AP Physics B Practice Exam

From the 2013 Administration

Revised April 2014

This Practice Exam is provided by the College Board for AP Exam preparation. Teachers are permitted to download the materials and make copies to use with their students in a classroom setting only. To maintain the security of this exam, teachers should collect all materials after their administration and keep them in a secure location.

Exams may **not** be posted on school or personal websites, nor electronically redistributed for any reason. Further distribution of these materials outside of the secure College Board site disadvantages teachers who rely on uncirculated questions for classroom testing. Any additional distribution is in violation of the College Board's copyright policies and may result in the termination of Practice Exam access for your school as well as the removal of access to other online services such as the AP Teacher Community and Online Score Reports.

Contents

Exam Instructions
Student Answer Sheet for the Multiple-Choice Section
Section I: Multiple-Choice Questions
Section II: Free-Response Questions
Multiple-Choice Answer Key
Free-Response Scoring Guidelines
Scoring Worksheet

Note: This publication shows the page numbers that appeared in the *2012–13 AP Exam Instructions* book and in the actual exam. This publication was not repaginated to begin with page 1.

© 2013 The College Board. College Board, Advanced Placement Program, AP, SAT and the acorn logo are registered trademarks of the College Board. All other products and services may be trademarks of their respective owners. Permission to use copyrighted College Board materials may be requested online at: www.collegeboard.com/inquiry/cbpermit.html.

Exam Instructions

The following contains instructions taken from the ***2012–13 AP Exam Instructions*** book.

AP® Physics B Exam

Regularly Scheduled Exam Date: Monday afternoon, May 13, 2013

Late-Testing Exam Date: Friday morning, May 24, 2013

Section I: At a Glance

Total Time:
1 hour, 30 minutes
Number of Questions:
70
Percent of Total Score:
50%
Writing Instrument:
Pencil required
Electronic Device:
None allowed

Section II: At a Glance

Total Time:
1 hour, 30 minutes
Number of Questions:
7*
Percent of Total Score:
50%
Writing Instrument:
Either pencil or pen with black or dark blue ink
Electronic Device:
Calculator allowed
Percent of Section II Score:
See breakdown on test book cover

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

Section I: Multiple Choice Booklet Instructions

Section I of this exam contains 70 multiple-choice questions. Fill in only the circles for numbers 1 through 70 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

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

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

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

Section II: Free Response Booklet 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.

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2012-13 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Extra paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited in the testing room"

Students are permitted to use four-function, scientific, or graphing calculators to answer the questions in Section II of the AP Physics B Exam. Students are not allowed to use calculators in Section I. 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 42 of the *2012-13 AP Coordinator's Manual*. See pages 39–42 of the *2012-13 AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 40 of the *2012-13 AP Coordinator's Manual*.

During the administration of Section II, students may have no more than two calculators on their desks. Calculators may not be shared. Calculator memories do not need to be cleared before or after the exam. Students with Hewlett-Packard 48–50 Series and Casio FX-9860 graphing calculators may use cards designed for use with these calculators. Proctors should make sure infrared ports (Hewlett-Packard) are not facing each other. **Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the cancellation of AP Exam scores.**

Rulers and straightedges may be used for the entire exam.

SECTION I: Multiple Choice

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

This exam includes survey questions. The time allowed for the survey questions is in addition to the actual test-taking time.

Make sure you begin the exam at the designated time.

If you are giving the regularly scheduled exam, say:

It is Monday afternoon, May 13, and you will be taking the AP Physics B Exam.

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

It is Friday morning, May 24, and you will be taking the AP Physics B Exam.

In a moment, you will open the packet that contains your exam materials. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2012-13 Bulletin for AP Students and Parents*. You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

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

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

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

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

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

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

Are there any questions? . . .

Section I is the multiple-choice portion of the exam. You may never discuss these specific multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .

You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. Rulers and straightedges may be used for the entire exam, but calculators are not allowed for Section I of the exam. Please put all of your calculators under your chair. Are there any questions? . . .

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

Note Start Time here _____. Note Stop Time here _____. Check that students are marking their answers in pencil on their answer sheets, and that they are not looking at their shrinkwrapped Section II booklets. After 1 hour and 30 minutes, say:

Stop working and turn to the last page of your booklet. . . .

You have 2 minutes to answer Questions 101–106. These are survey questions and will not affect your score. You may not go back to work on any of the exam questions. You may now begin.

To help you and your proctors make sure students are not working on the exam questions, the two pages with the survey questions are identified with a large S on the upper corner of each page. Give students 2 minutes to answer the survey questions. Then say:

Close your booklet and put your answer sheet on your desk, face up. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. I will now collect your answer sheet.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label. Then say:

Now you must seal your exam booklet. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, face up. I will now collect your Section I booklet. . . .

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

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

Please listen carefully to these instructions before we take a 10-minute break. Everything you placed under your chair at the beginning of the exam must stay there. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, or textbooks about the exam 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 are not allowed to discuss the multiple-choice section of this exam. If you do not follow these rules, your score could be canceled. Are there any questions? . . .

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

SECTION II: Free Response

After the break, say:

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

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

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

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

Read the last statement. . . .

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

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

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

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

Read Item 4. . . .

Are there any questions? . . .

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

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

Collect the Student Packs. Then say:

Are there any questions? . . .

Calculators may be used for Section II. You may get your calculators from under your chair and place them 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. You must write your answers in the exam booklet using a pen 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 piece of paper you use, be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .

You may begin.

Note Start Time here _____. Note Stop Time here _____. Check that students are writing their answers in their exam 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 and close your exam booklet. Place it on your desk, face up. . . .

If any students used extra paper for the free-response section, have those students staple the extra sheet/s to the first page corresponding to that question in their exam booklets. Then say:

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

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

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

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

If you are giving the regularly scheduled exam, say:

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

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

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

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

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

Then say:

You are now dismissed.

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

- Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2012-13 AP Coordinator's Manual*.
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2013

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

CollegeBoard

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

To maintain the security of the exam and the validity of my AP score, I will allow no one else to see the multiple-choice questions. I will seal the multiple-choice booklet when asked to do so, and I will not discuss these questions with anyone at any time after completing the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the *2012-13 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

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

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

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

C. YOUR AP NUMBER

D. EXAM DATE Month Day

E. EXAM START TIME AM PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE | School Name | City | State | Country

K. DATE OF BIRTH

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

Day | Year

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE

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

College Name | City | State | Country

N. CURRENT GRADE LEVEL

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

O. STUDENT SEARCH SERVICE®

Yes No

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

768252

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 2 Option 2

9411-00657 • TF213E4735 • UNLWEB213

Q3468/1-4

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, 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). Use a No. 2 pencil only. Mark only one response per question. If a question has only four answer options, do not mark option E. Answers written in the multiple-choice booklet will not be scored.

Your answer sheet will be scored by machine. Any improper gridding may affect your score.

- **Completely fill in the circle for your response next to the number of the question you are answering.**
- **Erase carefully and completely. Stray marks and smudges could be read as answers.**

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

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

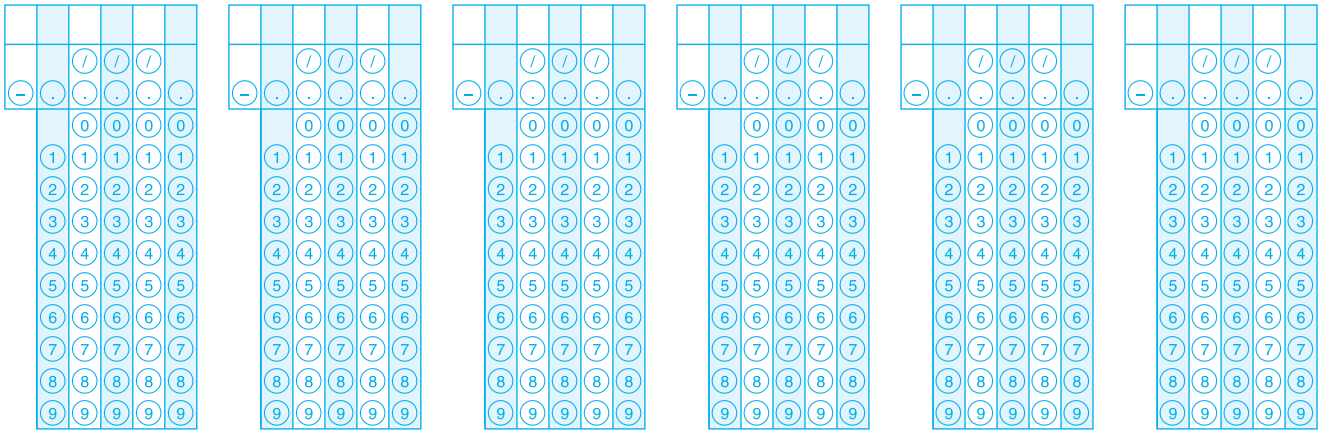
Be sure each mark is dark and completely fills the circle. If a question has only four answer options, do not mark option E.

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

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



ETS USE ONLY

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

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

© 2012 The College Board. College Board, AP, Student Search Service and the acorn logo are registered trademarks of the College Board.

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. ETHNICITY/RACE

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

Y. PARENTAL EDUCATION LEVEL

Father/ Male Guardian	Mother/ Female Guardian	
○	○	Grade school
○	○	Some high school
○	○	High school diploma or equivalent
○	○	Business or trade school
○	○	Some college
○	○	Associate or two-year degree
○	○	Bachelor's or four-year degree
○	○	Some graduate or professional school
○	○	Graduate or professional degree

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY ○ If your address does not fit in the spaces provided in Item R, fill in as many circles as you can, then fill in the circle in Item S and print the remainder of your address in the spaces provided.

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS By providing your email address, you are granting the College Board permission to use your email in accordance with the policies in the *2012-13 Bulletin for AP Students and Parents*.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2013 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.)

PLACE SEAL HERE

AP® Physics B Exam

SECTION I: Multiple Choice

2013

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
70
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 70 multiple-choice questions. Fill in only the circles for numbers 1 through 70 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

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

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

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

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

PLACE SEAL HERE

Form I
Form Code 4JBP4-S

78

PLACE SEAL HERE
DO NOT seal answer sheet inside

TABLE OF INFORMATION DEVELOPED FOR 2012

CONSTANTS AND CONVERSION FACTORS

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

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

PHYSICS B
SECTION I
Time—90 minutes
70 Questions

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

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

1. Three distinct forces are applied to an object, but the object remains stationary. Which of the following must be correct?

   (A) The forces have the same magnitude.
   (B) The forces have the same direction.
   (C) The forces are perpendicular to each other.
   (D) The vector sum of the forces is zero.
   (E) The sum of the magnitudes of the forces is zero.

