CollegeBoard

AP® Chemistry Practice Exam

From the 2015 Administration

NOTE: This is a modified version of the 2015 AP Chemistry Exam.

Contents

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

Exam Instructions

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

AP® Chemistry Exam

Regularly Scheduled Exam Date: Monday morning, May 4, 2015

Late-Testing Exam Date: Thursday afternoon, May 21, 2015

Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 45 min.

Section I	**Total Time:** 1 hour 30 minutes Calculator not permitted **Percent of Total Score:** 50% **Writing Instrument:** Pencil required	**Number of Questions:** 60* **The number of questions may vary slightly depending on the form of the exam.*
Section II	**Total Time:** 1 hour 45 minutes Calculators allowed for all of Section II **Percent of Total Score:** 50% **Writing Instrument:** Either pencil or pen with black or dark blue ink	**Number of Questions:** 7 *(3 ten-point and 4 four-point questions; 105 minutes)*

What Proctors Need to Bring to This Exam

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

Note: Tables of equations and constants are provided in the exam booklets for both sections of the exam.

Students are not allowed to use calculators in Section I of the AP Chemistry Exam. However, students are permitted to use four-function, scientific, or graphing calculators to answer questions in Section II. Before starting the exam administration, make sure that each student has an appropriate calculator and that any student with a graphing calculator has a model from the approved list on page 46 of the *2014-15 AP Coordinator's Manual*. See pages 43–46 of the *2014-15 AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide, or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 44 of the *2014-15 AP Coordinator's Manual*.

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.**

Students will be allowed to use the table of equations and constants on both sections of the exam.

SECTION I: Multiple Choice

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

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

If you are giving the regularly scheduled exam, say:

It is Monday morning, May 4, and you will be taking the AP Chemistry Exam.

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

It is Thursday afternoon, May 21, and you will be taking the AP Chemistry Exam.

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

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

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

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

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

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

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

Are there any questions? . . .

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

You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses 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. Calculators are not allowed for this section. Please put 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 20 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working. Close your booklet and put your answer sheet on your desk, face up. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. Sit quietly while I collect your answer sheets.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label. After all answer sheets have been collected, say:

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

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

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

Please listen carefully to these instructions before we take a 10-minute break. All items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. Leave your shrinkwrapped Section II packet on top of your desk during the break. You are not allowed to consult teachers, other students, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic

or communication device. Remember, you may never discuss the multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .

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

SECTION II: Free Response

After the break, say:

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

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

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

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

Read the last statement. . . .

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

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

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

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

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 exam 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 45 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 with black or dark blue ink or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read. If you need more paper during the exam, raise your hand. At the top of each extra sheet of paper you use, be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .

You may begin.

 Note Start Time here _____. Note Stop Time here _____. Proctors 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 35 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

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

If any students used extra paper for the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report and include any exam booklets with extra sheets of paper in an Incident Report return envelope (see page 57 of the *AP Coordinator's Manual* for details). Then say:

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

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

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

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

If you are giving the regularly scheduled exam, say:

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

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

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

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

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

Then say:

You are now dismissed.

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

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

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

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2015

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

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 *2014-15 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

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

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

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

C. YOUR AP NUMBER

D. EXAM DATE Month | Day

E. EXAM START TIME AM | PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE 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

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

779934

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 2 Option 2

104246-00657 • UNLWEB315

Q3914/1-4

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

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

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

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

◯ Yes ◯ No

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

◯ Yes ◯ No

QUESTIONS 1–75

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

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS 

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

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

ETS USE ONLY

Exam		⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨
		⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨
Exam		⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨
		⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

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

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

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

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

QUESTIONS 121–126

For Students Taking AP Biology

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

121 122 123 124 125 126

QUESTIONS 131–142

For Students Taking AP Physics 1 or AP Physics 2

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

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

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

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

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

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

U. STUDENT SEARCH SERVICE®

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

Would you like us to supply your information?

- ◯ Yes
- ◯ No

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

V. SEX

- ◯ Female
- ◯ Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. ETHNICITY/RACE

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

Y. PARENTAL EDUCATION LEVEL

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

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

R. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address	City	State or Province	Country	ZIP or Postal Code

S. STUDENT IDENTIFIER (Student ID Number)

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

Section I: Multiple-Choice Questions

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

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

PLACE SEAL HERE

AP® Chemistry Exam

SECTION I: Multiple Choice

2015

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

At a Glance

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

Instructions

Section I of this exam contains 50 multiple-choice questions. Fill in only the circles for numbers 1 through 50 on your answer sheet. Pages containing a periodic table and lists containing equations and constants are also printed in this booklet.

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.

Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question. 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	Ⓐ ● Ⓒ Ⓓ Ⓔ

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

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

PLACE SEAL HERE

Form I
Form Code 4LBP4-S

25

PLACE SEAL HERE
DO NOT seal answer sheet inside

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1												13	14	15	16	17	18
1 **H** 1.008	2																2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30	3	4	5	6	7	8	9	10	11	12	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (97)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **†Ac** (227)	104 **Rf** (267)	105 **Db** (270)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (282)	112 **Cn** (285)	113 **Uut** (285)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

*Lanthanoid Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
†Actinoid Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

AP® CHEMISTRY EQUATIONS AND CONSTANTS

Throughout the exam the following symbols have the definitions specified unless otherwise noted.

L, mL	=	liter(s), milliliter(s)	mm Hg	=	millimeters of mercury
g	=	gram(s)	J, kJ	=	joule(s), kilojoule(s)
nm	=	nanometer(s)	V	=	volt(s)
atm	=	atmosphere(s)	mol	=	mole(s)

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy
ν = frequency
λ = wavelength

Planck's constant, $h = 6.626 \times 10^{-34}$ J s
Speed of light, $c = 2.998 \times 10^{8}$ m s^{-1}
Avogadro's number = 6.022×10^{23} mol^{-1}
Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

EQUILIBRIUM

$K_c = \dfrac{[C]^c[D]^d}{[A]^a[B]^b}$, where $a\ A + b\ B \rightleftarrows c\ C + d\ D$

$K_p = \dfrac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$

$K_a = \dfrac{[H^+][A^-]}{[HA]}$

$K_b = \dfrac{[OH^-][HB^+]}{[B]}$

$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C

$= K_a \times K_b$

$pH = -\log[H^+]$, $pOH = -\log[OH^-]$

$14 = pH + pOH$

$pH = pK_a + \log\dfrac{[A^-]}{[HA]}$

$pK_a = -\log K_a$, $pK_b = -\log K_b$

Equilibrium Constants

K_c (molar concentrations)
K_p (gas pressures)
K_a (weak acid)
K_b (weak base)
K_w (water)

KINETICS

$\ln[A]_t - \ln[A]_0 = -kt$

$\dfrac{1}{[A]_t} - \dfrac{1}{[A]_0} = kt$

$t_{1/2} = \dfrac{0.693}{k}$

k = rate constant
t = time
$t_{1/2}$ = half-life

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = ^\circ\text{C} + 273$$

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

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

Molarity, M = moles of solute per liter of solution

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
m = mass
$\boldsymbol{M}$ = molar mass
D = density
KE = kinetic energy
v = velocity
A = absorbance
a = molar absorptivity
b = path length
c = concentration

Gas constant, R = 8.314 J mol^{-1} K^{-1}
= 0.08206 L atm mol^{-1} K^{-1}
= 62.36 L torr mol^{-1} K^{-1}

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol^{-1}

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT \ln K$$
$$= -nFE^\circ$$

$$I = \frac{q}{t}$$

q = heat
m = mass
c = specific heat capacity
T = temperature
S° = standard entropy
H° = standard enthalpy
G° = standard Gibbs free energy
n = number of moles
E° = standard reduction potential
I = current (amperes)
q = charge (coulombs)
t = time (seconds)

Faraday's constant, F = 96,485 coulombs per mole of electrons

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

CHEMISTRY
Section I
50 Questions
Time—90 minutes

CALCULATORS ARE NOT ALLOWED FOR SECTION I.

Note: For all questions, assume that the temperature is 298 K, the pressure is 1.0 atm, and solutions are aqueous unless otherwise specified.

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

1. A 0.5 mol sample of He(g) and a 0.5 mol sample of Ne(g) are placed separately in two 10.0 L rigid containers at 25°C. Each container has a pinhole opening. Which of the gases, He(g) or Ne(g), will escape faster through the pinhole and why?

   (A) He(g) will escape faster because the He(g) atoms are moving at a higher average speed than the Ne(g) atoms.
   (B) Ne(g) will escape faster because its initial pressure in the container is higher.
   (C) Ne(g) will escape faster because the Ne(g) atoms have a higher average kinetic energy than the He(g) atoms.
   (D) Both gases will escape at the same rate because the atoms of both gases have the same average kinetic energy.

2. The lattice energy of a salt is related to the energy required to separate the ions. For which of the following pairs of ions is the energy that is required to separate the ions largest? (Assume that the distance between the ions in each pair is equal to the sum of the ionic radii.)

   (A) $Na^+(g)$ and $Cl^-(g)$
   (B) $Cs^+(g)$ and $Br^-(g)$
   (C) $Mg^{2+}(g)$ and $O^{2-}(g)$
   (D) $Ca^{2+}(g)$ and $O^{2-}(g)$

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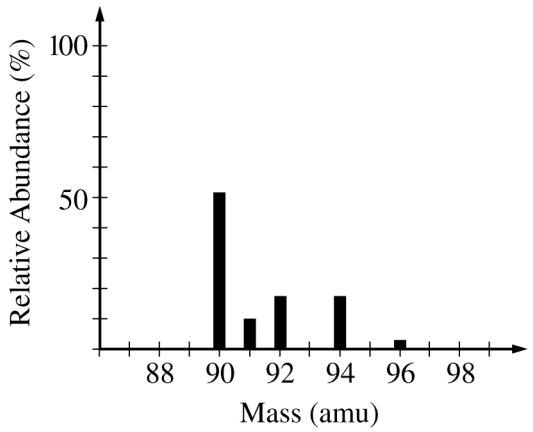
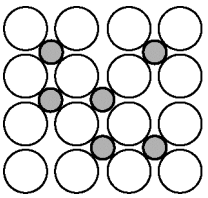


3. The mass spectrum of element X is presented in the diagram above. Based on the spectrum, which of the following can be concluded about element X?

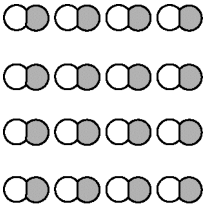
   (A) X is a transition metal, and each peak represents an oxidation state of the metal.
   (B) X contains five electron sublevels.
   (C) The atomic mass of X is 90.
   (D) The atomic mass of X is between 90 and 92.

4. Which of the following diagrams best depicts an alloy of Ni and B ?

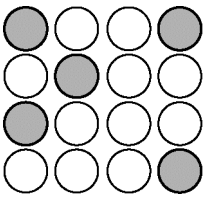
(A)



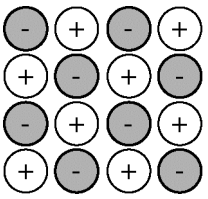
(B)



(C)



(D)



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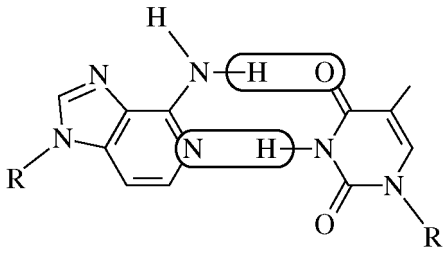

5. Which of the following is the strongest type of interaction that occurs between the atoms within the circled areas of the two molecules represented above?

   (A) Polar covalent bond
   (B) Nonpolar covalent bond
   (C) Hydrogen bond
   (D) London dispersion forces

6. A hot iron ball is dropped into a 200. g sample of water initially at 50.° C. If 8.4 kJ of heat is transferred from the ball to the water, what is the final temperature of the water? (The specific heat of water is 4.2 J/(g·°C).)

