From the 2017 Administration

AP CollegeBoard

Chemistry

Practice Exam

NOTE: This is a modified version of the 2017 AP Chemistry Exam.

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Further distribution of these materials outside of the secure College Board site disadvantages teachers who rely on uncirculated questions for classroom testing. Any additional distribution is in violation of the College Board's copyright policies and may result in the termination of Practice Exam access for your school as well as the removal of access to other online services such as the AP Teacher Community and Online Score Reports.

Contents

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

Exam Instructions

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

AP® Chemistry Exam

Regularly Scheduled Exam Date: Monday morning, May 1, 2017
Late-Testing Exam Date: Thursday afternoon, May 18, 2017

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)*

What Proctors Need to Bring to This Exam

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

Before Distributing Exams: Check that the title on all exam covers is **Chemistry.** If there are any exam booklets with a different title, contact the AP coordinator immediately.

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

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

If you are giving the regularly scheduled exam, say:

It is Monday morning, May 1, 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 18, 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 *2016-17 Bulletin for AP Students and Parents*.

Look at your exam packet and confirm that the exam title is "AP Chemistry." Raise your hand if your exam packet contains any title other than "AP Chemistry" and I will help you.

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

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

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

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

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

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

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

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

Are there any questions? . . .

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

Open your answer sheet to page 2. The answer sheet has circles A–E for each question. For Chemistry, you will use only the circles marked A–D. 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, notes, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic or communication device. Remember, you may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled. Are there any questions? . . .

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

SECTION II: Free Response

After the break, say:

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

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

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

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

Read the last statement. . . .

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

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

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

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

Read Item 4. . . .

Are there any questions? . . .

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

Read the information on the back cover of the exam booklet. Do not open the 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 question number you are working on. Do not write your name. Are there any questions? . . .

You may begin.

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

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

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

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

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

If you are giving the regularly scheduled exam, say:

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

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

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

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

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

Then say:

You are now dismissed.

Post-Exam Tasks

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

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

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

- Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2016-17 AP Coordinator's Manual.*
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2017

AP Number Label
(from Student Pack)

123456789

AP Exam Label
(from Section I Booklet)

CollegeBoard

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

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

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

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

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

C. YOUR AP NUMBER

D. EXAM DATE Month Day

E. EXAM START TIME AM PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

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

792107

SCHOOL USE ONLY
Section Number 1 2 3 4 5 6 7 8 9
Fee Reduction Granted 1 Option 1 2 Option 2

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

L. SOCIAL SECURITY NUMBER (Optional)

COMPLETE THIS AREA ONLY ONCE.

J. SCHOOL YOU ATTEND
SCHOOL CODE
School Name
City
State
Country

K. DATE OF BIRTH
Month Day Year
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT
COLLEGE CODE
Using the college code listed in the AP Student Pack, indicate the **ONE** college that you want to receive your AP score report.
College Name
City
State
Country

N. CURRENT GRADE LEVEL
Not yet in 9th grade
9th
10th
11th
12th
No longer in high school

O. STUDENT SEARCH SERVICE®
Colleges and scholarship programs may request your information to inform you of educational opportunities and financial aid.
Would you like us to supply your information?
Yes No
If you don't answer and previously chose to participate in this service, we will continue providing your information.

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COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

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

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

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

◯ Yes ◯ No

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

◯ Yes ◯ No

QUESTIONS 1–75

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

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS

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

1 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	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 Computer Science Principles, AP Physics 1, or AP Physics 2

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

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

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

R. YOUR MAILING ADDRESS

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

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

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

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

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

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. RACIAL/ETHNIC GROUP

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

(You may mark all that apply.)

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

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

b. What is your race?

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

Y. PARENTAL EDUCATION LEVEL

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

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

Section I: Multiple-Choice Questions

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

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

AP® Chemistry Exam

SECTION I: Multiple Choice

2017

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
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.

Form I
Form Code 4NBP4-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

$$PV = nRT$$

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

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

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

$$\text{K} = \text{°C} + 273$$

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

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

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

$$q = mc\Delta T$$

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

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

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

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

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

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

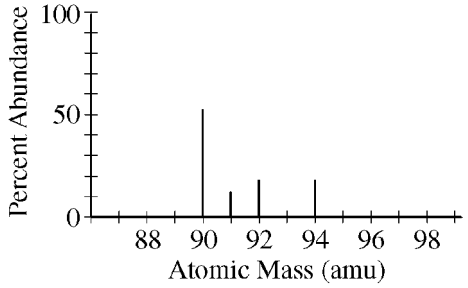
50 Questions

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. The mass spectrum of an average sample of a pure element is shown in the figure above. Which of the following is the identity of the element?

   (A) Y
   (B) Zr
   (C) Nb
   (D) Th

2. The ideal gas law best describes the properties of which of the following gases at 0°C and 1 atm?

   (A) PH_3
   (B) HBr
   (C) SO_2
   (D) N_2

3. At 298 K and 1 atm, Br_2 is a liquid with a high vapor pressure, and Cl_2 is a gas. Those observations provide evidence that under the given conditions, the

   (A) forces among Br_2 molecules are stronger than those among Cl_2 molecules
   (B) forces among Cl_2 molecules are stronger than the Cl–Cl bond
   (C) Br–Br bond is stronger than the Cl–Cl bond
   (D) Cl–Cl bond is stronger than the Br–Br bond

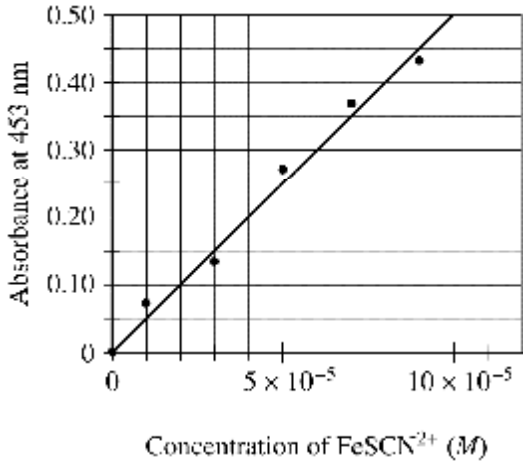
4. Which of the following has the bonds arranged in order of decreasing polarity?

   (A) H–F > N–F > F–F
   (B) H–I > H–Br > H–F
   (C) O–N > O–S > O–Te
   (D) Sb–I > Sb–Te > Sb–Cl

GO ON TO THE NEXT PAGE.

$$Fe^{3+}(aq) + KSCN(s) \rightarrow FeSCN^{2+}(aq) + K^{+}(aq)$$

5. To determine the moles of $Fe^{3+}(aq)$ in a 100. mL sample of an unknown solution, excess $KSCN(s)$ is added to convert all the $Fe^{3+}(aq)$ into the dark red species $FeSCN^{2+}(aq)$, as represented by the equation above. The absorbance of $FeSCN^{2+}(aq)$ at different concentrations is shown in the graph below.



If the absorbance of the mixture is 0.20 at 453 nm, how many moles of $Fe^{3+}(aq)$ were present in the 100. mL sample? (Assume that any volume change due to adding the $KSCN(s)$ is negligible.)

(A) 4×10^{-4} mol
(B) 3×10^{-4} mol
(C) 4×10^{-6} mol
(D) 3×10^{-6} mol

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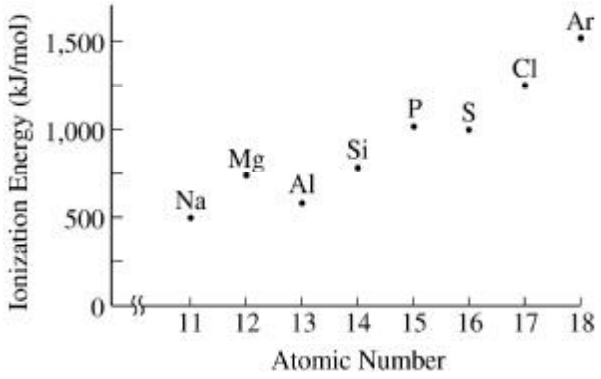
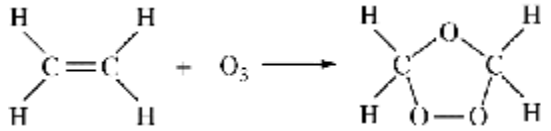


6. The first ionization energy of an element is the energy required to remove an electron from a gaseous atom of the element (i.e., $X(g) \rightarrow X^+(g) + e^-$). The values of the first ionization energies for the third-row elements are shown in the graph above. On the basis of the information given, which of the following reactions is exothermic?