2. Which of the following is a true statement about the conservation of linear momentum?

   (A) It is conserved only when no net external force acts on the system under consideration.
   (B) It is conserved only when the center of mass of a system is at rest.
   (C) It is conserved only in collisions between macroscopic objects.
   (D) It is conserved only in two-body collisions.
   (E) It is conserved only in one-dimensional and two-dimensional motion.

3. A person of mass 60 kg sliding along level ice at a speed of 3.0 m/s collides with a second person who is initially at rest. Assume that friction is negligible. If the two people hold onto each other and their common final speed after colliding is 2.0 m/s, the mass of the second person is

   (A) 10 kg
   (B) 30 kg
   (C) 40 kg
   (D) 80 kg
   (E) 90 kg

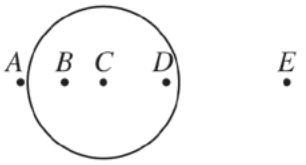
4. An automobile traveling on a straight, level road has an initial speed v when the brakes are applied. In coming to rest with a constant acceleration, it travels a distance x. How far would the automobile travel in coming to rest if it had the same acceleration but an initial speed $2v$?

   (A) $\frac{1}{4}x$
   (B) $\frac{1}{2}x$
   (C) x
   (D) $2x$
   (E) $4x$

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

Questions 5-6



An isolated, hollow aluminum sphere is positively charged. A cross section through the center of the sphere is shown above.

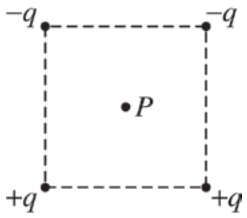
5. The magnitude of the electric field is greatest at point

   (A) *A*
   (B) *B*
   (C) *C*
   (D) *D*
   (E) *E*

6. The direction of the electric field is correctly indicated in which of the following?

   I. To the left at point *A*
   II. To the right at point *D*
   III. To the right at point *E*

   (A) I only
   (B) II only
   (C) III only
   (D) I and III
   (E) II and III

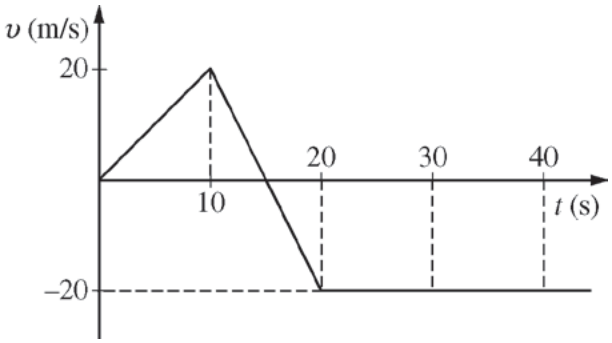


7. The four charged particles shown above are held fixed at the corners of a square. The electric field at point *P*, the center of the square, is directed

   (A) toward the left
   (B) toward the right
   (C) out of the plane of the page
   (D) toward the bottom of the page
   (E) toward the top of the page

8. How much current flows through a 5 Ω resistor that is dissipating heat at a rate of 500 J/s?

   (A) 0.01 A
   (B) 0.1 A
   (C) 1 A
   (D) 10 A
   (E) 100 A



9. An object begins at position $x = 0$ and moves one-dimensionally along the x-axis with a velocity v expressed as a function of time t according to the graph above. At what time does the object pass through $x = 0$ again?

   (A) Between 10 s and 20 s
   (B) Between 20 s and 30 s
   (C) At 30 s exactly
   (D) Between 30 s and 40 s
   (E) After 40 s

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

10. A car with speed v and an identical car with speed $2v$ both travel the same circular section of an unbanked road. If the frictional force required to keep the faster car on the road without skidding is F, then the frictional force required to keep the slower car on the road without skidding is

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

11. A planet with half Earth's mass and half Earth's radius is discovered. What would an astronaut who weighs 800 N on Earth weigh on the planet?

(A) 100 N
(B) 200 N
(C) 400 N
(D) 800 N
(E) 1600 N

12. Two tuning forks with which of the following pairs of frequencies will produce the greatest frequency of beats when sounded together?

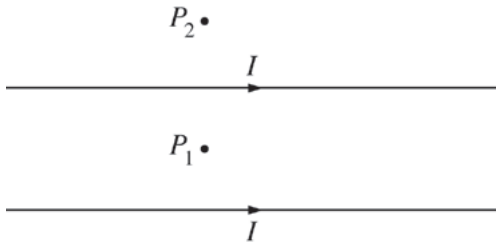
(A) 250 and 256 Hz
(B) 300 and 303 Hz
(C) 634 and 639 Hz
(D) 763 and 764 Hz
(E) 1420 and 1422 Hz

13. The principle of superposition states that

(A) every point on a wave front may be considered to behave like a point source of waves
(B) the width of a single-source diffraction pattern depends on the ratio of the wavelength to the size of the source
(C) transverse waves can be polarized, but longitudinal waves cannot
(D) as a wave moves from one medium to another, the wave speed changes
(E) the displacement of the medium at a point where waves meet is the sum of the displacements of the individual waves

14. A small metal sphere X is charged by losing 500 electrons. An identical metal sphere Y is charged by gaining 1000 electrons. The two spheres are first put in contact with each other and then separated. If $-e$ is the charge on an electron, what is the charge on each sphere after separation?

	Sphere X	Sphere Y
(A)	$+500e$	$+500e$
(B)	$+250e$	$+250e$
(C)	$-250e$	$+250e$
(D)	$-250e$	$-250e$
(E)	$-500e$	$-500e$

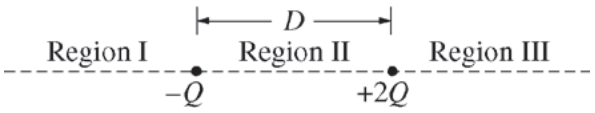


15. Two long, parallel, straight wires in the plane of the page each carry a current I to the right, as shown above. Points P_1 and P_2 are in the plane of the page, with P_1 being midway between the wires. Which of the following is true of the net magnetic field at the two points that result from the two currents?

	Point P_1	Point P_2
(A)	Directed out of page	Directed into page
(B)	Directed out of page	Directed out of page
(C)	Has magnitude zero	Directed into page
(D)	Has magnitude zero	Directed out of page
(E)	Directed into page	Directed into page

Unauthorized copying or reuse of any part of this page is illegal.

Questions 16-18



A particle with a charge $-Q$ is located a distance D from a particle with a charge $+2Q$, as shown in the figure above.

16. Which of the following best describes the location of a point, other than at infinity, at which the net electric field created by the two charges is equal to zero?

(A) In region I
(B) In region II, closer to $-Q$
(C) In region II, midway between the charges
(D) In region II, closer to $+2Q$
(E) In region III

17. In which of the regions is there a location, other than at infinity, at which the electric potential is zero?

(A) Region I only
(B) Region II only
(C) Region III only
(D) Region I and region II
(E) Region II and region III

18. How much work must be done by an external force to move the particle with charge $+2Q$ from rest at the position shown to rest at a distance of $2D$ from the other particle?

(A) $\frac{2kQ^2}{D}$
(B) $\frac{kQ^2}{2D}$
(C) $\frac{kQ^2}{D}$
(D) $-\frac{kQ^2}{D}$
(E) $-\frac{2kQ^2}{D}$

19. If the charge of each of two particles is doubled and the separation between them is also doubled, the force between the two particles is

(A) quadrupled
(B) doubled
(C) the same as before
(D) halved
(E) quartered

20. A student holds a large concave mirror of focal length 1.0 m that faces a teacher. Which of the following describes the teacher's image as the student approaches the teacher from a distance of 2.0 m to a distance of 0.5 m?

(A) It continuously increases in size.
(B) It continuously decreases in size.
(C) It is first upright, then it is upside down.
(D) It is first upside down, then it is upright.
(E) It is always smaller than the teacher.

21. A ray of light has a wavelength of 800 nm in air. The light ray enters a material in which its wavelength is 600 nm. Assuming the index of refraction for air is 1.00, the index of refraction of the material is most nearly

(A) 0.75
(B) 1.00
(C) 1.25
(D) 1.33
(E) 1.50

22. A student throws a rock horizontally from the edge of a cliff that is 20 m high. The rock has an initial speed of $10\ \text{m/s}$. If air resistance is negligible, the distance from the base of the cliff to where the rock hits the level ground below the cliff is most nearly

(A) 5 m
(B) 10 m
(C) 20 m
(D) 40 m
(E) 200 m

Unauthorized copying or reuse of any part of this page is illegal.

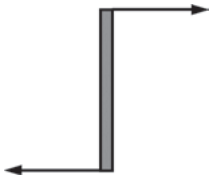
GO ON TO THE NEXT PAGE.

23. A block moving to the right on a level surface with friction is pulled by an increasing horizontal force also directed to the right. As the applied force increases, which of the following is true of the normal force and the frictional force on the block?

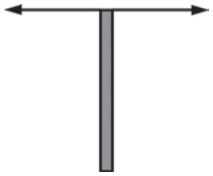
	Normal Force	Frictional Force
(A)	Increases	Increases
(B)	Increases	Remains constant
(C)	Remains constant	Increases
(D)	Remains constant	Decreases
(E)	Remains constant	Remains constant

24. The figures below indicate forces acting on a rod in different situations. The lengths of the force vectors are proportional to the magnitudes of the forces. In which situation is the rod in both translational and rotational equilibrium?

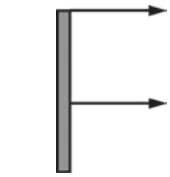
(A)



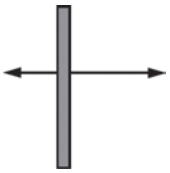
(B)



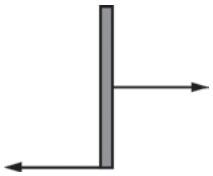
(C)



(D)



(E)



25. An object is in simple harmonic motion. Of the following quantities related to the object, which set of three can have maximum magnitudes at the same instant of time?