   (A) 40.°C
   (B) 51°C
   (C) 60.°C
   (D) 70.°C

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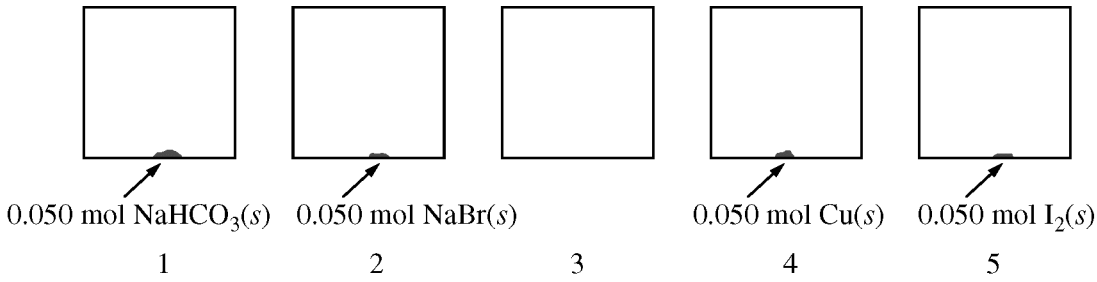
Questions 7-9 refer to the following information.



At 27°C, five identical rigid 2.0 L vessels are filled with $N_2(g)$ and sealed. Four of the five vessels also contain a 0.050 mol sample of $NaHCO_3(s)$, NaBr(s), Cu(s), or $I_2(s)$, as shown in the diagram above. The volume taken up by the solids is negligible, and the initial pressure of $N_2(g)$ in each vessel is 720 mm Hg. All four vessels are heated to 127°C and allowed to reach a constant pressure.

7. At 127°C, the pressure in vessel 1 is found to be higher than that in vessel 2. Which of the following reactions best accounts for the observation?

   (A) $NaHCO_3(s) \rightarrow Na(s) + HCO_3(s)$

   (B) $NaHCO_3(s) \rightarrow NaH(s) + CO_3(s)$

   (C) $2\ NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

   (D) $2\ NaHCO_3(s) + N_2(g) \rightarrow 2\ NaNO_3(s) + C_2H_2(g)$

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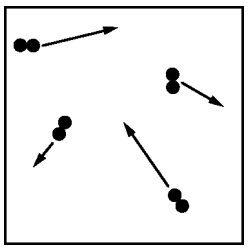
8. At 127°C, the entire sample of I_2 is observed to have vaporized. How does the mass of vessel 5 at 127°C compare to its mass at 27°C?

(A) The mass is less, since the I_2 is in the vapor phase.

(B) The mass is the same, since the number of each type of atom in the vessel is constant.

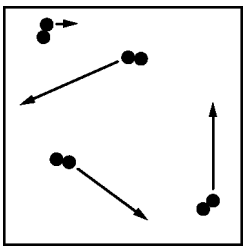
(C) The mass is greater, since the I_2 will react with N_2 to form NI_3, which has a greater molar mass.

(D) The mass is greater, since the pressure is greater and the particles have a higher average kinetic energy.

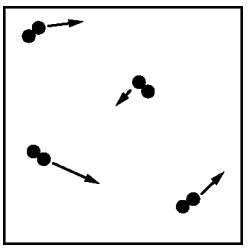


9. The gas particles in vessel 3 at 27°C are represented in the diagram above. The lengths of the arrows represent the speeds of the particles. Which of the following diagrams best represents the particles when vessel 3 is heated to 127°C?

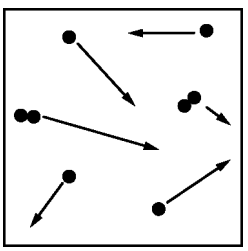
(A)



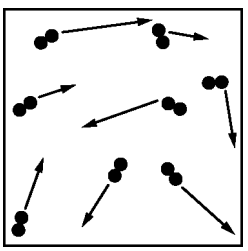
(B)



(C)



(D)



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10. An acetate buffer solution is prepared by combining 50. mL of 0.20 *M* acetic acid, $HC_2H_3O_2(aq)$, and 50. mL of 0.20 *M* sodium acetate, $NaC_2H_3O_2(aq)$. A 5.0 mL sample of 0.10 *M* NaOH(*aq*) is added to the buffer solution. Which of the following is a correct pairing of the acetate species present in greater concentration and of the pH of the solution after the NaOH(*aq*) is added? (The pK_a of acetic acid is 4.7.)

	Acetate Species	pH
(A)	$HC_2H_3O_2$	< 4.7
(B)	$HC_2H_3O_2$	> 4.7
(C)	$C_2H_3O_2^-$	< 4.7
(D)	$C_2H_3O_2^-$	> 4.7

Name	Molecular Formula	Molar Mass (g/mol)
Ethane	C_2H_6	30
Butane	C_4H_{10}	58

11. The molecular formula and molar mass of two straight-chain hydrocarbons are listed in the table above. Based on the information in the table, which compound has the higher boiling point, and why is that compound's boiling point higher?

(A) C_4H_{10}, because it has more hydrogen atoms, resulting in more hydrogen bonding

(B) C_4H_{10}, because it has more electrons, resulting in greater polarizability and stronger dispersion forces

(C) C_2H_6, because its molecules are smaller and they can get closer to one another, resulting in stronger dispersion forces

(D) C_2H_6, because its molecules are more polar, resulting in stronger dipole-dipole attractions

	Ionization Energy (kJ/mol)
First	801
Second	2,430
Third	3,660
Fourth	25,000
Fifth	32,820

12. The first five ionization energies of a second-period element are listed in the table above. Which of the following correctly identifies the element and best explains the data in the table?

(A) B, because it has five core electrons
(B) B, because it has three valence electrons
(C) N, because it has five valence electrons
(D) N, because it has three electrons in the *p* sublevel

$$Mg(OH)_2(s) \rightleftarrows Mg^{2+}(aq) + 2\,OH^-(aq)$$

13. The exothermic dissolution of $Mg(OH)_2(s)$ in water is represented by the equation above. The K_{sp} of $Mg(OH)_2$ is 1.8×10^{-11}. Which of the following changes will increase the solubility of $Mg(OH)_2$ in an aqueous solution?

(A) Decreasing the pH
(B) Increasing the pH
(C) Adding NH_3 to the solution
(D) Adding $Mg(NO_3)_2$ to the solution

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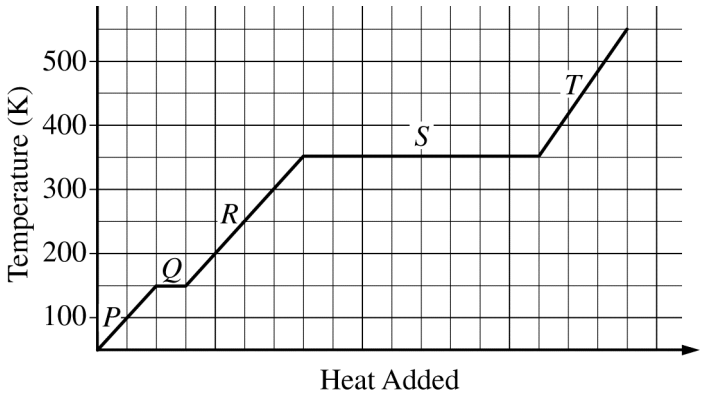


14. The heating curve for a sample of pure ethanol is provided above. The temperature was recorded as a 50.0 g sample of solid ethanol was heated at a constant rate. Which of the following explains why the slope of segment *T* is greater than the slope of segment *R* ?

(A) The specific heat capacity of the gaseous ethanol is less than the specific heat capacity of liquid ethanol.
(B) The specific heat capacity of the gaseous ethanol is greater than the specific heat capacity of liquid ethanol.
(C) The heat of vaporization of ethanol is less than the heat of fusion of ethanol.
(D) The heat of vaporization of ethanol is greater than the heat of fusion of ethanol.

$H_3PO_4 \rightleftarrows H^+ + H_2PO_4^-$ $\quad K_{a_1} = 7.2 \times 10^{-3}$

$H_2PO_4^- \rightleftarrows H^+ + HPO_4^{2-}$ $\quad K_{a_2} = 6.3 \times 10^{-8}$

$HPO_4^{2-} \rightleftarrows H^+ + PO_4^{3-}$ $\quad K_{a_3} = 4.5 \times 10^{-13}$

15. A solution is prepared by mixing 50 mL of 1 *M* NaH_2PO_4 with 50 mL of 1 *M* Na_2HPO_4. On the basis of the information above, which of the following species is present in the solution at the lowest concentration?

(A) Na^+
(B) HPO_4^{2-}
(C) $H_2PO_4^-$
(D) PO_4^{3-}

$$2\,XY(g) \rightleftarrows X_2(g) + Y_2(g) \qquad K_p = 230$$

16. A certain gas, $XY(g)$, decomposes as represented by the equation above. A sample of each of the three gases is put in a previously evacuated container. The initial partial pressures of the gases are shown in the table below.

Gas	Initial Partial Pressure (atm)
XY	0.010
X_2	0.20
Y_2	2.0

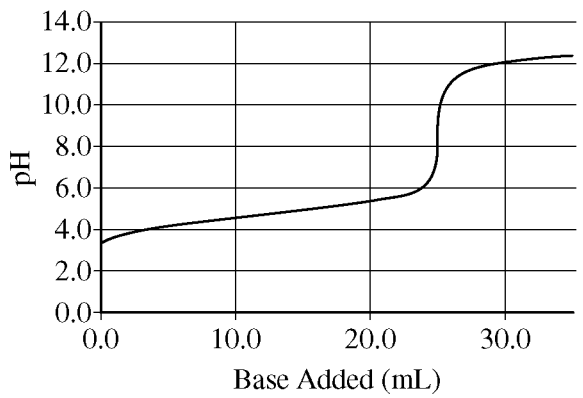
The temperature of the reaction mixture is held constant. In which direction will the reaction proceed?

(A) The reaction will form more products.
(B) The reaction will form more reactant.
(C) The mixture is at equilibrium, so there will be no change.
(D) It cannot be determined unless the volume of the container is known.

Questions 17-20 refer to the following information.

A 0.35 g sample of $Li(s)$ is placed in an Erlenmeyer flask containing 100 mL of water at 25°C. A balloon is placed over the mouth of the flask to collect the hydrogen gas that is generated.

After all of the $Li(s)$ has reacted with $H_2O(l)$, the solution in the flask is added to a clean, dry buret and used to titrate an aqueous solution of a monoprotic acid. The pH curve for this titration is shown in the diagram below.



17. Which of the following changes will most likely increase the rate of reaction between $Li(s)$ and water?

(A) Using 125 mL of water instead of 100 mL
(B) Using a 0.25 g sample of $Li(s)$ instead of a 0.35 g sample
(C) Using a 0.35 g sample of $Li(s)$ cut into small pieces
(D) Decreasing the water temperature before adding the $Li(s)$

18. What will be the effect on the amount of gas produced if the experiment is repeated using 0.35 g of $K(s)$ instead of 0.35 g of $Li(s)$?

(A) No gas will be produced when $K(s)$ is used.
(B) Some gas will be produced but less than the amount of gas produced with $Li(s)$.
(C) Equal quantities of gas will be produced with the two metals.
(D) More gas will be produced with $K(s)$ than with $Li(s)$.

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19. On the basis of the pH curve, the pK_a value of the acid is closest to

(A) 4
(B) 5
(C) 8
(D) 12

20. Which of the following is the balanced net-ionic equation for the reaction between $Li(s)$ and water?

(A) $2\ Li(s) + 2\ H^+(aq) + 2\ OH^-(aq) \rightarrow 2\ Li^+(aq) + 2\ OH^-(aq) + H_2(g)$
(B) $2\ Li(s) + 2\ H_2O(l) \rightarrow 2\ Li^+(aq) + 2\ OH^-(aq) + H_2(g)$
(C) $2\ Li(s) + 2\ H_2O(l) \rightarrow 2\ LiOH(s) + H_2(g)$
(D) $2\ Li(s) + 2\ H_2O(l) \rightarrow 2\ LiH(s) + H_2(g)$

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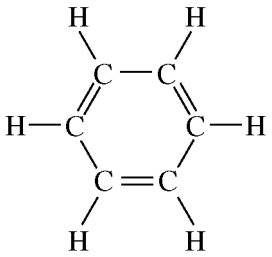

21. Benzene, C_6H_6, has the structure shown above. Considering the observation that benzene is only sparingly soluble in water, which of the following best describes the intermolecular forces of attraction between water and benzene?