(A) $Cl(g) + Mg^+(g) \rightarrow Cl^+(g) + Mg(g)$
(B) $Al(g) + Mg^+(g) \rightarrow Al^+(g) + Mg(g)$
(C) $P(g) + Mg^+(g) \rightarrow P^+(g) + Mg(g)$
(D) $S(g) + Mg^+(g) \rightarrow S^+(g) + Mg(g)$



7. In the reaction represented above, what is the hybridization of the C atoms before and after the reaction occurs?

	Before	After
(A)	sp	sp^2
(B)	sp	sp^3
(C)	sp^2	sp
(D)	sp^2	sp^3

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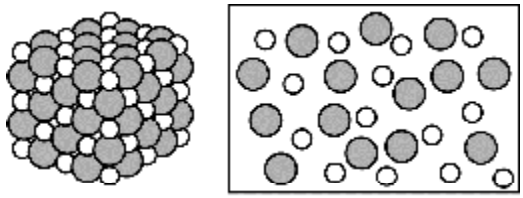

Solid MgO Liquid MgO

8. Based on the diagram above, which of the following best helps to explain why MgO(*s*) is not able to conduct electricity, but MgO(*l*) is a good conductor of electricity?

   (A) MgO(*s*) does not contain free electrons, but MgO(*l*) contains free electrons that can flow.

   (B) MgO(*s*) contains no water, but MgO(*l*) contains water that can conduct electricity.

   (C) MgO(*s*) consists of separate Mg^{2+} ions and O^{2-} ions, but MgO(*l*) contains MgO molecules that can conduct electricity.

   (D) MgO(*s*) consists of separate Mg^{2+} ions and O^{2-} ions held in a fixed lattice, but in MgO(*l*) the ions are free to move and conduct electricity.

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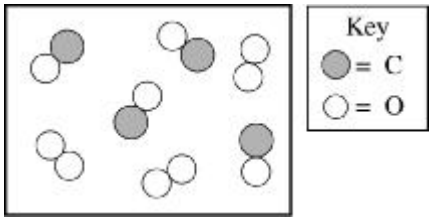
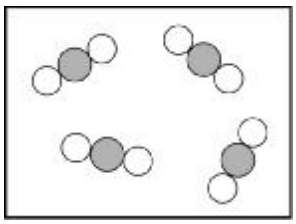
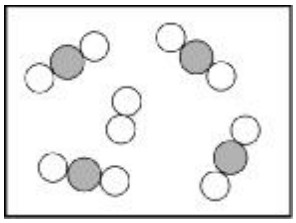
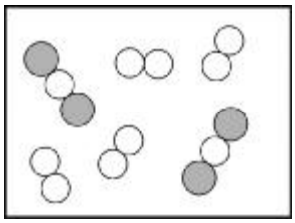
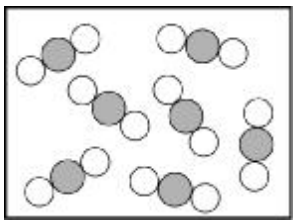


9. A mixture of $CO(g)$ and $O_2(g)$ is placed in a container, as shown above. A reaction occurs, forming $CO_2(g)$. Which of the following best represents the contents of the box after the reaction has proceeded as completely as possible?

(A) 

(B) 

(C) 

(D) 

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Questions 10-13 refer to the following information.

$$Cu(s) + 4\ HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ NO_2(g) + 2\ H_2O(l)$$

Each student in a class placed a 2.00 g sample of a mixture of Cu and Al in a beaker and placed the beaker in a fume hood. The students slowly poured 15.0 mL of 15.8 *M* $HNO_3(aq)$ into their beakers. The reaction between the copper in the mixture and the $HNO_3(aq)$ is represented by the equation above. The students observed that a brown gas was released from the beakers and that the solutions turned blue, indicating the formation of $Cu^{2+}(aq)$. The solutions were then diluted with distilled water to known volumes.

10. Which of the following is true about the reaction?

(A) It is a Brønsted-Lowry acid-base reaction, because the solution is neutral at the end.

(B) It is a Brønsted-Lowry acid-base reaction, because $HNO_3(aq)$ is a strong acid.

(C) It is a redox reaction, because $Cu(s)$ is oxidized and $H^+(aq)$ is reduced.

(D) It is a redox reaction, because $Cu(s)$ is oxidized and the nitrogen atom in $NO_3^-(aq)$ is reduced.

$[Cu^{2+}]$	Absorbance
0.025	0.059
0.050	0.235
0.100	0.117
0.200	0.468
Unknown (from sample of mixture)	0.330

11. To determine the number of moles of Cu in the sample of the mixture, the students measured the absorbance of known concentrations of $Cu(NO_3)_2(aq)$ using a spectrophotometer. A cuvette filled with some of the solution produced from the sample of the mixture was also tested. The data recorded by one student are shown in the table above. On the basis of the data provided, which of the following is a possible error that the student made?

(A) The $Cu(NO_3)_2(aq)$ from the sample of the mixture was not diluted properly.

(B) The spectrophotometer was calibrated with tap water instead of distilled water.

(C) The student labeled the cuvettes incorrectly, reversing the labels on two of the solutions of known concentration.

(D) The spectrophotometer was originally set to an inappropriate wavelength, causing the absorbance to vary unpredictably.

GO ON TO THE NEXT PAGE.

12. The students determined that the reaction produced 0.010 mol of $Cu(NO_3)_2$. Based on the measurement, what was the percent of Cu by mass in the original 2.00 g sample of the mixture?

(A) 16%
(B) 32%
(C) 64%
(D) 96%

13. In one student's experiment the reaction proceeded at a much slower rate than it did in the other students' experiments. Which of the following could explain the slower reaction rate?

(A) In the student's sample the metal pieces were much smaller than those in the other students' samples.
(B) The student heated the reaction mixture as the $HNO_3(aq)$ was added.
(C) The student used a 1.5 *M* solution of $HNO_3(aq)$ instead of a 15.8 *M* solution of $HNO_3(aq)$.
(D) The student used a 3.00 g sample of the mixture instead of the 2.00 g sample that was used by the other students.

14. A student is given a sample of a pure, white crystalline substance. Which of the following would be most useful in providing data to determine if the substance is an ionic compound?

(A) Examining the crystals of the substance under a microscope
(B) Determining the density of the substance
(C) Testing the electrical conductivity of the crystals
(D) Testing the electrical conductivity of an aqueous solution of the substance

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Ne, HF, C_2H_6, CH_4

15. Which of the substances listed above has the highest boiling point, and why?

(A) Ne, because its atoms have the largest radius
(B) HF, because its molecules form hydrogen bonds
(C) C_2H_6, because each molecule can form multiple hydrogen bonds
(D) CH_4, because its molecules have the greatest London dispersion forces

16. A sample of a solid labeled as NaCl may be impure. A student analyzes the sample and determines that it contains 75 percent chlorine by mass. Pure NaCl(*s*) contains 61 percent chlorine by mass. Which of the following statements is consistent with the data?