I. Displacement
II. Velocity
III. Acceleration
IV. Kinetic energy
V. Potential energy

(A) I, II, and III
(B) I, II, and IV
(C) I, III, and V
(D) II, III, and IV
(E) II, III, and V

26. A solid object of mass m is suspended vertically from a spring balance. The spring balance reads W when the object is in air. When the object is submerged in water while still attached to the balance, the reading on the balance is

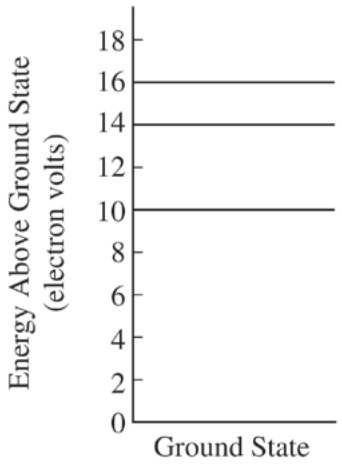
(A) always exactly W
(B) always greater than W
(C) greater than W only if the density of the object is greater than the density of water
(D) always less than W
(E) less than W only if the density of the object is greater than the density of water

27. A fluid flows through a pipe of radius r at a speed v for a time t. The volume of fluid that flows past a point in the pipe during this time is equal to

(A) $2\pi rvt$
(B) $\pi r^2 vt$
(C) $2\pi rv/t$
(D) $2\pi r^2 v/t$
(E) $\pi r^2/vt$

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



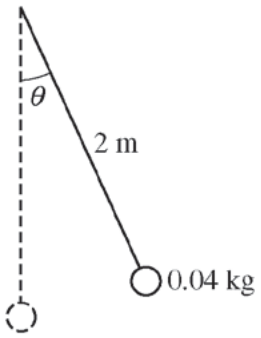
28. A particular atomic system has energy states as indicated in the energy-level diagram above. Such a system could, under the proper conditions, absorb any of the following amounts of energy without being ionized EXCEPT

(A) 2 eV
(B) 4 eV
(C) 6 eV
(D) 8 eV
(E) 10 eV

29. A nuclear reactor uses uranium 235 to produce energy. What is the order of magnitude of the energy equivalent of 6×10^{-4} kg of uranium 235 ?

(A) 10^5 J
(B) 10^8 J
(C) 10^{14} J
(D) 10^{17} J
(E) 10^{20} J

Questions 30-31



The pendulum illustrated above has a length of 2 m and a bob of mass 0.04 kg. It is held at an angle θ, as shown, where $\cos\theta = 0.9$.

30. If the pendulum is released from rest, the maximum speed the bob attains is most nearly

(A) 1 m/s
(B) $\sqrt{2}$ m/s
(C) 2 m/s
(D) 4 m/s
(E) 6 m/s

31. The frequency of oscillation is most nearly

(A) 4π Hz
(B) $2\pi\sqrt{0.2}$ Hz
(C) $(0.25/\pi)$ Hz
(D) $\left(\sqrt{0.2}/2\pi\right)$ Hz
(E) $\left(\sqrt{5}/2\pi\right)$ Hz

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

32. An object of mass m attached to a spring with constant k oscillates with amplitude A. Assuming air resistance and the mass of the spring to be negligible, which of the following changes alone would cause the period of this oscillation to increase?

I. Increasing m
II. Increasing A
III. Using a spring with greater k

(A) I only
(B) II only
(C) I or III only
(D) II or III only
(E) I, II, or III

33. Which of the following is a correct unit of measurement for torque?

(A) Joule/second
(B) Meter/second
(C) Newton/meter
(D) Newton·meter
(E) Kilogram·meter/second^2

34. Each of the following nuclei has been stripped of all electrons and placed the same distance from an alpha particle. Which nucleus exerts the strongest electrostatic force on the alpha particle?

(A) ${}^{12}_{6}\mathrm{C}$
(B) ${}^{12}_{7}\mathrm{N}$
(C) ${}^{16}_{8}\mathrm{O}$
(D) ${}^{19}_{8}\mathrm{O}$
(E) ${}^{17}_{9}\mathrm{F}$

35. The success of the Einstein photoelectric effect equation, $KE_{\max} = hf - \phi$, gives strong support to which of the following models?

(A) Rutherford model of the atom
(B) Particle model of light
(C) Wave model of light
(D) Particle model of the electron
(E) Wave model of the electron

36. A beam of which of the following will produce the widest diffraction pattern (i.e., adjacent minima will be the farthest apart) if all the particles have the same speed and pass through the same slit?

(A) Electrons
(B) Protons
(C) Hydrogen atoms
(D) Helium nuclei
(E) None of the above; particles do not exhibit diffraction.

37. A gas undergoes an expansion in which 400 J of energy is added to the gas by heating. The internal energy of the gas changes from 700 J to 800 J. The work done by the gas is

(A) 1,900 J
(B) 1,100 J
(C) 500 J
(D) 300 J
(E) 100 J

38. A metal cup that is left outdoors undergoes a temperature difference between nighttime and daytime of $20°\mathrm{C}$. As the cup's temperature increases, which of the following statements about the inner and outer circumferences of the cup is true?

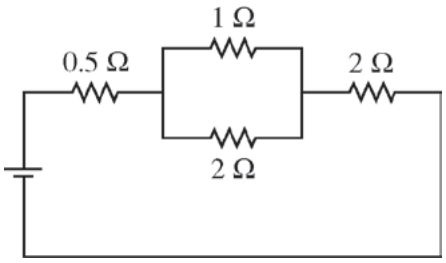
(A) The outer circumference will remain the same, but the inner circumference will decrease.
(B) The outer circumference will increase, but the inner circumference will remain the same.
(C) The outer circumference will increase, but the inner circumference will decrease.
(D) Both the outer and the inner circumferences will increase.
(E) Nothing can be determined about the inner or outer circumferences without knowing their original values.

39. In a radioactive decay, a particle is emitted from the nucleus of an atom and the atom's atomic number increases by one. The emitted particle could be which of the following?

(A) A neutron
(B) A proton
(C) A gamma ray
(D) An alpha particle (helium nucleus)
(E) A negative beta particle (electron)

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



40. In the circuit represented above, the current in the 1 Ω resistor is 4 A. What is terminal voltage V of the battery?

(A) 6 V
(B) 12 V
(C) 18 V
(D) 19 V
(E) 30 V

41. A 100-turn wire coil has a resistance of 400 Ω and a cross-sectional area of $0.01\ \text{m}^2$. The coil is placed in a magnetic field directed parallel to the axis of the coil. If the field changes at a rate of $-0.4\ \text{T/s}$, what is the current induced in the coil?

(A) 1×10^{-5} A
(B) 1×10^{-4} A
(C) 1×10^{-3} A
(D) 1×10^{-2} A
(E) 1×10^{-1} A

42. An organ pipe of length L is open at one end and closed at the other. The standing wave of next-to-lowest frequency which can exist in this pipe has a wavelength nearest to

(A) $\frac{1}{3}L$
(B) $\frac{1}{2}L$
(C) L
(D) $\frac{4}{3}L$
(E) $2L$

43. When a light wave passes from air into glass, the quantities that change include which of the following?

I. Frequency
II. Wavelength
III. Wave speed

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

44. A parallel beam of light of wavelength 4.5×10^{-7} m is incident on a pair of slits that are 5.0×10^{-4} m apart. The interference pattern is focused on a screen 2.0 m from the slits. The separation between two adjacent bright fringes is most nearly

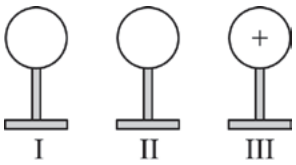
(A) 0.9×10^{-3} m
(B) 1.8×10^{-3} m
(C) 2.7×10^{-3} m
(D) 3.6×10^{-3} m
(E) 5.4×10^{-3} m

45. An air-filled parallel-plate capacitor of capacitance C is connected to a battery and charged to a voltage V. The capacitor is then disconnected from the battery. If the distance between the capacitor plates is halved while the charge on the capacitor remains the same, which of the following is true?

(A) Neither C nor V will change.
(B) Both C and V will be halved.
(C) C will be doubled and V will be halved.
(D) C will be halved and V will be doubled.
(E) Both C and V will be doubled.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



46. Three identical conducting spheres, I, II, and III, are mounted on insulating stands and placed as shown above. Spheres I and II are each uncharged, and III carries a positive charge. Spheres I and II are connected to each other by a conducting wire. After the wire is removed, sphere III is moved far away. Which of the following statements about the subsequent charges on spheres I and II is correct?

(A) They are each still uncharged.
(B) They are charged with equal positive charges.
(C) They are charged with equal negative charges.
(D) Sphere I is positively charged and sphere II is negatively charged.
(E) Sphere I is negatively charged and sphere II is positively charged.

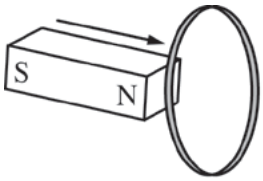


Figure 1

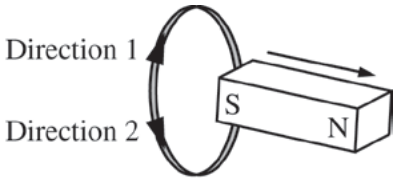
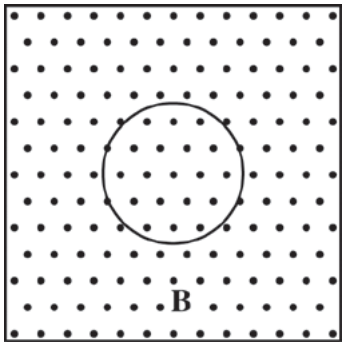


Figure 2

47. A bar magnet is pushed from left to right completely through a loop of metal wire, as shown in the figures above. The two possible directions for current in the loop are also shown. Which of the following indicates the directions of the induced current in the loop, if any, as the magnet is moving through the positions shown?

	Figure 1	Figure 2
(A)	Direction 1	Direction 1
(B)	Direction 1	Direction 2
(C)	Direction 2	Direction 1
(D)	Direction 2	Direction 2
(E)	None (no current)	None (no current)

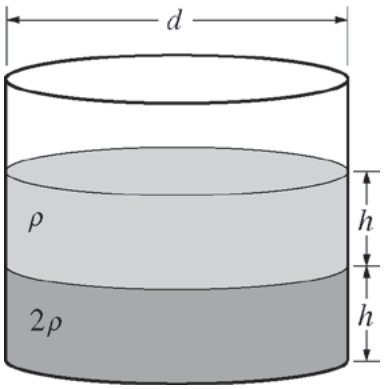


48. A circular conducting loop is in a region of magnetic field **B** directed out of the page, as shown above. The magnitude of the magnetic field is decreasing. The direction of the induced current in the loop is

(A) clockwise
(B) counterclockwise
(C) undefined because the current is zero
(D) impossible to determine without knowing the rate of change of the field
(E) impossible to determine without knowing the radius of the loop

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



49. Two fluids of densities ρ and 2ρ are layered in a cylindrical container of diameter d, as shown above. The height of each fluid is h, and the pressure at the top of the column is P_0. What is the absolute pressure at the inside surface of the bottom of the container?

(A) $3\rho gh$
(B) $4\rho gh$
(C) $\dfrac{4\rho g}{\pi d^2}$
(D) $P_0 + 3\rho gh$
(E) $P_0 + \dfrac{12\rho gh}{\pi d^2}$

50. An underground tunnel has two openings, with one opening a few meters higher than the other. If air moves past the higher opening at a greater speed than it moves past the lower opening, what happens inside the tunnel?

(A) The air does not move.
(B) Air moves from the lower opening toward the higher opening.
(C) Air moves from the higher opening toward the lower opening.
(D) Air enters both openings.
(E) Air leaves both openings.