(A) Benzene is nonpolar, therefore there are no forces between water and benzene.
(B) The H atoms in benzene form hydrogen bonds with the O atoms in water.
(C) Benzene is hydrophobic, therefore there is a net repulsion between water and benzene.
(D) There are dipole-induced dipole and London dispersion interactions between water and benzene.

Solution	Acid	K_a
1	CH_3CO_2H	1.75×10^{-5}
2	CF_3CO_2H	1.0×10^{0}

22. Acid-dissociation constants of two acids are listed in the table above. A 20. mL sample of a 0.10 *M* solution of each acid is titrated to the equivalence point with 20. mL of 0.10 *M* NaOH. Which of the following is a true statement about the pH of the solutions at the equivalence point?

(A) Solution 1 has a higher pH at the equivalence point because CH_3CO_2H is the stronger acid.
(B) Solution 1 has a higher pH at the equivalence point because CH_3CO_2H has the stronger conjugate base.
(C) Solution 1 has a lower pH at the equivalence point because CH_3CO_2H is the stronger acid.
(D) Solution 1 has a lower pH at the equivalence point because CH_3CO_2H has the stronger conjugate base.

23. A 1.0 g sample of a cashew was burned in a calorimeter containing 1000. g of water, and the temperature of the water changed from 20.0°C to 25.0°C. In another experiment, a 3.0 g sample of a marshmallow was burned in a calorimeter containing 2000. g of water, and the temperature of the water changed from 25.0°C to 30.0°C. Based on the data, which of the following can be concluded about the energy content for 1.0 g of each of the two substances? (The specific heat of water is 4.2 J/(g·°C).)

(A) The combustion of 1.0 g of cashew releases less energy than the combustion of 1.0 g of marshmallow.
(B) The combustion of 1.0 g of cashew releases the same amount of energy as the combustion of 1.0 g of marshmallow.
(C) The combustion of 1.0 g of cashew releases more energy than the combustion of 1.0 g of marshmallow.
(D) No comparison can be made because the two systems started with different masses of food, different masses of water, and different initial temperatures.

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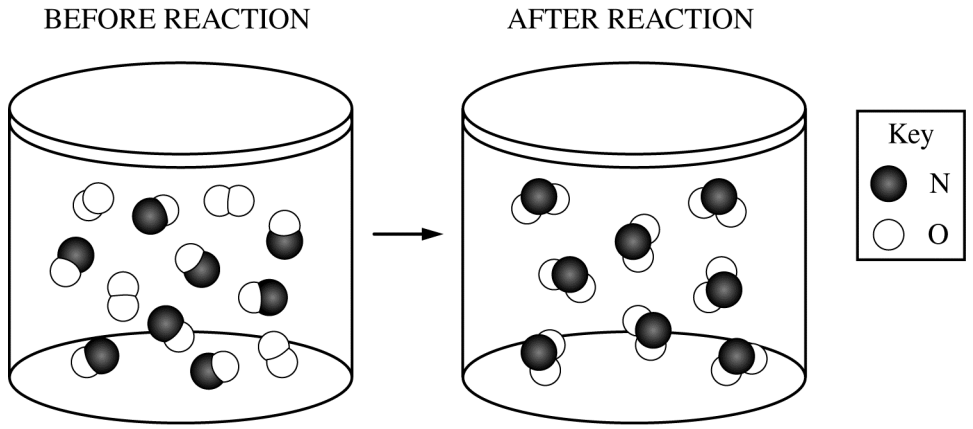

24. The reaction between $NO(g)$ and $O_2(g)$ to produce $NO_2(g)$ in a rigid reaction vessel is represented in the diagram above. The pressure inside the container is recorded using a pressure gauge. Which of the following statements correctly predicts the change in pressure as the reaction goes to completion at constant temperature, and provides the correct explanation?

(A) The pressure will increase because the product molecules have a greater mass than either of the reactant molecules.
(B) The pressure will decrease because there are fewer molecules of product than of reactants.
(C) The pressure will decrease because the product molecules have a lower average speed than the reactant molecules.
(D) The pressure will not change because the total mass of the product molecules is the same as the total mass of the reactant molecules.

GO ON TO THE NEXT PAGE.

Questions 25-29 refer to the following information.

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g) \qquad \Delta H^\circ = -196\ \text{kJ/mol}_{rxn}$$

The decomposition of $H_2O_2(aq)$ is represented by the equation above. A student monitored the decomposition of a 1.0 L sample of $H_2O_2(aq)$ at a constant temperature of 300. K and recorded the concentration of H_2O_2 as a function of time. The results are given in the table below.

Time (s)	$[H_2O_2]$
0	2.7
200.	2.1
400.	1.7
600.	1.4

25. Which of the following identifies the element(s) being oxidized and reduced in the reaction?

(A) Hydrogen is oxidized and oxygen is reduced.
(B) Oxygen is oxidized and hydrogen is reduced.
(C) Oxygen is both oxidized and reduced.
(D) No elements are oxidized or reduced; the reaction is not a redox reaction.

26. The $O_2(g)$ produced from the decomposition of the 1.0 L sample of $H_2O_2(aq)$ is collected in a previously evacuated 10.0 L flask at 300. K. What is the approximate pressure in the flask after 400. s? (For estimation purposes, assume that 1.0 mole of gas in 1.0 L exerts a pressure of 24 atm at 300. K.)

(A) 1.2 atm
(B) 2.4 atm
(C) 12 atm
(D) 24 atm

27. Which of the following statements is a correct interpretation of the data regarding how the order of the reaction can be determined?

(A) The reaction must be first order because there is only one reactant species.
(B) The reaction is first order if the plot of $\ln [H_2O_2]$ versus time is a straight line.
(C) The reaction is first order if the plot of $1/[H_2O_2]$ versus time is a straight line.
(D) The reaction is second order because 2 is the coefficient of H_2O_2 in the chemical equation.

28. The reaction is thermodynamically favorable. The signs of ΔG° and ΔS° for the reaction are which of the following?

	ΔG°	ΔS°
(A)	Positive	Positive
(B)	Negative	Positive
(C)	Positive	Negative
(D)	Negative	Negative

GO ON TO THE NEXT PAGE.

29. Assume that the bond enthalpies of the oxygen-hydrogen bonds in H_2O are not significantly different from those in H_2O_2. Based on the value of $\Delta H°$ of the reaction, which of the following could be the bond enthalpies (in kJ/mol) for the bonds broken and formed in the reaction?

	O–O in H_2O_2	O=O in O_2	O–H
(A)	300	500	500
(B)	150	500	500
(C)	500	300	150
(D)	250	300	150

30. Which of the following accounts for the observation that the pH of pure water at 37°C is 6.8 ?

(A) At 37°C water is naturally acidic.
(B) At 37°C the autoionization constant for water, K_w, is larger than it is at 25°C.
(C) At 37°C water has a lower density than it does at 25°C; therefore, $[H^+]$ is greater.
(D) At 37°C water ionizes to a lesser extent than it does at 25°C.

31. To gravimetrically analyze the silver content of a piece of jewelry made from an alloy of Ag and Cu, a student dissolves a small preweighed sample in $HNO_3(aq)$. $Ag^+(aq)$ and $Cu^{2+}(aq)$ ions form in the solution. Which of the following should be the next step in the analytical process?

(A) Centrifuging the solution to isolate the heavier ions
(B) Evaporating the solution to recover the dissolved nitrates
(C) Adding enough base solution to bring the pH up to 7.0
(D) Adding a solution containing an anion that forms an insoluble salt with only one of the metal ions

32. A sample of a compound that contains only the elements C, H, and N is completely burned in O_2 to produce 44.0 g of CO_2, 45.0 g of H_2O, and some NO_2. A possible empirical formula of the compound is

(A) CH_2N
(B) CH_5N
(C) C_2H_5N
(D) $C_3H_3N_2$

$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq)$$

33. The dissociation of the weak acid HF in water is represented by the equation above. Adding a 1.0 mL sample of which of the following would increase the percent ionization of $HF(aq)$ in 10 mL of a solution of 1.0 *M* HF ?

(A) 1.0 *M* KF
(B) 1.0 *M* H_2SO_4
(C) 10.0 *M* HF
(D) Distilled water

GO ON TO THE NEXT PAGE.

Questions 34-36 refer to the reactions represented below, which are involved in a demonstration commonly known as "underwater fireworks."

Reaction 1: $CaC_2(s) + 2\ H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(s)$

Reaction 2: $NaOCl(aq) + 2\ HCl(aq) \rightarrow Cl_2(g) + NaCl(aq) + H_2O(l)$

Reaction 3: $C_2H_2(g) + Cl_2(g) \rightarrow C_2H_2Cl_2(g)$

34. $Ca(OH)_2(s)$ precipitates when a 1.0 g sample of $CaC_2(s)$ is added to 1.0 L of distilled water at room temperature. If a 0.064 g sample of $CaC_2(s)$ (molar mass 64 g/mol) is used instead and all of it reacts, which of the following will occur and why? (The value of K_{sp} for $Ca(OH)_2$ is 8.0×10^{-8}.)

(A) $Ca(OH)_2$ will precipitate because $Q > K_{sp}$.

(B) $Ca(OH)_2$ will precipitate because $Q < K_{sp}$.

(C) $Ca(OH)_2$ will not precipitate because $Q > K_{sp}$.

(D) $Ca(OH)_2$ will not precipitate because $Q < K_{sp}$.

35. Reaction 2 occurs when an excess of 6 *M* HCl(*aq*) solution is added to 100. mL of NaOCl(*aq*) of unknown concentration. If the reaction goes to completion and 0.010 mol of $Cl_2(g)$ is produced, then what was the molarity of the NaOCl(*aq*) solution?

(A) 0.0010 *M*
(B) 0.010 *M*
(C) 0.10 *M*
(D) 1.0 *M*

36. When Reaction 3 occurs, does the hybridization of the carbon atoms change?

(A) Yes; it changes from *sp* to sp^2.

(B) Yes; it changes from *sp* to sp^3.

(C) Yes; it changes from sp^2 to sp^3.

(D) No; it does not change.

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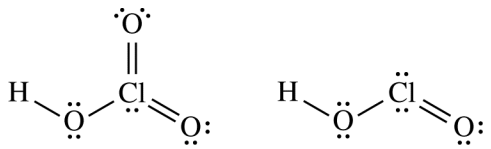
	K_a
$HC_3H_5O_3(aq)$	8.3×10^{-4}
$CH_3NH_3^+(aq)$	2.3×10^{-11}

37. The acid-dissociation constants of $HC_3H_5O_3(aq)$ and $CH_3NH_3^+(aq)$ are given in the table above. Which of the following mixtures is a buffer with a pH of approximately 3 ?

(A) A mixture of 100. mL of 0.1 *M* CH_3NH_3Cl and 50. mL of 0.1 *M* NaOH
(B) A mixture of 100. mL of 0.1 *M* $HC_3H_5O_3$ and 50. mL of 0.1 *M* NaOH
(C) A mixture of 100. mL of 0.1 *M* $NaC_3H_5O_3$ and 100. mL of 0.1 *M* NaOH
(D) A mixture of 100. mL of 0.1 *M* CH_3NH_3Cl and 100. mL of 0.1 *M* CH_3NH_2



38. The Lewis electron-dot diagrams of the $HClO_3$ molecule and the $HClO_2$ molecule are shown above at the left and right, respectively. Which of the following statements identifies the stronger acid and correctly identifies a factor that contributes to its being the stronger acid?