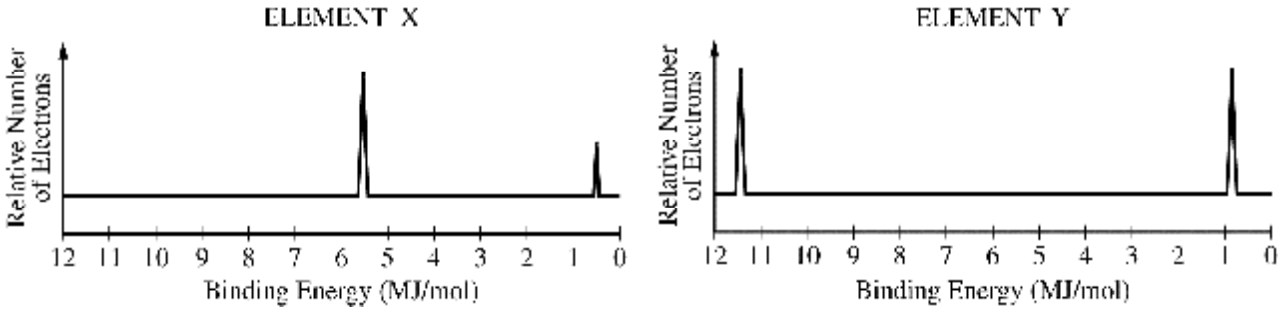
(A) The sample contains only NaCl(*s*).
(B) The sample contains NaCl(*s*) and NaI(*s*).
(C) The sample contains NaCl(*s*) and KCl(*s*).
(D) The sample contains NaCl(*s*) and LiCl(*s*).

17. If a pure sample of an oxide of sulfur contains 40. percent sulfur and 60. percent oxygen by mass, then the empirical formula of the oxide is

(A) SO_3
(B) SO_4
(C) S_2O_6
(D) S_2O_8

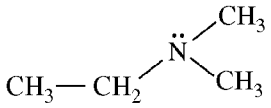
18. When 4.0 L of He(*g*), 6.0 L of N_2(*g*), and 10. L of Ar(*g*), all at 0°C and 1.0 atm, are pumped into an evacuated 8.0 L rigid container, the final pressure in the container at 0°C is

(A) 0.5 atm
(B) 1.0 atm
(C) 2.5 atm
(D) 4.0 atm

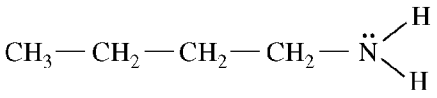


19. The complete photoelectron spectra of neutral atoms of two unknown elements, X and Y, are shown above. Which of the following can be inferred from the data?

(A) Element X has a greater electronegativity than element Y does.
(B) Element X has a greater ionization energy than element Y does.
(C) Element Y has a greater nuclear charge than element X does.
(D) The isotopes of element Y are approximately equal in abundance, but those of element X are not.



Compound 1



Compound 2

20. Based on the structures shown above, which of the following statements identifies the compound with the higher boiling point and provides the best explanation for the higher boiling point?

(A) Compound 1, because it has stronger dipole-dipole forces than compound 2
(B) Compound 1, because it forms hydrogen bonds, whereas compound 2 does not
(C) Compound 2, because it is less polarizable and has weaker London dispersion forces than compound 1
(D) Compound 2, because it forms hydrogen bonds, whereas compound 1 does not

21. On the basis of molecular structure and bond polarity, which of the following compounds is most likely to have the greatest solubility in water?

(A) CH_4
(B) CCl_4
(C) NH_3
(D) PH_3

Questions 22-25 refer to the following information.

$$\underset{\text{colorless}}{N_2O_4(g)} \rightleftarrows \underset{\text{brown}}{2\,NO_2(g)} \qquad K_p = 3.0 \text{ at } 70^\circ C$$

A mixture of $NO_2(g)$ and $N_2O_4(g)$ is placed in a glass tube and allowed to reach equilibrium at 70°C, as represented above.

22. If $P_{N_2O_4}$ is 1.33 atm when the system is at equilibrium at 70°C, what is P_{NO_2} ?

(A) 0.44 atm
(B) 2.0 atm
(C) 2.3 atm
(D) 4.0 atm

23. Which of the following statements best helps to explain why the contents of the tube containing the equilibrium mixture turned a lighter color when the tube was placed into an ice bath?

(A) The forward reaction is exothermic.
(B) The forward reaction is endothermic.
(C) The ice bath lowered the activation energy.
(D) The ice bath raised the activation energy.

24. Which of the following best predicts how the partial pressures of the reacting species will be affected if a small amount of $Ar(g)$ is added to the equilibrium mixture at constant volume?

(A) P_{NO_2} will decrease and $P_{N_2O_4}$ will increase.
(B) P_{NO_2} will increase and $P_{N_2O_4}$ will decrease.
(C) Both P_{NO_2} and $P_{N_2O_4}$ will decrease.
(D) No change will take place.

25. Which of the following statements about ΔH° for the reaction is correct?

(A) $\Delta H^\circ < 0$ because energy is released when the N–N bond breaks.
(B) $\Delta H^\circ < 0$ because energy is required to break the N–N bond.
(C) $\Delta H^\circ > 0$ because energy is released when the N–N bond breaks.
(D) $\Delta H^\circ > 0$ because energy is required to break the N–N bond.

GO ON TO THE NEXT PAGE.

Reaction A: $4\ HCl(g) + O_2(g) \rightleftarrows 2\ Cl_2(g) + 2\ H_2O(g)$

Reaction B: $N_2O_4(g) \rightleftarrows 2\ NO_2(g)$

Reaction C: $H_2(g) + I_2(g) \rightleftarrows 2\ HI(g)$

Reaction D: $2\ NH_3(g) \rightleftarrows N_2(g) + 3\ H_2(g)$

26. The reactions represented above are carried out in sealed, rigid containers and allowed to reach equilibrium. If the volume of each container is reduced from 1.0 L to 0.5 L at constant temperature, for which of the reactions will the amount of product(s) be increased?

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

Type of Steel	% Carbon	Characteristics	Uses
Low-carbon steel	< 0.2 %	Malleable and ductile	Chains and nails
High-carbon steel	0.6 – 1.5 %	Hard and brittle	Cutting tools

27. The table above provides some information about two types of steel, both of which are alloys of iron and carbon. Which of the following best helps to explain why high-carbon steel is more rigid than low-carbon steel?

(A) Elemental carbon is harder than elemental iron.
(B) The additional carbon atoms within the alloy make the high-carbon steel less dense.
(C) The additional carbon atoms within the alloy increase the thermal conductivity of the high-carbon steel.
(D) The additional carbon atoms within the alloy make it more difficult for the iron atoms to slide past one another.

$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$$

28. The reaction between $NO_2(g)$ and $CO(g)$ is represented above. The elementary steps of a proposed reaction mechanism are represented below.

$$\text{Step 1: } 2\,NO_2(g) \rightarrow NO(g) + NO_3(g) \qquad (\textit{slow})$$
$$\text{Step 2: } NO_3(g) + CO(g) \rightarrow NO_2(g) + CO_2(g) \qquad (\textit{fast})$$

Which of the following is the rate law for the overall reaction that is consistent with the proposed mechanism?

(A) Rate = $k\,[NO_2][CO]$
(B) Rate = $k\,[NO_2]^2$
(C) Rate = $k\,[NO_3][CO]$
(D) Rate = $k\,[NO_2][NO_3][CO]$

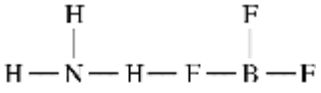
$$Cl^-(aq) + ClO^-(aq) + 2\ H^+(aq) \rightarrow Cl_2(g) + H_2O(l)$$

29. What effect will increasing $[H^+]$ at constant temperature have on the reaction represented above?

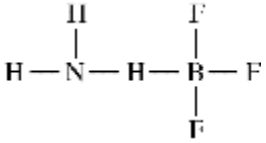
(A) The activation energy of the reaction will increase.
(B) The activation energy of the reaction will decrease.
(C) The frequency of collisions between $H^+(aq)$ ions and $ClO^-(aq)$ ions will increase.
(D) The value of the rate constant will increase.

30. NH_3 reacts with BF_3 to form a single species. Which of the following structural diagrams is the most likely representation of the product of the reaction?

