From the 2018 Administration

AP CollegeBoard

# AP Physics 2: Algebra-Based

## Practice Exam

**NOTE: This is a modified version of the 2018 AP Physics 2: Algebra-Based Exam.**

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Note: This publication shows the page numbers that appeared in the ***2017–18 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

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# Exam Instructions

The following contains instructions taken from the ***2017–18 AP Exam Instructions*** book.

# AP Physics 1: Algebra-Based Exam

**Regularly Scheduled Exam Date:** Tuesday afternoon, May 8, 2018
**Late-Testing Exam Date:** Thursday morning, May 24, 2018

# AP Physics 2: Algebra-Based Exam

**Regularly Scheduled Exam Date:** Wednesday afternoon, May 9, 2018
**Late-Testing Exam Date:** Thursday afternoon, May 24, 2018

| | |
|---|---|
| **Section I** | **Total Time:** 1 hour and 30 minutes<br>Calculator allowed<br>**Number of Questions:** 50<br>*(The number of questions may vary slightly depending on the form of the exam.)*<br>**Percent of Total Score:** 50%<br>**Writing Instrument:** Pencil required |
| **Section II** | **Total Time:** 1 hour and 30 minutes<br>Calculator allowed<br>**Number of Questions Physics 1:** 5<br>**Number of Questions Physics 2:** 4<br>**Percent of Total Score:** 50%<br>**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
- ☐ *2017-18 AP Coordinator's Manual*
- ☐ This book—*2017-18 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ School Code and Homeschool/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 during the test administration, including breaks"

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

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for these entire exams (Sections I and II). Before starting the exam administration, make sure each student has an appropriate calculator, and any student with a graphing calculator has a model from the approved list on page 52 of the *2017-18 AP Coordinator's Manual*. See pages 49–52 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, they must hand copy, date, and sign the release statement on page 51 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 303–304 for a seating chart template and instructions. See the *2017-18 AP Coordinator's Manual* for exam seating requirements (pages 55–58).

### Physics 1: Algebra-Based

**If you are giving the regularly scheduled exam, say:**
**It is Tuesday afternoon, May 8, and you will be taking the AP Physics 1: Algebra-Based Exam.**

**If you are giving the alternate exam for late testing, say:**
**It is Thursday morning, May 24, 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 9, 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 Thursday afternoon, May 24, and you will be taking the AP Physics 2: Algebra-Based Exam.**

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

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

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

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

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

**In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2017-18 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. Place it on page 1 of your answer sheet on the light blue box near the top right corner that reads "AP Exam Label."**

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

**Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.**

Give students enough time to complete each step. Don't move on until all students are ready.

**Read the statements on the front cover of the Section I booklet. . . .**

**Sign your name and write today's date. . . .**

**Now print your full legal name where indicated. . . .**

**Turn to the back cover of your exam booklet and read it completely. . . .**

**Are there any questions? . . .**

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

**Open your answer sheet to page 2. You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses on pages 2 and 3 of your answer sheet. Remember, for numbers 1 through 45 on answer sheet page 2, mark only the single best answer to each question. The answer sheet has circles marked A–E for each of these questions. For this exam, you will use only the circles marked A–D. For numbers 131 through 135 at the bottom of answer sheet page 3, mark the two best answer choices for each question. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. Rulers, straightedges, and**

**calculators may be used for the entire exam. You may place these items on your desk. Are there any questions? . . .**

**You have 1 hour and 30 minutes for this section. Open your Section I booklet and begin.**

**Note Start Time _____ . Note Stop Time _____ .**

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. 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. Close your booklet and put your answer sheet on your desk, faceup. 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, faceup. I will now collect your Section I booklet. . . .**

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

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

**Please listen carefully to these instructions before we take a 10-minute break. Please put all of your calculators under your chair. Your calculators and all items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, notes, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic or communication device. Remember, you may never discuss the multiple-choice exam content with anyone, and if you disclose the content through any means, your AP Exam score will be canceled. Are there any questions? . . .**

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

## SECTION II: Free Response

**After the break, say:**

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

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

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

**Now take an AP number label from your Student Pack and place it on the shaded box. If you don't have any AP number labels, write your AP number in the box. Look up when you have finished. . . .**

**Read the last statement. . . .**

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

**Turn to the back cover and, 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? . . .**

**If this is your last AP Exam, you may keep your Student Pack. Place it under your chair for now. Otherwise I will collect all Student Packs. . . .**

**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, 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 _____. Note Stop Time _____.**

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, faceup. . . .**

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 after the exam (see page 67 of the *2017-18 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 their initials and today's date.
- Exam booklet back cover: The student completed the "Important Identification Information" area.

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

**If you are giving the regularly scheduled exam, say:**
**You may not discuss or share the free-response exam content with anyone unless it is released on the College Board website in about two days. Your AP Exam score results will be available online in July.**

**If you are giving the alternate exam for late testing, say:**
**None of the content in this exam may ever be discussed or shared in any way at any time. Your AP Exam score results will be available online in July.**

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

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

**Then say:**

**You are now dismissed.**

# After-Exam Tasks

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

**NOTE:** If you administered exams to students with accommodations, review the *2017-18 AP Coordinator's Manual* and the *2017-18 AP SSD Guidelines* for information about completing the NAR form, and returning these exams.

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

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration (regular or late testing), as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).
- Return all exam materials to secure storage until they are shipped back to the AP Program. (See page 26 of the *2017-18 AP Coordinator's Manual* for more information about secure storage.) 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 *2017-18 AP Coordinator's Manual.*
  - Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

# Student Answer Sheet for the Multiple-Choice Section

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

CollegeBoard AP

# Answer Sheet 2018

**AP Number Label**
(from Student Pack)

AP FPO X123456789 X

**AP Exam Label**
(from Section I Booklet)



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

I am aware of and agree to follow the policies and procedures in the *2017-18 Bulletin for AP Students and Parents* to maintain the security of the exam and the validity of my AP score. I understand and accept that my exam score may be canceled if I do not follow these policies and procedures, if I disregard any exam day instructions, or if my exam is administered improperly. I certify that I am the person whose information appears on this answer sheet.

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

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

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

**C. YOUR AP NUMBER**

**D. EXAM DATE** Month Day

**E. EXAM START TIME** AM PM

**F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER** S

**G. ONLINE PROVIDER CODE**

**COMPLETE THIS AREA ONLY ONCE.**

**I. AREA CODE AND PHONE NUMBER**

**INTERNATIONAL PHONE**

**J. SCHOOL YOU ATTEND**

SCHOOL CODE | School Name | City | State | Country

**K. DATE OF BIRTH**

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

Day | Year

**L. SOCIAL SECURITY NUMBER (Optional)**

**M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT**

COLLEGE CODE

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

College Name | City | State | Country

**N. CURRENT GRADE LEVEL**

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

**O. STUDENT SEARCH SERVICE®**

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

Would you like us to supply your information?

- Yes
- No

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

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

801356

**SCHOOL USE ONLY**

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

Fee Reduction Granted: 1 Option 1 2 Option 2

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Q4546/1-4

**COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).**

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

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

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

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

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

◯ Yes ◯ No

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

◯ Yes ◯ No

**QUESTIONS 1–75**

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

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS 

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

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

**FOR OFFICIAL USE ONLY**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Exam | | (0)(1)(2)(3)(4)(5)(6)(7)(8)(9) | | | | | | | | |
| | | (0)(1)(2)(3)(4)(5)(6)(7)(8)(9) | | | | | | | | |
| Exam | | (0)(1)(2)(3)(4)(5)(6)(7)(8)(9) | | | | | | | | |
| | | (0)(1)(2)(3)(4)(5)(6)(7)(8)(9) | | | | | | | | |

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

DO NOT WRITE IN THIS AREA

## QUESTIONS 76–120

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

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

## QUESTIONS 121–126

**For Students Taking AP Biology**

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

121 122 123 124 125 126

## QUESTIONS 131–142

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

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

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

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DO NOT WRITE IN THIS AREA

## COMPLETE THIS AREA ONLY ONCE.

### R. YOUR MAILING ADDRESS

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

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

**CITY**

**ZIP OR POSTAL CODE**

**COUNTRY CODE**

**STATE**

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

### V. SEX

- Female
- Male

### W. WHICH LANGUAGE DO YOU KNOW BEST?

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

### X. RACIAL/ETHNIC GROUP

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

(You may mark all that apply.)

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

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

**b. What is your race?**

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

### Y. PARENTAL EDUCATION LEVEL

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

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

### S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

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

### T. STUDENT IDENTIFIER (Student ID Number)

### U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email address in accordance with the policies in the *2017-18 Bulletin for AP Students and Parents*.

# Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2018 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 2018. Therefore, the timing indicated here may not be appropriate
for a practice exam.

# AP® Physics 2: Algebra-Based Exam

## SECTION I: Multiple Choice

2018

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

### At a Glance

**Total Time**
1 hour and 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<br>(A) state<br>(B) city<br>(C) country<br>(D) continent | Ⓐ ● Ⓒ Ⓓ Ⓔ |

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

| Sample Question | Sample Answer |
|---|---|
| New York is a<br>(A) state<br>(B) city<br>(C) country<br>(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 4OBP4-S**
84

# AP® PHYSICS 2 TABLE OF INFORMATION

## CONSTANTS AND CONVERSION FACTORS

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

| | |
|---|---|
| 1 unified atomic mass unit, | $1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\text{ MeV}/c^2$ |
| Planck's constant, | $h = 6.63 \times 10^{-34}\text{ J·s} = 4.14 \times 10^{-15}\text{ eV·s}$ |
| | $hc = 1.99 \times 10^{-25}\text{ J·m} = 1.24 \times 10^{3}\text{ eV·nm}$ |
| Vacuum permittivity, | $\varepsilon_0 = 8.85 \times 10^{-12}\text{ C}^2/\text{N·m}^2$ |
| Coulomb's law constant, | $k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}\text{ N·m}^2/\text{C}^2$ |
| 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, | $1\text{ atm} = 1.0 \times 10^{5}\text{ N/m}^2 = 1.0 \times 10^{5}\text{ Pa}$ |

| 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 | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | $0^\circ$ | $30^\circ$ | $37^\circ$ | $45^\circ$ | $53^\circ$ | $60^\circ$ | $90^\circ$ |
| $\sin\theta$ | 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 | $\sqrt{3}$ | $\infty$ |

The following conventions are used in this exam.

