to rest in a new equilibrium configuration.

25. Let $y = 0$ be the vertical position of the uncharged spheres, with positive y toward the top of the page. Which of the following correctly ranks the new vertical positions y_A and y_B of spheres A and B, respectively, in the new equilibrium configuration?

(A) $(y_A = y_B) > 0$
(B) $y_A > y_B > 0$
(C) $y_A > (y_B = 0)$
(D) $y_B > y_A > 0$

26. Let E_A be the magnitude of the electric field produced by sphere A near the location of sphere B, and let E_B be the magnitude of the electric field produced by sphere B near the location of sphere A. Which of the following correctly ranks E_A and E_B and provides a correct justification for the ranking?

(A) $E_A < E_B$, because at the same distance away from a point charge, a larger-magnitude charge will produce a larger-magnitude electric field, and sphere B has twice as much charge on it.

(B) $E_A = E_B$, because Newton's third law indicates that the electric field produced by one charge must be equal in magnitude and opposite in direction to the electric field produced by another charge.

(C) $E_A = E_B$, because in the expression for electrostatic force, $\frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$, the product of $10\ \mu C$ and $20\ \mu C$ is the same regardless of which charge is labeled Q_1 or Q_2.

(D) $E_A > E_B$, because at the same distance away from a point charge, a larger charge will produce a larger electric field, and sphere A has more charge on it because $-10\ \mu C$ is greater (less negative) than $-20\ \mu C$.

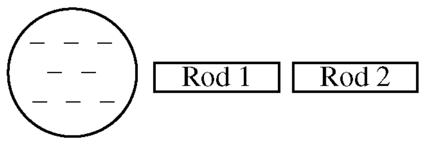
GO ON TO THE NEXT PAGE.

27. Consider a system defined as only spheres A and B. In the new equilibrium configuration, how (if at all) has the potential energy of the system changed compared to when the spheres were initially uncharged, and why?

(A) The potential energy of the system has remained the same, because the spheres are still at the same height as each other, so no energy is stored.
(B) The potential energy of the system has increased, because the two spheres repel each other, storing energy in an electric field.
(C) The potential energy of the system has increased, because the charged spheres are at a higher vertical position, storing energy in a gravitational field.
(D) The potential energy of the system has decreased, because the charged spheres will repel each other rather than attract, reducing the energy stored in the electric field.

28. Consider a position P located halfway between the charged spheres in their new equilibrium configuration. Which of the following correctly indicates whether the electric potential at this position is positive, negative, or zero and explains why?

(A) Zero, because without a charge at position P no electric potential can exist there.
(B) Zero, because both spheres are located the same distance from position P, so the contributions from each charge cancel each other out.
(C) Positive, because both negatively charged spheres contribute a negative electric potential, and these negatives multiplied together produce a net positive electric potential.
(D) Negative, because both negatively charged spheres contribute a negative electric potential to the total.

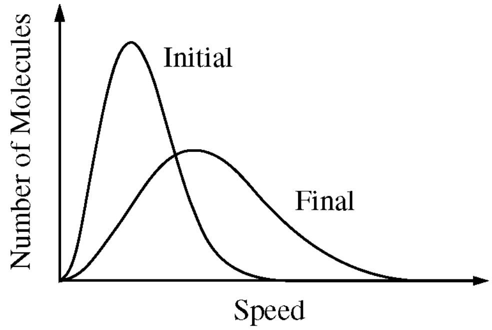


29. Two electrically neutral conducting rods are near a negatively charged sphere, as shown in the figure above. Rod 1 is touched to rod 2 for several seconds, and then the rods are separated. The rods are then both removed from the vicinity of the charged sphere. Which of the following best describes the resulting net charge on each rod?

(A) Rod 1 is positively charged, and rod 2 is negatively charged.
(B) Rod 2 is positively charged, and rod 1 is negatively charged.
(C) Rods 1 and 2 are both negatively charged.
(D) Rods 1 and 2 are both uncharged.

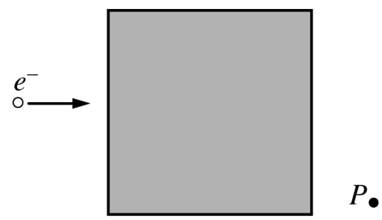
30. The Sun's energy production is due to the fusion of ^{1}H into ^{4}He. How does the mass of four ^{1}H nuclei $(4m_{\text{H}})$ compare with the mass of one ^{4}He nucleus (m_{He})?

(A) $4m_{\text{H}} = m_{\text{He}}$
(B) $4m_{\text{H}} < m_{\text{He}}$
(C) $4m_{\text{H}} > m_{\text{He}}$
(D) It cannot be determined without knowing the amount of energy released.



31. The graph above shows the initial and final molecular speed distributions of a gas as a result of a thermodynamic process. Which of the following processes could produce this change?

(A) Expansion of the gas at constant temperature
(B) Compression of the gas with no transfer of energy by heating
(C) Cooling of the gas at constant volume
(D) Cooling of the gas at constant pressure



32. An electron is moving to the right, as shown in the figure above. It passes through the shaded region, which contains a magnetic field. The electron travels along a path that takes it through point P. The gravitational force on the electron is negligible. What is the direction of the magnetic field?

(A) Into the page
(B) Out of the page
(C) Toward the top of the page
(D) Toward the bottom of the page

33. Water flowing in a horizontal pipe speeds up as it goes from a section with a large diameter to a section with a small diameter. Which of the following can explain why the speed of the water increases?

(A) The gravitational potential energy of the water-Earth system increases.
(B) The gravitational potential energy of the water-Earth system decreases.
(C) Work is done because the water in the larger pipe has a higher pressure.
(D) Work is done because the water in the larger pipe has a lower pressure.