(A) $HClO_3(aq)$ is the stronger acid because its molecules experience stronger London dispersion forces.
(B) $HClO_3(aq)$ is the stronger acid because the additional electronegative oxygen atom on the chlorine atom stabilizes the conjugate base.
(C) $HClO_2(aq)$ is the stronger acid because its molecules experience weaker London dispersion forces.
(D) $HClO_2(aq)$ is the stronger acid because the lone pairs of electrons on the chlorine atom stabilize the conjugate base.

39. If equal masses of the following compounds undergo complete combustion, which will yield the greatest mass of CO_2 ?

(A) Benzene, C_6H_6
(B) Cyclohexane, C_6H_{12}
(C) Glucose, $C_6H_{12}O_6$
(D) Methane, CH_4

$$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

$$\Delta H^\circ = 178 \text{ kJ/mol}_{rxn}$$

40. The reaction system represented above is at equilibrium. Which of the following will decrease the amount of $CaO(s)$ in the system?

(A) Increasing the volume of the reaction vessel at constant temperature
(B) Lowering the temperature of the system
(C) Removing some $CO_2(g)$ at constant temperature
(D) Removing some $CaCO_3(s)$ at constant temperature

Acid Solution	Volume of NaOH Added (mL)
A	40
B	75
C	115
D	200

41. To maximize the yield in a certain manufacturing process, a solution of a weak monoprotic acid that has a concentration between 0.20 *M* and 0.30 *M* is required. Four 100. mL samples of the acid at different concentrations are each titrated with a 0.20 *M* NaOH solution. The volume of NaOH needed to reach the end point for each sample is given in the table above. Which solution is the most suitable to maximize the yield?

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

GO ON TO THE NEXT PAGE.

Questions 42-44 refer to the following information.

When free $Cl(g)$ atoms encounter $O_3(g)$ molecules in the upper atmosphere, the following reaction mechanism is proposed to occur.

$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$	*slow step*	
$ClO(g) + O_3(g) \rightarrow Cl(g) + 2\ O_2(g)$	*fast step*	
$2\ O_3(g) \rightarrow 3\ O_2(g)$	*overall reaction*	$\Delta H = -285\ \text{kJ/mol}_{rxn}$

42. Which of the following rate laws for the overall reaction corresponds to the proposed mechanism?

(A) Rate = $k[O_3]^2$

(B) Rate = $k[Cl][O_3]$

(C) Rate = $k[ClO][O_3]^2$

(D) Rate = $k\dfrac{[O_2]^3}{[O_3]^2}$

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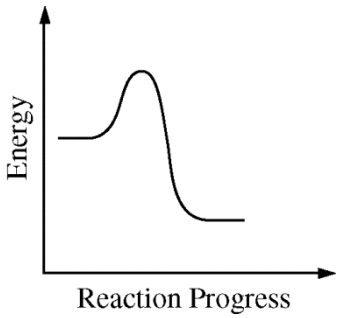
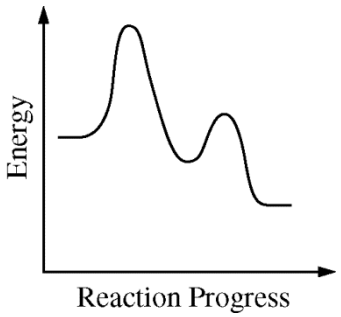
43. Which of the following reaction energy profiles best corresponds to the proposed mechanism?

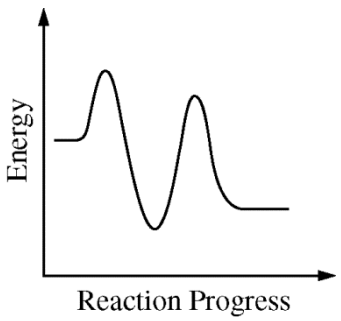
(A)



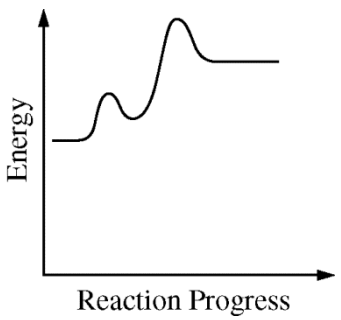
(B)



(C)



(D)



$$X + O_3 \rightarrow XO + O_2$$
$$XO + O_3 \rightarrow X + 2\,O_2$$
$$2\,O_3 \rightarrow 3\,O_2$$

44. The proposed mechanism can be written in a more general form, as shown above. Species other than Cl can also decompose O_3 through the same mechanism. Which of the following chemical species is most likely to decompose O_3 in the upper atmosphere through the above mechanism?

(A) He
(B) Br
(C) N_2
(D) O_2

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$$HX(aq) + Y^-(aq) \rightleftarrows HY(aq) + X^-(aq) \qquad K_{eq} > 1$$

45. A solution of a salt of a weak acid HY is added to a solution of another weak acid HX. Based on the information given above, which of the following species is the strongest base?

(A) $HX(aq)$
(B) $Y^-(aq)$
(C) $HY(aq)$
(D) $X^-(aq)$

$$X(g) + 2\,Q(g) \rightleftarrows R(g) + Z(g) \qquad K_c = 1.3 \times 10^5 \text{ at } 50°C$$

46. A 1.0 mol sample of $X(g)$ and a 1.0 mol sample of $Q(g)$ are introduced into an evacuated, rigid 10.0 L container and allowed to reach equilibrium at 50°C according to the equation above. At equilibrium, which of the following is true about the concentrations of the gases?

(A) $[R] = \frac{1}{2}[Q]$

(B) $[Q] = \frac{1}{2}[X]$

(C) $[R] = [Z] > [Q]$

(D) $[X] = [Q] = [R] = [Z]$

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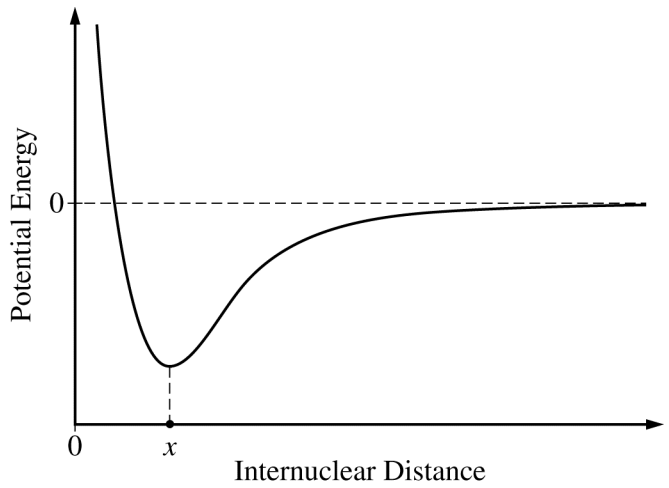

47. The potential energy of a system of two atoms as a function of their internuclear distance is shown in the diagram above. Which of the following is true regarding the forces between the atoms when their internuclear distance is x?

(A) The attractive and repulsive forces are balanced, so the atoms will maintain an average internuclear distance x.
(B) There is a net repulsive force pushing the atoms apart, so the atoms will move further apart.
(C) There is a net attractive force pulling the atoms together, so the atoms will move closer together.
(D) It cannot be determined whether the forces between atoms are balanced, attractive, or repulsive, because the diagram shows only the potential energy.

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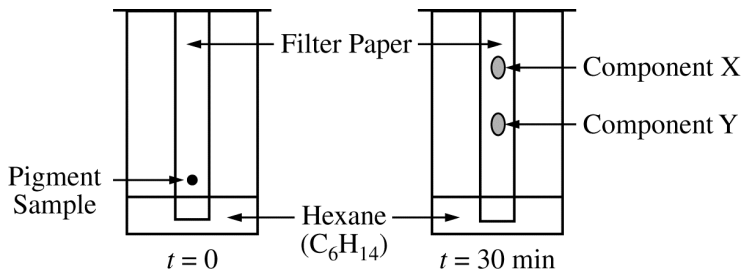
$$X(g) + 2\,Y(g) \rightarrow XY_2(g)$$

48. In order to determine the order of the reaction represented above, the initial rate of formation of XY_2 is measured using different initial values of [X] and [Y]. The results of the experiment are shown in the table below.

Trial	[X]	[Y]	Initial Rate of Formation of XY_2 ($M\ s^{-1}$)
1	0.50	0.50	8.0×10^{-3}
2	1.00	0.50	3.2×10^{-2}
3	1.00	1.00	6.4×10^{-2}

In trial 2 which of the reactants would be consumed more rapidly, and why?

(A) X, because it has a higher molar concentration.
(B) X, because the reaction is second order with respect to X.
(C) Y, because the reaction is second order with respect to Y.
(D) Y, because the rate of disappearance will be double that of X.



49. In a paper chromatography experiment, a sample of a pigment is separated into two components, X and Y, as shown in the figure above. The surface of the paper is moderately polar. What can be concluded about X and Y based on the experimental results?

(A) X has a larger molar mass than Y does.
(B) Y has a larger molar mass than X does.
(C) X is more polar than Y.
(D) Y is more polar than X.

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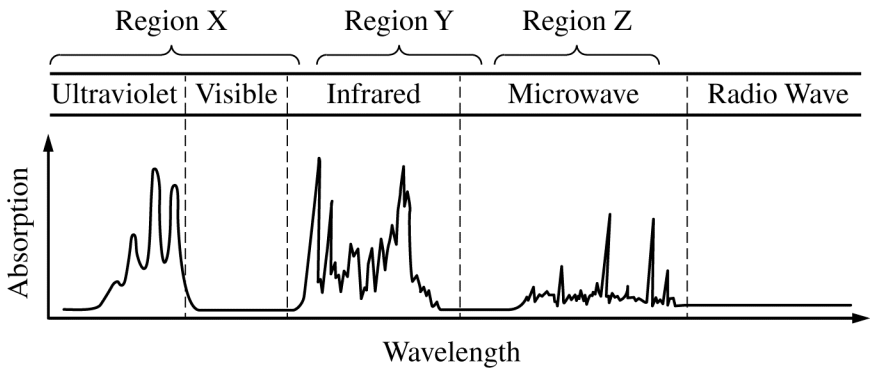
ABSORPTION SPECTRUM



50. The diagram above represents the absorption spectrum for a pure molecular substance. Which of the following correctly indicates the type of transition observed for the substance in each of the regions of the absorption spectrum?

	Region X	Region Y	Region Z
(A)	Molecular vibration	Molecular rotation	Electronic transition
(B)	Electronic transition	Molecular rotation	Molecular vibration
(C)	Molecular rotation	Molecular vibration	Electronic transition
(D)	Electronic transition	Molecular vibration	Molecular rotation

GO ON TO THE NEXT PAGE.

END OF SECTION I

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

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

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

Section II: Free-Response Questions

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

AP® Chemistry Exam

SECTION II: Free Response

2015

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

At a Glance

Total Time
1 hour, 45 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

Suggested Time
Approximately 23 minutes each for questions 1—3 and 9 minutes each for questions 4—7

Weight
Approximate weights:
Questions 1—3: 22% each
Questions 4—7: 9% each

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
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Instructions

The questions for Section II are printed in this booklet. Pages containing a periodic table and lists containing equations and constants are also printed in this booklet.

You may use the pages that the questions are printed on to organize your answers or for scratch work, but you must write your answers in the areas designated for each response. Only material written in the space provided will be scored.

Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored.

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 4LBP4-S

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1												13	14	15	16	17	18
1 **H** 1.008	2																2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30	3	4	5	6	7	8	9	10	11	12	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (97)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **†Ac** (227)	104 **Rf** (267)	105 **Db** (270)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (282)	112 **Cn** (285)	113 **Uut** (285)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

*Lanthanoid Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
†Actinoid Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

AP® CHEMISTRY EQUATIONS AND CONSTANTS

Throughout the exam the following symbols have the definitions specified unless otherwise noted.