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

# AP® PHYSICS 2 EQUATIONS

## MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

$\Delta L = \tau \Delta t$

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

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

$a$ = acceleration
$A$ = amplitude
$d$ = distance
$E$ = energy
$F$ = force
$f$ = frequency
$I$ = rotational inertia
$K$ = kinetic energy
$k$ = spring constant
$L$ = angular momentum
$\ell$ = 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
$\alpha$ = angular acceleration
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed

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

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

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

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

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

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

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

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

## ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

# AP® PHYSICS 2 EQUATIONS

## FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho gh$

$F_b = \rho Vg$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

## GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

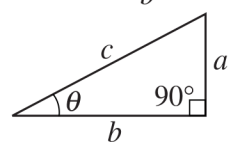
Rectangular solid
$V = \ell wh$

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
$\ell$ = 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

### Time—1 hour and 30 minutes

### 50 Questions

**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. Two waves are created in air and move toward outer space. Wave $X$ cannot travel in the vacuum of outer space, but wave $Y$ can. What types of waves are $X$ and $Y$?

| | Wave $X$ | Wave $Y$ |
|---|---|---|
| (A) | Electromagnetic | Mechanical |
| (B) | Electromagnetic | Electromagnetic |
| (C) | Mechanical | Mechanical |
| (D) | Mechanical | Electromagnetic |

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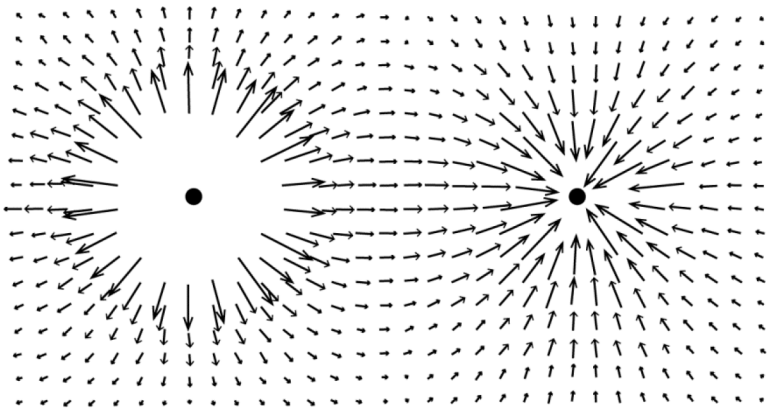

2. Which of the following is a correct description of the field diagram shown above?

   (A) It shows field vectors for two particles with charges of opposite sign and about the same magnitude, and it could also represent their gravitational field if they have about the same mass.

   (B) It shows field vectors for two particles with charges of opposite sign and about the same magnitude, but it could not represent their gravitational field.

   (C) It shows field vectors for two particles with charges of the same sign and about the same magnitude, and it could also represent their gravitational field if they have about the same mass.

   (D) It shows field vectors for two particles with charges of the same sign and about the same magnitude, but it could not represent their gravitational field.

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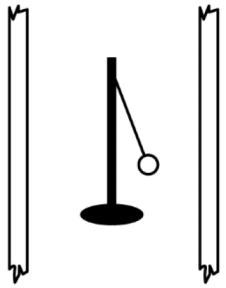
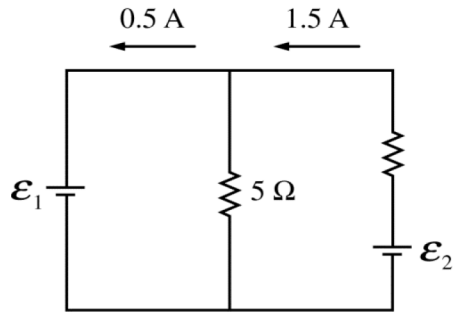


Note: Figure not drawn to scale.

3. Some students are trying to determine whether the radius of a metal sphere affects the amount of charge that it can hold. The students have metal spheres of different radii and known masses that can be attached to a stand by a string, as shown above. The stand is midway between a set of large plates that are connected to a battery to create a nearly uniform electric field in the region between them and near their centers. The students rub a rod with cloth and touch it to each sphere to charge the sphere, and they observe the deflection of the sphere as it is attracted to one plate. They keep adding charge to each sphere until they cannot observe any change in deflection. Which of the following data will give them information that is useful for quantitatively comparing the amount of charge on each sphere?

   (A) The number of times they rub the cloth back and forth on the rod
   (B) The number of times they touch the rod to the sphere
   (C) The string's angle of deflection
   (D) The string's direction of deflection




4. What are the value and the direction of the current through the $5\ \Omega$ resistor in the circuit shown above?

   (A) 1.0 A toward the top of the page
   (B) 1.0 A toward the bottom of the page
   (C) 2.0 A toward the top of the page
   (D) 2.0 A toward the bottom of the page

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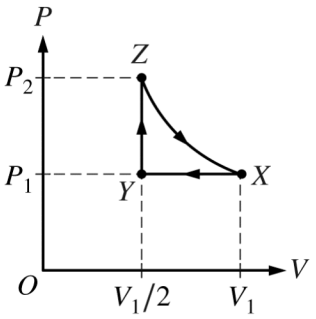
**Questions 5-7 refer to the following material.**




A closed chamber filled with a gas that is modeled as ideal has a movable piston of area $A$. The graph above of pressure $P$ as a function of volume $V$ shows three processes that make up cycle $XYZX$ through which the gas is taken. Process $ZX$ is isothermal.

5. During which process is no work done on or by the gas?

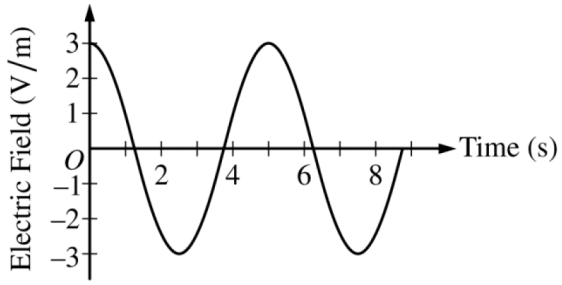
   (A) $XY$
   (B) $YZ$
   (C) $ZX$
   (D) Work was done on or by the gas during every process.

6. What is the force exerted on the piston by the gas during process $XY$ ?

   (A) $P_1V_1$
   (B) $P_1V_1/2$
   (C) $P_1A$
   (D) $P_1A/2$

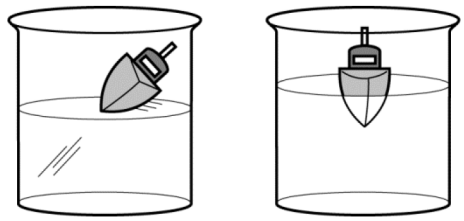
7. During which process is the amount of work done on the gas equal to the amount of energy that the gas exchanges with its surroundings through heating or cooling?

   (A) $XY$
   (B) $YZ$
   (C) $ZX$
   (D) None of the processes; the amount of work done on the gas is always greater than the amount of energy that the gas exchanges with its surroundings through heating or cooling.




8. The graph above represents the magnitude $E$ of the electric field at a point in space as a function of time $t$. Which of the following is a correct equation for the field if $E$ is in V/m and $t$ is in s?

   (A) $E = 3\cos(2\pi t/5)$
   (B) $E = 3\cos(2\pi t/3)$
   (C) $E = 5\cos(2\pi t/5)$
   (D) $E = 5\cos(2\pi t/3)$



9. A toy boat sits atop a cylinder of ice in a beaker, as shown above on the left. A normal force is exerted on the boat by the surface of the ice. Later the ice has melted, and the boat floats while partially submerged in the water, as shown on the right. A buoyant force is exerted on the boat by the water. Which of the forces, if either, is greater and why?

   (A) The normal force is greater because molecules in solids exert larger interatomic forces on other objects than molecules in liquids do.
   (B) The buoyant force is greater because more molecules of water are in contact with the boat, so the net interatomic force between the water and the boat is greater.
   (C) The forces are equal because each molecule of ice in contact with the boat exerts the same interatomic force on the boat as each molecule of water in contact with the boat.
   (D) The forces are equal because in both cases the net interatomic force exerted by the ice or water on the boat and the gravitational force on the boat balance.

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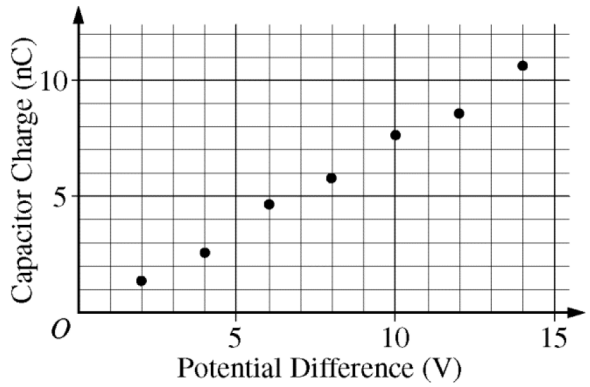
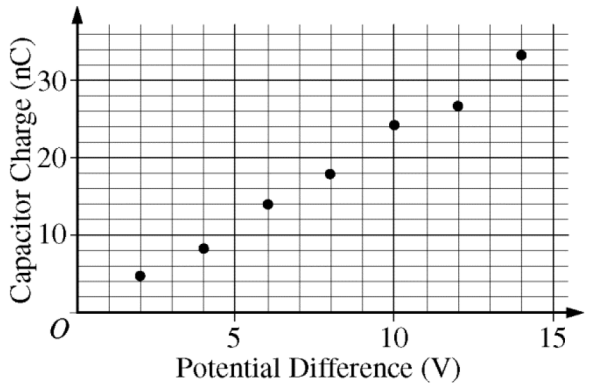


Graph 1: Capacitor with Air



Graph 2: Capacitor with Dielectric

10. A capacitor initially has only air between its plates. The charge on the capacitor as a function of applied potential difference is measured, and the results are shown in graph 1 above. The capacitor is discharged, a dielectric material is inserted between the plates, and the charge as a function of applied potential difference is measured again. The results are shown in graph 2. Which of the following is equal to the dielectric constant of the material inserted into the capacitor?

(A) The slope of graph 1 divided by the slope of graph 2
(B) The slope of graph 2 divided by the slope of graph 1
(C) The vertical intercept of graph 1 divided by the vertical intercept of graph 2
(D) The vertical intercept of graph 2 divided by the vertical intercept of graph 1

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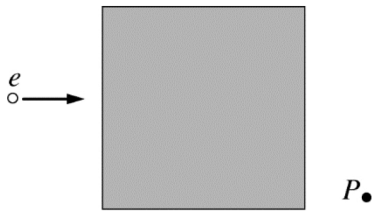
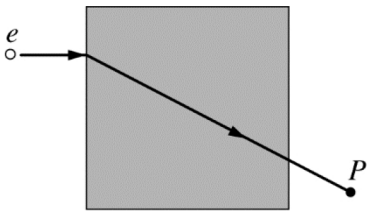
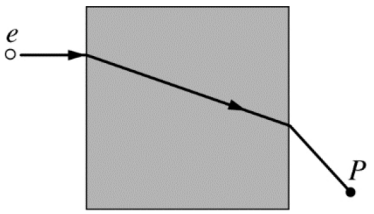
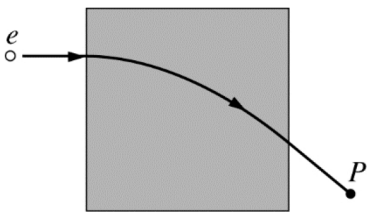
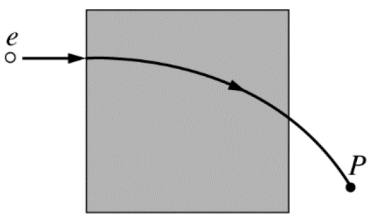



11. An electron is moving to the right, as shown in the figure above. It passes through the shaded region, which contains a magnetic field directed into the page. The electron travels along a path that takes it through point *P*. The gravitational force on the electron is negligible. Which of the following is a possible path of the electron?

(A)



(B)



(C)



(D)



| Object Distance from Lens | Orientation of Image | Type of Image | Size of Image Compared to Object |
|---|---|---|---|
| 5 cm | Upright | Virtual | Larger |
| 10 cm | Upright | Virtual | Larger |
| 15 cm | Inverted | Real | Larger |
| 25 cm | Inverted | Real | Smaller |

12. A student uses a convex lens to create images and collects the data shown above. The focal length of the lens is in which of the following ranges?