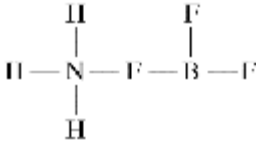
(A)



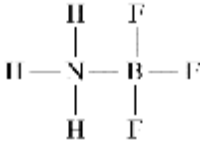
(B)



(C)



(D)



Half-Reaction	E° (V)
$Mg^{2+}(aq) + 2\ e^- \rightarrow Mg(s)$	– 2.37
$Cr^{3+}(aq) + 3\ e^- \rightarrow Cr(s)$	– 0.74

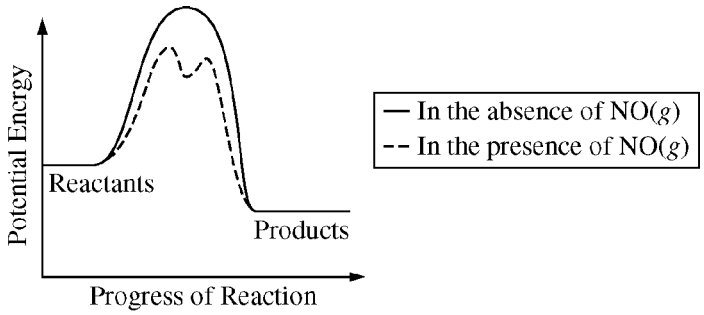
31. Based on the information in the table above, which of the following shows the cell potential and the Gibbs free energy change for the overall reaction that occurs in a standard galvanic cell?

	E°_{cell} (V)	ΔG° (kJ/mol$_{rxn}$)
(A)	+1.63	–157
(B)	+1.63	–944
(C)	+5.63	–543
(D)	+5.63	–3262

GO ON TO THE NEXT PAGE.

$$O_3(g) + O(g) \rightarrow 2\,O_2(g)$$

32. The decomposition of $O_3(g)$ in the upper atmosphere is represented by the equation above. The potential energy diagram for the decomposition of $O_3(g)$ in the presence and absence of $NO(g)$ is given below.



Which of the following mechanisms for the catalyzed reaction is consistent with the equation and diagram above?

(A) $2\,O_3(g) + 2\,NO(g) \rightarrow 4\,O_2(g) + N_2(g)$ *slow*

(B) $O_3(g) + NO(g) \rightarrow NO_2(g) + O_2(g)$ *slow*
$NO_2(g) + O(g) \rightarrow NO(g) + O_2(g)$ *fast*

(C) $NO_2(g) + O_3(g) \rightarrow NO(g) + 2\,O_2(g)$ *slow*
$NO(g) + O(g) \rightarrow NO_2(g)$ *fast*

(D) $NO_2(g) + O(g) \rightarrow NO_3(g)$ *slow*
$NO_3(g) + O_3(g) \rightarrow NO_2(g) + 2\,O_2(g)$ *fast*

GO ON TO THE NEXT PAGE.

$$\underset{\text{orange}}{Cr_2O_7^{2-}(aq)} + 3\ H_2O(l) \rightleftarrows 2\ \underset{\text{yellow}}{CrO_4^{2-}(aq)} + 2\ H_3O^+(aq)$$

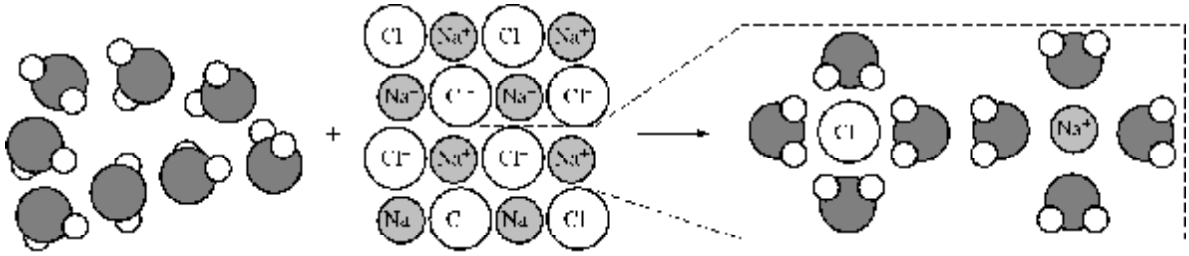
33. The equilibrium system represented by the equation above initially contains equal concentrations of $Cr_2O_7^{2-}(aq)$ and $CrO_4^{2-}(aq)$. Which of the following statements correctly predicts the result of adding a sample of 6.0 *M* $NaOH(aq)$ to the system, and provides an explanation?

(A) The mixture will become more orange because $OH^-(aq)$ will oxidize the Cr in $CrO_4^{2-}(aq)$.

(B) The mixture will become more yellow because $OH^-(aq)$ will reduce the Cr in $Cr_2O_7^{2-}(aq)$.

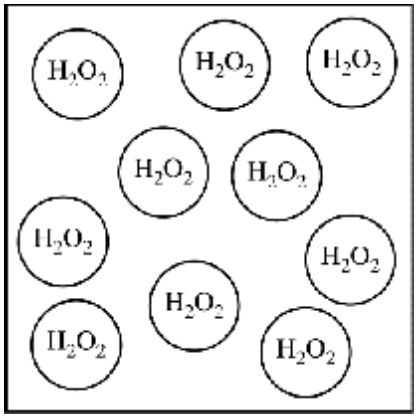
(C) The mixture will become more yellow because $OH^-(aq)$ will shift the equilibrium toward products.

(D) The color of the mixture will not change because $OH^-(aq)$ does not appear in the equilibrium expression.



34. The process of dissolution of NaCl(s) in $H_2O(l)$ is represented in the diagram above. Which of the following summarizes the signs of $\Delta H°$ and $\Delta S°$ for each part of the dissolution process?

	Breaking solvent-solvent interactions		Breaking solute-solute interactions		Forming solute-solvent interactions	
	$\Delta H°$	$\Delta S°$	$\Delta H°$	$\Delta S°$	$\Delta H°$	$\Delta S°$
(A)	+	+	+	+	–	–
(B)	+	+	+	+	–	+
(C)	–	–	–	–	+	+
(D)	–	+	–	+	+	–

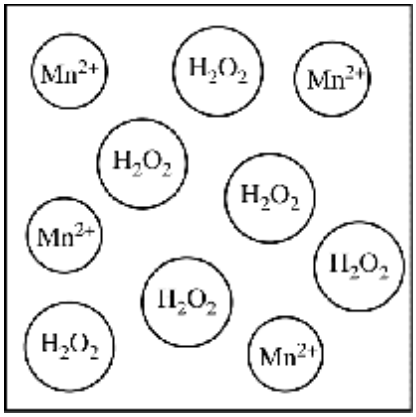


35. A particle view of a sample of $H_2O_2(aq)$ is shown above. The $H_2O_2(aq)$ is titrated with $KMnO_4(aq)$, as represented by the equation below.

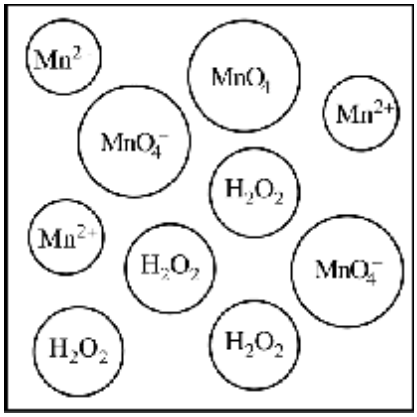
$$2\ MnO_4^-(aq) + 5\ H_2O_2(aq) + 6\ H^+(aq) \rightarrow 2\ Mn^{2+}(aq) + 5\ O_2(g) + 8\ H_2O(l)$$

Which of the following particle views best represents the mixture when the titration is halfway to the equivalence point? (H_2O molecules and H^+ ions are not shown.)