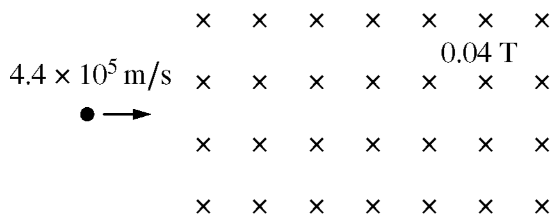
34. An ideal gas with molecules of mass m is contained in a cube with sides of area A. The pressure exerted by the gas on the top of the cube is P, and N molecules hit the top of the cube in a time Δt. What is the average vertical component of the velocity of the gas molecules?

(A) $PA\Delta t/m$

(B) $PA\Delta t/2m$

(C) $PA\Delta t/Nm$

(D) $PA\Delta t/2Nm$



35. A proton is moving at 4.4×10^5 m/s in the plane of the page when it enters a magnetic field of magnitude 0.04 T perpendicular to the page, as shown in the figure above. The radius of curvature of the path of the proton as it moves through the magnetic field is approximately which of the following?

(A) 1×10^4 m

(B) 1×10^1 m

(C) 1×10^{-4} m

(D) 1×10^{-1} m

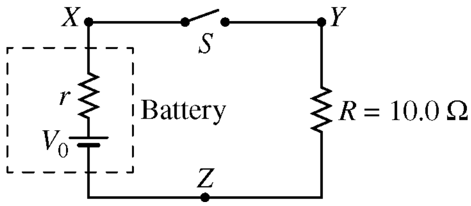
36. An object is placed in front of a thin lens. An upright image is formed that is one-third the height of the object. If the image is 6.0 cm from the lens, what is the focal length of the lens?

(A) −27 cm
(B) −9 cm
(C) 9 cm
(D) 27 cm

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. Which of the following phenomena involving light can be explained with a particle model? Select two answers.

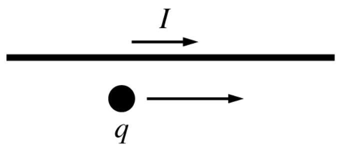
(A) The photoelectric effect
(B) Diffraction
(C) Atomic emission
(D) Thin-film interference



132. A battery of unknown emf V_0 and unknown internal resistance r is placed in a circuit with a switch S and a resistor of known resistance $R = 10\ \Omega$, as shown in the figure above. The internal resistance r can be determined by taking measurements with the switch open and with the switch closed. Which of the following pairs of measurements with the switch open and closed can be used to determine the value of r? Select two answers.

	With Switch Open	With Switch Closed
(A)	Potential difference between X and Z	Current at Y
(B)	Potential difference between X and Z	Potential difference between Y and Z
(C)	Potential difference between Y and Z	Current at X
(D)	Potential difference between Y and Z	Potential difference between X and Z

GO ON TO THE NEXT PAGE.



133. An object with charge q is initially moving at a constant speed v parallel to a wire carrying current I, as shown in the figure above. The object is at a distance d from the wire, and the magnetic force exerted on the object by the wire is F. Which of the following changes, when made individually, will result in a magnetic force of $2F$? Select two answers.

(A) Increasing the charge to $\sqrt{2}q$
(B) Increasing the current to $2I$
(C) Decreasing the speed to $v/\sqrt{2}$
(D) Decreasing the distance to $0.5d$

134. A simple generator contains a conducting loop that rotates between the poles of a magnet. Which of the following helps explain why this rotation generates a potential difference? Select two answers.

(A) The magnitude of the magnetic field produced by the magnet changes.
(B) The component of the magnetic field perpendicular to the loop changes.
(C) The area of the loop changes.
(D) The angle between the plane of the loop and the magnetic field changes.

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 2016 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics 2: Algebra-Based Exam

SECTION II: Free Response **2016**

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 4MBP4-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,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant,	$R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

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

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

PREFIXES		
Factor	Prefix	Symbol
10^{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 <u>on</u> 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

$\Delta E = W = F_{\parallel} d = F d \cos\theta$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

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

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

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

AP® PHYSICS 2 EQUATIONS

FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\,\Delta V$

$\Delta U = Q + W$

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

$E = hf$

$K_{max} = hf - \phi$

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

$E = mc^2$

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

WAVES AND OPTICS

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

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

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

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

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

$\Delta L = m\lambda$

$d\sin\theta = m\lambda$

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

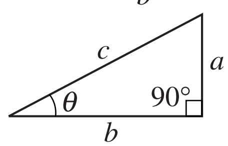
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

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

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

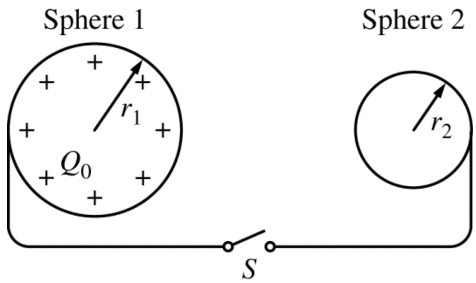
$\cos\theta = \dfrac{b}{c}$

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



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.



Note: Figure not drawn to scale.

1. (10 points, suggested time 20 minutes)

The figure above shows two metal spheres that are far apart compared to their size and that are held in place. The spheres are connected by wires to either side of switch S. Initially, the switch is open. Sphere 1 has mass m_1, radius r_1, and a net positive charge $+Q_0$. Sphere 2 has mass m_2 and radius $r_2 < r_1$ and is initially uncharged. The switch is then closed. Afterward, sphere 1 has a charge Q_1 and is at potential V_1, and the electric field strength just outside its surface is E_1. The corresponding values for sphere 2 are Q_2, V_2, and E_2. Neglect air resistance and gravitational interactions.