(A) 0–5 cm
(B) 5–10 cm
(C) 10–15 cm
(D) 15–25 cm

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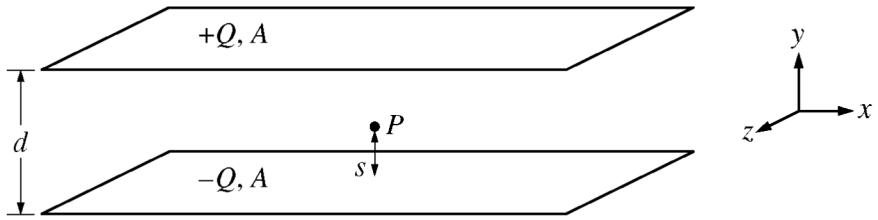
**Questions 13-15 refer to the following material.**




Two conducting plates of area $A$ are separated by a distance $d$, as shown above. The upper plate has a net charge of $+Q$ and the lower plate has a net charge of $-Q$. Point $P$ is located a distance $s$ above the center of the lower plate and closer to the lower plate than the upper plate. Assume the plate dimensions are very large compared to $d$ and all gravitational forces are negligible.

13. Which of the following indicates the direction of the electric field at point $P$ and the reason it has that direction?

(A) The electric field is in the $+x$ direction because the charges are equal and opposite.
(B) The electric field is in the $-y$ direction because point $P$ is farther from the positively charged plate.
(C) The electric field is in the $-y$ direction because electric fields point away from positive charge and toward negative charge.
(D) The electric field is in the $+y$ direction because electric fields point away from negative charge and toward positive charge.

14. Assume the magnitude of the electric field at point $P$ is $5.0 \times 10^4$ N/C. What is the magnitude and direction of the force on an electron at point $P$ due to the electric field?

(A) $3.1 \times 10^{23}$ N in the same direction as the electric field
(B) $3.1 \times 10^{23}$ N in the direction opposite to the electric field
(C) $8.0 \times 10^{-15}$ N in the same direction as the electric field
(D) $8.0 \times 10^{-15}$ N in the direction opposite to the electric field

15. If the magnitude of the electric field at point $P$ is $5.0 \times 10^4$ N/C and the distance between the plates is 0.80 mm, what is the electrical potential difference between the plates?

(A) 40 V
(B) 62.5 V
(C) 4000 V
(D) 6250 V

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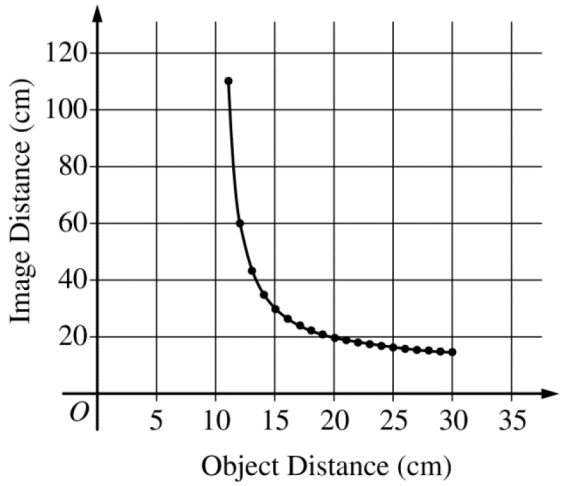
$$^{238}_{92}\mathrm{U} + X \rightarrow {}^{239}_{92}\mathrm{U}$$

$$^{239}_{92}\mathrm{U} \rightarrow {}^{239}_{93}\mathrm{Np} + Y + \overline{\nu}$$

$$^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + Y + \overline{\nu}$$

16. The three reactions shown above, with unidentified particles $X$ and $Y$, occur in the manufacturing process of plutonium. What particles do $X$ and $Y$ represent?

| | $X$ | $Y$ |
|---|---|---|
| (A) | $^{1}_{0}\mathrm{n}$ | $\alpha$ |
| (B) | $\gamma$ | $\beta^{-}$ |
| (C) | $\gamma$ | $\alpha$ |
| (D) | $^{1}_{0}\mathrm{n}$ | $\beta^{-}$ |




17. Some students collect data to determine the focal length of a concave mirror. Using a small candle as the object, they move a piece of white cardboard until they see a focused image of the candle flame on it. The students measure the distances of the candle and the image from the mirror. A graph of the data is shown above. Which of the following is closest to the focal length of the mirror?

(A) 10 cm
(B) 15 cm
(C) 20 cm
(D) 30 cm

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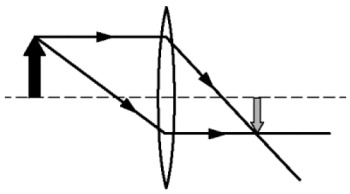
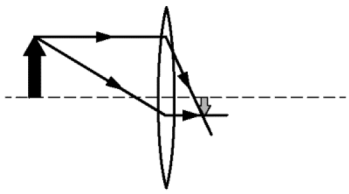
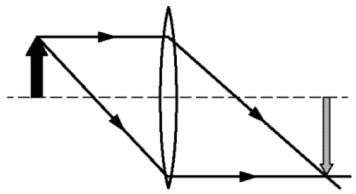


Lens 1



Lens 2



Lens 3

18. A student is comparing three lenses of the same size and shape that are made of different materials. A small object, represented by the thick black arrow, is held on one side of each lens. The ray diagrams above show the formation of the image, represented by the gray arrow, for each lens. Which of the following correctly ranks the index of refraction $n$ of the lenses?

(A) $n_1 > n_2 > n_3$

(B) $n_2 > n_1 > n_3$

(C) $n_3 > n_1 > n_2$

(D) $n_3 > n_2 > n_1$

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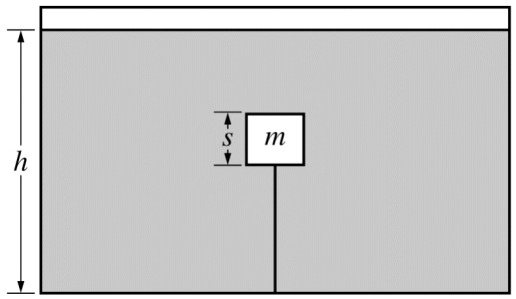
**Questions 19-20 refer to the following material.**




A cube of mass $m$ with sides of length $s$ is completely submerged in a tank of fluid of density $\rho$ and held in place by a string attached to the bottom of the tank, as shown above. The height of the fluid is $h$, and the string has a nonzero tension $F_T$.

19. Which of the following indicates how the density of the cube compares with the density of the fluid and provides correct evidence for the comparison?

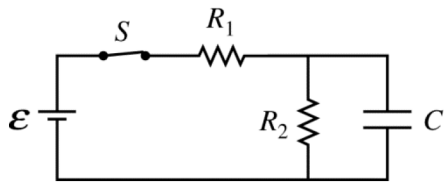
(A) The fact that the cube is completely submerged is evidence that the density of the cube is greater than the density of the fluid.
(B) The fact that the cube is completely submerged is evidence that the density of the cube is less than the density of the fluid.
(C) The fact that there is tension in the string is evidence that the density of the cube is greater than the density of the fluid.
(D) The fact that there is tension in the string is evidence that the density of the cube is less than the density of the fluid.

20. Which of the following is a correct expression for the density of the cube?

(A) $\left(\rho s^3 g + F_T\right) / s^3 g$
(B) $\left(\rho s^3 g - F_T\right) / s^3 g$
(C) $\left(F_T + mg\right) / s^3 g$
(D) $\left(F_T - mg\right) / s^3 g$

21. About $1 \times 10^{-29}$ kg of mass is lost when an atom of a certain isotope of plutonium, Pu-239, undergoes a single alpha decay. A small sample is composed of $3 \times 10^{19}$ Pu-239 atoms. If all the nuclei in the sample undergo alpha decay, the energy released is most nearly

(A) $9 \times 10^{-13}$ J
(B) $9 \times 10^{-2}$ J
(C) $3 \times 10^{7}$ J
(D) $3 \times 10^{21}$ J




22. The circuit shown above includes a battery, two resistors, and a capacitor with values as labeled. The current through the battery is $I$. Which of the following is a correct equation for potential differences in the circuit a long time after the switch is closed?

(A) $\mathcal{E} - IR_1 - IR_2 = 0$
(B) $\mathcal{E} + IR_1 + IR_2 = 0$
(C) $\mathcal{E} - IR_1 - IR_2 - C\mathcal{E} = 0$
(D) $\mathcal{E} - IR_1 - IR_2 + C\mathcal{E} = 0$

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23. The figure above represents three identical closed containers holding the same number of moles of different gases at the same temperature. From left to right, the gases are in order from smallest molar mass $(H_2)$ to largest molar mass $(O_2)$. Modeling the gases as ideal, which gas, if any, has the greatest internal energy?

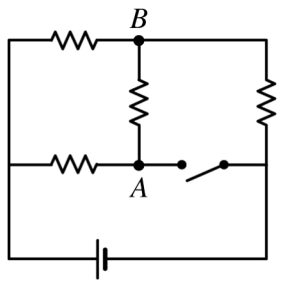
(A) $H_2$
(B) $N_2$
(C) $O_2$
(D) All have the same internal energy.

24. A plutonium nucleus of mass $M$ is at rest when it spontaneously emits a high-energy photon of frequency $f$. After the decay, the photon moves off in one direction and the nucleus recoils with speed $v$ in the opposite direction. The nucleus' mass decreases by an amount $\Delta m$. Which of the following equations correctly represents the conservation of energy in the decay?

(A) $(\Delta m)c^2 = \frac{1}{2}(M - \Delta m)v^2 + hf$
(B) $(\Delta m)c^2 = \frac{1}{2}(M - \Delta m)v^2 - hf$
(C) $Mc^2 = \frac{1}{2}(M - \Delta m)v^2 + hf$
(D) $Mc^2 = \frac{1}{2}(M - \Delta m)v^2 - hf$

25. A student wants to increase the temperature of an ideal gas in a cylinder that is initially at room temperature. The cylinder has a movable piston with negligible friction. Which of the following correctly indicates an action the student could take to increase the temperature of the gas, and why the temperature increases?

(A) Pull the piston out rapidly. The gas will expand violently and increase in temperature.
(B) Pull the piston out slowly. The gas will have time to absorb energy from the surroundings by heating as it expands.
(C) Push the piston in rapidly. The temperature of the gas will increase because no energy will be transferred to the surroundings by cooling.
(D) Push the piston in slowly. The gas will have time to absorb energy from the surroundings by heating as it is compressed.