L, mL	=	liter(s), milliliter(s)	mm Hg	=	millimeters of mercury
g	=	gram(s)	J, kJ	=	joule(s), kilojoule(s)
nm	=	nanometer(s)	V	=	volt(s)
atm	=	atmosphere(s)	mol	=	mole(s)

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy
ν = frequency
λ = wavelength

Planck's constant, $h = 6.626 \times 10^{-34}$ J s
Speed of light, $c = 2.998 \times 10^{8}$ m s^{-1}
Avogadro's number = 6.022×10^{23} mol^{-1}
Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

EQUILIBRIUM

$K_c = \dfrac{[C]^c[D]^d}{[A]^a[B]^b}$, where $a\ A + b\ B \rightleftarrows c\ C + d\ D$

$K_p = \dfrac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$

$K_a = \dfrac{[H^+][A^-]}{[HA]}$

$K_b = \dfrac{[OH^-][HB^+]}{[B]}$

$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C

$= K_a \times K_b$

$pH = -\log[H^+]$, $pOH = -\log[OH^-]$

$14 = pH + pOH$

$pH = pK_a + \log\dfrac{[A^-]}{[HA]}$

$pK_a = -\log K_a$, $pK_b = -\log K_b$

Equilibrium Constants

K_c (molar concentrations)
K_p (gas pressures)
K_a (weak acid)
K_b (weak base)
K_w (water)

KINETICS

$\ln[A]_t - \ln[A]_0 = -kt$

$\dfrac{1}{[A]_t} - \dfrac{1}{[A]_0} = kt$

$t_{1/2} = \dfrac{0.693}{k}$

k = rate constant
t = time
$t_{1/2}$ = half-life

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = ^\circ\text{C} + 273$$

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

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

Molarity, M = moles of solute per liter of solution

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
m = mass
$\boldsymbol{M}$ = molar mass
D = density
KE = kinetic energy
v = velocity
A = absorbance
a = molar absorptivity
b = path length
c = concentration

Gas constant, R = 8.314 J mol^{-1} K^{-1}
= 0.08206 L atm mol^{-1} K^{-1}
= 62.36 L torr mol^{-1} K^{-1}

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol^{-1}

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT \ln K$$
$$= -nFE^\circ$$

$$I = \frac{q}{t}$$

q = heat
m = mass
c = specific heat capacity
T = temperature
S° = standard entropy
H° = standard enthalpy
G° = standard Gibbs free energy
n = number of moles
E° = standard reduction potential
I = current (amperes)
q = charge (coulombs)
t = time (seconds)

Faraday's constant, F = 96,485 coulombs per mole of electrons

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

SECTION II BEGINS ON PAGE 6.

CHEMISTRY

Section II

7 Questions

Time—1 hour and 45 minutes

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

Half-Reaction	$E°$ (V)
$2\ CO_2(g) + 12\ H^+(aq) + 12\ e^- \rightarrow C_2H_5OH(aq) + 3\ H_2O(l)$	– 0.085
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$	1.229

1. A student uses a galvanic cell to determine the concentration of ethanol, C_2H_5OH, in an aqueous solution. The cell is based on the half-cell reactions represented in the table above.

   (a) Write a balanced equation for the overall reaction that occurs in the cell.

   (b) Calculate $E°$ for the overall reaction that occurs in the cell.

   (c) A 10.0 mL sample of $C_2H_5OH(aq)$ is put into the electrochemical cell. The cell produces an average current of 0.10 amp for 20. seconds, at which point the $C_2H_5OH(aq)$ has been totally consumed.

   (i) Calculate the charge, in coulombs, that passed through the cell.

   (ii) Calculate the initial $[C_2H_5OH]$ in the solution.

   An alternative approach to determine the concentration of $C_2H_5OH(aq)$ in a solution is based on the reaction represented below.

$$3\ C_2H_5OH(aq) + 2\ Cr_2O_7^{2-}(aq) + 16\ H^+(aq) \rightarrow 4\ Cr^{3+}(aq) + 3\ CH_3COOH(aq) + 11\ H_2O(l)$$

orange *blue-green*

GO ON TO THE NEXT PAGE.

A solution has an initial $Cr_2O_7^{2-}(aq)$ concentration of 1.0×10^{-3} *M* and an initial $C_2H_5OH(aq)$ concentration of 0.500 *M*. The solution contains enough strong acid to keep the pH essentially constant throughout the reaction. The student places a sample of the solution in a cuvette that has a path length of 0.50 cm and places it in a spectrophotometer set to measure absorbance at 440 nm. ($Cr_2O_7^{2-}(aq)$ is the only species in the reaction mixture that absorbs light at this wavelength.) The absorbance of $Cr_2O_7^{2-}(aq)$ in the solution is monitored as the reaction proceeds; the table below shows the absorbance as a function of time for the first trial.

Time (min)	Absorbance at 440 nm
0.00	0.782
1.50	0.553
3.00	0.389
4.50	0.278
6.00	0.194

(d) Calculate the value of $[Cr_2O_7^{2-}]$ at 1.50 min.

(e) The student runs a second trial but this time uses a cuvette that has a path length of 1.00 cm. Describe how the experimental setup should be adjusted to keep the initial absorbance at 0.782. Justify your answer with respect to the factors that influence the absorbance of a sample in a spectrophotometer.

For the concentrations of reactants used in the experiment, the rate of the reaction can be written as follows.

$$\text{Rate} = k_{observed}[Cr_2O_7^{2-}]^y, \text{ where } k_{observed} = k[C_2H_5OH]$$

(f) Explain how the experimental data indicate that the reaction is first order with respect to $Cr_2O_7^{2-}$.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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2. Answer the following questions about Fe and Al compounds.

(a) $Fe_2O_3(s)$ and $Al_2O_3(s)$ have similar chemical properties; some similarities are due to the oxides having similar lattice energies. Give two reasons why the lattice energies of the oxides are similar.

Use the following reactions that involve Fe and Al compounds to answer parts (b) and (c).

In distilled water

Reaction 1: $Fe_2O_3(s) + 3\ H_2O(l) \rightarrow 2\ Fe(OH)_3(s)$

Reaction 2: $Al_2O_3(s) + 3\ H_2O(l) \rightarrow 2\ Al(OH)_3(s)$

In base

Reaction 3: $Fe(OH)_3(s) + NaOH(aq) \rightarrow$ no reaction

Reaction 4: $Al(OH)_3(s) + NaOH(aq) \rightarrow NaAl(OH)_4(aq)$

In acid

Reaction 5: $Fe(OH)_3(s) + 3\ HCl(aq) \rightarrow FeCl_3(aq) + 3\ H_2O(l)$

Reaction 6: $Al(OH)_3(s) + 3\ HCl(aq) \rightarrow AlCl_3(aq) + 3\ H_2O(l)$

Reaction 7: $NaAl(OH)_4(aq) + HCl(aq) \rightarrow Al(OH)_3(s) + NaCl(aq) + H_2O(l)$

When heated

Reaction 8: $2\ Fe(OH)_3(s) \xrightarrow{heat} Fe_2O_3(s) + 3\ H_2O(g)$

Reaction 9: $2\ Al(OH)_3(s) \xrightarrow{heat} Al_2O_3(s) + 3\ H_2O(g)$

Compound	K_{sp}
$Fe(OH)_3$	4×10^{-38}
$Al(OH)_3$	1×10^{-33}

(b) The K_{sp} values for $Fe(OH)_3$ and $Al(OH)_3$ are given in the table above. A 1.0 g sample of powdered $Fe_2O_3(s)$ and a 1.0 g sample of powdered $Al_2O_3(s)$ are mixed together and placed in 1.0 L of distilled water.

(i) Which ion, $Fe^{3+}(aq)$ or $Al^{3+}(aq)$, will be present in the higher concentration? Justify your answer with respect to the K_{sp} values provided.

(ii) Write a balanced chemical equation for the dissolution reaction that results in the production of the ion that you identified in part (i).

(c) Students are asked to develop a plan for separating $Al_2O_3(s)$ from a mixture of powdered $Fe_2O_3(s)$ and powdered $Al_2O_3(s)$ using chemical reactions and laboratory techniques.

(i) One student proposes that $Al_2O_3(s)$ can be separated from the mixture by adding water to the mixture and then filtering. Explain why this approach is not reasonable.

(ii) A second student organizes a plan using a table. The first two steps have already been entered in the table, as shown below. Complete the plan by listing the additional steps that are needed to recover the $Al_2O_3(s)$. List the steps in the correct order and refer to the appropriate reaction by number, if applicable.

Step	Description	Reaction(s)
1	Add NaOH(aq) to convert $Al_2O_3(s)$ to $Al(OH)_3(s)$ and then to $NaAl(OH)_4(aq)$.	2 and 4
2	Filter out the solid $Fe(OH)_3$ from the mixture and save the filtrate.	–
3		
4		
5		

(iii) The second student recovers 5.5 g of $Al_2O_3(s)$ from a 10.0 g sample of the mixture. Calculate the percent of Al by mass in the mixture of the two powdered oxides. (The molar mass of Al_2O_3 is 101.96 g/mol, and the molar mass of Fe_2O_3 is 159.70 g/mol.)

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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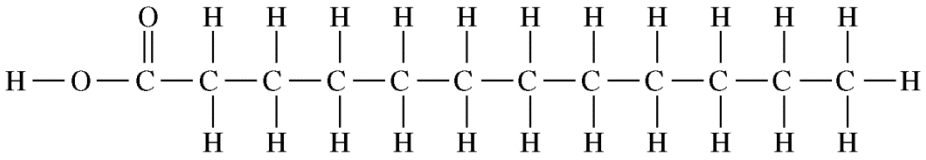
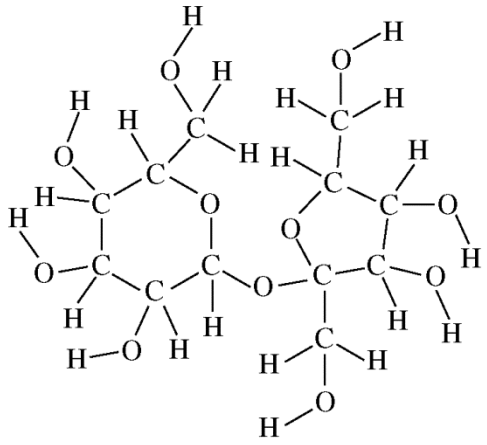


Lauric Acid



Sucrose

3. The structures of two compounds commonly found in food, lauric acid, $C_{12}H_{24}O_2$, and sucrose, $C_{12}H_{22}O_{11}$, are shown above.

   (a) Which compound, lauric acid or sucrose, is more soluble in water? Justify your answer in terms of the intermolecular forces present between water and each of the compounds.

   (b) Assume that a 1.5 g sample of lauric acid is combusted and all of the heat energy released is transferred to a 325 g sample of water initially at 25°C. Calculate the final temperature of the water if $\Delta H_{combustion}$ of lauric acid is −37 kJ/g and the specific heat of water is 4.18 J/(g·K).

   (c) In an attempt to determine $\Delta H_{combustion}$ of lauric acid experimentally, a student places a 1.5 g sample of lauric acid in a ceramic dish underneath a can made of Al containing 325 g of water at 25°C. The student ignites the sample of lauric acid with a match and records the highest temperature reached by the water in the can.

      (i) The experiment is repeated using a can of the same mass, but this time the can is made of Cu. The specific heat of Cu is 0.39 J/(g·K), and the specific heat of Al is 0.90 J/(g·K). Will the final temperature of the water in the can made of Cu be greater than, less than, or equal to the final temperature of the water in the can made of Al? Justify your answer.

      (ii) In both experiments it was observed that the measured final temperature of the water was less than the final temperature calculated in part (b). Identify one source of experimental error that might account for this discrepancy and explain why the error would make the measured final temperature of the water lower than predicted.

(d) The experiment described above is repeated using a 1.5 g sample of sucrose. The combustion reaction for sucrose in air is represented below.

$$C_{12}H_{22}O_{11}(s) + 12\ O_2(g) \rightarrow 12\ CO_2(g) + 11\ H_2O(g)$$

(i) Even though ΔG° for the combustion of sucrose in air has a value of $-5837\ \text{kJ/mol}_{rxn}$, the combustion reaction does not take place unless it is ignited. Explain.