(a)

i. Indicate whether V_1 is larger than, smaller than, or equal to V_2. Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

ii. Indicate whether Q_1 is larger than, smaller than, or equal to Q_2. Briefly explain your reasoning using appropriate physics principles and/or mathematical models.

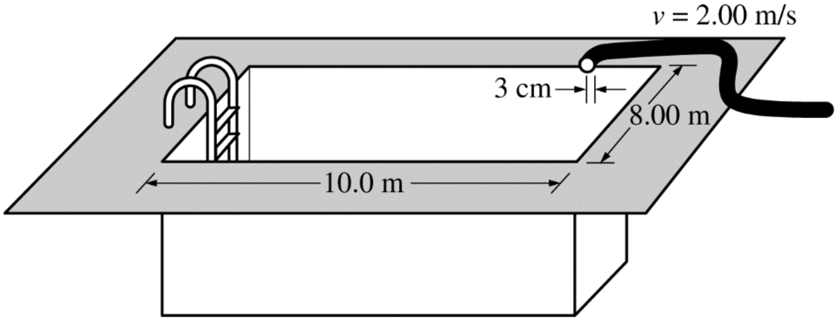
iii. Indicate whether E_1 is larger than, smaller than, or equal to E_2. Show how you arrived at your answer using appropriate physics principles and/or mathematical models.

(b) The distance between the centers of sphere 1 and sphere 2 is D. The switch is now opened, the wires are disconnected from the spheres, and the spheres are released, all without changing the charges on the spheres. Write but do NOT solve equations that could be used to determine the velocities v_1 and v_2 of the spheres a long time after they are released, in terms of m_1, m_2, Q_1, Q_2, D, and physical constants, as appropriate.

(c) The spheres are now returned to their original locations. Sphere 1 once again has initial net charge $+Q_0$, and sphere 2 is initially uncharged. The switch is again closed and then reopened. Sphere 3, an uncharged metal sphere of radius $r_3 > r_1 > r_2$ on an insulating handle, is now brought into contact with sphere 2. Sphere 3 is then moved away.

i. Indicate the sign of the final charge on each sphere.

ii. Rank the absolute value of the final charge on each of the three spheres. Explain how you arrived at this answer.



Note: Figure not drawn to scale.

2. (12 points, suggested time 25 minutes)

Water flows at a speed v of $2.00\ \text{m/s}$ through a hose of radius 3 cm and into a large empty rectangular pool. The pool has a level bottom and measures 10.0 m long by 8.00 m wide. The density of water is $1.00 \times 10^3\ \text{kg/m}^3$ and atmospheric pressure is $1.01 \times 10^5\ \text{Pa}$. Express all numerical answers to the following parts to at least three significant figures.

(a) Calculate the total pressure exerted downward on the bottom of the pool after the water has been running for 3 hours.

(b) A small ball is floating in the water as the pool fills. Indicate whether the buoyant force on the floating ball increases, decreases, or stays the same as the amount of water in the pool increases. Briefly explain your reasoning.

GO ON TO THE NEXT PAGE.

(c) A person gets impatient because it is taking too long to fill the pool. The person attaches a nozzle to the end of the hose that reduces the radius of the opening to 1.5 cm. Assume the speed of the water in the hose (before it reaches the nozzle) remains at $2.00\ \text{m/s}$. The person claims that the water now comes out of the nozzle faster than it did from the hose without the nozzle and therefore the pool will fill faster.

i. Do you agree that the pool will fill faster? Explain your reasoning in terms of conservation principles.

ii. Calculate the speed of the water as it leaves the nozzle. Explain how your calculation is consistent with the conservation principles used in part (c)(i).

(d) When the water in the pool is 1.50 m deep, the hose is turned off. A person who is 1.80 m tall then floats in the pool.

i. Is the net downward force exerted on the bottom of the pool now greater than, less than, or the same as it was before the person got into the pool? Explain your reasoning in terms of the forces exerted on the person.

ii. Would your answer to part (d)(i) be different if the person was standing on the bottom of the pool? Explain your reasoning.

(e) Consider the total pressure exerted by the water on the sides of the pool near the bottom of the pool. When the person floats in the pool, is this pressure greater than, less than, or the same as it was before the person got into the pool? Explain your reasoning.

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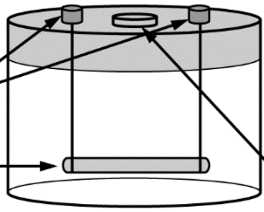


3. (12 points, suggested time 25 minutes)

Students observe that a graphite rod gets hot when there is an electric potential difference ΔV applied across it that causes an electric current I in it. The graphite rod is placed in an apparatus that consists of a clear plastic container with a lid, as shown above. The lid is equipped with electrical connectors and an opening that can be sealed around an inserted sensor. The graphite rod is connected to the electrical connectors by wires and sealed inside the container so that all the energy emitted by the rod goes into heating the air in the container. The teacher tells the students that in this situation the change in the internal energy of the air is equal to $(5/2)Nk_B\,\Delta T$, where N is the number of molecules and T is the temperature, and the air can be treated as an ideal gas.