26. The circuit shown above contains four identical resistors connected to a battery and a switch. Which of the following correctly describes the direction of the current, if any, between points $A$ and $B$ when the switch is open and when it is closed?

| | Switch Open | Switch Closed |
|---|---|---|
| (A) | From $B$ to $A$ | From $B$ to $A$ |
| (B) | From $B$ to $A$ | From $A$ to $B$ |
| (C) | From $A$ to $B$ | No current |
| (D) | From $A$ to $B$ | From $B$ to $A$ |

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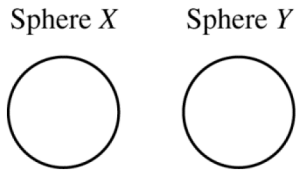
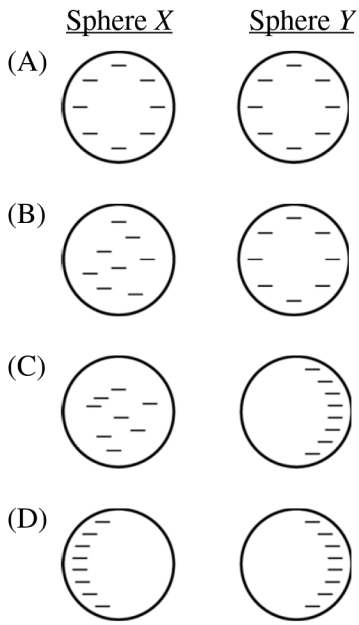



27. Small solid sphere $X$ is made of an insulating material and has negative charge distributed throughout its volume. Small solid sphere $Y$ is made of a conducting material and is also negatively charged. The spheres are initially far apart and are then brought near each other, as shown above. Which of the following cross sections best represents the charge distribution on the two spheres when they are near each other?




| Current Through Bulb (A) | Intensity of Light from the Bulb $\left(\mathrm{W/m^2}\right)$ |
|---|---|
| 5 | 74 |
| 10 | 298 |
| 15 | 675 |
| 20 | 1200 |
| 40 | 4800 |

28. A student wishes to determine if a particular lightbulb is an ohmic resistor. The student assumes that the intensity of light from the bulb is directly proportional to the power it dissipates. The student measures the light intensity at one location near the bulb and the current through the bulb as the voltage across the bulb is varied. The data are shown above. Based on the data, is the bulb ohmic, and why?

(A) No, because the power is a linear function of the current.
(B) No, because the power is a quadratic function of the current.
(C) Yes, because the power is a linear function of the current.
(D) Yes, because the power is a quadratic function of the current.

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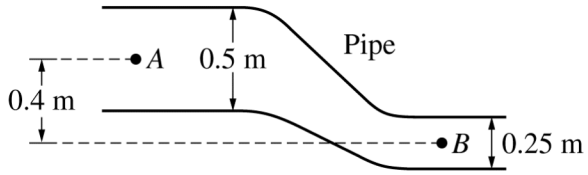
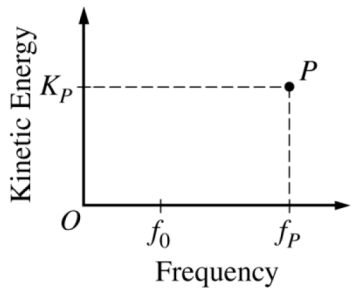



29. An ideal fluid with density $960\ \text{kg/m}^3$ fills the pipe shown in the side view above and flows through it. The pipe has a circular cross section, and the speed of the fluid at point $A$ is $0.6\ \text{m/s}$. The difference in the pressure of the fluid at points $A$ and $B$ is most nearly

(A) $1.2 \times 10^3$ Pa
(B) $2.6 \times 10^3$ Pa
(C) $3.8 \times 10^3$ Pa
(D) $6.4 \times 10^3$ Pa

30. Student 1 brings a negatively charged rod with an insulating handle near to but not touching an uncharged metal sphere and finds that the objects attract. She wants the sphere to be repelled by the rod. Student 2, who is uncharged, suggests that this can be accomplished if he touches the sphere. Which of the following indicates whether this will work, and if so, gives a procedure that will cause the repulsion?

(A) Yes, Student 2 could touch the sphere while the rod is held near it, because that would make the sphere negatively charged.
(B) Yes, Student 2 could touch the sphere while the rod is kept far away, because that would make the sphere negatively charged.
(C) Yes, Student 2 could touch the sphere while the rod is kept far away, because that would make the sphere positively charged.
(D) No, there is no way that having Student 2 touch the sphere will work.




31. When light of frequency $f_P$ is incident on a metal with threshold frequency $f_0$, electrons are ejected with maximum kinetic energy $K_P$. This is represented in the graph above by point $P$. How would the location of point $P$ on the graph change if the intensity of the same light source were increased?

(A) $P$ would not move.
(B) $P$ would move vertically up.
(C) $P$ would move horizontally to the right.
(D) $P$ would move diagonally up and to the right.

32. A student is doing an experiment in which monochromatic light passes through a double slit, creating a pattern of dark and bright lines on a nearby screen. The student has a red light and a green light. The student also has two sets of slits, one with a small separation between the slits and one with a large separation. Which of the following lists the color and slit separation that will create the pattern with the greatest separation between the bright lines?

| | Color | Slit Separation |
|---|---|---|
| (A) | Green | Large |
| (B) | Green | Small |
| (C) | Red | Large |
| (D) | Red | Small |

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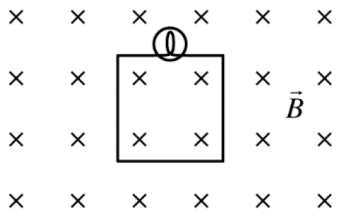


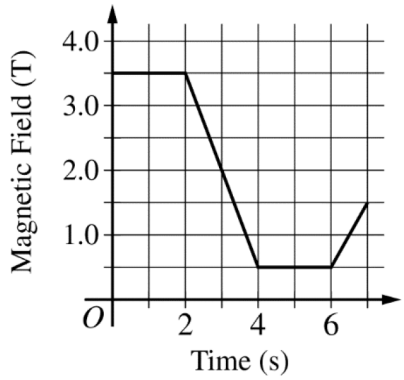


33. A circuit containing only a lightbulb is placed in a uniform magnetic field $\vec{B}$ directed into the page, as shown above on the left. The variation of the magnetic field as a function of time is shown in the graph. During which of the following intervals will the bulb be brightest?

(A) 0-2 s
(B) 2-4 s
(C) 4-6 s
(D) 6-7 s

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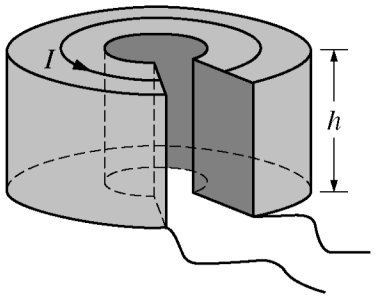
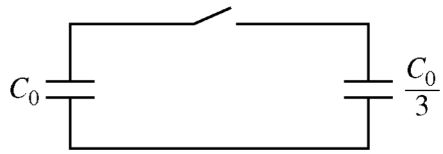
34. Electronic transitions between the $n = 2$ and $n = 4$ energy levels of a hydrogen atom are associated with the emission or absorption of photons of visible light of frequency $f$. Which of the following statements about the electronic transition from the $n = 1$ to the $n = 4$ energy level of hydrogen must be true as a consequence of energy conservation?

(A) A photon with a frequency greater than $f$ must be absorbed by the atom.
(B) A photon with a frequency greater than $f$ must be emitted by the atom.
(C) A photon with a frequency smaller than $f$ must be absorbed by the atom.
(D) A photon with a frequency smaller than $f$ must be emitted by the atom.




35. A piece of a thick ring of metal with height $h$ and resistance $R$ is connected to a battery, creating a uniform current $I$ throughout the piece of ring, as shown in the figure above. A second piece of a ring has height $2h$ but is otherwise identical to the first piece. The second piece of ring is connected to the battery in the same way as the first piece. What is the resistance of the second piece?

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




36. A capacitor with capacitance $C_0$ has a charge $Q_0$. It is then connected in a circuit with a switch and an initially uncharged capacitor with capacitance $C_0/3$, as shown in the figure above. What are the final charges on the capacitors a long time after the switch is closed?

| | Charge on $C_0$ | Charge on $C_0/3$ |
|---|---|---|
| (A) | $\frac{Q_0}{2}$ | $\frac{Q_0}{2}$ |
| (B) | $\frac{Q_0}{3}$ | $\frac{2Q_0}{3}$ |
| (C) | $\frac{3Q_0}{4}$ | $\frac{Q_0}{4}$ |
| (D) | $\frac{2Q_0}{3}$ | $\frac{Q_0}{3}$ |

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

131. Conducting rod *A* will be given a positive charge in a procedure that uses some or all of the following steps in an appropriate order.

Step W: Rod *A* is connected to ground.

Step X: Negatively charged rod *B* is brought near, but does not touch, rod *A*.

Step Y: The connection between ground and rod *A* is removed.

Step Z: Rod *B* is moved away.

Which of the following lists sufficient steps in an order that will give rod *A* a positive charge? Select two answers.

(A) W, X, Y
(B) W, X, Z
(C) W, X, Y, Z
(D) W, X, Z, Y

132. Which of the following accurately describe how the kinetic energy of atoms in a sample of monatomic ideal gas changes when the temperature is increased? Select two answers.

(A) The kinetic energy of each individual atom in the gas increases.
(B) The kinetic energy of each individual atom in the gas may increase or decrease.
(C) The average kinetic energy of the whole sample of atoms increases.
(D) The kinetic energy of some individual atoms increases, but the average kinetic energy of the whole sample of atoms does not change.

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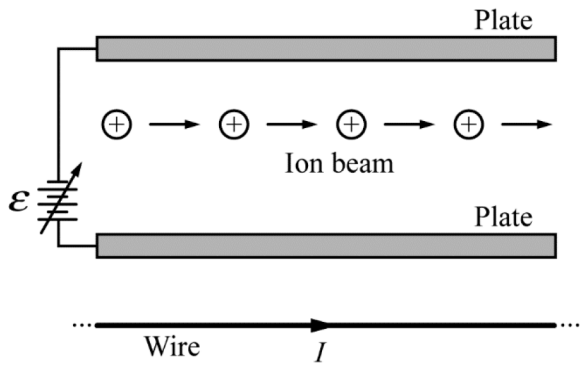


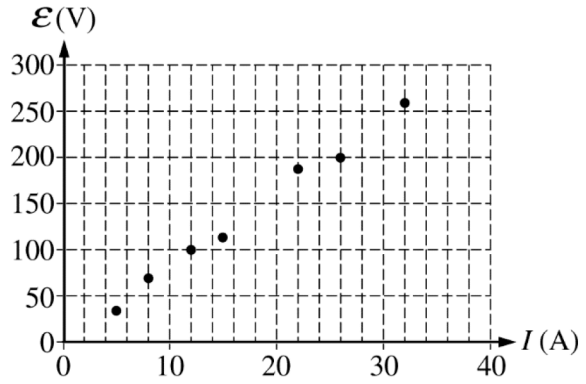


133. A beam of identical positively charged ions moves from left to right between two parallel plates, as shown in the figure on the left above. A wire is located below the plates and parallel to the ion beam. The distance between the plates, the length of the plates, and the distance between the ion beam and the wire are known. A current $I$ in the wire deflects the ion beam from a straight path. The potential difference $\varepsilon$ across the plates is then adjusted to return the beam to the straight path. The graph above plots the potential difference across the plates as a function of the current in the wire. Which of the following can be determined from the slope of the graph? Select two answers.

(A) The mass of an ion in the beam if the charge on the ion is known
(B) The average speed of the ions in the beam
(C) The amount of charge on an ion in the beam if the mass of the ion is known
(D) The time an ion spends between the plates

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GO ON TO THE NEXT PAGE.

134. One way to model the allowed states of a hydrogen atom is to treat the atom's single electron as a standing wave with a wavelength $\lambda$. Which of the following could be the radius of the orbit of the electron in such a model? Select two answers.

(A) $2\lambda/\pi$

(B) $\lambda/4\pi$

(C) $\lambda/2\pi$

(D) $\lambda/2$

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**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 2018 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

2018

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

### At a Glance

**Total Time**
1 hour and 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 4OBP4-S**

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# AP® PHYSICS 2 TABLE OF INFORMATION

## CONSTANTS AND CONVERSION FACTORS

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

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

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

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

| VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | $0^\circ$ | $30^\circ$ | $37^\circ$ | $45^\circ$ | $53^\circ$ | $60^\circ$ | $90^\circ$ |
| $\sin\theta$ | 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 | $\sqrt{3}$ | $\infty$ |

The following conventions are used in this exam.