(ii) Predict the sign of ΔS° for the reaction and justify your prediction.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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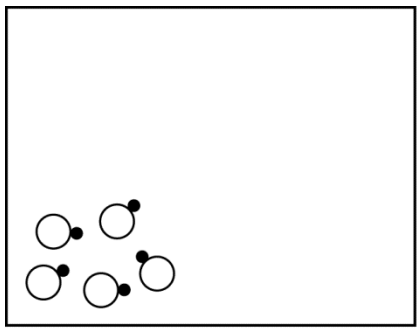
Molecule	Boiling Point of Compound (K)	Dipole Moment (debyes)	Polarizability (10^{-24} cm^3)
HCl	188	1.05	2.63
HBr	207	0.80	3.61
HI	238	0.38	5.44

4. The boiling points, dipole moments, and polarizabilities of three hydrogen halides are given in the table above.

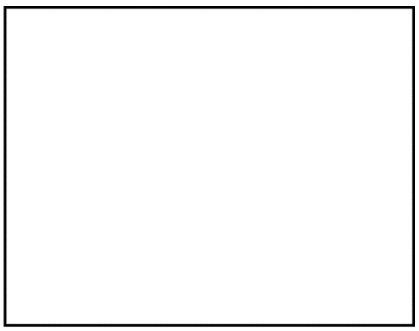
   (a) Based on the data in the table, what type of intermolecular force among the molecules HCl(*l*), HBr(*l*), and HI(*l*) is able to account for the trend in boiling points? Justify your answer.

   (b) Based on the data in the table, a student predicts that the boiling point of HF should be 174 K. The observed boiling point of HF is 293 K. Explain the failure of the student's prediction in terms of the types and strengths of the intermolecular forces that exist among HF molecules.

   (c) A representation of five molecules of HBr in the liquid state is shown in box 1 below. In box 2, draw a representation of the five molecules of HBr after complete vaporization has occurred.



Box 1



Box 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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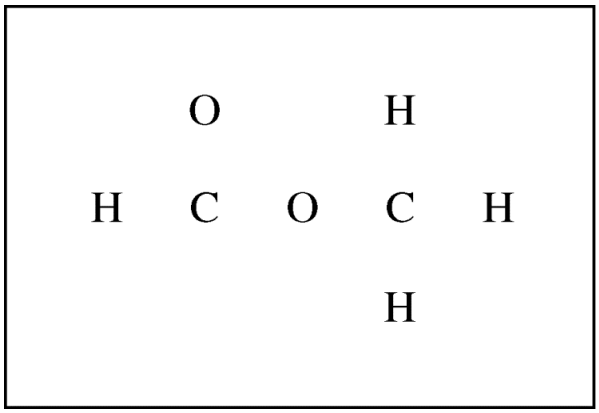
5. Answer the following questions about two isomers, methyl methanoate and ethanoic acid. The molecular formula of the compounds is $C_2H_4O_2$.

(a) Complete the Lewis electron-dot diagram of methyl methanoate in the box below. Show all valence electrons.



A student puts 0.020 mol of methyl methanoate into a previously evacuated rigid 1.0 L vessel at 450 K. The pressure is measured to be 0.74 atm. When the experiment is repeated using 0.020 mol of ethanoic acid instead of methyl methanoate, the measured pressure is lower than 0.74 atm. The lower pressure for ethanoic acid is due to the following reversible reaction.

$$CH_3COOH(g) + CH_3COOH(g) \rightleftarrows (CH_3COOH)_2(g)$$

(b) Assume that when equilibrium has been reached, 50. percent of the ethanoic acid molecules have reacted.

(i) Calculate the total pressure in the vessel at equilibrium at 450 K.

(ii) Calculate the value of the equilibrium constant, K_p, for the reaction at 450 K.

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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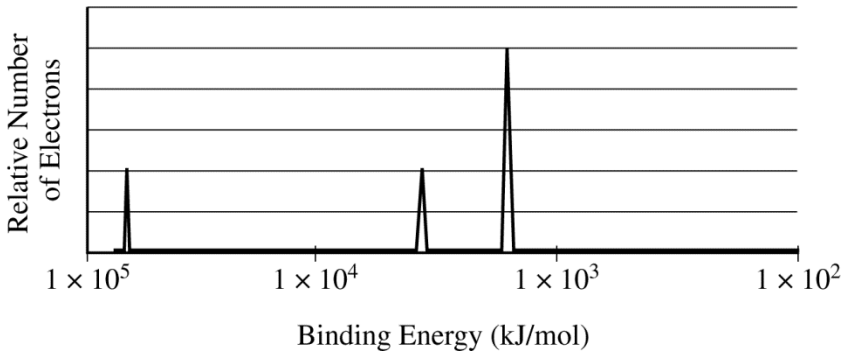
PHOTOELECTRON SPECTRUM



Peak 1	Peak 2	Peak 3
6.72×10^4 kJ/mol	3.88×10^3 kJ/mol	1.68×10^3 kJ/mol

6. The complete photoelectron spectrum of an unknown element is shown above. The frequency ranges of different regions of the electromagnetic spectrum are given in the table below.

Region of Electromagnetic Spectrum	Frequency Range (s^{-1})
Infrared (IR)	1×10^{12} to 4×10^{14}
Ultraviolet/visible (UV/vis)	4×10^{14} to 5×10^{16}
X-rays	5×10^{16} to 1×10^{19}
Gamma rays	$> 1 \times 10^{19}$

(a) To generate the spectrum above, a source capable of producing electromagnetic radiation with an energy of 7×10^4 kJ per mole of photons was used. Such radiation is from which region of the electromagnetic spectrum? Justify your answer with a calculation.

(b) A student examines the spectrum and proposes that the second ionization energy of the element is 3.88×10^3 kJ/mol. To refute the proposed interpretation of the spectrum, identify the following.

(i) The subshell from which an electron is removed in the second ionization of an atom of the element

(ii) The subshell that corresponds to the second peak of the photoelectron spectrum above

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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$$HC_9H_7O_4(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_9H_7O_4^-(aq)$$

7. The molecular formula of acetylsalicylic acid, also known as aspirin, is $HC_9H_7O_4$. The dissociation of $HC_9H_7O_4(aq)$ is represented by the equation above. The pH of 0.0100 *M* $HC_9H_7O_4(aq)$ is measured to be 2.78.

   (a) Write the expression for the equilibrium constant, K_a, for the reaction above.

   (b) Calculate the value of K_a for acetylsalicylic acid.

   (c) An aqueous solution of aspirin is buffered to have equal concentrations of $HC_9H_7O_4(aq)$ and $C_9H_7O_4^-(aq)$. Calculate the pH of the solution.

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 7

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

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

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

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

Multiple-Choice Answer Key

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

Answer Key for AP Chemistry Practice Exam, Section I

Question 1: A

Question 2: C

Question 3: D

Question 4: A

Question 5: C

Question 6: C

Question 7: C

Question 8: B

Question 9: A

Question 10: D

Question 11: B

Question 12: B

Question 13: A

Question 14: A

Question 15: D

Question 16: B

Question 17: C

Question 18: B

Question 19: B

Question 20: B

Question 21: D

Question 22: B

Question 23: C

Question 24: B

Question 25: C

Question 26: A

Question 27: B

Question 28: B

Question 29: B

Question 30: B

Question 31: D

Question 32: B

Question 33: D

Question 34: D

Question 35: C

Question 36: A

Question 37: B

Question 38: B

Question 39: A

Question 40: B

Question 41: C

Question 42: B

Question 43: B

Question 44: B

Question 45: B

Question 46: C

Question 47: A

Question 48: D

Question 49: D

Question 50: D

Free-Response Scoring Guidelines

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

AP® CHEMISTRY
2015 SCORING GUIDELINES

Question 1

Half-Reaction	$E°$ (V)
$2\ CO_2(g) + 12\ H^+(aq) + 12\ e^- \rightarrow C_2H_5OH(aq) + 3\ H_2O(l)$	− 0.085
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$	1.229

A student uses a galvanic cell to determine the concentration of ethanol, $C_2H_5OH(aq)$, in an aqueous solution. The cell is based on the half-cell reactions represented in the table above.

(a) Write a balanced equation for the overall reaction that occurs in the cell.

$C_2H_5OH(aq) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(l)$	1 point is earned for the correct reactants and products. 1 point is earned for balancing the equation.

(b) Calculate $E°$ for the overall reaction that occurs in the cell.

$E° = -(-0.085\ \text{V}) + 1.229\ \text{V} = +1.314\ \text{V}$	1 point is earned for a correct answer that is consistent with the equation in part (a).

(c) A 10.0 mL sample of $C_2H_5OH(aq)$ is put into the electrochemical cell. The cell produces an average current of 0.10 amp for 20. seconds, at which point the $C_2H_5OH(aq)$ has been totally consumed.

(i) Calculate the charge, in coulombs, that passed through the cell.

$I = \frac{q}{t} \Rightarrow q = It = 0.10\ \text{amp} \times 20.\ \text{s} = 2.0\ \text{C}$	1 point is earned for the correct charge.

(ii) Calculate the initial $[C_2H_5OH]$ in the solution.

$2.0\ \text{C} \times \frac{1\ \text{mol}\ e^-}{96{,}485\ \text{C}} \times \frac{1\ \text{mol}\ C_2H_5OH}{12\ \text{mol}\ e^-} = 1.7 \times 10^{-6}\ \text{mol}\ C_2H_5OH$	1 point is earned for the number of moles of C_2H_5OH.
$\frac{1.7 \times 10^{-6}\ \text{mol}\ C_2H_5OH}{10.0\ \text{mL}} \times \frac{1000\ \text{mL}}{1.0\ \text{L}} = 1.7 \times 10^{-4}\ M$	1 point is earned for the initial molarity of C_2H_5OH.

Question 1 (continued)

An alternative approach to determine the concentration of $C_2H_5OH(aq)$ in a solution is based on the reaction represented below.

$$3\ C_2H_5OH(aq) + 2\ Cr_2O_7^{2-}(aq) + 16\ H^+(aq) \rightarrow 4\ Cr^{3+}(aq) + 3\ CH_3COOH(aq) + 11\ H_2O(l)$$
orange *blue-green*

A solution has an initial $Cr_2O_7^{2-}(aq)$ concentration of $1.0 \times 10^{-3}\ M$ and an initial $C_2H_5OH(aq)$ concentration of 0.500 *M*. The solution contains enough strong acid to keep the pH essentially constant throughout the reaction. The student places a sample of the solution in a cuvette that has a path length of 0.50 cm and places it in a spectrophotometer set to measure absorbance at 440 nm. ($Cr_2O_7^{2-}(aq)$ is the only species in the reaction mixture that absorbs light at this wavelength.) The absorbance of $Cr_2O_7^{2-}(aq)$ in the solution is monitored as the reaction proceeds; the table below shows the absorbance as a function of time for the first trial.

Time (min)	Absorbance at 440 nm
0.00	0.782
1.50	0.553
3.00	0.389
4.50	0.278
6.00	0.194

(d) Calculate the value of $[Cr_2O_7^{2-}]$ at 1.50 min.

Absorbance is proportional to $[Cr_2O_7^{2-}]$. $\frac{1.0 \times 10^{-3}\ M}{0.782} = \frac{x}{0.553}$ $x = 7.1 \times 10^{-4}\ M$ OR Initial condition: $a = \frac{A}{bc} = \frac{0.782}{(0.50\ \text{cm})(1.0 \times 10^{-3}\ M)} = 1564\ M^{-1}\,\text{cm}^{-1}$ At 1.50 min: $c = \frac{A}{ab} = \frac{0.553}{(1564\ M^{-1}\,\text{cm}^{-1})(0.50\ \text{cm})} = 7.1 \times 10^{-4}\ M$	1 point is earned for the correct concentration.