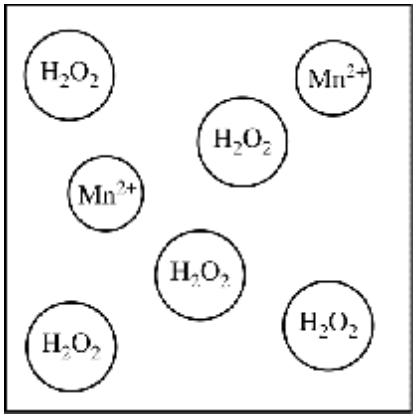
(A)



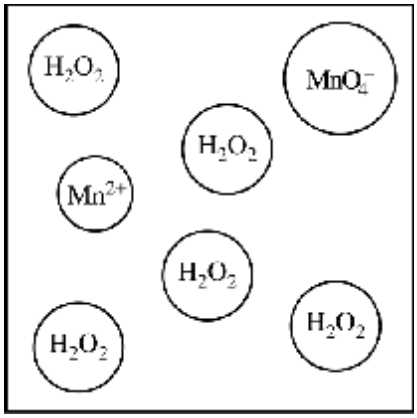
(B)



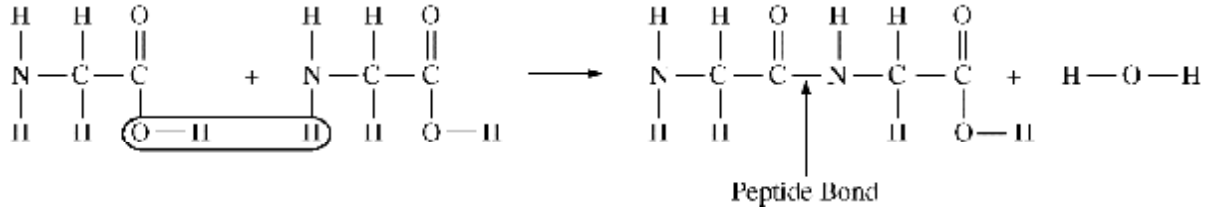
(C)



(D)



Questions 36-38 refer to the following information.



Two molecules of the amino acid glycine join through the formation of a peptide bond, as shown above. The thermodynamic data for the reaction are listed in the following table.

ΔG°_{298}	ΔH°_{298}	ΔS°_{298}
+15 kJ/mol$_{rxn}$	+12 kJ/mol$_{rxn}$	−10 J/(K·mol$_{rxn}$)

36. Under which of the following temperature conditions is the reaction thermodynamically favored?

(A) It is only favored at high temperatures.
(B) It is only favored at low temperatures.
(C) It is favored at all temperatures.
(D) It is not favored at any temperature.

Bond	Bond Energy (kJ/mol)
C–O	360
N–H	390
O–H	460

37. Based on the bond energies listed in the table above, which of the following is closest to the bond energy of the C–N bond?

(A) 200 kJ/mol
(B) 300 kJ/mol
(C) 400 kJ/mol
(D) 500 kJ/mol

38. Based on the thermodynamic data, which of the following is true at 298 K?

(A) $K_{eq} = 0$
(B) $0 < K_{eq} < 1$
(C) $K_{eq} = 1$
(D) $K_{eq} > 1$

Solution	Solute	K_{sp} at 25°C
X	AgBr	5.0×10^{-13}
Y	AgCl	1.8×10^{-10}
Z	AgI	8.3×10^{-17}

39. Three saturated solutions (X, Y, and Z) are prepared at 25°C. Based on the information in the table above, which of the following lists the solutions in order of increasing $[Ag^+]$?

(A) X < Z < Y
(B) Y < X < Z
(C) Z < Y < X
(D) Z < X < Y

GO ON TO THE NEXT PAGE.

40. When 5.0 g of $NH_4ClO_4(s)$ is added to 100. mL of water in a calorimeter, the temperature of the solution formed decreases by 3.0°C. If 5.0 g of $NH_4ClO_4(s)$ is added to 1000. mL of water in a calorimeter initially at 25.0°C, the final temperature of the solution will be approximately

(A) 22.0°C
(B) 24.7°C
(C) 25.3°C
(D) 28.0°C

$$3\ O_2(g) \rightleftarrows 2\ O_3(g) \qquad K_c = 1.8 \times 10^{-56} \text{ at } 570\ K$$

41. For the system represented above, $[O_2]$ and $[O_3]$ initially are 0.150 mol/L and 2.5 mol/L respectively. Which of the following best predicts what will occur as the system approaches equilibrium at 570 K?

(A) The amount of $O_3(g)$ will increase, because $Q < K_c$.
(B) The amount of $O_3(g)$ will decrease, because $Q < K_c$.
(C) The amount of $O_3(g)$ will increase, because $Q > K_c$.
(D) The amount of $O_3(g)$ will decrease, because $Q > K_c$.

Questions 42-43 refer to the following.

$$H_2(g) + Cl_2(g) \rightleftarrows 2\,HCl(g) \qquad K_p = 2 \times 10^{30} \text{ at } 298 \text{ K}$$

$HCl(g)$ can be synthesized from $H_2(g)$ and $Cl_2(g)$ as represented above. A student studying the kinetics of the reaction proposes the following mechanism.

Step 1: $Cl_2(g) \rightarrow 2\,Cl(g)$	(*slow*)	$\Delta H^\circ = 242 \text{ kJ/mol}_{rxn}$
Step 2: $H_2(g) + Cl(g) \rightarrow HCl(g) + H(g)$	(*fast*)	$\Delta H^\circ = 4 \text{ kJ/mol}_{rxn}$
Step 3: $H(g) + Cl(g) \rightarrow HCl(g)$	(*fast*)	$\Delta H^\circ = -432 \text{ kJ/mol}_{rxn}$

42. Which of the following statements identifies the greatest single reason that the value of K_p for the overall reaction at 298 K has such a large magnitude?

(A) The activation energy for step 1 of the mechanism is large and positive.
(B) The activation energy for step 2 of the mechanism is small and positive.
(C) The value of ΔS° for the overall reaction is small and positive.
(D) The value of ΔH° for the overall reaction is large and negative.

43. What is the value of the enthalpy change per mole of $HCl(g)$ produced?

(A) −93 kJ
(B) −121 kJ
(C) −186 kJ
(D) −242 kJ

GO ON TO THE NEXT PAGE.

44. The compound CCl_4 is nonflammable and was once commonly used in fire extinguishers. On the basis of the periodic properties, which of the following compounds can most likely be used as a fire-resistant chemical?

(A) BCl_3
(B) CH_4
(C) CBr_4
(D) $PbCl_2$

Reaction	K_{eq}
$La^{3+} + OH^- + HCO_3^- \rightleftarrows LaCO_3^+ + H_2O$	K_1
$HCO_3^- \rightleftarrows H^+ + CO_3^{2-}$	K_a
$H_2O \rightleftarrows H^+ + OH^-$	K_w

45. Based on the information above, which of the following expressions represents the equilibrium constant, K, for the reaction represented by the equation below?

$$La^{3+} + CO_3^{2-} \rightleftarrows LaCO_3^+$$

(A) $K = (K_1)(K_a)(K_w)$

(B) $K = \dfrac{(K_1)(K_a)}{K_w}$

(C) $K = \dfrac{K_1}{(K_a)(K_w)}$

(D) $K = \dfrac{(K_1)(K_w)}{K_a}$

GO ON TO THE NEXT PAGE.

$$ClO_2^-(aq) + HCOOH(aq) \rightleftarrows HClO_2(aq) + HCOO^-(aq) \qquad K_{eq} < 1$$

46. What are the relative strengths of the acids and bases in the reaction represented by the equation above?

	Acid Strength	Base Strength
(A)	$HClO_2 < HCOOH$	$ClO_2^- < HCOO^-$
(B)	$HClO_2 < HCOOH$	$ClO_2^- > HCOO^-$
(C)	$HClO_2 > HCOOH$	$ClO_2^- > HCOO^-$
(D)	$HClO_2 > HCOOH$	$ClO_2^- < HCOO^-$

$$Ag^+(aq) + NH_3(aq) \rightleftarrows Ag(NH_3)^+(aq) \qquad K_{eq_1} = 2.0 \times 10^3$$

$$Ag(NH_3)^+(aq) + NH_3(aq) \rightleftarrows Ag(NH_3)_2^+(aq) \qquad K_{eq_2} = 8.0 \times 10^3$$

47. Equal volumes of 0.1 *M* $AgNO_3(aq)$ and 2.0 *M* $NH_3(aq)$ are mixed and the reactions represented above occur. Which Ag species will have the highest concentration in the equilibrium system shown below, and why?

$$Ag^+(aq) + 2\,NH_3(aq) \rightleftarrows Ag(NH_3)_2^+(aq) \qquad K_{eq_3} = ?$$

(A) $Ag^+(aq)$, because $K_{eq_3} = 4$

(B) $Ag^+(aq)$, because $K_{eq_1} < K_{eq_2}$

(C) $Ag(NH_3)_2^+(aq)$, because $K_{eq_3} = 1.6 \times 10^7$

(D) $Ag(NH_3)_2^+(aq)$, because $K_{eq_1} < K_{eq_2}$

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$$

48. When $H_2(g)$ and $O_2(g)$ are mixed together in a rigid reaction vessel at 25°C, no reaction occurs. When the mixture is sparked, however, the gases react vigorously according to the equation above, releasing heat. Which of the following statements correctly explains why the spark is needed for the reaction to occur when the gases are originally at 25°C?
    (A) The reaction is not thermodynamically favorable at 25°C.
    (B) ΔH° for the reaction has a large positive value at 25°C.
    (C) ΔS° for the reaction has a large negative value at 25°C.
    (D) The reaction has a large activation energy at 25°C.