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

# AP® PHYSICS 2 EQUATIONS

## MECHANICS

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

$L = I\omega$

$\Delta L = \tau \Delta t$

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

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

$a$ = acceleration
$A$ = amplitude
$d$ = distance
$E$ = energy
$F$ = force
$f$ = frequency
$I$ = rotational inertia
$K$ = kinetic energy
$k$ = spring constant
$L$ = angular momentum
$\ell$ = 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
$\alpha$ = angular acceleration
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed

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

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

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

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

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

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

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

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

## ELECTRICITY AND MAGNETISM

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

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

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

$\Delta U_E = q\Delta V$

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

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

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

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

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

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

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

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

$P = I\,\Delta V$

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

$R_s = \sum_i R_i$

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

$C_p = \sum_i C_i$

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

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

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

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

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

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

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

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

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

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

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

# AP® PHYSICS 2 EQUATIONS

## FLUID MECHANICS AND THERMAL PHYSICS

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

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

$P = P_0 + \rho gh$

$F_b = \rho Vg$

$A_1 v_1 = A_2 v_2$

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

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

$PV = nRT = Nk_BT$

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

$W = -P\Delta V$

$\Delta U = Q + W$

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

## GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

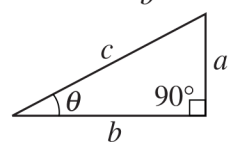
Rectangular solid
$V = \ell wh$

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
$\ell$ = length
$w$ = width
$r$ = radius

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



## PHYSICS 2

**Section II**

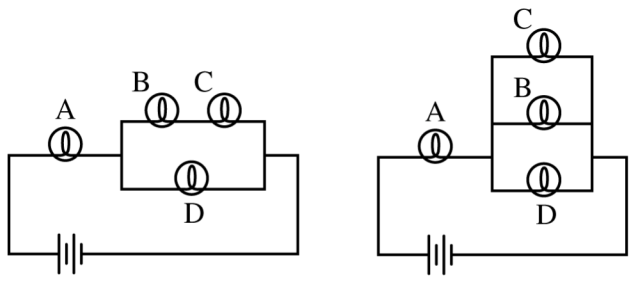
**Time—1 hour and 30 minutes**

**4 Questions**

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

1. (10 points, suggested time 20 minutes)

   A student is performing some lab experiments with batteries, ohmic resistors, capacitors, and some identical ohmic lightbulbs.




Circuit 1 Circuit 2

   (a) The student first connects four lightbulbs and an ideal battery as shown above in circuit 1 and observes the brightness of each lightbulb. The student then moves lightbulb C to obtain circuit 2. In a coherent, paragraph-length response, describe how the brightnesses of lightbulbs A and D in circuit 2 compare to their brightnesses in circuit 1. Support your claims with appropriate physics principles.

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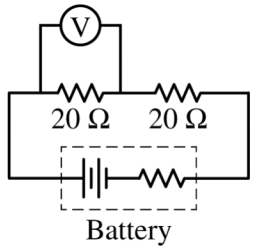
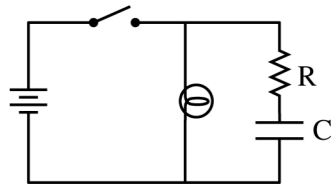



(b) The student thinks that one of the available batteries has a nonnegligible internal resistance. The student measures the potential difference across the battery as 9 V when it is not connected to any other circuit elements. The student then connects the circuit shown above, where the battery is represented by the circuit elements in the dashed box. The voltmeter indicates that the potential difference across one resistor is 4 V. Calculate the internal resistance of the battery.

(c) One of the lightbulbs is now connected with an ideal battery, an open switch, a resistor R and an initially uncharged capacitor C, as shown below. The resistance of the lightbulb and the resistor are about the same. The switch is then closed and left closed for a long time. Describe how, if at all, the brightness of the lightbulb changes during the time the switch remains closed, and explain why.

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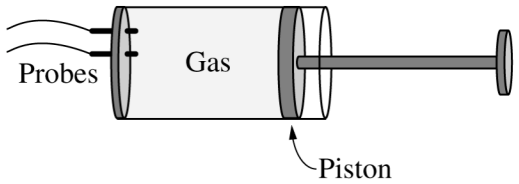


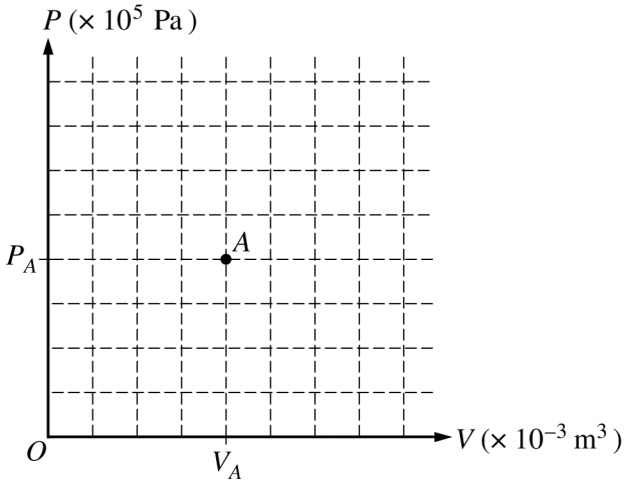

2. (12 points, suggested time 25 minutes)

A cylinder with a movable piston contains a sample of ideal gas. A temperature probe and a pressure probe are inserted into the cylinder, as shown above. The sample of gas is taken through a three-step cycle, *ABCA*.

- In process *AB*, the volume is decreased to $1/4$ its original value while constant pressure is maintained.
- In process *BC*, the gas expands back to its original volume isothermally.
- In process *CA*, the gas returns to its original state without any work being done on or by the gas.

(a)

i. On the axes below, draw a graph of pressure *P* as a function of volume *V* for the three-step process *ABCA*, labeling states *B* and *C*. The pressure and volume of state *A* are $P_A$ and $V_A$, respectively. Label the axes with the values of pressure and volume for states *B* and *C* in terms of $P_A$ and $V_A$.




ii. For process *BC*, is energy added to the gas by heating or removed from the gas by cooling? Support your claim using physics principles.

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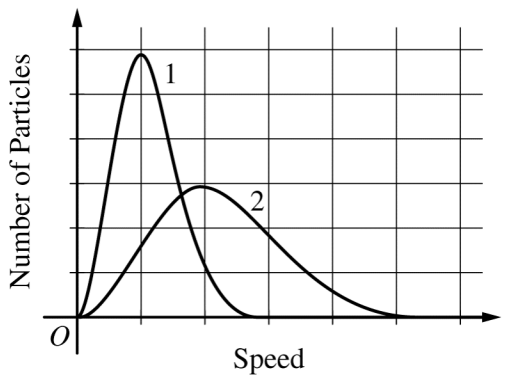
(b) For process *CA*, is the net flow of energy into the gas or out of the gas? Explain your reasoning using physics principles. Describe one method by which this flow of energy could be accomplished in the laboratory.

(c) Curves 1 and 2 below show the distributions of particle speeds when the sample of gas is in two of the states, with curve 1 a state that occurs before curve 2 as the gas goes through the cycle. Which states correspond to curve 1 and 2? Support your claim using physics principles.

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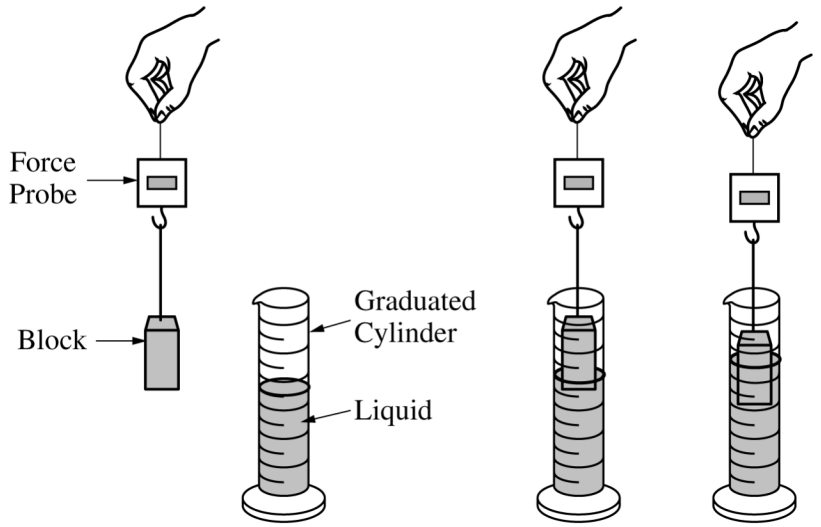


3. (12 points, suggested time 25 minutes)

Two groups of students are given samples of the same unknown liquid and are asked to identify the liquid. The first group decides to do this by determining its density $\rho_L$. The students pour a volume $V_i$ of the liquid into a graduated cylinder. They then hang a long solid block of mass $m_b$ from a force probe and lower the block partially into the liquid, as shown above. The students record the reading on the force probe and the volume reading $V_f$ on the graduated cylinder for various amounts of the block lowered into the liquid.

(a)

i. On the square below, which represents the block, draw and label the forces (not components) that are exerted on the block when it is stationary and partially submerged in the liquid. Each force must be represented by a distinct arrow starting on, and pointing away from, the square.

ii. Derive an equation for the force probe reading $F_p$ in terms of $\rho_L$, $m_b$, $V_i$, $V_f$, and physical constants, as appropriate.

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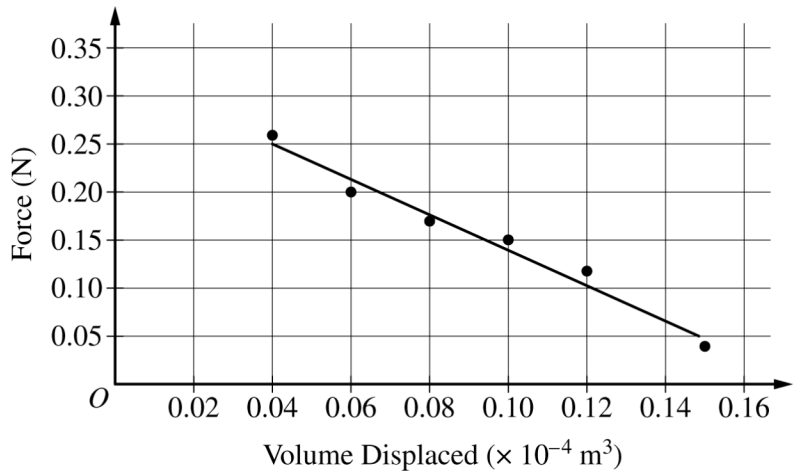
The data the students collected and the graph they plotted are shown below. The initial volume $V_i$ of liquid in the cylinder is $1.00 \times 10^{-4}$ m$^3$.

| Volume Reading $V_f$ $\left(\times 10^{-4}\ \text{m}^3\right)$ | 1.04 | 1.06 | 1.08 | 1.1 | 1.12 | 1.15 |
|---|---|---|---|---|---|---|
| Volume Displaced $\Delta V$ $\left(\times 10^{-4}\ \text{m}^3\right)$ | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.15 |
| Force Probe Reading (N) | 0.26 | 0.20 | 0.17 | 0.15 | 0.12 | 0.04 |




(b)

i. State the physical meaning of the slope of the line and its intercept with the vertical axis.

ii. Use the graph to calculate the density of the liquid.