51. A photon of which of the following types of electromagnetic radiation carries the least amount of energy?

(A) X-rays
(B) Infrared light
(C) Ultraviolet light
(D) Green light
(E) Gamma rays

52. An electron moves with speed v. If the de Broglie wavelength of the electron doubles, then the new speed of the electron is

(A) $v/4$
(B) $v/2$
(C) v
(D) $2v$
(E) $4v$

53. An engine has an efficiency of 25% and produces 2000 J of mechanical work during one cycle. How much energy is transferred out of the engine by heating the environment during one cycle?

(A) 0 J
(B) 500 J
(C) 2000 J
(D) 6000 J
(E) 8000 J

54. A dog of mass 10 kg sits on a skateboard of mass 2 kg that is initially traveling south at 2 m/s. The dog jumps off with a velocity of 1 m/s north relative to the ground. Which of the following is the best estimate of the velocity of the skateboard immediately after the dog has jumped?

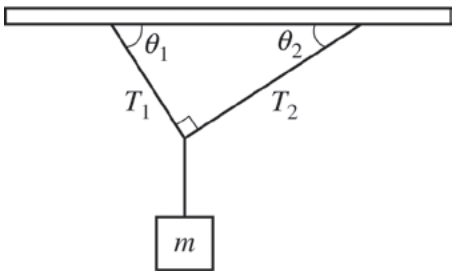
(A) 1 m/s north
(B) 1 m/s south
(C) 3 m/s south
(D) 7 m/s south
(E) 17 m/s south

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

55. A person applies an impulse of 5.0 kg•m/s to a box in order to set it in motion. If the person is in contact with the box for 0.25 s, what is the average force exerted by the person on the box?

(A) 1.25 N
(B) 2.00 N
(C) 12.5 N
(D) 20.0 N
(E) 200 N



56. A box of mass m hangs from massless strings, as shown in the figure above. The angle between strings 1 and 2 is 90°, and the angles that the strings make with the ceiling are θ_1 and θ_2, respectively. If T_1 is the tension in string 1, which of the following are the magnitudes of the horizontal and vertical components of the tension in string 2 ?

	Horizontal Component	Vertical Component
(A)	$T_1 \cos\theta_1$	$mg - T_1 \sin\theta_1$
(B)	$T_1 \cos\theta_1$	$mg - T_1 \cos\theta_1$
(C)	$T_1 \sin\theta_1$	$mg - T_1 \sin\theta_1$
(D)	$T_1 \sin\theta_1$	$mg - T_1 \cos\theta_1$
(E)	$T_1 \sin\theta_1$	$mg + T_1 \sin\theta_1$

57. Planet 1 orbits Star 1 and Planet 2 orbits Star 2 in circular orbits of the same radius. However, the orbital period of Planet 1 is longer than the orbital period of Planet 2. What could explain this?

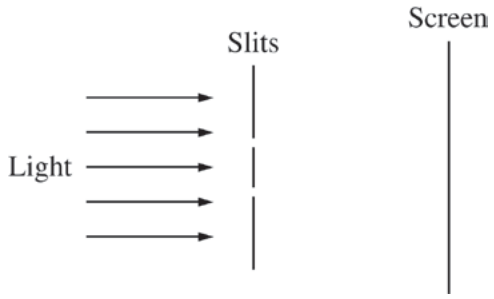
(A) Star 1 has less mass than Star 2.
(B) Star 1 has more mass than Star 2.
(C) Planet 1 has less mass than Planet 2.
(D) Planet 1 has more mass than Planet 2.
(E) The masses of the planets are much less than the masses of the stars.

58. A stationary source emits sound waves of frequency f and wavelength λ that travel through the air with speed v. If the frequency of the source is changed to $2f$, what will be the wavelength and speed of the new wave?

	Wavelength	Speed
(A)	2λ	v
(B)	λ	$2v$
(C)	λ	$v/2$
(D)	$\lambda/2$	$2v$
(E)	$\lambda/2$	v

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



59. At separate times, red light and blue light pass through the same two narrow slits, and each forms an interference pattern on the screen represented above. How do the spacings of the bright fringes in the two patterns compare?

(A) The red fringes are spaced farther apart than the blue fringes are.
(B) The blue fringes are spaced farther apart than the red fringes are.
(C) The fringes have the same spacing in both patterns.
(D) The patterns cannot be compared without knowing the slit separation.
(E) The patterns cannot be compared without knowing the distance from the slits to the screen.

60. A train moves at constant speed away from a stationary listener standing next to the track. The train's whistle, which has a constant frequency, is sounded. The wavelength of the sound from the whistle as heard by the listener is

(A) steadily increasing
(B) steadily decreasing
(C) constant but shorter than the wavelength of the sound heard when the train is stationary
(D) constant but longer than the wavelength of the sound heard when the train is stationary
(E) alternately shorter and longer than the wavelength of the sound heard when the train is stationary

Questions 61-62

An empty container is filled with helium to a pressure P at a temperature T. Neon, which has atoms that are 5 times more massive than those of helium, is then added to the container until the new pressure in the container is $2P$ at the same temperature T.

61. The ratio of the average speed of the helium atoms to the average speed of the neon atoms is

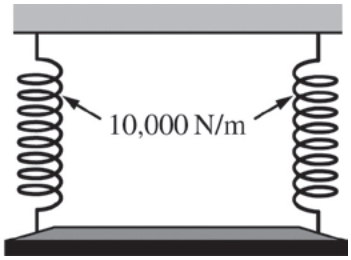
(A) 25 to 1
(B) 5 to 1
(C) $\sqrt{5}$ to 1
(D) $\sqrt{2}$ to 1
(E) 1 to 1

62. The ratio of the number of helium atoms in the container to the number of neon atoms in the container is

(A) 25 to 1
(B) 5 to 1
(C) $\sqrt{5}$ to 1
(D) $\sqrt{2}$ to 1
(E) 1 to 1

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



63. A board is hung from two springs, as shown in the figure above, with the board in equilibrium. Each spring has a spring constant of 10,000 N/m. How far will each spring stretch when a person of mass 50 kg sits on the board and the board again comes to equilibrium?

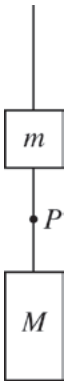
(A) $\frac{1}{400}$ m
(B) $\frac{1}{200}$ m
(C) $\frac{1}{40}$ m
(D) $\frac{1}{20}$ m
(E) $\frac{1}{10}$ m

64. A student wants to determine the coefficient of static friction μ between a block of wood and an adjustable inclined plane. Of the following, the minimum additional equipment the student needs to determine a value for μ is a

(A) protractor only
(B) timer only
(C) protractor and timer
(D) meterstick and timer
(E) meterstick and string

65. A block is projected up a frictionless plane with an initial speed v_0. The plane is inclined 30° above the horizontal. What is the approximate acceleration of the block at the instant that it reaches its highest point on the inclined plane?

(A) Zero
(B) 5 m/s^2 down the incline
(C) 10 m/s^2 down the incline
(D) 10 m/s^2 up the incline
(E) It cannot be calculated without knowing the value of v_0.



66. Two blocks of masses m and M are suspended as shown above by strings of negligible mass. If a person holding the upper string lowers the blocks so that they have a constant downward acceleration a, the tension in the string at point P is

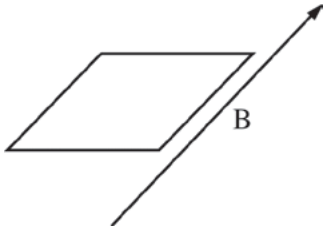
(A) $(M+m)g - ma$
(B) $(M+m)g - Ma$
(C) $Mg - (M+m)a$
(D) Mg
(E) $M(g-a)$

Unauthorized copying or reuse of any part of this page is illegal.

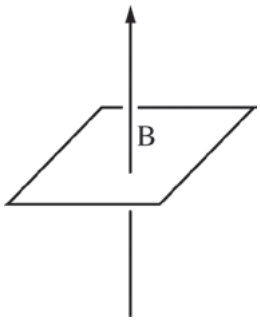
GO ON TO THE NEXT PAGE.

67. A square loop is located in a region containing a magnetic field of magnitude B. The following figures show five possible directions of the magnetic field relative to the loop. For which of the directions is the magnetic flux through the loop greatest?

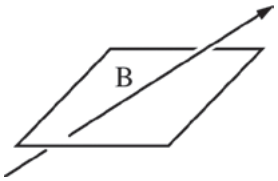
(A)



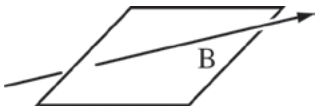
(B)



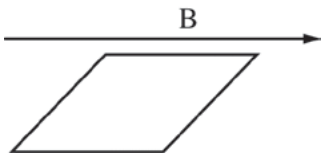
(C)

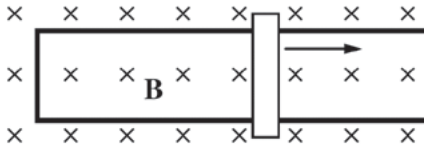


(D)



(E)





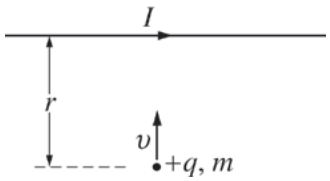
Top View

68. The figure above shows a metal bar that is supported by two sections of a fixed, conducting U-shaped horizontal rail. The rod and rail are located in a region of magnetic field **B** directed into the page. The bar is moving to the right at a constant speed. Which of the following is true of the horizontal forces acting on the bar?

(A) There are no forces.
(B) There is only a magnetic force.
(C) There is only an external applied force.
(D) There is both a magnetic force and an external applied force.
(E) Nothing can be said about the forces without knowing the magnitude of the magnetic field.

Unauthorized copying or reuse of any part of this page is illegal.

Questions 69-70



A particle of charge $+q$ and mass m moves toward a long wire that carries a current I. At the instant shown above, the particle is a distance r from the wire and is moving perpendicularly toward the wire with speed v. There is a magnetic force on the particle as a result of the current.

69. What is the direction of the magnetic force on the particle at the instant shown?

(A) Toward the wire
(B) Toward the left
(C) Toward the right
(D) Out of the plane of the page
(E) Into the plane of the page

70. Of the following five quantities, which could have a different value without changing the magnitude of the magnetic force on the particle, assuming the other four quantities remain constant?