Question 1 (continued)

(e) The student runs a second trial but this time uses a cuvette that has a path length of 1.00 cm. Describe how the experimental setup should be adjusted to keep the initial absorbance at 0.782. Justify your answer with respect to the factors that influence the absorbance of a sample in a spectrophotometer.

$A = abc$ If path length (b) is doubled, and molar absorptivity (a) is constant, the initial concentration of $Cr_2O_7^{2-}$ (c) must be halved to keep the initial absorbance (A) constant.	1 point is earned for reference to a factor that affects absorbance. 1 point is earned for the correct adjustment.

For the concentrations of reactants used in the experiment, the rate of the reaction can be written as follows.

$$\text{Rate} = k_{observed}[Cr_2O_7^{2-}]^y, \text{ where } k_{observed} = k[C_2H_5OH]$$

(f) Explain how the experimental data indicate that the reaction is first order with respect to $Cr_2O_7^{2-}$.

Absorbance is proportional to concentration of $Cr_2O_7^{2-}$. Absorbance is halved after 3.00 min and again after another 3.00 min. Thus the half-life of the reaction is constant, so the reaction must be first order with respect to $Cr_2O_7^{2-}$. OR Demonstration that the rate of change in ln(A) over time is constant.	1 point is earned for a correct explanation that uses the data.

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Question 2

Answer the following questions about Fe and Al compounds.

(a) $Fe_2O_3(s)$ and $Al_2O_3(s)$ have similar chemical properties; some similarities are due to the oxides having similar lattice energies. Give two reasons why the lattice energies of the oxides are similar.

Fe^{3+} and Al^{3+} have similar sizes (radii). Fe^{3+} and Al^{3+} have the same charge.	1 point is earned for <u>each</u> reason.

Use the following reactions that involve Fe and Al compounds to answer parts (b) and (c).

<u>In distilled water</u>

Reaction 1: $Fe_2O_3(s) + 3\ H_2O(l) \rightarrow 2\ Fe(OH)_3(s)$

Reaction 2: $Al_2O_3(s) + 3\ H_2O(l) \rightarrow 2\ Al(OH)_3(s)$

<u>In base</u>

Reaction 3: $Fe(OH)_3(s) + NaOH(aq) \rightarrow$ no reaction

Reaction 4: $Al(OH)_3(s) + NaOH(aq) \rightarrow NaAl(OH)_4(aq)$

<u>In acid</u>

Reaction 5: $Fe(OH)_3(s) + 3\ HCl(aq) \rightarrow FeCl_3(aq) + 3\ H_2O(l)$

Reaction 6: $Al(OH)_3(s) + 3\ HCl(aq) \rightarrow AlCl_3(aq) + 3\ H_2O(l)$

Reaction 7: $NaAl(OH)_4(aq) + HCl(aq) \rightarrow Al(OH)_3(s) + NaCl(aq) + H_2O(l)$

<u>When heated</u>

Reaction 8: $2\ Fe(OH)_3(s) \xrightarrow{heat} Fe_2O_3(s) + 3\ H_2O(g)$

Reaction 9: $2\ Al(OH)_3(s) \xrightarrow{heat} Al_2O_3(s) + 3\ H_2O(g)$

Compound	K_{sp}
$Fe(OH)_3$	4×10^{-38}
$Al(OH)_3$	1×10^{-33}

(b) The K_{sp} values for $Fe(OH)_3$ and $Al(OH)_3$ are given in the table above. A 1.0 g sample of powdered $Fe_2O_3(s)$ and a 1.0 g sample of powdered $Al_2O_3(s)$ are mixed together and placed in 1.0 L of distilled water.

(i) Which ion, $Fe^{3+}(aq)$ or $Al^{3+}(aq)$, will be present in the higher concentration? Justify your answer with respect to the K_{sp} values provided.

Question 2 (continued)

Al^{3+} will be present in higher concentration. $Al(OH)_3$ has the same stoichiometry as $Fe(OH)_3$ but a greater K_{sp}.	1 point is earned for the correct choice and explanation.

(ii) Write a balanced chemical equation for the dissolution reaction that results in the production of the ion that you identified in part (i).

$Al(OH)_3(s) \rightarrow Al^{3+}(aq) + 3\ OH^-(aq)$ OR $Al_2O_3(s) + 3\ H_2O(l) \rightarrow 2\ Al^{3+}(aq) + 6\ OH^-(aq)$	1 point is earned for a balanced equation.

(c) Students are asked to develop a plan for separating $Al_2O_3(s)$ from a mixture of powdered $Fe_2O_3(s)$ and powdered $Al_2O_3(s)$ using chemical reactions and laboratory techniques.

(i) One student proposes that $Al_2O_3(s)$ can be separated from the mixture by adding water to the mixture and then filtering. Explain why this approach is not reasonable.

This approach only works when there is a significant difference in water solubility between two substances.	1 point is earned for a correct explanation.

(ii) A second student organizes a plan using a table. The first two steps have already been entered in the table, as shown below. Complete the plan by listing the additional steps that are needed to recover the $Al_2O_3(s)$. List the steps in the correct order and refer to the appropriate reaction by number, if applicable.

Question 2 (continued)

Step	Description	Reaction(s)
1	Add NaOH(*aq*) to convert $Al_2O_3(s)$ to $Al(OH)_3(s)$ and then to $NaAl(OH)_4(aq)$.	2 and 4
2	Filter out the solid $Fe(OH)_3$ from the mixture and save the filtrate.	–
3	Add HCl to the filtrate until a precipitate of $Al(OH)_3$ forms.	7
4	Filter out the solid $Al(OH)_3$.	–
5	Heat the solid $Al(OH)_3$ to form Al_2O_3.	9

(See rows 3-5 in table.)	1 point is earned for each correct row (description plus reaction number, if applicable).

(iii) The second student recovers 5.5 g of $Al_2O_3(s)$ from a 10.0 g sample of the mixture. Calculate the percent of Al by mass in the mixture of the two powdered oxides. (The molar mass of Al_2O_3 is 101.96 g/mol, and the molar mass of Fe_2O_3 is 159.70 g/mol.)

$5.5 \text{ g } Al_2O_3 \times \frac{1 \text{ mol } Al_2O_3}{101.96 \text{ g } Al_2O_3} \times \frac{2 \text{ mol Al}}{1 \text{ mol } Al_2O_3} \times \frac{26.98 \text{ g Al}}{1 \text{ mol Al}} = 2.9 \text{ g Al}$ $\frac{2.9 \text{ g}}{10.0 \text{ g}} \times 100 = 29\%$	1 point is earned for the number of grams of Al. 1 point is earned for the mass percent Al.

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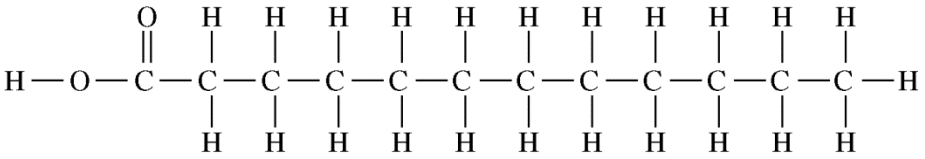
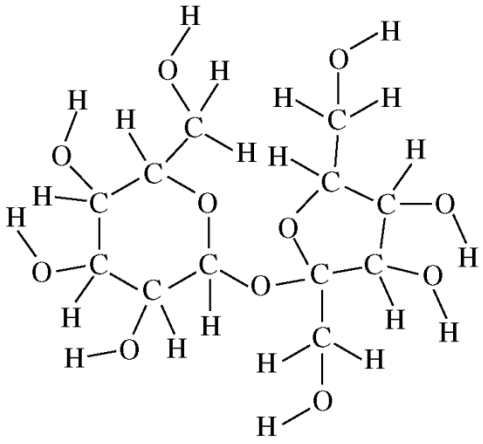
Question 3



Lauric Acid



Sucrose

The structures of two compounds commonly found in food, lauric acid, $C_{12}H_{24}O_2$, and sucrose, $C_{12}H_{22}O_{11}$, are shown above.

(a) Which compound, lauric acid or sucrose, is more soluble in water? Justify your answer in terms of the intermolecular forces present between water and each of the compounds.

Sucrose is more soluble than lauric acid. Stronger interactions occur between sucrose and water molecules due to a greater capacity for hydrogen bonding as a result of a larger number of $-OH$ groups in sucrose. Although lauric acid molecules have one site for hydrogen bonding, the long hydrocarbon chain causes London dispersion forces to be the predominant, yet weaker, interaction with water molecules.	1 point is earned for discussion of hydrogen bonding between each substance and water. 1 point is earned for a valid conclusion about solubility based on a comparison of these forces.

(b) Assume that a 1.5 g sample of lauric acid is combusted and all of the heat energy released is transferred to a 325 g sample of water initially at 25°C. Calculate the final temperature of the water if $\Delta H_{combustion}$ of lauric acid is −37 kJ/g and the specific heat of water is 4.18 J/(g·K).

Question 3 (continued)

37 kJ/g × 1.5 g = 56 kJ released $q = mc\Delta T \Rightarrow \Delta T = \frac{q}{mc} = \frac{56{,}000 \text{ J}}{(325 \text{ g})(4.18 \text{ J/(g·K)})} = 41 \text{ K } (41°C)$ Final temperature = 25°C + 41°C = 66°C	1 point is earned for heat released. 1 point is earned for a final temperature consistent with the heat released.

(c) In an attempt to determine $\Delta H_{combustion}$ of lauric acid experimentally, a student places a 1.5 g sample of lauric acid in a ceramic dish underneath a can made of Al containing 325 g of water at 25°C. The student ignites the sample of lauric acid with a match and records the highest temperature reached by the water in the can.

(i) The experiment is repeated using a can of the same mass, but this time the can is made of Cu. The specific heat of Cu is 0.39 J/(g·K), and the specific heat of Al is 0.90 J/(g·K). Will the final temperature of the water in the can made of Cu be greater than, less than, or equal to the final temperature of the water in the can made of Al? Justify your answer.

The temperature will be greater in the can made of Cu. Since Cu has a lower specific heat than Al, more heat will be absorbed by the water in the Cu can than the water in the Al can.	1 point is earned for the correct answer. 1 point is earned for an appropriate explanation.

(ii) In both experiments it was observed that the measured final temperature of the water was less than the final temperature calculated in part (b). Identify one source of experimental error that might account for this discrepancy and explain why the error would make the measured final temperature of the water lower than predicted.

Possible answers include: Heat is lost to the environment. The temperature of the water is lower because less heat is transferred to the water. OR Heat is transferred to the can or thermometer. The temperature of the water is lower because less heat is transferred to the water. OR Incomplete combustion of the lauric acid. The temperature of the water is lower because less heat was released from the combustion reaction.	1 point is earned for a valid source of error. 1 point is earned for an acceptable explanation.

Question 3 (continued)

(d) The experiment described above is repeated using a 1.5 g sample of sucrose. The combustion reaction for sucrose in air is represented below.

$$C_{12}H_{22}O_{11}(s) + 12\ O_2(g) \rightarrow 12\ CO_2(g) + 11\ H_2O(g)$$

(i) Even though ΔG° for the combustion of sucrose in air has a value of −5837 kJ/mol$_{rxn}$, the combustion reaction does not take place unless it is ignited. Explain.

The reaction has a high activation energy. The ignition source provides energy to the molecules; some of them can then overcome the activation energy barrier. The reaction is exothermic, so the heat released allows the reaction to continue.	1 point is earned for a correct explanation.

(ii) Predict the sign of ΔS° for the reaction and justify your prediction.

ΔS° for the reaction is positive; there are 23 moles of gaseous products for every 12 moles of gaseous reactant.	1 point is earned for the correct sign and justification.

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Question 4

Molecule	Boiling Point of Compound (K)	Dipole Moment (debyes)	Polarizability (10^{-24} cm^3)
HCl	188	1.05	2.63
HBr	207	0.80	3.61
HI	238	0.38	5.44

The boiling points, dipole moments, and polarizabilities of three hydrogen halides are given in the table above.