Question 3 continues on the next page.

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The students in the second group decide to determine the index of refraction of the liquid. They have a laser pointer and a transparent, thin-walled rectangular container to hold the liquid. They also have access to common laboratory equipment.

(c) Describe an experimental procedure this group could use to determine the index of refraction of the unknown liquid. In your description include the measurements to be taken. Also include the corresponding equipment needed. Sketch a diagram showing the experimental setup with labels corresponding to the measurements you indicated. Describe how the measurements will be used to calculate the index of refraction of the liquid.

Write procedure here.

Draw labeled diagram here.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

GO ON TO THE NEXT PAGE.

4. (10 points, suggested time 20 minutes)

The allowed energy levels of a hypothetical atom have principal quantum numbers $n$ = 1, 2, 3, and 4 and energies of -8 eV, -5 eV, -2 eV, and -1 eV.

(a)

i. Draw the energy-level diagram for the atom. Label each level with the appropriate energy and principal quantum number.

ii. Calculate the frequency of a photon that will excite the atom from its ground state to the $n = 3$ state.

iii. A photon of wavelength 124 nm is incident on the atom and causes an electron in the ground state to be ejected from the atom. Neglecting relativistic effects, calculate the speed of the electron.

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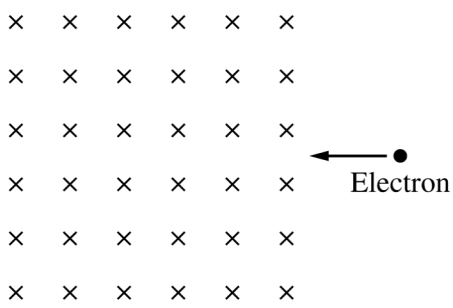
(b) The ejected electron then enters a region of space that contains a constant, uniform magnetic field directed into the plane of the page. The electron is moving to the left in the plane of the page when it enters the field.




i. On the figure above, draw a possible path for the electron as it travels through the region of the magnetic field. Describe what happens to the speed of the electron as it passes through the field, and explain why this happens.

ii. To make the electron travel in a straight line to the left through the magnetic field, an electric field can be applied in the region. What is the direction of the required electric field? Justify your choice based on physics principles.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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

---

**THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.**

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE FRONT COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

## Multiple-Choice Answer Key

The following contains the answers to
the multiple-choice questions in this exam.

# Answer Key for AP Physics 2
## Practice Exam, Section I

Question 1: D
Question 2: B
Question 3: C
Question 4: B
Question 5: B
Question 6: C
Question 7: C
Question 8: A
Question 9: D
Question 10: B
Question 11: C
Question 12: C
Question 13: C
Question 14: D
Question 15: A
Question 16: D
Question 17: A
Question 18: B
Question 19: D
Question 20: B
Question 21: C
Question 22: A
Question 23: D
Question 24: A
Question 25: C
Question 26: D
Question 27: C
Question 28: D
Question 29: A
Question 30: D
Question 31: A
Question 32: D
Question 33: B
Question 34: A
Question 35: B
Question 36: C
Question 132: A, C
Question 133: B, C
Question 134: B, D
Question 135: A, C

# Free-Response Scoring Guidelines

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

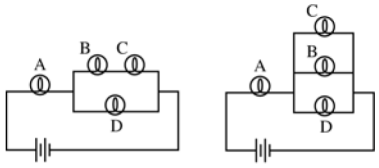
# AP® PHYSICS 2
# 2018 SCORING GUIDELINES

## Question 1

**10 points total** **Distribution of points**

A student is performing some lab experiments with batteries, ohmic resistors, capacitors, and some identical ohmic lightbulbs.

(a) LO 4.E.5.2, SP 6.1, 6.4; LO 5.C.3.4, SP 7.2
5 points




The student first connects four lightbulbs and an ideal battery as shown above in circuit 1 and observes the brightness of each lightbulb. The student then moves lightbulb C to obtain circuit 2. In a coherent, paragraph-length response, describe how the brightnesses of lightbulbs A and D in circuit 2 compare to their brightnesses in circuit 1. Support your claims with appropriate physics principles.

| | | |
|---|---|---|
| For indicating that moving C decreases the equivalent resistance of the circuit or increases the current through the battery | | 1 point |
| For indicating the link between brightness and current, potential difference, or power | | 1 point |
| For indicating that the brightness of A is greater, with correct reasoning | | 1 point |
| For indicating that the brightness of D is lower, with correct reasoning | | 1 point |
| For a logical, relevant, and internally consistent response that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response | | 1 point |
| Example: With C in the new position, the equivalent resistance of the three parallel branches is less than the two branches in circuit 1. That is added to only one bulb, so the total resistance of circuit 2 is less than circuit 1. That means the total current in circuit 2 is greater. The total current goes through A, so it's brighter in 2. Since the parallel branches have less resistance, they have a smaller potential difference in circuit 2. That means D is dimmer. | | |

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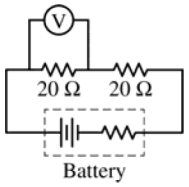
## Question 1 (continued)

**Distribution of points**

(b) LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.6, SP 2.2; LO 5.B.9.7, SP 5.3
3 points

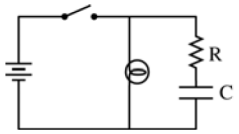



The student thinks that one of the available batteries has a nonnegligible internal resistance. The student measures the potential difference across the battery as 9 V when it is not connected to any other circuit elements. The student then connects the circuit shown above, where the battery is represented by the circuit elements in the dashed box. The voltmeter indicates that the potential difference across one resistor is 4 V. Calculate the internal resistance of the battery.

| | | |
|---|---|---|
| For correctly using Ohm's law to find the current in the circuit (either the numerical value or an equivalent expression embedded in another equation) | | 1 point |
| $4\ \text{V} = I(20\ \Omega)$ | | |
| $I = 0.2\ \text{A}$ | | |
| For a correct expression for the terminal voltage or use of the loop rule | | 1 point |
| $(9 - 4 - 4)\ \text{V} = 1\ \text{V}$ across the battery's internal resistance, and $R = 1\ \text{V}/0.2\ \text{A}$<br>OR $9\ \text{V} = (40\ \Omega + R)(0.2\ \text{A})$, $(9\ \text{V})/(0.2\ \text{A}) = 45\ \Omega = 40\ \Omega + R$ | | |
| For the correct answer with units | | 1 point |
| $R = 5\ \Omega$ | | |

(c) LO 4.E.5.2, SP 6.1, 6.4; LO 5.B.9.5, SP 6.4
2 points

One of the lightbulbs is now connected with an ideal battery, an open switch, a resistor R and an initially uncharged capacitor C, as shown below. The resistance of the lightbulb and the resistor are about the same. The switch is then closed and left closed for a long time. Describe how, if at all, the brightness of the lightbulb changes during the time the switch remains closed, and explain why.




| | | |
|---|---|---|
| For indicating that the brightness of the bulb stays the same with an attempt at a justification | | 1 point |
| For a correct justification | | 1 point |
| Example: The potential difference across the bulb is constant since it is in parallel with the battery | | |

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## Question 1 (continued)

Learning Objectives (LO)

**LO 4.E.5.2:** The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. **[SP 6.1, 6.4]**

**LO 5.B.9.5:** The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. **[SP 6.4]**

**LO 5.B.9.6:** The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. **[SP 2.1, 2.2]**

**LO 5.B.9.7:** The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's Loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. **[SP 4.1, 4.2, 5.1, 5.3]**

**LO 5.C.3.4:** The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. **[SP 6.4, 7.2]**

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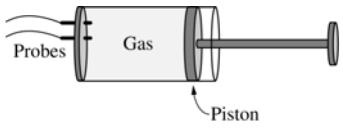
# AP® PHYSICS 2
# 2018 SCORING GUIDELINES

## Question 2

**12 points total** **Distribution of points**



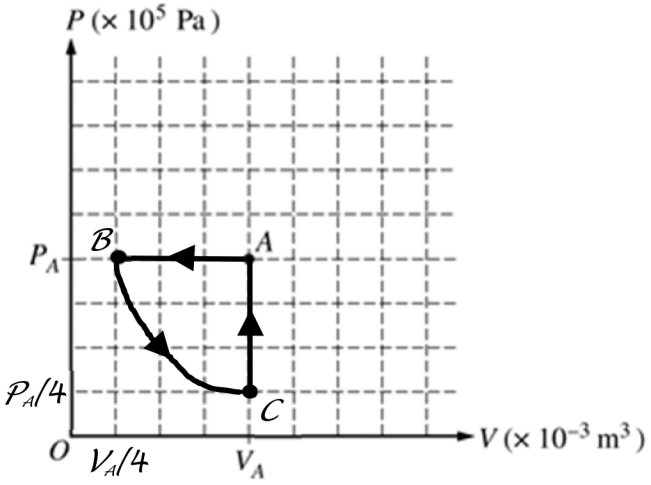

A cylinder with a movable piston contains a sample of ideal gas. A temperature probe and a pressure probe are inserted into the cylinder, as shown above. The sample of gas is taken through a three-step cycle, *ABCA*.

- In process *AB*, the volume is decreased to $1/4$ its original value while constant pressure is maintained.
- In process *BC*, the gas expands back to its original volume isothermally.
- In process *CA*, the gas returns to its original state without any work being done on or by the gas.

a)

i) LO 5.B.7.2, SP 1.1; LO 5.B.7.3, SP 2.2
5 points

On the axes below, draw a graph of pressure *P* as a function of volume *V* for the three-step process *ABCA*, labeling states *B* and *C*. The pressure and volume of state *A* are $P_A$ and $V_A$, respectively. Label the axes with the values of pressure and volume for states *B* and *C* in terms of $P_A$ and $V_A$.




| | | |
|---|---|---|
| For a horizontal line to the left of *A*, that stops at $V_A/4$ | | 1 point |
| For a concave up curve representing an isotherm for process *BC* (does not have to go through all the right points between *B* and *C*) | | 1 point |
| For a vertical line for *CA* | | 1 point |
| For locating *C* such that $P_C = P_A/4$ | | 1 point |
| For labeling axes and points (scaling of grid doesn't matter here, as long as labels are logical with respect to *A*) | | 1 point |
| Applying this scheme, if *B* is to the right of *A* you cannot earn the point for isotherm but can still get the point for the vertical line. | | |

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## Question 2 (continued)

**Distribution of points**

a) (continued)

ii) LO 5.B.7.1, SP 6.4; LO 5.B.7.3, SP 1.4, 2.2

3 points

For process *BC*, is energy added to the gas by heating or removed from the gas by cooling? Support your claim using physics principles.

| | | |
|---|---|---|
| For recognizing that $\Delta U = 0$ because the process is isothermal | | 1 point |
| For recognizing that the gas loses energy via work | | 1 point |
| For using the first law of thermodynamics or conservation of energy with above two ideas to get a consistent answer for the energy transfer | | 1 point |
| Any appropriate sign convention can be used when applying the first law. | | |

(b) LO 4.C.3.1, SP 6.4

2 points

For process *CA*, is the net flow of energy into the gas or out of the gas? Explain your reasoning using physics principles. Describe one method by which this flow of energy could be accomplished in the laboratory.