49. A student prepares a solution by combining 100 mL of 0.30 *M* $HNO_2(aq)$ and 100 mL of 0.30 *M* $KNO_2(aq)$. Which of the following equations represents the reaction that best helps to explain why adding a few drops of 1.0 *M* $HCl(aq)$ does not significantly change the pH of the solution?
    (A) $K^+(aq) + Cl^-(aq) \rightarrow KCl(s)$
    (B) $HNO_2(aq) \rightarrow H^+(aq) + NO_2^-(aq)$
    (C) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
    (D) $H^+(aq) + NO_2^-(aq) \rightarrow HNO_2(aq)$

$$2\ H_2O_2(l) \rightarrow 2\ H_2O(l) + O_2(g)$$

50. The exothermic process represented above is best classified as a
    (A) physical change because a new phase appears in the products
    (B) physical change because $O_2(g)$ that was dissolved comes out of solution
    (C) chemical change because entropy increases as the process proceeds
    (D) chemical change because covalent bonds are broken and new covalent bonds are formed

GO ON TO THE NEXT PAGE.

END OF SECTION I

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

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

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

Section II: Free-Response Questions

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

AP® Chemistry Exam

SECTION II: Free Response

2017

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

At a Glance

Total Time
1 hour, 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
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. 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 4NBP4-S

25

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

$$PV = nRT$$

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

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

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

$$\text{K} = \text{°C} + 273$$

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

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

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

$$q = mc\Delta T$$

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

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

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

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

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

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.

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_2H_3O_2^-(aq)$$

1. The dissociation of ethanoic acid, $HC_2H_3O_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $HC_2H_3O_2(aq)$ using two different experimental procedures.

   (a) The student is first asked to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$ using a 2.000 *M* standard solution.

   (i) Calculate the volume, in mL, of 2.000 *M* $HC_2H_3O_2(aq)$ the student needs to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$.

   (ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 *M* $HC_2H_3O_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

   - 100 mL beaker
   - 100 mL graduated cylinder
   - 100 mL volumetric flask
   - Eye dropper
   - 500 mL wash bottle filled with distilled water
   - 2.000 *M* $HC_2H_3O_2(aq)$ in a 50 mL buret

   (b) Using a pH probe, the student determines that the pH of 0.115 *M* $HC_2H_3O_2(aq)$ is 2.92.

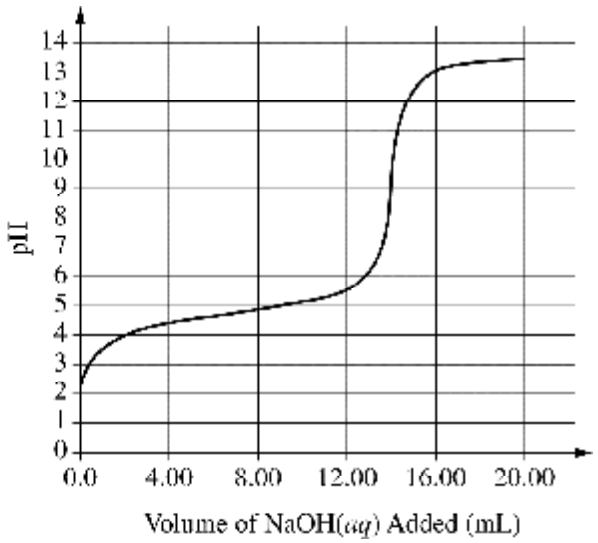
   (i) Using the pH value, calculate the value of K_a for $HC_2H_3O_2(aq)$.

   (ii) Calculate the percent dissociation of ethanoic acid in 0.115 *M* $HC_2H_3O_2(aq)$.

   In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 *M* $HC_2H_3O_2(aq)$ with an $NaOH(aq)$ solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

GO ON TO THE NEXT PAGE.

Volume of NaOH(*aq*) Added (mL)	pH
0.00	2.23
2.00	3.99
4.00	4.37
6.00	4.65
8.00	4.90
10.00	5.17
12.00	5.55
14.00	9.35
16.00	13.04
18.00	13.31
20.00	13.46



(c) Write the balanced net ionic equation for the reaction that occurs when $HC_2H_3O_2(aq)$ and NaOH(aq) are combined.

(d) Calculate the molar concentration of the NaOH(aq) solution.

(e) Explain how the student can estimate the value of K_a for $HC_2H_3O_2(aq)$ using the titration curve.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

GO ON TO THE NEXT PAGE.

$$H_2O_2(aq) + OCl^-(aq) \rightarrow H_2O(l) + Cl^-(aq) + O_2(g)$$

2. A student investigates the reaction between $H_2O_2(aq)$ and $NaOCl(aq)$, which is represented by the net-ionic equation shown above.

   (a) Is the reaction represented above a redox reaction? Justify your answer.

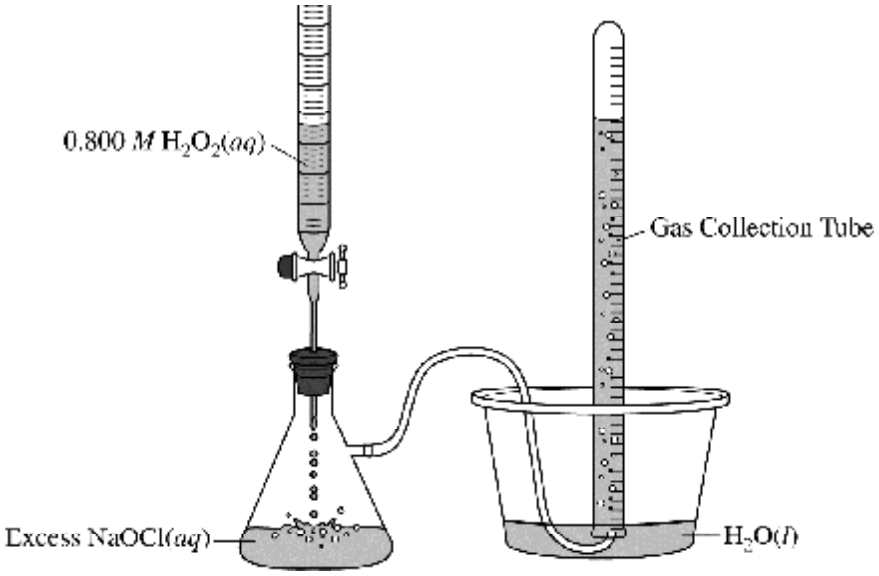
   To better understand the reaction, the student looks up thermodynamic data for the reaction. For the reaction represented above, the value of ΔG°_{298} is -197 kJ/mol$_{rxn}$ and the value of ΔS°_{298} is 144 J/(K·mol$_{rxn}$).

   (b) Calculate the value of ΔH°_{298} for the reaction in kJ/mol$_{rxn}$.

   (c) Does the temperature inside the flask increase, decrease, or remain the same as the reaction proceeds? Justify your answer.