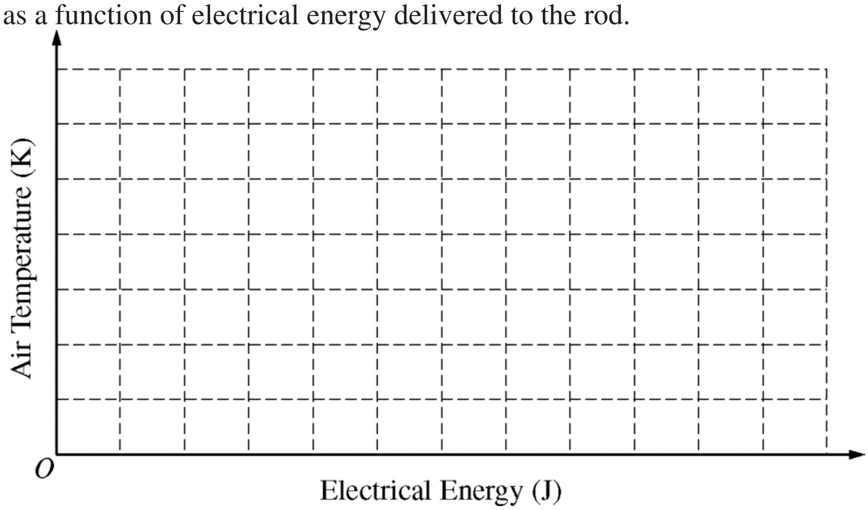
(a) Derive an expression for the temperature change of the air as a function of time t as a result of the electrical energy dissipated by the rod and delivered to the air in the container. Express your answer in terms of I, ΔV, N, and physical constants, as appropriate. Assume that the temperature of the graphite rod remains constant while the air is being heated.

GO ON TO THE NEXT PAGE.

The students are asked to design an experiment using the apparatus shown to investigate this heating. The students have an ammeter, a voltmeter, a fixed DC power supply, a stopwatch, an electronic temperature sensor, and a pressure sensor. Assume that the electrical connectors and connecting wires have negligible resistance.

(b) Outline an experimental procedure that can be used to gather data to determine how the air temperature in the container depends on the electrical energy delivered to the rod. Indicate the measurements to be taken and how the measurements will be used to obtain the data needed. On the diagram on the previous page, show how the container will be connected to instruments to take the necessary measurements.

(c) On the axes below, sketch the line or curve you predict will represent a plot of the temperature of the air in the container as a function of electrical energy delivered to the rod.

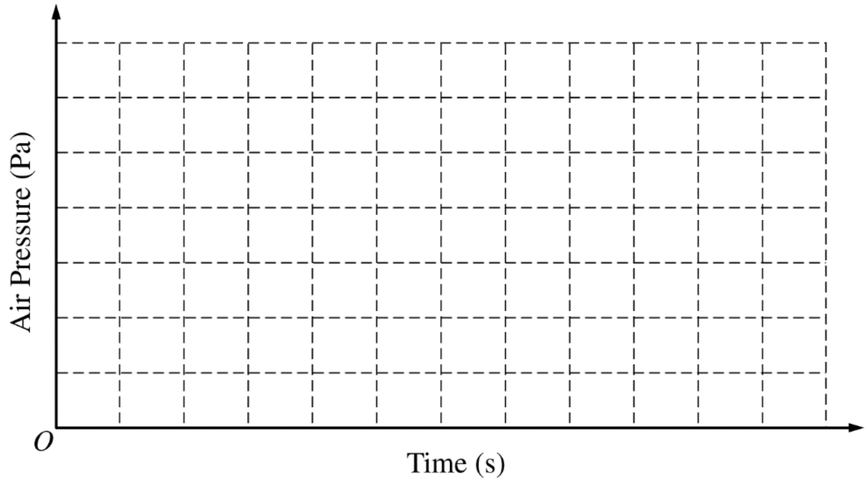


Question 3 continues on the next 2 pages.

GO ON TO THE NEXT PAGE.

(d)

i. On the axes below, sketch a line or curve you predict will represent a plot of the pressure of the air in the container as a function of time. Clearly label the sketch as R_1.

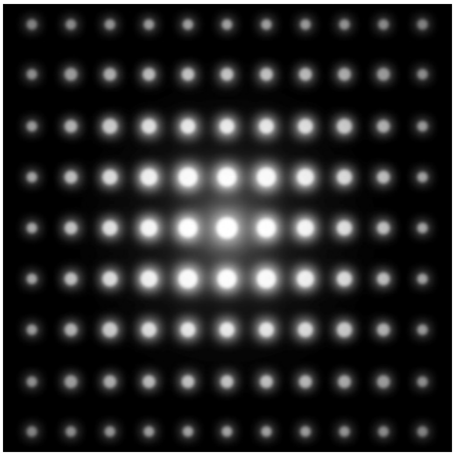


Explain why your graph has this shape.

ii. The rod is now replaced by a second graphite rod that has twice the length but the same radius. The potential difference across the new rod is the same as that across the original rod. On the axes in part (d)(i), sketch a line or curve you predict will represent a plot of the pressure of the air in the container as a function of time for the second rod. Clearly label the sketch as R_2. Compare this graph to the graph from part (d)(i) and explain why it is the same or different.

GO ON TO THE NEXT PAGE.

(e) Another group of students performing this experiment notices a gap in the seal of the container opening and thinks that some gas has leaked out of the container. If this is true, how would this group's graph of air temperature as a function of electrical energy compare to the graph you drew in part (c) ?



4. (10 points, suggested time 20 minutes)

The picture above appears in a magazine with a caption indicating that the picture represents electron diffraction by atoms in a crystal. The picture was created by directing a beam of electrons through a thin slice of crystal. The article states that a diffraction pattern like the one shown in the picture can be used to determine the distance between atoms in the crystal used in the experiment.

(a) In a coherent paragraph-length response, explain how electrons can be used to form a diffraction pattern and how the pattern can be used to determine the spacing of atoms in a crystal. Your answer may include a diagram that supports your explanation of the pattern formation.