(A) q
(B) m
(C) v
(D) I
(E) r

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

S T O P

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 2013 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 B Exam

SECTION II: Free Response

2013

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
7
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Percent of Section II Score
Questions 1 and 2: 37.5%

Questions 3, 4, 5, 6 and 7: 62.5%

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 Z-4GBP2-S

78

TABLE OF INFORMATION DEVELOPED FOR 2012

CONSTANTS AND CONVERSION FACTORS

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

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N·m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N·m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

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

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

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

NEWTONIAN MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$F_{fric} \le \mu N$$

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

$$\tau = rF \sin\theta$$

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

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

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

$$\Delta U_g = mgh$$

$$W = F\Delta r \cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = Fv\cos\theta$$

$$\mathbf{F}_s = -k\mathbf{x}$$

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

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

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

$$T = \frac{1}{f}$$

$$F_G = -\frac{Gm_1m_2}{r^2}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{kq_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$U_E = qV = \frac{kq_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \ldots\right)$$

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

$$C = \frac{\epsilon_0 A}{d}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

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

$$V = IR$$

$$P = IV$$

$$C_p = C_1 + C_2 + C_3 + \ldots$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

$$R_s = R_1 + R_2 + R_3 + \ldots$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

$$F_B = qvB\sin\theta$$

$$F_B = BI\ell\sin\theta$$

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

$$\phi_m = BA\cos\theta$$

$$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

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

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

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho gh$

$F_{buoy} = \rho V g$

$A_1 v_1 = A_2 v_2$

$P + \rho gy + \frac{1}{2}\rho v^2 = \text{ const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

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

$PV = nRT = Nk_BT$

$K_{avg} = \frac{3}{2}k_BT$

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
v = velocity or speed
v_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

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

$\Delta E = (\Delta m)c^2$

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

WAVES AND OPTICS

$v = f\lambda$

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

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

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

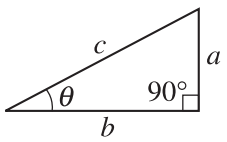
$x_m \approx \frac{m\lambda L}{d}$

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

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$
Triangle
$A = \frac{1}{2}bh$
Circle
$A = \pi r^2$
$C = 2\pi r$
Rectangular Solid
$V = \ell wh$
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

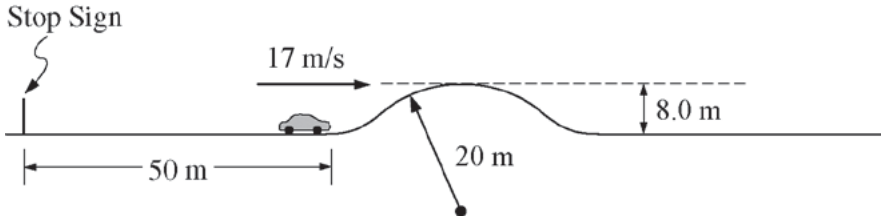
Right Triangle
$a^2 + b^2 = c^2$
$\sin\theta = \frac{a}{c}$
$\cos\theta = \frac{b}{c}$
$\tan\theta = \frac{a}{b}$



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

PHYSICS B
SECTION II
Time—90 minutes
7 Questions

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested times are about 17 minutes for answering each of Questions 1-2 and about 11 minutes for answering each of Questions 3-7. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. (15 points)

You are assigned to do some calculations for a movie stunt that involves a car on a straight road. The road, pictured above, has a hill that rises 8.0 m above the flat region. The top of the hill is a circular arc of radius 20 m. You need to determine whether a car traveling under certain conditions will lose contact with the road at the top of the hill. There is a stop sign 50 m from the beginning of the hill. You are to assume that a car of mass 1600 kg accelerates uniformly from rest at the stop sign, has a speed of 17 m/s when it reaches the beginning of the hill, and then coasts with the engine off. Assume energy losses due to friction and air resistance are negligible.

(a) Calculate the magnitude of the acceleration of the car during the first 50 m.

(b) Calculate the time it takes the car to reach the beginning of the hill.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

(c) Calculate the magnitude of the net force required to accelerate the car during the first 50 m.

(d) On the dot below that represents the car, draw and label the forces (not components) that act on the car at the top of the hill if it travels over the hill without losing contact.



(e) Calculate the minimum speed the car must have at the top of the hill to momentarily lose contact with the road. If you need to draw anything other than what you have shown in part (d) to assist in your solution, use the space below. Do NOT add anything to the figure in part (d).

(f) Calculate the speed the car must have at the beginning of the hill in order to have the speed at the top of the hill you calculated in part (e).

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

2. (15 points)

A student is asked to determine whether a particular carbon resistor obeys Ohm's law by using all the equipment listed below.

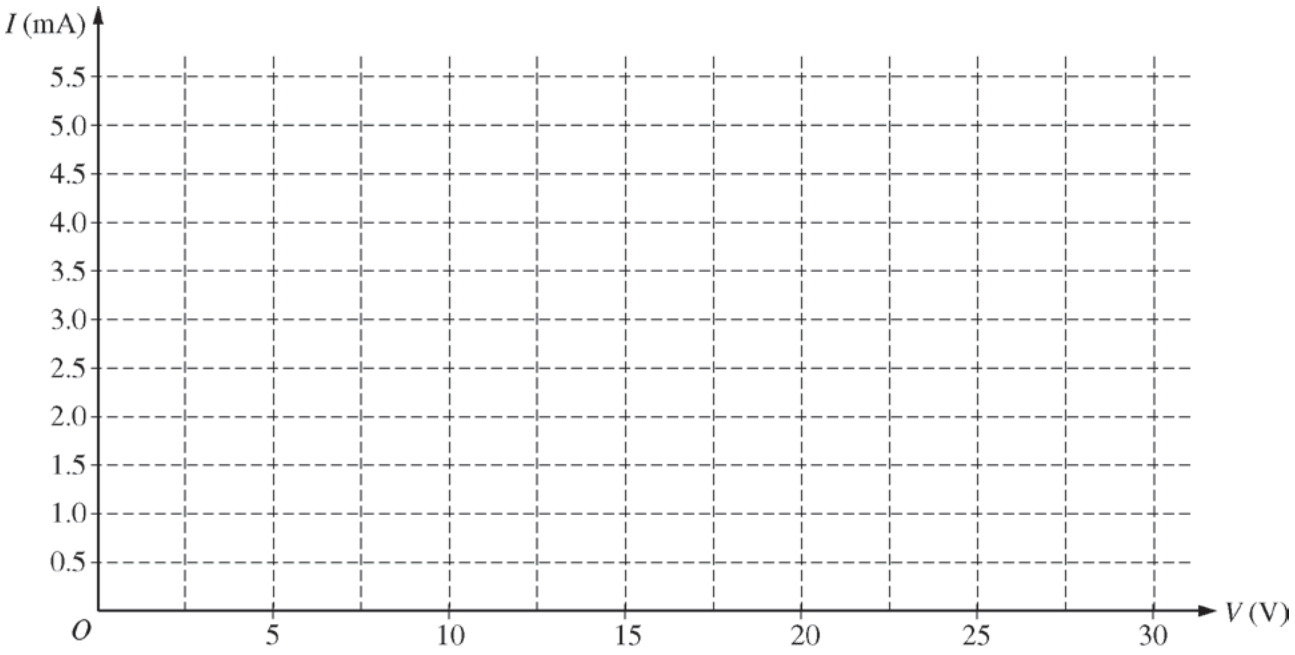
Carbon resistor	Ammeter
Switch	Voltmeter
Variable voltage supply	Wires

(a) Draw a circuit diagram, using appropriate circuit symbols, showing how the student should connect all the equipment listed above in a circuit.

The student obtains the data for current versus voltage shown in the table below.

Current (mA)	0	1.0	1.7	2.8	3.5	4.8
Voltage (V)	0	5	10	15	20	25

(b) Plot the data points on the grid below and draw a straight line or smooth curve that best represents the data.



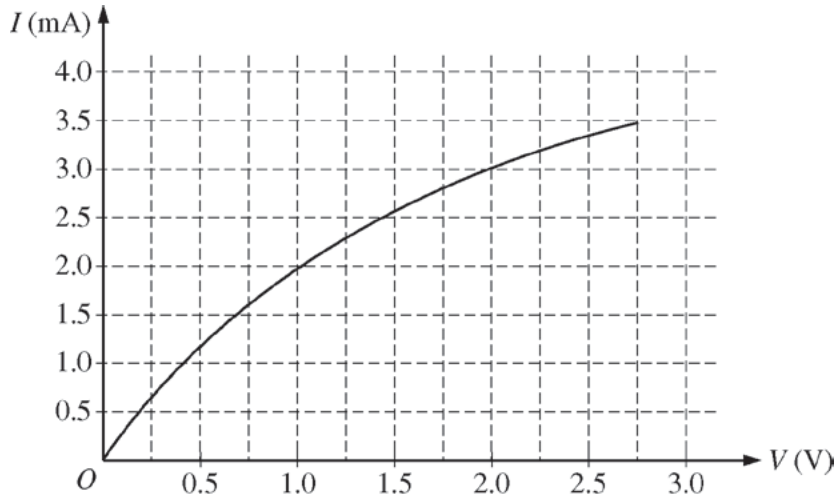
(c) Based on your line or curve, does the carbon resistor obey Ohm's law? Justify your answer.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

(d) Calculate the resistance of the carbon resistor from your line or curve.

The student now replaces the carbon resistor with a lightbulb and obtains the nonlinear graph of current versus voltage below.



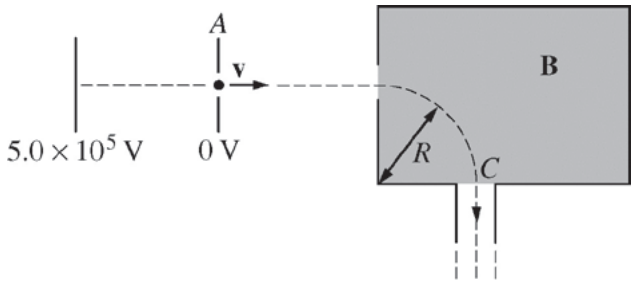
(e) Indicate whether the resistance of the bulb increases, decreases, or remains the same as the current through it increases.

____ Increases ____ Decreases ____ Remains the same

Justify your choice, based on the graph.

(f) From the graph, estimate the resistance of the bulb at room temperature. Explain your method.

Unauthorized copying or reuse of any part of this page is illegal.



3. (10 points)

The figure above shows a proton accelerating horizontally from rest through a potential difference of 5.0×10^5 V to velocity **v**. After traveling a short distance, the proton enters the shaded region that contains a uniform magnetic field **B**. The proton follows a circular path of radius $R = 0.15$ m, leaves the magnetic field through the opening at C, and moves vertically downward. Assume gravity and air resistance can be neglected.

(a) Indicate the direction of the magnetic field **B**.

____ Into the page	____ Toward the top of the page	____ To the left
____ Out of the page	____ Toward the bottom of the page	____ To the right

(b) Calculate the speed v of the proton once it passes through the hole in plate A.