   (d) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

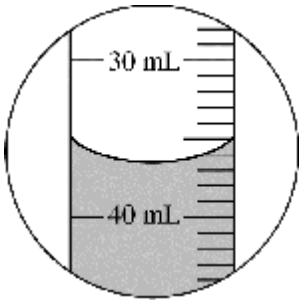
   The student decides to produce 40.0 mL of $O_2(g)$ at a pressure of 0.988 atm and a temperature of 298 K using the reaction represented above. The student uses the equipment shown below. The student sets up a 250 mL Erlenmeyer flask fitted with a one-hole stopper. The flask is connected to a 50 mL gas-collection tube that initially is completely filled with water.



   (e) Calculate the volume of 0.800 M $H_2O_2(aq)$ that the student should add to excess $NaOCl(aq)$ to produce 40.0 mL of $O_2(g)$ at 0.988 atm and 298 K.

GO ON TO THE NEXT PAGE.

(f) The student added the amount of $H_2O_2(aq)$ calculated in part (e) to excess $NaOCl(aq)$. However, instead of producing 40.0 mL of $O_2(g)$, the volume indicated in the diagram below was produced.



(i) Based on the diagram above, what volume of gas was produced?

(ii) Assuming that all the gas in the tube is $O_2(g)$, calculate the percent yield of $O_2(g)$.

(iii) Is the assumption that all the gas in the tube is $O_2(g)$ correct? Explain.

(g) To account for the percent yield being less than 100 percent, the student claims that the reaction reached equilibrium before the expected amount of $O_2(g)$ was produced. Considering your answer to part (d) above, do you agree or disagree with the student's claim? Justify your answer.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

GO ON TO THE NEXT PAGE.

3. Answer the following questions about ozone.

(a) The O_3 molecule has a central oxygen atom bonded to two outer oxygen atoms that are not bonded to one another. In the box below, draw the Lewis electron-dot diagram of the O_3 molecule. Include all valid resonance structures.

(b) Based on the diagram you drew in part (a), what is the shape of the ozone molecule?

Ozone decomposes according to the reaction represented below.

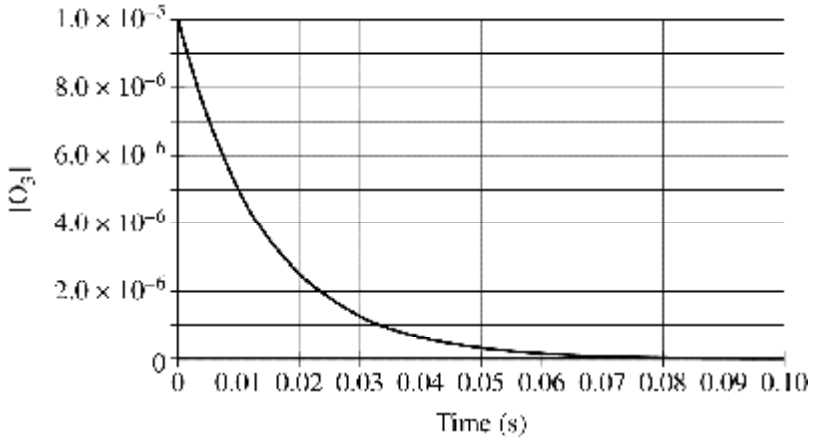
$$2\ O_3(g) \rightarrow 3\ O_2(g) \qquad \Delta H^\circ = -285\ \text{kJ/mol}_{rxn}$$

(c) The bond enthalpy of the oxygen-oxygen bond in O_2 is 498 kJ/mol. Based on the enthalpy of the reaction represented above, what is the average bond enthalpy, in kJ/mol, of an oxygen-oxygen bond in O_3 ?

Ozone can oxidize $HSO_3^-(aq)$, as represented by the equation below.

$$HSO_3^-(aq) + O_3(aq) \rightarrow HSO_4^-(aq) + O_2(g)$$

A solution is prepared in which the initial concentration of $HSO_3^-(aq)$ $(6.4 \times 10^{-4}\ M)$ is much larger than that of $O_3(aq)$ $(1.0 \times 10^{-5}\ M)$. The concentration of $O_3(aq)$ is monitored as the reaction proceeds, and the data are plotted in the graph below.



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(d) The data are consistent with the following rate law: rate = $k_1[O_3]$.

(i) Based on the graph on the previous page, determine the half-life of the reaction.

(ii) Determine the value of the rate constant, k_1, for the rate law. Include units with your answer.

(iii) Considering the relative concentrations of the reactants, briefly explain why the data in the graph are also consistent with the following rate law: rate = $k_2[O_3][HSO_3^-]$.

(iv) Briefly describe an experiment that could provide evidence to support the rate law given in part (d)(iii).

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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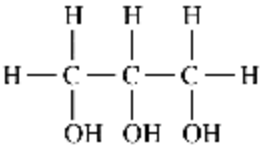
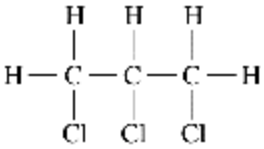


Glycerol

Boiling point 290°C



Trichloropropane

Boiling point 157°C

4. The structural formulas of glycerol and trichloropropane are given above. Both compounds are liquids at 25°C.

   (a) For each compound, identify all types of intermolecular forces present in the liquid. Explain why glycerol has the higher boiling point in terms of the relative strengths of the intermolecular forces.

   (b) Glycerol (molar mass 92.09 g/mol) has been suggested for use as an alternative fuel. The enthalpy of combustion, ΔH°_{comb}, of glycerol is −1654 kJ/mol. What mass of glycerol would need to be combusted to heat 500.0 g of water from 20.0°C to 100.0°C ? (The specific heat capacity of water is 4.184 J/(g · °C). Assume that all the heat released by the combustion reaction is absorbed by the water.)

ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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Overall reaction: $Pb(s) + PbO_2(s) + 2\ H^+(aq) + 2\ HSO_4^-(aq) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$

Cathode half-cell reaction: $PbO_2(s) + 3\ H^+(aq) + HSO_4^-(aq) + 2\ e^- \rightarrow PbSO_4(s) + 2\ H_2O(l)$

5. The equations above represent reactions associated with the operation of a lead storage battery. The first is the overall reaction that occurs as the battery produces an electrical current, and the second is the half-reaction that occurs at the cathode.

   (a) Determine the oxidation number of sulfur in the overall reaction.

   (b) Write the equation for the half-reaction that occurs at the anode as the battery operates.

   After the battery has operated for some time, it can be recharged by applying a current to reverse the overall reaction.

   (c) Calculate the time, in seconds, needed to regenerate 100. g of $Pb(s)$ in the battery by applying a current of 5.00 amp.

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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6. Answer the following questions about the solubility of $AgCl(s)$. The value of K_{sp} for $AgCl(s)$ is 1.8×10^{-10}.

(a) Calculate the value of $[Ag^+]$ in a saturated solution of $AgCl$ in distilled water.

(b) The concentration of $Cl^-(aq)$ in seawater is $0.54\ M$.

(i) Calculate the molar solubility of $AgCl(s)$ in seawater.

(ii) Explain why $AgCl(s)$ is less soluble in seawater than in distilled water.

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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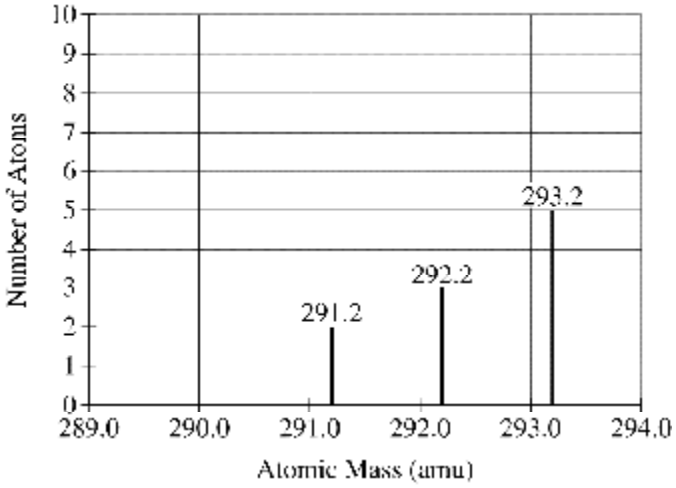
7. A new element with atomic number 116 was discovered in 2000. In 2012 it was named livermorium, Lv. Although Lv is radioactive and short-lived, its chemical properties and reactivity should follow periodic trends.