GO ON TO THE NEXT PAGE.

(b) The article states that x-ray diffraction can also be used to determine crystal spacing. It describes one experiment in which a beam of x-rays with wavelength 8.30 nm was used and another experiment in which a beam of 100 eV electrons was used.

i. Calculate the energy of a photon in the x-ray beam.

ii. Calculate the de Broglie wavelength of an electron in the electron beam.

iii. Will directing the x-ray beam at a crystal with atoms spaced 0.6 nm apart result in the formation of a diffraction pattern? Will directing the electron beam at the same crystal result in the formation of a diffraction pattern? Explain your reasoning in terms of appropriate physics principles.

GO ON TO THE NEXT PAGE.

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 21: B
Question 2: C	Question 22: C
Question 3: *	Question 23: C
Question 4: C	Question 24: B
Question 5: D	Question 25: A
Question 6: B	Question 26: A
Question 7: B	Question 27: B
Question 8: A	Question 28: D
Question 9: C	Question 29: A
Question 10: C	Question 30: C
Question 11: B	Question 31: B
Question 12: D	Question 32: A
Question 13: D	Question 33: C
Question 14: D	Question 34: D
Question 15: C	Question 35: D
Question 16: D	Question 36: B
Question 17: A	Question 131: A, C
Question 18: D	Question 132: A, B
Question 19: C	Question 133: B, D
Question 20: B	Question 134: B, D

*Item 3 was not used in scoring.

Free-Response Scoring Guidelines

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

Question 1

10 points total | **Distribution of points**

(a)

i) 1 point

For indicating that $V_1 = V_2$ and giving a correct explanation — 1 point

Examples:

- When the switch is closed, charge flows to eliminate the initial potential difference between the spheres.
- There is no source of potential besides the spheres, and they are now effectively one conductor.

ii) 2 points

For using the fact that $V_1 = V_2$ (or whatever relationship was indicated in part i) — 1 point

For equating the expressions for potential, $kQ_1/r_1 = kQ_2/r_2$, and indicating that since $r_1 > r_2$, $Q_1 > Q_2$ (or logic consistent with answer to part i) — 1 point

Alternate Solution — *Alternate points*

For indicating that the larger sphere has more surface area — *1 point*

For indicating that a greater surface area will hold more charge — *1 point*

iii) 1 point

For combining $E = kQ/r^2$ and $V = kQ/r$ and using $V_1 = V_2$ and $r_1 > r_2$ to show that $E_1 < E_2$ (or logic consistent with answer to part i) — 1 point

Alternate solution — *Alternate points*

Since the fields are just outside the spheres, $E \approx \sigma/\varepsilon_0$. Letting $r_1 = cr_2$, we have $Q_1 = cQ_2$. Then $\sigma_1 = Q_1/4\pi r_1^2 = cQ_2/4\pi(cr_2)^2 = \sigma_2/c$. So $\sigma_1 < \sigma_2$ and $E_1 < E_2$. — *1 point*

(b) 3 points

For any indication that when the spheres are released, the electric potential energy is converted into kinetic energy of the spheres — 1 point

For any indication that momentum of the spheres must be conserved — 1 point

For both correct equations — 1 point

$$kQ_1Q_2/D = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

$$0 = m_1\vec{v}_1 + m_2\vec{v}_2 \text{ or } m_1v_1 = m_2v_2$$

Question 1 (continued)

	Distribution of points
(c)	
i) 1 point	
For indicating that spheres 1 and 3 have a positive charge, which is always true	1 point
If spheres 1 and 2 are well separated, all three spheres will ultimately have a positive charge. If the student assumes spheres 1 and 2 are close enough that charging by induction can occur, sphere 2 might end up with positive, zero, or negative charge depending on the size and placement of sphere 3 relative to sphere 2.	
ii) 2 points	
For indicating that charge on sphere 2 is split between spheres 2 and 3 when they come into contact, which implies that $Q_1 > Q_3$ since it was shown that $Q_1 > Q_2$	1 point
For indicating that sphere 3 has more charge than sphere 2 because it is larger, which justifies the ranking of $Q_1 > Q_3 > Q_2$ (or some correct reasoning relating the charges on spheres 1 and 3 based on the answer to part (a) and part (c)i	1 point

Question 2

12 points total | **Distribution of points**

(a) 3 points

For indicating that the volume of water in the pool is given by $V = A_{\text{hose}}vt$ — 1 point

For combining the volume expression with the appropriate expression for total pressure — 1 point

$P_{tot} = P_{\text{atm}} + \rho gh$

$P_{tot} = P_{\text{atm}} + \rho gA_{\text{hose}}vt/A_{\text{pool}}$

$$\rho gA_{\text{hose}}vt = \left(1\times10^3\ \text{kg/m}^3\right)\left(10\ \text{m/s}^2\right)\pi\left(3\times10^{-2}\ \text{m}\right)^2(2.00\ \text{m/s})(3\ \text{hr})(3600\ \text{s/hr})$$
$$= 6.1\times10^{13}\ \text{Pa•m}^2$$

$A_{\text{pool}} = (10.0\ \text{m})(8.00\ \text{m}) = 80.0\ \text{m}^2$

$P_{tot} = 1.01\times10^5\ \text{Pa} + \left(6.1\times10^{13}\ \text{Pa•m}^2\right)/80.0\ \text{m}^2$

For the correct numerical answer with units — 1 point

$P_{tot} = 1.09\times10^5\ \text{Pa}$ (or $1.08\times10^5\ \text{Pa}$ using atmospheric pressure from the table of information)

(b) 1 point

For indicating that the buoyant force stays the same with a correct justification — 1 point

Examples:

The buoyant force on the ball depends only on the amount of water displaced by the ball which does not change as long as the ball is floating.