(c) Calculate the magnitude of the magnetic field **B**.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

(d) After passing through the opening at C, the proton travels in a vacuum down a vertical 20 m tube. If gravity is now not neglected, calculate the increase in the proton's kinetic energy due to its descent as a fraction of its kinetic energy at C.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

4. (10 points)

At a certain location, a river is 60 m wide and can be approximated as having a uniform depth of 3.0 m. At that location the water is moving at $1.5\ \text{m/s}$. Assume the density of water is $1000\ \text{kg/m}^3$.

(a) Calculate the number of kilograms of water that pass by that location each second.

At a point downstream, just before a waterfall, the width of the river is 50 m, and it has an approximately uniform depth of 1.6 m.

(b) Calculate the speed of the water just before it reaches the waterfall.

(c) Calculate the kinetic energy of the water that passes by the location just before the waterfall each second.

(d) The water is moving horizontally as it goes over the waterfall and then drops a distance of 40 m. The depth of the water at the top is sufficiently small compared with the height of the waterfall that it can be ignored. Calculate the horizontal distance the water travels between leaving the top of the waterfall and landing at the bottom.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

5. (10 points)

A gasoline engine is used to run a water pump. The engine uses 3.60×10^{-4} kg of gasoline each second. When the gasoline is burned, it releases thermal energy at the rate of 4.60×10^{7} J/kg.

(a) Calculate the thermal energy available from the gasoline in 30 s.

The efficiency of the gasoline engine part of the system is 0.32.

(b) Calculate the work done by the engine in 30 s.

(c) Calculate the thermal energy exhausted by the engine in 30 s.

The pump raises 4.30 kg of water each second from a depth of 100 m to the surface of Earth.

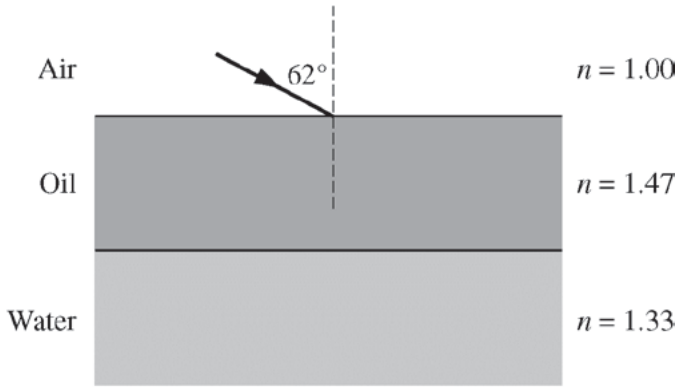
(d) Calculate the rate of increase in the potential energy of the water.

(e) As well as the thermal energy exhausted by the engine, additional energy goes unused in raising the water. Calculate the additional energy that goes unused in 30 s.

(f) Where might the additional energy calculated in part (e) go?

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.



6. (10 points)

A puddle of water has a thin film of oil on top of it. For yellow light of wavelength 580 nm in air, the index of refraction of the oil is 1.47 and the index of refraction of the water is 1.33. A beam of this yellow light strikes the oil at an angle of incidence of $62°$, as shown above.

(a) On the figure above, draw rays to show the path of the beam of light as it passes through the oil and into the water.

(b) Calculate the angle of refraction in the oil.

(c) Calculate the wavelength of the yellow light in the oil.

(d) The yellow light is now incident normally on the oil. Calculate the minimum thickness of oil that gives a maximum brightness for the reflected light.

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

7. 10 (points)

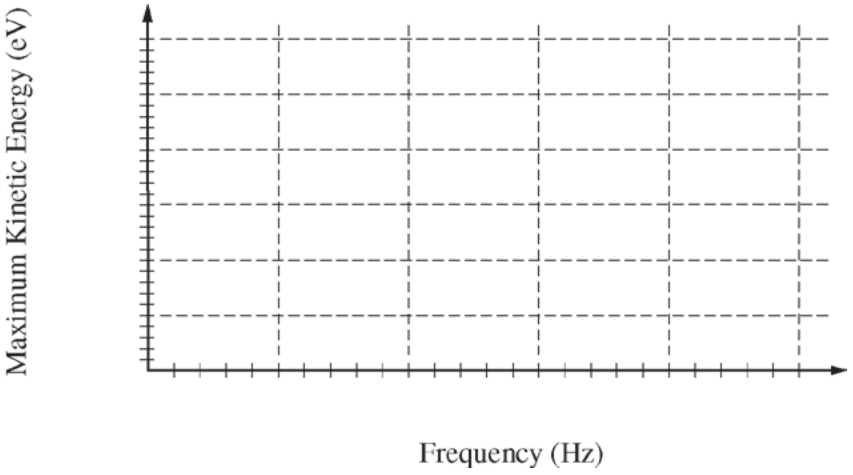
A laser beam with a frequency of 2.5×10^{15} Hz shines on a sheet of metal that has a work function of 5.1 eV.

(a) Calculate the energy per photon of the light, in eV.

(b) Calculate the maximum kinetic energy of an electron emitted from the metal, in eV.

(c) Calculate the minimum frequency of incident light needed to allow an electron to escape the metal.

(d) Using values given and calculated above, construct a graph that shows the relationship between maximum kinetic energy of an emitted electron and frequency of incident light. Indicate the scale on both axes.



(e) What physical quantity does the slope of your graph represent?

Unauthorized copying or reuse of any part of this page is illegal.

GO ON TO THE NEXT PAGE.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **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 B
Practice Exam, Section I

Question 1: D
Question 2: A
Question 3: B
Question 4: E
Question 5: A
Question 6: D
Question 7: E
Question 8: D
Question 9: B
Question 10: E
Question 11: E
Question 12: A
Question 13: E
Question 14: D
Question 15: D
Question 16: A
Question 17: D
Question 18*: —
Question 19: C
Question 20: D
Question 21: D
Question 22: C
Question 23: E
Question 24: B
Question 25: C
Question26: D
Question 27: B
Question 28: D
Question 29: C
Question 30: C
Question 31: E
Question 32: A
Question 33: D
Question 34: E
Question 35: B
Question 36: A
Question 37: D
Question 38: D
Question 39: E
Question 40: D
Question 41: C
Question 42: D
Question 43: D
Question 44: B
Question 45: C
Question 46: D
Question 47: B
Question 48: B
Question 49: D
Question 50: B
Question 51: B
Question 52: B
Question 53: D
Question 54: E
Question 55: D
Question 56: A
Question 57: A
Question 58: E
Question 59: A
Question 60: D
Question 61: C
Question 62: E
Question 63: C
Question 64: A
Question 65: B
Question 66: E
Question 67: B
Question 68: D
Question 69: B
Question 70: B

*Item 18 was not used in scoring.

Free-Response Scoring Guidelines

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

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 1

15 points total | **Distribution of points**

(a) 2 points

For using the correct equation to solve for the acceleration — 1 point

$v^2 = v_0^2 + 2ax$

$v_0 = 0$, so $a = \dfrac{v^2}{2x}$

$a = \dfrac{(17\ \text{m/s})^2}{(2)(50\ \text{m})}$

For the correct answer with units — 1 point

$a = 2.89\ \text{m/s}^2$

(b) 2 points

For using a correct expression to calculate the time — 1 point

$x = x_0 + v_0 t + \dfrac{1}{2}at^2$

For substituting values consistent with the answer from part (a) — 1 point

$x = 0 + (0)t + \dfrac{1}{2}at^2$

$t = \sqrt{\dfrac{2x}{a}}$

$t = \sqrt{\dfrac{(2)(50\ \text{m})}{(2.89\ \text{m/s}^2)}}$

$t = 5.88\ \text{s}$

Alternate Solution | *Alternate Points*

For using a correct expression to calculate the time — *1 point*

$v = v_0 + at$

For substituting values consistent with the answer from part (a) — *1 point*

$v = 0 + at$

$t = \dfrac{v}{a}$

$t = \dfrac{(17\ \text{m/s})}{(2.89\ \text{m/s}^2)}$

$t = 5.88\ \text{s}$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 1 (continued)

Distribution of points

(b) (continued)

Alternate Solution — *Alternate Points*

For using a correct expression to calculate the time — *1 point*

$$x = v_{avg}t = \frac{1}{2}(v + v_0)t$$

For substituting correct values — *1 point*

$$x = \frac{1}{2}(v + 0)t$$

$$t = \frac{2x}{v}$$

$$t = \frac{(2)(50\text{ m})}{(17\text{ m/s})}$$

$$t = 5.88\text{ s}$$

(c) 2 points

For using Newton's 2nd law — 1 point

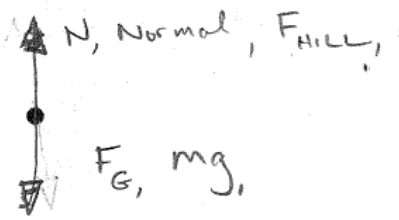
$F = ma$

For substituting the correct value for m and a value for a consistent with part (a) — 1 point

$$F = (1600\text{ kg})\left(2.89\text{ m/s}^2\right)$$

$$F = 4624\text{ N}$$

(d) 3 points



For a correctly labeled vector representing the normal force — 1 point
For a correctly labeled vector representing the weight of the car — 1 point
For no incorrect or extraneous vectors or labeling — 1 point

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 1 (continued)

Distribution of points

(e) 3 points

For equating the centripetal force exerted on the car to the net force — 1 point

$F_C = W + N$

$\frac{mv^2}{r} = mg + N$

For setting the normal force equal to zero — 1 point

$\frac{mv^2}{r} = mg + 0$

Solving for v and substituting

$v = \sqrt{rg}$

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

For a correct answer with units — 1 point

$v = 14\text{ m/s}$

(f) 3 points

For any indication of the use of conservation of energy — 1 point

For a correct expression for the conservation of energy — 1 point

$K_1 = K_2 + U_2$

$\frac{1}{2}mv_1^2 = \frac{1}{2}mv_2^2 + mgh_2$

For correct substitution, with v_2 consistent with part (e) — 1 point

$v_1^2 = v_2^2 + 2gh_2$

$v_1 = \sqrt{v_2^2 + 2gh_2}$

$v_1 = \sqrt{(14\text{ m/s})^2 + (2)\left(9.8\text{ m/s}^2\right)(8.0\text{ m})}$

$v_1 = 18.8\text{ m/s}$

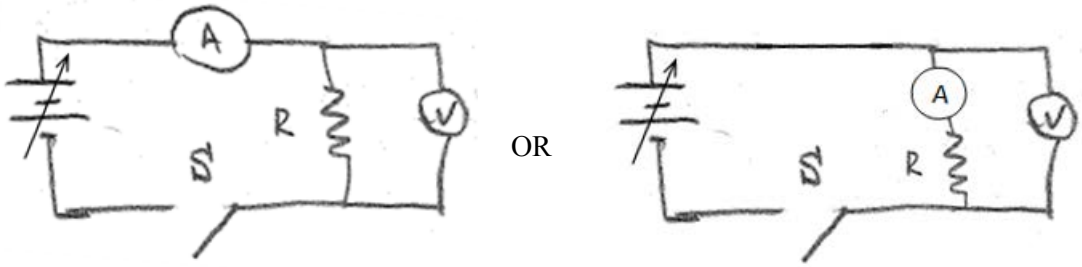
© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 2