| | | |
|---|---|---|
| For correctly justifying that the net flow of energy is into the gas | | 1 point |
| For a correct procedure to accomplish process *CA* experimentally that is consistent with the heat flow direction stated | | 1 point |
| Example: By the ideal gas law the temperature increases and thus the internal energy, so energy must be added. This can be accomplished by fixing the piston and placing the cylinder in a warm bath. | | |


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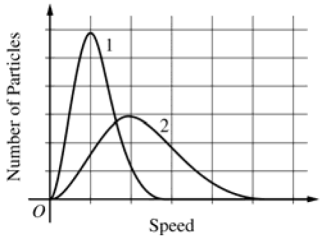
# AP® PHYSICS 2
# 2018 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(c) LO 7.A.2.2, SP 7.1; LO 7.A.3.3, SP 5.1
2 points

Curves 1 and 2 below show the distributions of particle speeds when the sample of gas is in two of the states, with curve 1 a state that occurs before curve 2 as the gas goes through the cycle. Which states correspond to curve 1 and 2? Support your claim using physics principles.




| | | |
|---|---|---|
| For identifying the curves with the states consistent with previous responses | | 1 point |
| Given correct previous responses, curve 1 is state *C* and/or *B* and curve 2 is state *A*. | | |
| For a correct justification | | 1 point |
| Example: Curve 1 represents a lower temperature since the distribution has a lower average speed. Since *B* and *C* are on the same isotherm they have the same temperature so it cannot be these two states. Using $PV = nRT$, state *A* has a higher temperature than *B* and *C*. Since the lower temperature occurs first, curve 1 is state *C* and curve 2 is state *A*. | | |
| Note: Students can be awarded the second point for clearly indicating an understanding that the speed distribution shown in Curve 2 relates to a greater temperature or internal energy than Curve 1. | | |

Learning Objectives (LO)

**LO 4.C.3.1:** The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. **[SP 6.4]**

**LO 5.B.7.1:** The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles. **[SP 6.4, 7.2]**

**LO 5.B.7.2:** The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. **[SP 1.1]**

**LO 5.B.7.3:** The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). **[SP 1.1, 1.4, 2.2]**

**LO 7.A.2.2:** The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. **[SP 7.1]**

**LO 7.A.3.3:** The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. **[SP 5.1]**

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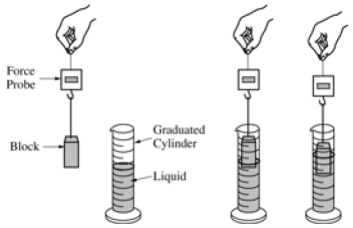
# AP® PHYSICS 2
# 2018 SCORING GUIDELINES

## Question 3

**12 points total** **Distribution of points**

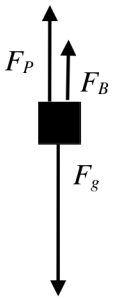



Two groups of students are given samples of the same unknown liquid and are asked to identify the liquid. The first group decides to do this by determining its density $\rho_L$. The students pour a volume $V_i$ of the liquid into a graduated cylinder. They then hang a long solid block of mass $m_b$ from a force probe and lower the block partially into the liquid, as shown above. The students record the reading on the force probe and the volume reading $V_f$ on the graduated cylinder for various amounts of the block lowered into the liquid.

(a)

i) LO 3.A.2.1, SP 1.1
2 points

On the square below, which represents the block, draw and label the forces (not components) that are exerted on the block when it is stationary and partially submerged in the liquid. Each force must be represented by a distinct arrow starting on, and pointing away from, the square.




| | | |
|---|---|---|
| For one correct force pointing toward the top of the page with a reasonable label | | 1 point |
| For a second correct force toward the top of the page and the weight toward the bottom of the page, with reasonable labels, and no extraneous forces | | 1 point |

ii) LO 1.E.1.2, SP 4.1; LO 3.A.2.1, SP 1.1; LO 5.B.10.1, SP 2.2
2 points

Derive an equation for the force probe reading $F_p$ in terms of $\rho_L$, $m_b$, $V_i$, $V_f$, and physical constants, as appropriate.

| | | |
|---|---|---|
| For applying Newton's second law in a manner consistent with the forces drawn in a(i) | | 1 point |
| $F_P + F_B = F_g$ and $F_g = m_b g$, therefore $F_P = m_b g - F_B$ | | |
| For a correct equation for $F_p$ using the expression for buoyant force | | 1 point |
| $F_P = m_b g - \rho_L g\left(V_f - V_i\right)$, where $V_i$ is the initial volume of water | | |

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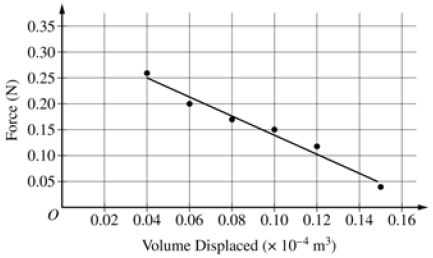
## Question 3 (continued)

**Distribution of points**

(b)

The data the students collected and the graph they plotted are shown below. The initial volume $V_i$ of liquid in the cylinder is $1.00 \times 10^{-4}\ \text{m}^3$.

| Volume Reading $V_f$ $\left(\times 10^{-4}\ \text{m}^3\right)$ | 1.04 | 1.06 | 1.08 | 1.1 | 1.12 | 1.15 |
|---|---|---|---|---|---|---|
| Volume Displaced $\Delta V$ $\left(\times 10^{-4}\ \text{m}^3\right)$ | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.15 |
| Force Probe Reading (N) | 0.26 | 0.20 | 0.17 | 0.15 | 0.12 | 0.04 |




i) LO 1.E.1.2, SP 4.1; LO 3.A.2.1, SP 1.1; LO 5.B.10.1, SP 2.2
2 points

State the physical meaning of the slope of the line and its intercept with the vertical axis.

| | | |
|---|---|---|
| For correctly identifying the slope of the best fit line as the density of the liquid times $g$, with or without reference to the negative sign | | 1 point |
| For correctly identifying the vertical intercept as the weight of the object | | 1 point |

ii) LO 1.E.1.2, SP 4.1; LO 5.B.10.1, SP 2.2
2 points

Use the graph to calculate the density of the liquid.

| | | |
|---|---|---|
| For correct calculation of the slope value using two points from the best fit line (not data points since none are on the best-fit line) | | 1 point |
| For correctly using the slope to determine the density of the object (no units needed) | | 1 point |
| $\text{slope} = \dfrac{(0.25 - 0.05)\ \text{N}}{(0.04 - 0.15)\left(\times 10^{-4}\ \text{m}^3\right)} = -1.8 \times 10^4\ \ \text{N/m}^3$ | | |
| $\rho_L = \left\lvert \text{slope} \middle/ \left(9.8\ \text{m/s}^2\right) \right\rvert = 1.9 \times 10^3\ \ \text{kg/m}^3$ (or $1.8 \times 10^3\ \ \text{kg/m}^3$ using $g = 10\ \text{m/s}^2$) | | |

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## Question 3 (continued)

**Distribution of points**

(b) (ii) (continued)

| *Alternate Solution* | *Alternate Points* |
|---|---|
| *For using the intercept with the vertical axis to determine $m_b g$, then using any other point on the line with the equation from part (a)(ii)* | *1 point* |
| *When $\Delta V = 0$, $F_p = 0.325\ \text{N} = m_b g$* | |
| *From part (a)(ii): $F_P = m_b g - \rho_L g\left(V_f - V_i\right)$* | |
| $\rho_L = \left(m_b g - F_P\right) \big/ g\left(V_f - V_i\right)$ | |
| | |
| *For correctly substituting values for one point on the line to determine the density of the object (no units needed)* | *1 point* |
| *Example:* | |
| $\rho_L = \left(0.325\ \text{N} - 0.10\ \text{N}\right) \big/ \left(9.8\ \text{m/s}^2\right)\left(0.12 \times 10^{-4}\ \text{m}^3\right) = 1.9 \times 10^3\ \text{kg/m}^3$ | |

The students in the second group decide to determine the index of refraction of the liquid. They have a laser pointer and a transparent, thin-walled rectangular container to hold the liquid. They also have access to common laboratory equipment.

(c) LO 6.E.3.1, SP 4.1, 5.1, 5.2, 5.3
4 points

Describe an experimental procedure this group could use to determine the index of refraction of the unknown liquid. In your description include the measurements to be taken. Also include the corresponding equipment needed. Sketch a diagram showing the experimental setup with labels corresponding to the measurements you indicated. Describe how the measurements will be used to calculate the index of refraction of the liquid.

| | | |
|---|---|---|
| For a diagram with a non-normal incident ray, and the angle of incidence and angle of refraction labeled in relationship to the normal line (or other angles or measurements that allow calculations equivalent to using these angles) | | 1 point |
| For a reasonable method to determine the angles based on measurements and explanation of what equipment is needed to make the measurements | | 1 point |
| Examples: use a protractor and measure the angles of incidence and refraction (from incident laser ray to normal); create a right angle triangle and determine the value of the angles of incidence and refraction using appropriate trigonometry | | |
| For a reasonable explanation of how the index of refraction can be determined from the experimental data using Snell's law | | 1 point |
| For reasonable evidence of multiple trials, either more than two measurements at the same angle or measurements at more than two angles | | 1 point |


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## Question 3 (continued)

Learning Objectives (LO)

**LO 1.E.1.2:** The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. **[SP 4.1, 6.4**]

**LO 3.A.2.1:** The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1**]

**LO 5.B.10.1:** The student is able to use Bernoulli's equation to make calculations related to a moving fluid. **[SP 2.2**]

**LO 6.E.3.1:** The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. **[SP 1.1, 1.4]**

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# AP® PHYSICS 2
# 2018 SCORING GUIDELINES

## Question 4

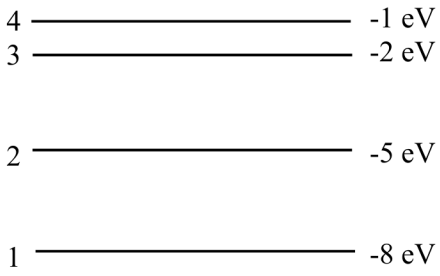
**10 points total** **Distribution of points**

The allowed energy levels of a hypothetical atom have principal quantum numbers $n$ = 1, 2, 3, and 4 and energies of -8 eV, -5 eV, -2 eV, and -1 eV.