Since the ball is moving up at constant speed as the pool fills, the net force on it is zero. Gravity and the buoyant force are the vertical forces, gravity is constant, and so the buoyant force must also be constant.

(c)

i) 1 point

For indicating that the pool fills at the same rate because mass is conserved or the volume flow rate stays the same $(A_1v_1 = A_2v_2)$ — 1 point

Example: Mass is conserved, and since the water is a non-compressible fluid, the volume flow rate of the water leaving the nozzle is the same as the rate at which it left the bare hose. So the pool will not fill faster.

ii) 2 points

For using the continuity equation $A_{\text{hose}}v_{\text{hose}} = A_{\text{nozzle}}v_{\text{nozzle}}$ to calculate that water leaves the nozzle at $8\ \text{m/s}$ — 1 point

For explaining the fill time remains constant despite the faster speed by referring to the conservation principle used in part (c)(i) — 1 point

Example: Although the water speed through the nozzle is greater, the area is smaller so that the volume of water that flows per time remains constant.

Question 2 (continued)

Distribution of points

(d)

i) 2 points

For indicating that the water exerts a buoyant force on the person that is equal and opposite to the force exerted by gravity (Newton's 2nd Law)	1 point
For using Newton's second and third laws to explain how the weight of the person causes an additional force on the bottom of the pool	1 point

Example: The person exerts a force on the water that is equal and opposite to the buoyant force exerted by the water on the person (Newton's 3rd Law). This means that the bottom of the pool must exert an additional force on the water to maintain it at rest, and by Newton's third law the water is thus exerting a greater force on the bottom of the pool.

ii) 1 point

For indicating that the force would not be different, with an explanation that in both cases the total mass is being supported by the bottom of the pool	1 point

(e) 2 points

For indicating that pressure of a fluid is exerted in all directions	1 point
For indicating that since the force is greater (as argued in (d)(i)) then the pressure is greater.	1 point
Alternate solution	*Alternate points*
For indicating the depth of the water increases due to the displacement by the floating person	*1 point*
For indicating the pressure on the sides is greater due to the increased water depth	*1 point*

Question 3

12 points total | **Distribution of points**

(a) 2 points

For electrical energy input ΔE correctly expressed in terms of a combination of ΔV, I, and t — 1 point

$\Delta E = I\Delta Vt$

For equating the electrical energy input to the energy of the gas expressed in terms of temperature, and an attempt to solve for ΔT — 1 point

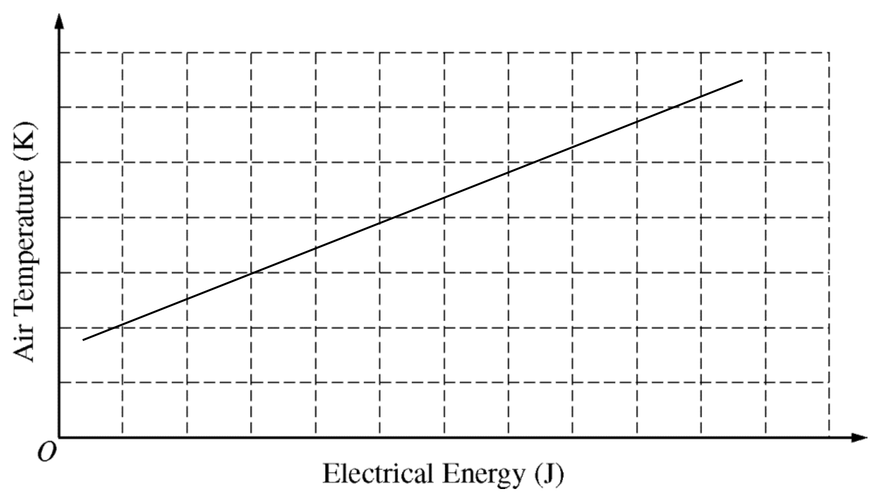
$I\Delta Vt = 5/2\, Nk_B \Delta T$

$\Delta T = 2\Delta VIt/5Nk_B$

(b) 4 points

For a valid description of the setup and procedure, including a diagram — 1 point
For measuring current and potential difference, with symbols defined as needed — 1 point
For measuring the temperature change of the air, with a symbol defined as needed — 1 point
For a description of how the measurements will be used to calculate the energy — 1 point

(c) 1 point



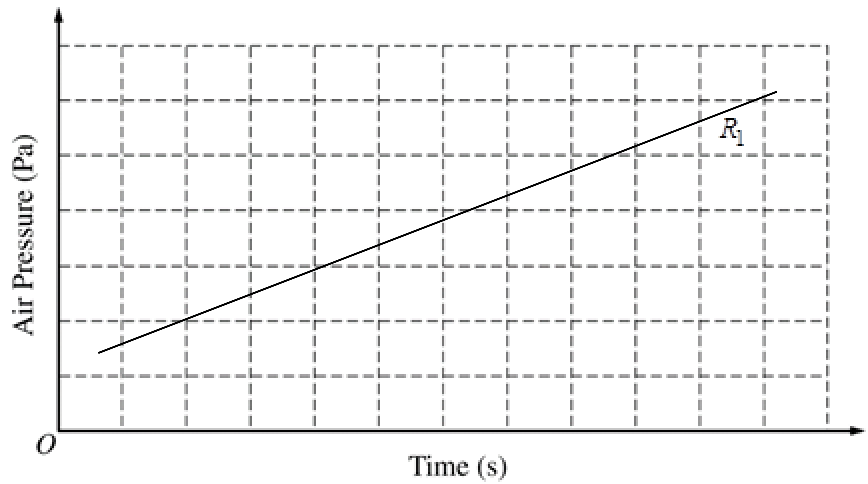
For a line with a positive slope and a positive temperature intercept (the line would not extend to the origin, because the air would initially be at ambient temperature) — 1 point