15 points total **Distribution of points**

(a) 4 points



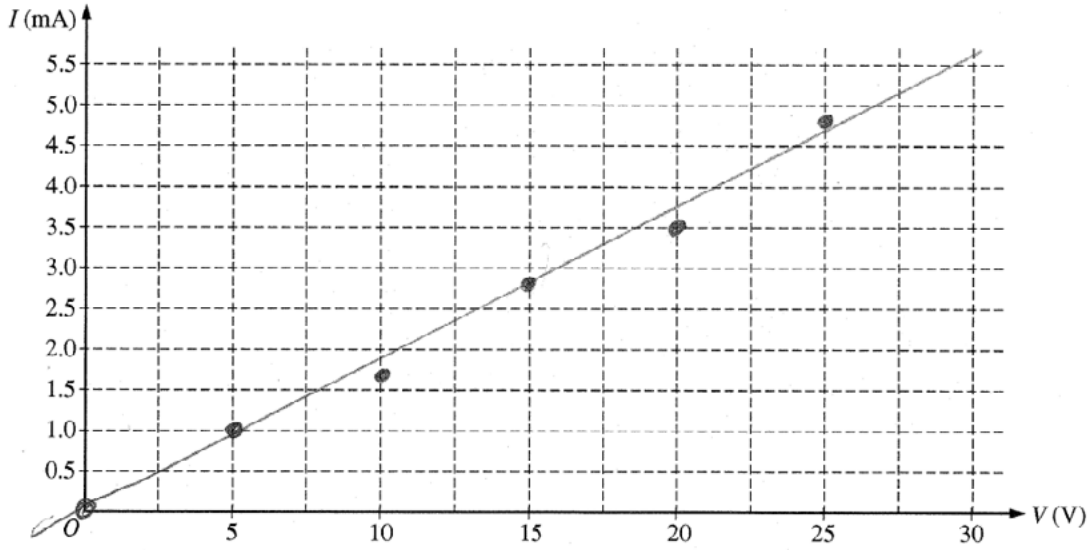
For a complete circuit with the resistor and voltage supply such that the current flows through the resistor in the absence of the meters — 1 point

For showing the ammeter in series with the resistor or resistor-voltmeter combination — 1 point

For a showing the voltmeter in parallel with the resistor or resistor-ammeter combination (when switch is closed) — 1 point

For correctly placing the switch anywhere in the circuit and having a circuit that will work as intended when the switch is closed — 1 point

(b) 2 points



For correctly plotting the data points — 1 point

For drawing a straight line that represents the data — 1 point

(c) 1 point

For correctly answering "yes" and providing a correct justification — 1 point

Example: Yes, the carbon resistor obeys Ohm's law. According to Ohm's law, a graph of current as a function of voltage should be a straight line, as we have above.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 2 (continued)

Distribution of points

(d) 2 points

For a correct use of the best fit line to determine the resistance (not data points unless they fall on the line drawn) — 1 point

$V = IR$

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

So slope $= \frac{1}{R}$ or $R = \frac{1}{\text{slope}}$

$R = \frac{V_2 - V_1}{I_2 - I_1} = \frac{(25\text{ V} - 5\text{ V})}{(4.7\text{ mA} - 1.0\text{ mA})}$

For a correct answer with units — 1 point

$R = 5.4\text{ k}\Omega$

(e) 3 points

For correctly choosing "Increases" — 1 point

For correct selection of evidence from the graph — 1 point

For a correct justification using the definition of resistance — 1 point

Example 1: On the graph, as the voltage increases, the rate at which the current changes decreases. Therefore the resistance increases because $R = V/I$.

Example 2: On the graph, as the voltage increases, the slope decreases. Therefore the resistance increases because resistance is $1/\text{slope}$.

Example 3: $R = V/I$. Using the point $V = 1\text{ V}$ and $I = 2\text{ mA}$ from the graph, $R = 500\ \Omega$. The point $V = 2\text{ V}$, $I = 3\text{ mA}$ gives $R = 667\ \Omega$.

(f) 3 points

For noting that the graph is nearly linear near $V = 0$ — 1 point

For picking sensible data to use — 1 point

For correctly substituting the data into an equation for resistance — 1 point

Example: The graph is nearly linear at the origin. It passes through $V = 0.25\text{ V}$ and $I = 0.7\text{ mA}$. So the resistance at room temperature would be approximately

$R = \frac{V_2 - V_1}{I_2 - I_1} = \frac{(0.25\text{ V} - 0)}{(0.7\text{ mA} - 0)} = 360\ \Omega$.

Credit was also awarded for drawing a line tangent to the curve at the origin, and calculating the resistance based on the slope of the line.

NOTE: If one point was already deducted because the value of *I* used in part (d) was not in milliamps, then no point was deducted for making the same mistake here.

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 3

10 points total | **Distribution of points**

(a) 1 point

For selecting "Out of the page" — 1 point

(b) 3 points

For the use of a valid starting expression — 1 point

$K_f = U_i$

For a correct expression relating the velocity and the given quantities — 1 point

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

Solving for the speed and substituting

$v = \sqrt{\frac{2qV}{m}}$

$v = \sqrt{\frac{(2)\left(1.60 \times 10^{-19}\ \text{C}\right)\left(5.0 \times 10^{5}\ \text{V}\right)}{\left(1.67 \times 10^{-27}\ \text{kg}\right)}}$

For a correct answer with units — 1 point

$v = 9.8 \times 10^{6}\ \text{m/s}$

(c) 3 points

For equating the magnetic force and the centripetal force — 1 point

$F_B = F_C$

For correct equations for the magnetic and centripetal forces — 1 point

$qvB = \frac{mv^2}{r}$

For solving the equation for B and explicit substitution consistent with the answer from part (b) — 1 point

$B = \frac{mv}{qr} = \frac{\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(9.8 \times 10^{6}\ \text{m/s}\right)}{\left(1.6 \times 10^{-19}\ \text{C}\right)(0.15\ \text{m})}$

$B = 0.68\ \text{T}$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 3 (continued)

Distribution of points

(d) 3 points

For a correct substitution into the gravitational potential energy equation — 1 point

$U_G = mgh = \left(1.67 \times 10^{-27}\ \text{kg}\right)\left(9.8\ \text{m/s}^2\right)(20\ \text{m})$

$U_G = 3.27 \times 10^{-25}\ \text{J}$

For calculating the kinetic energy using the correct mass and the speed from part (b), or using the potential difference between the plates — 1 point

$K_C = \frac{1}{2}mv^2$ or $K_C = q\,\Delta V$

$K_C = \left(\frac{1}{2}\right)\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(9.8 \times 10^{6}\ \text{m/s}\right)^2$ or $K_C = \left(1.60 \times 10^{-19}\,\text{C}\right)\left(5.0 \times 10^{5}\ \text{V}\right)$

$K_C = 8.0 \times 10^{-14}\ \text{J}$

For a correct expression for the ratio of the two energies and substitution of calculated values — 1 point

$\frac{U_G}{K_C} = \frac{3.27 \times 10^{-25}\ \text{J}}{8.0 \times 10^{-14}\ \text{J}}$

$\frac{U_G}{K_C} = 4.1 \times 10^{-12}$

Alternate Solution — *Alternate Points*

For a correct expression to determine the velocity at the bottom of the tube — *1 point*

$K_1 + U_1 = K_1$

$\frac{1}{2}mv_1^2 + mgh_1 = \frac{1}{2}mv_2^2$

$v_2^2 = v_1^2 + 2gh_1$

For correctly solving for the velocity at the bottom of the tube — *1 point*

$v_2 = \sqrt{{v_1}^2 + 2gh_1}$

$v_2 = \sqrt{\left(9.8 \times 10^{6}\ \text{m/s}\right)^2 + (2)\left(9.8\ \text{m/s}^2\right)(20\ \text{m})}$

$v_2 = 9.8 \times 10^{6}\ \text{m/s}$

Comparing the initial and final velocities, $v_2 \approx v_1$

For an answer indicating the fractional increase of energy is small — *1 point*

$K_{inrease} \approx 0$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 4

10 points total | **Distribution of points**

(a) 2 points

For use of a correct expression for the mass flow rate — 1 point

$\frac{m}{t} = \frac{\rho V}{t} = \rho A \frac{L}{t} = \rho w d \frac{L}{t}$

$\frac{m}{t} = \rho w d v$

$\frac{m}{t} = \left(1000 \text{ kg/m}^3\right)(60 \text{ m})(3.0 \text{ m})(1.5 \text{ m/s})$

For a correct answer — 1 point

$\frac{m}{t} = 2.7 \times 10^5 \text{ kg/s}$ or $m = 2.7 \times 10^5 \text{ kg}$ or number of kg $= 2.7 \times 10^5$

(b) 3 points

For the using the equation of continuity to solve for the velocity as the water reaches the waterfall — 1 point

$A_1 v_1 = A_2 v_2$

For a correct substitution for A_1 consistent with the answer in part (a) — 1 point

For a correct substitution for A_2 — 1 point

$(60 \text{ m})(3.0 \text{ m})(1.5 \text{ m/s}) = (50 \text{ m})(1.6 \text{ m}) v_2$

$v_2 = 3.4 \text{ m/s}$

(c) 2 points

For the use of a correct expression to calculate the kinetic energy — 1 point

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

$\frac{K}{t} = \frac{1}{2} \frac{m}{t} v^2$ or $\frac{K}{t} = \frac{1}{2} \rho w d \frac{L}{t} v^2 = \frac{1}{2} \rho w d v^3$

For substituting answers from parts (a) and (b), as appropriate — 1 point

$\frac{K}{t} = \frac{1}{2}\left(2.7 \times 10^5 \text{ kg/s}\right)(3.4 \text{ m/s})^2$ or $K = \frac{1}{2}\left(1000 \text{ kg/m}^3\right)(50 \text{ m})(1.6 \text{ m})(3.4 \text{ m/s})^3$

$K/t = 1.6 \times 10^6 \text{ J/s}$ or $K = 1.6 \times 10^6 \text{ J}$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 4 (continued)

Distribution of points

(d) 3 points

For a correct equation for the motion in the vertical direction — 1 point

$y = v_1 t + \frac{1}{2} a t^2$

Solving the above equation for time

$y = 0 + \frac{1}{2} g t^2$

$t = \sqrt{\frac{2y}{g}}$

For a correct equation for the motion in the horizontal direction — 1 point

$x = v_x t$

Substituting the expression for time into the horizontal motion equation

$x = v_x \sqrt{\frac{2y}{g}}$

For correctly substituting values, consistent with the answer in part (b) — 1 point