(a) Based on the data in the table, what type of intermolecular force among the molecules HCl(*l*), HBr(*l*), and HI(*l*) is able to account for the trend in boiling points? Justify your answer.

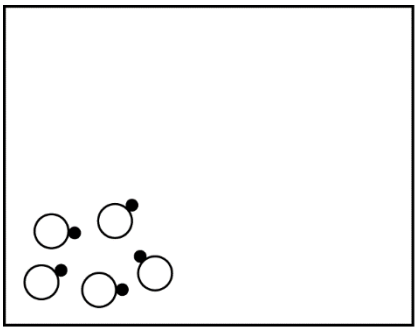
London dispersion forces account for the trend in boiling points. As polarizability of the molecules increases, so does the boiling point of the substance. London dispersion forces depend upon the polarizability of molecules, thus more polarizable molecules have stronger intermolecular forces.	1 point is earned for identifying London dispersion forces. 1 point is earned for explaining the link between polarizability and boiling point.

(b) Based on the data in the table, a student predicts that the boiling point of HF should be 174 K. The observed boiling point of HF is 293 K. Explain the failure of the student's prediction in terms of the types and strengths of the intermolecular forces that exist among HF molecules.

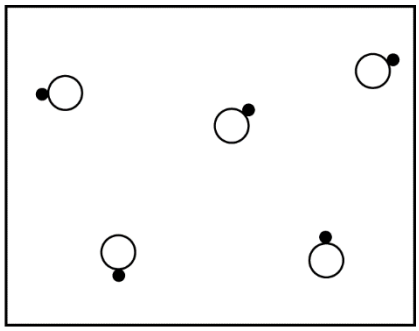
HF molecules have London dispersion forces and hydrogen bonding. The hydrogen bonding is stronger than both regular dipole-dipole forces and London dispersion forces and accounts for HF's higher boiling point.	1 point is earned for a correct explanation.

Question 4 (continued)

(c) A representation of five molecules of HBr in the liquid state is shown in box 1 below. In box 2, draw a representation of the five molecules of HBr after complete vaporization has occurred.



Box 1



Box 2

The drawing in Box 2 should show the undissociated molecules randomly distributed throughout the box.	1 point is earned for an acceptable diagram.

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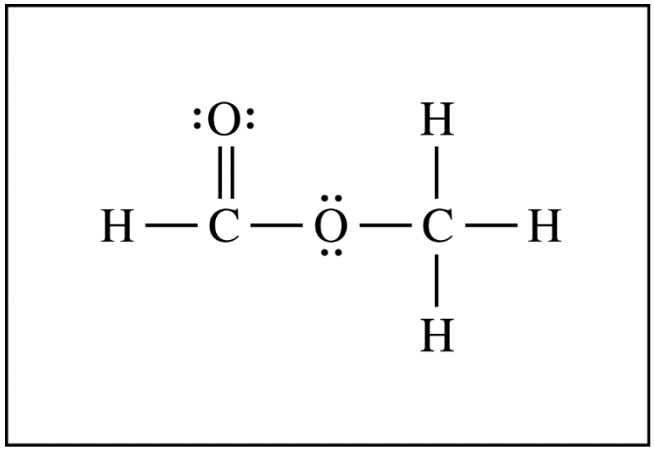
Question 5

Answer the following questions about two isomers, methyl methanoate and ethanoic acid. The molecular formula of the compounds is $C_2H_4O_2$.

(a) Complete the Lewis electron-dot diagram of methyl methanoate in the box below. Show all valence electrons.



See diagram above. (Note: A pair of electrons can be drawn as a pair of dots or a line segment.)	1 point is earned for a correct diagram.

A student puts 0.020 mol of methyl methanoate into a previously evacuated rigid 1.0 L vessel at 450 K. The pressure is measured to be 0.74 atm. When the experiment is repeated using 0.020 mol of ethanoic acid instead of methyl methanoate, the measured pressure is lower than 0.74 atm. The lower pressure for ethanoic acid is due to the following reversible reaction.

$$CH_3COOH(g) + CH_3COOH(g) \rightleftarrows (CH_3COOH)_2(g)$$

(b) Assume that when equilibrium has been reached, 50. percent of the ethanoic acid molecules have reacted.

Question 5 (continued)

(i) Calculate the total pressure in the vessel at equilibrium at 450 K.

Let $n_{initial}$ be the number of moles of gas particles before any reaction occurs. Because 50. percent of the molecules reacted, $n_{final} = 0.75\ n_{initial}$. $\frac{P_{initial}}{n_{initial}} = \frac{P_{final}}{n_{final}}$ $n_{CH_3COOH} = \frac{0.020\text{ mol}}{2} = 0.010\text{ mol}$ $n_{(CH_3COOH)_2} = \frac{0.010\text{ mol}}{2} = 0.0050\text{ mol}$ $P_{final} = \frac{(P_{initial})(n_{final})}{n_{initial}} = \frac{(0.74\text{ atm})(0.015\text{ mol gas particles})}{0.020\text{ mol gas particles}} = 0.56\text{ atm}$ OR $PV = nRT$ $P = \frac{(0.015\text{ mol})(0.08206\text{ L atm mol}^{-1}\text{ K}^{-1})(450\text{ K})}{1.0\text{ L}} = 0.55\text{ atm}$	1 point is earned for the correct pressure.

(ii) Calculate the value of the equilibrium constant, K_p, for the reaction at 450 K.

$P = 0.56$ atm Mole fraction $CH_3COOH = \frac{0.010\text{ mol}}{0.015\text{ mol}} = \frac{2}{3}$ Mole fraction $(CH_3COOH)_2 = \frac{0.0050\text{ mol}}{0.015\text{ mol}} = \frac{1}{3}$ $P_{CH_3COOH} = \frac{2}{3}(0.56\text{ atm}) = 0.37\text{ atm}$ $P_{(CH_3COOH)_2} = \frac{1}{3}(0.56\text{ atm}) = 0.19\text{ atm}$ $K_p = \frac{(P_{(CH_3COOH)_2})}{(P_{(CH_3COOH)})^2} = \frac{0.19}{(0.37)^2} = 1.4$	1 point is earned for the correct partial pressures. 1 point is earned for an answer that uses partial pressures correctly.

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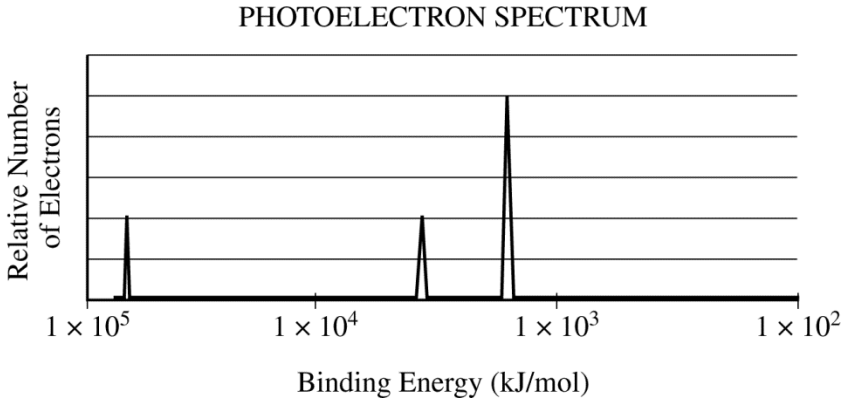
Question 6



Peak 1	Peak 2	Peak 3
6.72×10^4 kJ/mol	3.88×10^3 kJ/mol	1.68×10^3 kJ/mol

The complete photoelectron spectrum of an unknown element is shown above. The frequency ranges of different regions of the electromagnetic spectrum are given in the table below.

Region of Electromagnetic Spectrum	Frequency Range (s^{-1})
Infrared (IR)	1×10^{12} to 4×10^{14}
Ultraviolet/visible (UV/vis)	4×10^{14} to 5×10^{16}
X-rays	5×10^{16} to 1×10^{19}
Gamma rays	$> 1 \times 10^{19}$

(a) To generate the spectrum above, a source capable of producing electromagnetic radiation with an energy of 7×10^4 kJ per mole of photons was used. Such radiation is from which region of the electromagnetic spectrum? Justify your answer with a calculation.

$\frac{7 \times 10^4 \text{ kJ}}{1 \text{ mol photons}} \times \frac{1 \text{ mol photons}}{6.022 \times 10^{23} \text{ photons}} = 1.16 \times 10^{-19} \frac{\text{kJ}}{\text{photon}}$ $= 1 \times 10^{-19} \frac{\text{kJ}}{\text{photon}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} = 1 \times 10^{-16} \frac{\text{J}}{\text{photon}}$ $\nu = \frac{E}{h} = \frac{1.16 \times 10^{-16} \text{ J}}{6.626 \times 10^{-34} \text{ J s}} = 1.75 \times 10^{17} \text{ s}^{-1} = 2 \times 10^{17} \text{ s}^{-1}$ The radiation is in the X-ray region.	1 point is earned for calculating the amount of energy per photon. 1 point is earned for the frequency and region of the spectrum.

Question 6 (continued)

(b) A student examines the spectrum and proposes that the second ionization energy of the element is 3.88×10^3 kJ/mol. To refute the proposed interpretation of the spectrum, identify the following.

(i) The subshell from which an electron is removed in the second ionization of an atom of the element

$2p$	1 point is earned for the correct answer.

(ii) The subshell that corresponds to the second peak of the photoelectron spectrum above

$2s$	1 point is earned for the correct answer.

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Question 7

$$HC_9H_7O_4(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_9H_7O_4^-(aq)$$

The molecular formula of acetylsalicylic acid, also known as aspirin, is $HC_9H_7O_4$. The dissociation of $HC_9H_7O_4(aq)$ is represented by the equation above. The pH of 0.0100 M $HC_9H_7O_4(aq)$ is measured to be 2.78.

(a) Write the expression for the equilibrium constant, K_a, for the reaction above.

$K_a = \dfrac{[H_3O^+][C_9H_7O_4^-]}{[HC_9H_7O_4]}$	1 point is earned for the correct expression.

(b) Calculate the value of K_a for acetylsalicylic acid.

$[H_3O^+] = 10^{-pH} = 10^{-2.78} = 1.66 \times 10^{-3}\ M$ $[H_3O^+] = [C_9H_7O_4^-] = 1.66 \times 10^{-3}\ M$ $[HC_9H_7O_4] = 0.0100\ M - 1.66 \times 10^{-3}\ M$ $K_a = \dfrac{(1.66 \times 10^{-3})^2}{0.0100 - (1.66 \times 10^{-3})} = 3.3 \times 10^{-4}$	1 point is earned for the correct $[H_3O^+]$. 1 point is earned for the value of K_a.

(c) An aqueous solution of aspirin is buffered to have equal concentrations of $HC_9H_7O_4(aq)$ and $C_9H_7O_4^-(aq)$. Calculate the pH of the solution.

$pH = pK_a + \log \dfrac{[C_9H_7O_4^-]}{[HC_9H_7O_4]}$ $= -\log(3.3 \times 10^{-4}) + 0$ $= 3.48$	1 point is earned for a pH consistent with the K_a calculated in part (b).

Scoring Worksheet

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

2015 AP Chemistry Scoring Worksheet

Section I: Multiple Choice

_____	× 1.0000 =	_____
Number Correct (out of 50)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 10)	× 1.0869 =	_____ (Do not round)
Question 2	_____ (out of 10)	× 1.0869 =	_____ (Do not round)
Question 3	_____ (out of 10)	× 1.0869 =	_____ (Do not round)
Question 4	_____ (out of 4)	× 1.0869 =	_____ (Do not round)
Question 5	_____ (out of 4)	× 1.0869 =	_____ (Do not round)
Question 6	_____ (out of 4)	× 1.0869 =	_____ (Do not round)
Question 7	_____ (out of 4)	× 1.0869 =	_____ (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
Chemistry

Composite Score Range	AP Score
69-100	5
53-68	4
36-52	3
25-35	2
0-24	1

AP Chemistry

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