Question 3 (continued)

Distribution of points

(d)

i) 2 points

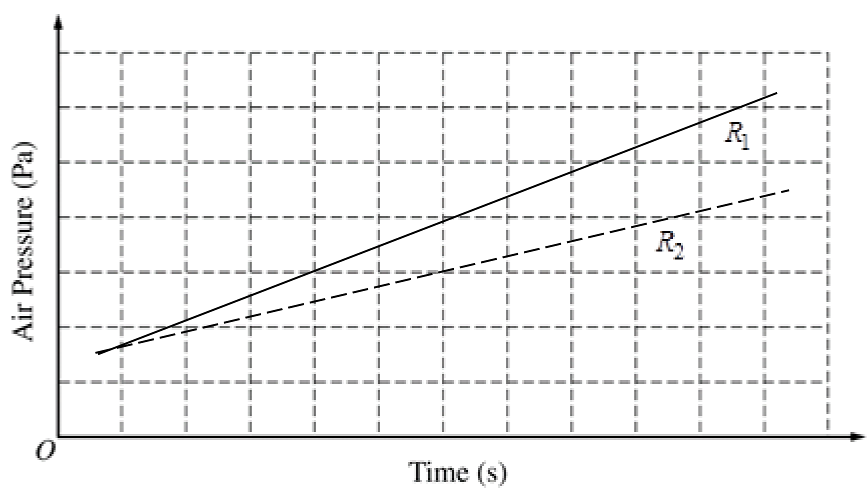


For a correct graph with positive slope and positive pressure intercept, or a graph consistent with the graph in part (c) — 1 point

For a correct explanation — 1 point

Example: Since the gas is ideal, $PV = nRT$ applies. Volume is constant, so pressure will rise in direct proportion to temperature. The power dissipated by the resistor is constant, so the temperature rises at a steady rate. The line does not go through zero because the lowest temperature is the nonzero temperature of the surrounding air.

ii) 2 points



For a second graph with a clear indication that R_2 has the smaller slope, or for a graph consistent with the graph in part (d)i that begins with a smaller slope — 1 point

For a correct explanation — 1 point

Example: A longer resistor means greater resistance. Since power is V^2/R and the potential difference is the same, the temperature and thus the pressure rise more slowly with time.

Question 3 (continued)

Distribution of points

(e) 1 point

For an indication that the new graph will have a different slope, and with no indication that the shape of the new graph would be different — 1 point

Question 4

10 points total **Distribution of points**

(a) 5 points

For indicating that electrons can have wave properties	1 point
For indicating that the wavelength of the electron can be about the same size as the spacing in the crystal	1 point
For indicating that the evenly spaced pattern of atoms in the crystal acts like slits	1 point
For indicating that the difference in path lengths that produce the constructive and destructive interference pattern can be used to determine the crystal spacing of the atoms in the crystal	1 point
For a response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response	1 point

(b)

i) 1 point

For using appropriate expression(s) with correct substitutions to calculate the energy of the x-rays — 1 point

$E = hf$ and $\lambda = c/f$, so $E = hc/\lambda$

$E = 1.24 \times 10^3 \text{ eV}\bullet\text{nm}/8.30 \text{ nm}$ or $1.99 \times 10^{-25} \text{ J}\bullet\text{m}/8.30 \times 10^{-9} \text{ m}$

$E = 149 \text{ eV}$ or $2.40 \times 10^{-17} \text{ J}$

ii) 2 points

For converting the electron energy to joules and using the expression for kinetic energy to calculate the speed or momentum of the electrons (Point is earned for correct setup; numerical answer need not be correct) — 1 point

$K = 1/2\, mv^2$ or $K = p^2/2m$

$v = \sqrt{2K/m}$ or $p = \sqrt{2mK}$

$v = \sqrt{2(100 \text{ eV})(1.6 \times 10^{-19} \text{ J/eV})/(9.11 \times 10^{-31} \text{ kg})} = 5.9 \times 10^6 \text{ m/s}$ or

$p = \sqrt{2(9.11 \times 10^{-31} \text{ kg})(100 \text{ eV})(1.6 \times 10^{-19} \text{ J/eV})} = 5.40 \times 10^{-24} \text{ kg}\bullet\text{m/s}$

For using the speed or momentum to calculate the de Broglie wavelength of the electrons (Point is earned for correct setup; numerical answer need not be correct) — 1 point

$\lambda = h/(mv)$ or h/p

$\lambda = 6.63 \times 10^{-34} \text{ J}\bullet\text{s}/(9.11 \times 10^{-31} \text{ kg})(5.9 \times 10^6 \text{ m/s})$ or

$6.63 \times 10^{-34} \text{ J}\bullet\text{s}/5.40 \times 10^{-24} \text{ kg}\bullet\text{m/s}$

$\lambda = 0.12 \text{ nm}$

Both points are earned if the equations are combined algebraically and then a single numerical calculation is performed.

Question 4 (continued)

	Distribution of points
iii) 2 points	
For indicating that the x-ray wavelength is much larger than the crystal spacing and will not be diffracted by the crystal	1 point
For indicating that the electron beam wavelength is on the order of the size of the crystal spacing, so a diffraction pattern will appear, or an answer consistent with part (b)i	1 point

Scoring Worksheet

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

2016 AP Physics 2 Scoring Worksheet

Section I: Multiple Choice

____________ × 1.0256 = ________________

Number Correct (out of 39*)

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
54-80	5
44-53	4
30-43	3
18-29	2
0-17	1

*Although 40 multiple-choice items were administered in Section I, item 3 was not used in scoring.