(a)

i) LO 1.A.4.1, SP 1.1
1 point

Draw the energy-level diagram for the atom. Label each level with the appropriate energy and principal quantum number.




| | | |
|---|---|---|
| For a correct energy level diagram that includes the four given states, with $-8$ eV at one end of the scale and -1 eV at other, and correctly labeled with quantum numbers ($n = 1$ is $-8$ eV etc.) ($n = \infty$ can also be included.) | | 1 point |

ii) LO 6.F.3.1, SP 6.4
2 points

Calculate the frequency of a photon that will excite the atom from its ground state to the $n = 3$ state.

| | | |
|---|---|---|
| For correctly calculating the energy difference between the ground state and the $n = 3$ state | | 1 point |
| $\Delta E = [-2 \text{ eV} - (-8 \text{ eV})] = 6 \text{ eV}$ | | |
| For correctly calculating the frequency of the incoming photon, using consistent units for Planck's constant | | 1 point |
| $\Delta E = hf$ | | |
| $f = \Delta E/h = (8 \text{ eV} - 2\text{eV})/(4.14 \times 10^{-15} \text{ eV•s})$ | | |
| $f = 1.45 \times 10^{15}$ Hz | | |

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## Question 4 (continued)

**Distribution of points**

(a) (continued)

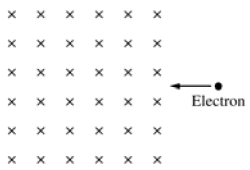
iii) LO 5.B.4.2, SP 2.2; LO 6.F.3.1, SP 6.4
3 points

A photon of wavelength 124 nm is incident on the atom and causes an electron in the ground state to be ejected from the atom. Neglecting relativistic effects, calculate the speed of the electron.

| | | |
|---|---|---|
| For correctly calculating the energy of the incoming photon | | 1 point |
| $E = hc/\lambda = \left(1.24 \times 10^3 \text{ eV•nm}\right)/(124 \text{ nm}) = 10 \text{ eV}$ | | |
| For determining the energy available as kinetic energy, consistent with photon energy | | 1 point |
| $K = 10 \text{ eV} - 8 \text{ eV} = 2 \text{ eV}$ | | |
| For calculating the speed of the ejected electron, with units, consistent with previous work | | 1 point |
| $K = (1/2)mv^2$ | | |
| $v = \sqrt{2K/m} = \sqrt{2(2\text{eV})\left(1.6 \times 10^{-19} \text{ J/eV}\right)/\left(9.11 \times 10^{-31} \text{ kg}\right)}$ | | |
| $v = 8.4 \times 10^5 \text{ m/s}$ | | |

(b)

The ejected electron then enters a region of space that contains a constant, uniform magnetic field directed into the plane of the page. The electron is moving to the left in the plane of the page when it enters the field.




i) LO 2.D.1.1, SP 2.2; LO 3.C.3.1, SP 1.4
2 points

On the figure above, draw a possible path for the electron as it travels through the region of the magnetic field. Describe what happens to the speed of the electron as it passes through the field, and explain why this happens.

| | | |
|---|---|---|
| For drawing a curved arc through the field, curved upward where the electron enters | | 1 point |
| Anything greater than a semi-circle or a path that does not reach the edge of the field does not earn credit. Any path after exiting the field is ignored. | | |
| For indicating that the speed does not change with a correct reason | | 1 point |
| Examples: the force is always perpendicular to the velocity; the force acts as a centripetal force; no work is done | | |

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## Question 4 (continued)

**Distribution of points**

(b) (continued)

ii) LO 2.C.1.1, SP 6.4; LO 3.B.1.4, SP 6.4, 7.2; LO 3.B.2.1, SP 1.1, 1.4
2 points

To make the electron travel in a straight line to the left through the magnetic field, an electric field can be applied in the region. What is the direction of the required electric field? Justify your choice based on physics principles.

| | | |
|---|---|---|
| For indicating that the electric force on the electron must be opposite the direction of the force of the magnetic field (credit awarded for specific direction consistent with path drawn) | | 1 point |
| For indicating that the electric field should be in the opposite direction to the electric force on the electron (credit awarded for specific direction consistent with path drawn) | | 1 point |

Learning Objectives (LO)

**LO 1.A.4.1:** The student is able to construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated. **[SP 1.1, 7.1**]

**LO 2.C.1.1:** The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge $q$ placed in an electric field $E$ using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$ ; a vector relation.**[SP 6.4, 7.2**]

**LO 2.D.1.1:** The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. **[SP 2.2**]

**LO 3.B.1.4:** The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. **[SP 6.4, 7.2]**

**LO 3.B.2.1:** The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. **[SP 1.1, 1.4, 2.2]**

**LO 3.C.3.1:** The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. **[SP 1.4]**

**LO 5.B.4.2:** The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. **[SP 1.4, 2.1, 2.2]**

**LO 6.F.3.1:** The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. **[SP 6.4**]


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## Scoring Worksheet

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

# 2018 AP Physics 2 Scoring Worksheet

**Section I: Multiple Choice**

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

**Section II: Free Response**

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

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

**Composite Score**

| _____ | + | _____ | = | _____ |
|---|---|---|---|---|
| Weighted Section I Score | | Weighted Section II Score | | Composite Score (Round to nearest whole number) |

AP Score Conversion Chart
Physics 2

| Composite Score Range | AP Score |
|---|---|
| 63-80 | 5 |
| 54-62 | 4 |
| 38-53 | 3 |
| 19-37 | 2 |
| 0-18 | 1 |

# Question Descriptors and Performance Data

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

# 2018 AP Physics 2: Algebra-Based
# Question Descriptors and Performance Data

## Multiple-Choice Questions

| Question | Learning Objectives | Essential Knowledge | Science Practice | Key | % Correct |
|---|---|---|---|---|---|
| 1 | 2-6.A.2.2 | 6.A.2 | 6.4\|7.2 | D | 90 |
| 2 | 2-2.C.4.1 | 2.C.4 | 6.4\|7.2 | B | 81 |
| 3 | 2-5.C.2.3 | 5.C.2 | 4.1 | C | 78 |
| 4 | 2-5.C.3.4\|2-5.C.3.5 | 5.C.3\|5.C.3 | 6.4\|1.4\|2.2 | B | 77 |
| 5 | 2-5.B.7.3 | 5.B.7 | 1.1\|2.2 | B | 80 |
| 6 | 2-7.A.1.2 | 7.A.1 | 1.4\|2.2 | C | 51 |
| 7 | 2-5.B.7.1 | 5.B.7 | 6.4 | C | 63 |
| 8 | 2-6.B.3.1 | 6.B.3 | 1.5 | A | 84 |
| 9 | 2-3.B.1.4\|2-3.C.4.1 | 3.B.1\|3.C.4 | 6.4\|7.2\|6.1 | D | 67 |
| 10 | 2-4.E.4.3 | 4.E.4 | 5.1 | B | 74 |
| 11 | 2-3.B.1.4\|2-3.C.3.1 | 3.B.1\|3.C.3 | 6.4\|7.2\|1.4 | C | 65 |
| 12 | 2-6.E.5.1\|2-6.E.5.2 | 6.E.5\|6.E.5 | 1.4\|5.1\|5.3 | C | 71 |
| 13 | 2-2.C.5.1 | 2.C.5 | 1.1 | C | 82 |
| 14 | 2-2.C.1.1 | 2.C.1 | 6.4 | D | 64 |
| 15 | 2-2.C.5.2 | 2.C.5 | 2.2 | A | 70 |
| 16 | 2-5.G.1.1 | 5.G.1 | 6.4 | D | 80 |
| 17 | 2-6.E.4.1\|2-6.E.4.2 | 6.E.4\|6.E.4 | 5.1\|5.3\|1.4\|2.2 | A | 70 |
| 18 | 2-6.E.3.3\|2-6.E.5.1 | 6.E.3\|6.E.5 | 6.4\|7.2\|1.4 | B | 67 |
| 19 | 2-1.E.1.1\|2-3.B.1.4\|2-3.B.2.1 | 1.E.1\|3.B.1\|3.B.2 | 6.4\|6.4\|7.2\|1.1\|1.4 | D | 88 |
| 20 | 2-3.B.2.1 | 3.B.2 | 1.1\|1.4\|2.2 | B | 41 |
| 21 | 2-4.C.4.1 | 4.C.4 | 2.2\|2.3\|7.2 | C | 58 |
| 22 | 2-5.B.9.5\|2-5.B.9.6 | 5.B.9\|5.B.9 | 6.4\|2.2 | A | 60 |
| 23 | 2-5.B.4.1\|2-7.A.2.1 | 5.B.4\|7.A.2 | 6.4\|7.1 | D | 62 |
| 24 | 2-4.C.4.1\|2-5.B.11.1\|2-6.F.3.1 | 4.C.4\|5.B.11\|6.F.3 | 2.2\|7.2\|2.2\|7.2\|6.4 | A | 29 |
| 25 | 2-5.B.5.4 | 5.B.5 | 6.4\|7.2 | C | 61 |
| 26 | 2-4.E.5.2\|2-5.C.3.5 | 4.E.5\|5.C.3 | 6.4\|1.4\|2.2 | D | 45 |
| 27 | 2-4.E.3.1\|2-4.E.3.3 | 4.E.3\|4.E.3 | 6.4\|1.1\|1.4\|6.4 | C | 53 |
| 28 | 2-5.B.9.7\|2-5.B.9.8 | 5.B.9\|5.B.9 | 5.1\|1.5 | D | 37 |
| 29 | 2-5.B.10.3 | 5.B.10 | 2.2 | A | 41 |
| 30 | 2-4.E.3.1\|2-4.E.3.5 | 4.E.3\|4.E.3 | 6.4\|3.2\|5.3 | D | 52 |
| 31 | 2-6.F.3.1 | 6.F.3 | 6.4 | A | 47 |
| 32 | 2-6.C.3.1 | 6.C.3 | 1.4\|6.4 | D | 43 |
| 33 | 2-4.E.2.1 | 4.E.2 | 6.4 | B | 51 |
| 34 | 2-5.B.8.1 | 5.B.8 | 1.2 | A | 55 |
| 35 | 2-4.E.4.1 | 4.E.4 | 6.4 | B | 47 |
| 36 | 2-1.B.1.1\|2-5.B.9.5\|2-5.B.9.6 | 1.B.1\|5.B.9\|5.B.9 | 6.4\|6.4\|2.2 | C | 38 |

# 2018 AP Physics 2: Algebra-Based
# Question Descriptors and Performance Data

| Question | Learning Objectives | Essential Knowledge | Science Practice | Key | % Correct |
|---|---|---|---|---|---|
| 131 | 2-4.E.3.4 | 4.E.3 | 1.1\|1.4\|6.4 | A,C | 61 |
| 132 | 2-7.A.2.1 | 7.A.2 | 7.1 | B,C | 44 |
| 133 | 2-2.D.1.1\|2-2.E.3.1\|2-3.C.3.2 | 2.D.1\|2.E.3\|3.C.3 | 2.2\|2.2\|5.1 | B,D | 26 |
| 134 | 2-7.C.2.1 | 7.C.2 | 1.4 | A,C | 26 |

## Free-Response Questions

| Question | Learning Objectives | Essential Knowledge | Science Practices | Mean Score |
|---|---|---|---|---|
| 1 | 2-4.E.5.2\|2-5.B.9.5\|2-5.B.9.6\|2-5.B.9.7\|2-5.C.3.4 | 4.E.5\|5.B.9\|5.B.9\|5.B.9\|5.C.3 | 6.1\|6.4\|6.4\|2.2\|5.3\|6.4\|7.2 | 4.55 |
| 2 | 2-4.C.3.1\|2-5.B.7.1\|2-5.B.7.2\|2-5.B.7.3\|2-7.A.2.1\|2-7.A.2.2 | 4.C.3\|5.B.7\|5.B.7\|25.B.7\|7.A.2\|7.A.2 | 6.4\|6.4\|1.1\|1.4\|2.2\|7.1\|7.1 | 6.17 |
| 3 | 2-1.E.1.2\|2-3.A.2.1\|2-5.B.10.1\|2-6.E.3.2 | 1.E.1\|3.A.2\|5.B.10\|6.E.3 | 4.1\|1.1\|2.2\|4.1\|5.1\|5.2\|5.3 | 6.23 |
| 4 | 2-1.A.4.1\|2-2.C.1.1\|2-2.D.1.1\|2-5.B.4.2\|2-6.F.3.1 | 1.A.4\|2.C.1\|2.D.1\|5.B.4\|6.F.3 | 1.1\|7.1\|6.4\|7.2\|2.2\|2.2\|6.4 | 4.70 |

# AP Physics 2: Algebra-Based

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