$x = (3.4 \text{ m/s}) \sqrt{\frac{(2)(40 \text{ m})}{(9.8 \text{ m/s}^2)}}$

$x = 9.7 \text{ m}$ (Answers will range between 9.5 m and 9.7 m if using $g = 10 \text{ m/s}^2$ and rounding intermediate values)

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 5

10 points total | **Distribution of points**

(a) 2 point

Deriving an equation to calculate the energy available in 30 s

$E = \left(\frac{m}{t}\right)\left(\frac{E}{m}\right)t$

For correctly substituting into the above equation — 1 point

$E = \left(3.60 \times 10^{-4}\ \text{kg/s}\right)\left(4.60 \times 10^{7}\ \text{J/kg}\right)(30\ \text{s})$

For a correct answer with units — 1 point

$E = 4.97 \times 10^{5}\ \text{J}$

(b) 1 point

Deriving an equation to calculate the work done by the engine

$e = W/E$

$W_{gas} = eE$

For substitutions consistent with the answer from part (a) — 1 point

$W_{gas} = (0.32)\left(4.97 \times 10^{5}\ \text{J}\right)$

$W_{gas} = 1.60 \times 10^{5}\ \text{J}$

(c) 2 point

For a correct equation relating the energy exhausted to E, W, and/or e — 1 point

$\Delta E = E - W$ or $\Delta E = (1 - e)E$

Substituting into the above equation using the answers from parts (a) and (b)

$\Delta E = \left(4.97 \times 10^{5}\ \text{J}\right) - \left(1.60 \times 10^{5}\ \text{J}\right)$

For an answer consistent with the answers from parts (a) and (b) — 1 point

$\Delta E = 3.38 \times 10^{5}\ \text{J}$

(d) 2 points

Deriving an equation to calculate the rate of increase in potential energy

$\frac{\Delta U_G}{t} = \frac{mg\Delta h}{t} = \left(\frac{m}{t}\right)g\Delta h$

For correctly substituting into the above equation — 1 point

$\frac{\Delta U_G}{t} = (4.3\ \text{kg/s})\left(9.8\ \text{m/s}^2\right)(100\ \text{m})$

For an answer with correct units — 1 point

$\frac{\Delta U_G}{t} = 4.2 \times 10^{3}\ \text{J/s}$ (or $4.3 \times 10^{3}\ \text{J/s}$ using $g = 10\ \text{m/s}^2$)

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 5 (continued)

Distribution of points

(e) 2 points

For a correct equation and substitution to calculate the work done in raising the water, consistent with the answer in part (d) — 1 point

$$W_{water} = \left(\frac{\Delta U_G}{t}\right)t = \left(4.2 \times 10^3 \text{ J/s}\right)(30 \text{ s}) = 1.26 \times 10^5 \text{ J}$$

For a correct equation and substitution from part (b) to calculate the energy lost in raising the water — 1 point

$$E_{lost} = E - \Delta E - W_{water} = W_{gas} - W_{water} = 1.60 \times 10^5 \text{ J} - 1.26 \times 10^5 \text{ J}$$

$$E_{lost} = 3.4 \times 10^4 \text{ J}$$

(f) 1 points

For a correct explanation of what happened to the additional energy from part (e) — 1 point
Example: Some of the energy would be transformed into sound energy and some would be lost to friction as the water is raised.

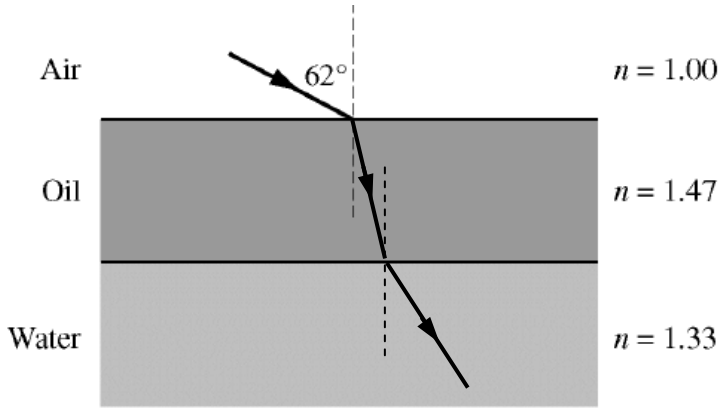
© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 6

10 points total **Distribution of points**

(a) 2 points



For a ray in the oil that is at a smaller angle with the normal than the ray in air 1 point
For a ray in the water that is at a larger angle with the normal than the ray in the oil 1 point

(b) 3 points

For a correct expression of Snell's law 1 point
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
For correct substitutions 1 point
$(1.00)(\sin 62°) = (1.47)(\sin\theta_2)$
For a correct answer 1 point
$\theta_2 = 37°$

(c) 2 points

For calculating the speed of light in oil 1 point

$$v = \frac{c}{n} = \frac{\left(3.00 \times 10^8 \text{ m/s}\right)}{(1.47)} = 2.04 \times 10^8 \text{ m/s}$$

Calculating the frequency of the yellow light

$$c = \lambda f$$

$$f = \frac{c}{\lambda} = \frac{\left(3.00 \times 10^8 \text{ m/s}\right)}{\left(5.80 \times 10^{-7} \text{ m}\right)} = 5.17 \times 10^{14} \text{ Hz}$$

For calculating the wavelength using the proper frequency 1 point

$$v = \lambda f$$

$$\lambda = \frac{v}{f} = \frac{\left(2.04 \times 10^8 \text{ m/s}\right)}{\left(5.17 \times 10^{14} \text{ Hz}\right)} = 3.95 \times 10^{-7} \text{ m} = 395 \text{ nm}$$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 6 (continued)

Distribution of points

(c) (continued)

Alternate Solution — *Alternate Points*

For directly calculating the wavelength using a proper formula — *2 points*

$$\lambda_{oil} = \frac{\lambda_{air}}{n} = \frac{(580 \text{ nm})}{(1.47)} = 395 \text{ nm}$$

(d) 3 points

For a correct expression for constructive interference relating the thickness of oil to the wavelength of light — 1 point

$2t = m\lambda$ or $2t = \left(m + \frac{1}{2}\right)\lambda$ OR $2nt = m\lambda$ or $2nt = \left(m + \frac{1}{2}\right)\lambda$

For correctly substituting an appropriate wavelength into one of the above equations — 1 point

$2t = \left(\frac{1}{2}\right)\left(3.95 \times 10^{-7} \text{ m}\right)$ OR $2(1.47)t = \left(\frac{1}{2}\right)\left(5.80 \times 10^{-7} \text{ m}\right)$

For a correct answer with units — 1 point

$t = 9.86 \times 10^{-8}$ m

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

AP® PHYSICS B
2013 SCORING GUIDELINES

Question 7

10 points total | **Distribution of points**

(a) 2 points

For correct use of the equation for the energy of a photon — 1 point

$E = hf = \left(4.14 \times 10^{-15}\ \text{eV•s}\right)\left(2.5 \times 10^{15}\ \text{Hz}\right)$

For a correct answer in eV — 1 point

$E = 10.4\ \text{eV}$

(b) 2 points

For correctly substituting values into an equation for the maximum kinetic energy of an emitted electron — 1 point

$K_{\text{max}} = hf - \phi = 10.4\ \text{eV} - 5.1\ \text{eV}$

For an answer in eV, consistent with the answer from part (a) — 1 point

$K_{\text{max}} = 5.3\ \text{eV}$

(c) 2 points

For correct use of the equation for the minimum frequency — 1 point

$\phi = hf$

$$f = \frac{\phi}{h} = \frac{(5.1\ \text{eV})}{\left(4.14 \times 10^{-15}\ \text{eV•s}\right)}$$

For a correct answer — 1 point

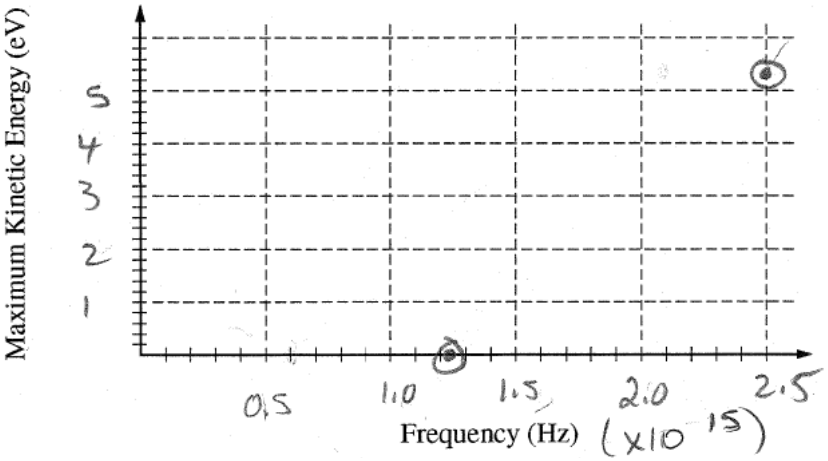
$f = 1.23 \times 10^{15}\ \text{Hz}$

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Question 7 (continued)

Distribution of points

(d) 3 points



For correct scaling and labeling that uses at least half the graph — 1 point

For plotting the point $\left(1.23 \times 10^{15} \text{ Hz}, 0\right)$, or a frequency consistent with part (c) — 1 point

For plotting the point $\left(2.5 \times 10^{15} \text{ Hz}, 5.3 \text{ eV}\right)$, or an energy consistent with part (b) — 1 point

Note: 1 earned point was deducted for any graph that is not a straight line.

(e) 1 point

Comparing the equation for the maximum kinetic energy to the equation for a straight line

$K_{\max} = hf - \phi$ and $y = mx + b$

For correctly identifying the slope as Planck's constant h — 1 point

© 2013 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

Scoring Worksheet

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

2013 AP Physics B Scoring Worksheet

Section I: Multiple Choice

_____	× 1.3043 =	_____
Number Correct (out of 69*)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 15)	× 1.1250 =	_____ (Do not round)	
Question 2	_____ (out of 15)	× 1.1250 =	_____ (Do not round)	
Question 3	_____ (out of 10)	× 1.1250 =	_____ (Do not round)	
Question 4	_____ (out of 10)	× 1.1250 =	_____ (Do not round)	
Question 5	_____ (out of 10)	× 1.1250 =	_____ (Do not round)	
Question 6	_____ (out of 10)	× 1.1250 =	_____ (Do not round)	
Question 7	_____ (out of 10)	× 1.1250 =	_____ (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 B

Composite Score Range	AP Score
123-180	5
97-122	4
70-96	3
52-69	2
0-51	1

*Although 70 multiple-choice items were administered in Section I, item 18 was not used in scoring.

AP Physics B

The College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program®. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

Visit the College Board on the Web: www.collegeboard.org.