Question Descriptors and Performance Data

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

2016 AP Physics 2: Algebra-Based
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
1	2-4.C.3.1	4.C.3	6.4	D	98
2	2-4.E.3.3	4.E.3	1.1|1.4|6.4	C	82
3	2-5.F.1.1	5.F.1	2.1|2.2|7.2	*	*
4	2-3.C.2.3	3.C.2	2.2	C	71
5	2-5.B.9.7	5.B.9	5.1	D	82
6	2-7.A.3.3	7.A.3	5.1	B	78
7	2-5.B.6.1	5.B.6	1.2	B	80
8	2-6.E.3.3	6.E.3	6.4|7.2	A	65
9	2-5.C.3.5	5.C.3	1.4|2.2	C	78
10	2-5.B.9.8	5.B.9	1.5	C	91
11	2-5.B.7.3	5.B.7	1.4|2.2	B	40
12	2-6.A.2.2	6.A.2	6.4	D	65
13	2-6.B.3.1	6.B.3	1.5	D	51
14	2-5.B.9.5|2-5.B.9.6	5.B.9	6.4|2.2	D	69
15	2-2.C.5.3	2.C.5	1.1|7.1	C	51
16	2-3.G.3.1	3.G.3	7.2	D	58
17	2-3.A.2.1|2-3.A.3.4|2-3.B.1.4|2-3.C.2.3|2-4.E.3.5	3.A.2|3.A.3|3.B.1|3.C.2|4.E.3	1.1|6.4|6.4|2.2|5.1	A	46
18	2-5.B.10.1	5.B.10	2.2	D	82
19	2-5.B.8.1|2-7.C.4.1	5.B.8|7.C.4	1.2|7.2|1.2	C	63
20	2-5.C.1.1|2-5.G.1.1	5.C.1|5.G.1	6.4|6.4	B	63
21	2-6.A.1.2	6.A.1	1.2	B	53
22	2-6.C.2.1	6.C.2	6.4	C	31
23	2-6.E.5.2	6.E.5	5.1	C	52
24	2-4.E.4.1	4.E.4	2.2|6.4	B	48
25	2-3.A.4.2|2-3.C.2.1	3.A.4|3.C.2	6.4|6.4	A	60
26	2-2.C.2.1	2.C.2	6.4	A	63
27	2-5.B.4.1	5.B.4	6.4|7.2	B	38
28	2-1.A.5.2|2-5.B.4.1	1.A.5|5.B.4	1.4|6.4	D	51
29	2-4.E.3.2|2-4.E.3.3	4.E.3	6.4|1.4|6.4	A	63
30	2-4.C.4.1|2-5.B.11.1	4.C.4|5.B.11	7.2|7.2	C	48
31	2-7.A.2.2	7.A.2	7.1	B	48
32	2-3.C.3.1	3.C.3	1.4	A	66
33	2-5.B.10.4	5.B.10	6.2	C	37
34	2-7.A.1.2	7.A.1	1.4|2.2	D	27
35	2-2.D.1.1	2.D.1	2.2	D	45
36	2-6.E.5.1	6.E.5	1.4|2.2	B	37

* Item not included in scoring

2016 AP Physics 2: Algebra-Based

Question Descriptors and Performance Data

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
131	2-1.D.1.1|2-5.B.8.1|2-6.C.1.1|2-6.C.3.1|2-6.F.3.1	1.D.1|5.B.8|6.C.1|6.C.3|6.F.3	6.3|1.2|6.4|6.4|6.4	A, C	53
132	2-5.B.9.7	5.B.9	4.1|4.2	A, B	33
133	2-2.D.1.1|2-2.D.2.1|2-3.C.3.1	2.D.1|2.D.2|3.C.3	2.2|1.1|1.4	B, D	70
134	2-4.E.2.1	4.E.2	6.4	B, D	46

Free-Response Questions

Question	Learning Objectives	Essential Knowledge	Science Practices	Mean Score
1	2-1.B.1.2|2-2.C.3.1|2-2.E.3.1|2-2.E.3.2|2-4.E.3.2|2-4.E.3.3|2-5.B.4.2|2-5.C.2.1|2-5.D.3.2	1.B.1|2.C.3|2.E.3|4.E.3|5.B.4|5.C.2|5.D.3	6.4|6.2|2.2|1.4|6.4|6.4|6.4|1.4|2.1|2.2|6.4|6.4	2.01
2	2-3.A.2.1|2-3.A.4.1|2-3.A.4.2|2-3.B.1.4|2-5.B.10.2|2-5.B.10.3|2-5.F.1.1	3.A.2|3.A.4|3.B.1|5.B.10|5.F.1	1.1|1.4|6.2|6.4|7.2|6.4|2.2|2.2|2.1|7.2	4.51
3	2-4.E.4.2|2-4.E.5.3|2-5.B.7.1|2-5.B.9.8|2-7.A.2.1|2-7.A.3.2|2-7.A.3.3	4.E.4|4.E.5|5.B.7|5.B.9|7.A.2|7.A.3	4.1|4.2|4.2|6.4|7.2|1.5|7.1|4.2|5.1	4.23
4	2-6.C.2.1|2-6.C.3.1|2-6.F.3.1|2-6.F.4.1|2-6.G.1.1|2-6.G.2.1|2-6.G.2.2	6.C.2|6.C.3|6.F.3|6.F.4|6.G.1|6.G.2	1.4|6.4|7.2|1.4|6.4|6.4|6.4|7.1|6.4|7.1|6.1|6.4	2.79

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