   (a) Write the electron configuration for the valence electrons of Lv in the ground state.

   (b) According to periodic properties, what would be the most likely formula for the product obtained when Lv reacts with $H_2(g)$?

   (c) The first ionization energy of polonium, Po, is 812 kJ/mol. Is the first ionization energy of Lv expected to be greater than, less than, or equal to that of Po? Justify your answer in terms of Coulomb's law.

   (d) Shown below is a hypothetical mass spectrum for a sample of Lv containing 10 atoms.



   Using the information in the graph, determine the average atomic mass of Lv in the sample to four significant figures.

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: B
Question 2: D
Question 3: A
Question 4: A
Question 5: C
Question 6: B
Question 7: D
Question 8: D
Question 9: B
Question 10: D
Question 11: C
Question 12: B
Question 13: C
Question 14: D
Question 15: B
Question 16: D
Question 17: A
Question 18: C
Question 19: C
Question 20: D
Question 21: C
Question 22: B
Question 23: B
Question 24: D
Question 25: D
Question 26: A
Question 27: D
Question 28: B
Question 29: C
Question 30: D
Question 31: B
Question 32: B
Question 33: C
Question 34: A
Question 35: C
Question 36: D
Question 37: B
Question 38: B
Question 39: D
Question 40: B
Question 41: D
Question 42: D
Question 43: A
Question 44: C
Question 45: D
Question 46: D
Question 47: C
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
2017 SCORING GUIDELINES

Question 1

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_2H_3O_2^-(aq)$$

The dissociation of ethanoic acid, $HC_2H_3O_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $HC_2H_3O_2(aq)$ using two different experimental procedures.

(a) The student is first asked to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$ using a 2.000 M standard solution.

(i) Calculate the volume, in mL, of 2.000 M $HC_2H_3O_2(aq)$ the student needs to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$.

$M_iV_i = M_fV_f$ $V_i = \frac{(0.115\ M)(100.0\ \text{mL})}{2.000\ M} = 5.75\ \text{mL}$	1 point is earned for the correct volume.

(ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

- 100 mL beaker
- 100 mL graduated cylinder
- 100 mL volumetric flask
- Eye dropper
- 500 mL wash bottle filled with distilled water
- 2.000 M $HC_2H_3O_2(aq)$ in a 50 mL buret

Use the buret to deliver 5.75 mL of 2.000 M $HC_2H_3O_2$ to the 100 mL volumetric flask. Then add distilled water from the wash bottle to the flask (adding the last few drops with an eyedropper) until the volume of liquid in the flask is at the calibration mark.	1 point is earned for dispensing from the buret. 1 point is earned for diluting the solution to the calibration mark of the volumetric flask.

AP® CHEMISTRY
2017 SCORING GUIDELINES

Question 1 (continued)

(b) Using a pH probe, the student determines that the pH of 0.115 *M* $HC_2H_3O_2(aq)$ is 2.92.

(i) Using the pH value, calculate the value of K_a for $HC_2H_3O_2(aq)$.

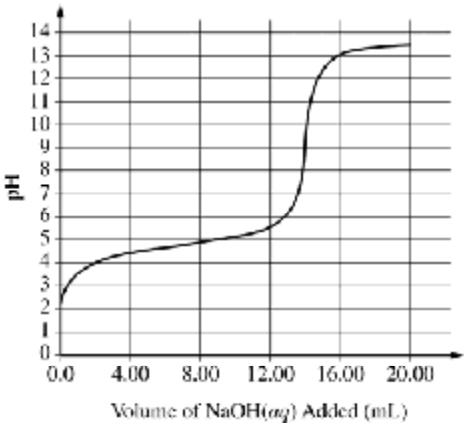
$pH = 2.92 \Rightarrow [H_3O^+] = 10^{-2.92} = 0.0012\ M$ $K_a = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$ Since $[H_3O^+] = [C_2H_3O_2^-]$, then $K_a = \frac{(0.0012)(0.0012)}{(0.115 - 0.0012)} = \frac{(0.0012)^2}{(0.114)} = 1.3 \times 10^{-5}$	1 point is earned for correct conversion of pH to $[H_3O^+]$. 1 point is earned for a value of K_a consistent with the student's value of $[H_3O^+]$.

(ii) Calculate the percent dissociation of ethanoic acid in 0.115 *M* $HC_2H_3O_2(aq)$.

Percent dissociation $= \frac{[C_2H_3O_2^-]}{[HC_2H_3O_2]_0} = \frac{0.0012}{0.115} \times 100 = 1.0\%$	1 point is earned for the correct percent dissociation.

In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 *M* $HC_2H_3O_2(aq)$ with an NaOH(*aq*) solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

Volume of NaOH(*aq*) Added (mL)	pH
0.00	2.23
2.00	3.99
4.00	4.37
6.00	4.65
8.00	4.90
10.00	5.17
12.00	5.55
14.00	9.35
16.00	13.04
18.00	13.31
20.00	13.46



Question 1 (continued)

(c) Write the balanced net ionic equation for the reaction that occurs when $HC_2H_3O_2(aq)$ and $NaOH(aq)$ are combined.

$HC_2H_3O_2(aq) + OH^-(aq) \rightarrow C_2H_3O_2^-(aq) + H_2O(l)$	1 point is earned for the correct equation.

(d) Calculate the molar concentration of the $NaOH(aq)$ solution.

From the pH curve, the equivalence point occurs at 14.0 mL. $10.0 \text{ mL} \times \frac{2.000 \text{ mol } HC_2H_3O_2}{1000 \text{ mL}} = 0.0200 \text{ mol } HC_2H_3O_2(aq)$ $0.0200 \text{ mol } HC_2H_3O_2(aq) \times \frac{1 \text{ mol NaOH}}{1 \text{ mol } HC_2H_3O_2} = 0.0200 \text{ mol NaOH}$ $\frac{0.0200 \text{ mol NaOH}}{0.0140 \text{ L solution}} = 1.43 \ M \text{ NaOH}(aq)$	1 point is earned for determining the moles of acid. 1 point is earned for determining the molar concentration of the base.

(e) Explain how the student can estimate the value of K_a for $HC_2H_3O_2(aq)$ using the titration curve.

At the half-equivalence point (~7.0 mL) the pH of the solution is equal to the pK_a of the acid. The antilog of the negative pH is equal to the value of K_a.	1 point is earned for a correct explanation (numerical explanation not required).

AP® CHEMISTRY
2017 SCORING GUIDELINES

Question 2

$$H_2O_2(aq) + OCl^-(aq) \rightarrow H_2O(l) + Cl^-(aq) + O_2(g)$$

A student investigates the reaction between $H_2O_2(aq)$ and $NaOCl(aq)$, which is represented by the net-ionic equation shown above.

(a) Is the reaction represented above a redox reaction? Justify your answer.

The reaction <u>is</u> a redox reaction because the oxidation numbers of some atoms changed during the reaction (both oxygen and chlorine undergo changes in oxidation number).	1 point is earned for the correct answer along with a valid justification.

To better understand the reaction, the student looks up thermodynamic data for the reaction. For the reaction represented above, the value of ΔG°_{298} is -197 kJ/mol$_{rxn}$ and the value of ΔS°_{298} is 144 J/(K·mol$_{rxn}$).

(b) Calculate the value of ΔH°_{298} for the reaction in kJ/mol$_{rxn}$.

$\Delta H^\circ = \Delta G^\circ + T\Delta S^\circ$ $= -197 \text{ kJ/mol}_{rxn} + (298 \text{ K})\left(\frac{144 \text{ J}}{\text{K} \cdot \text{mol}_{rxn}}\right)\left(\frac{1 \text{ kJ}}{1000 \text{ J}}\right)$ $= -154 \text{ kJ/mol}_{rxn}$	1 point is earned for the correct calculation of ΔH°.

(c) Does the temperature inside the flask increase, decrease, or remain the same as the reaction proceeds? Justify your answer.

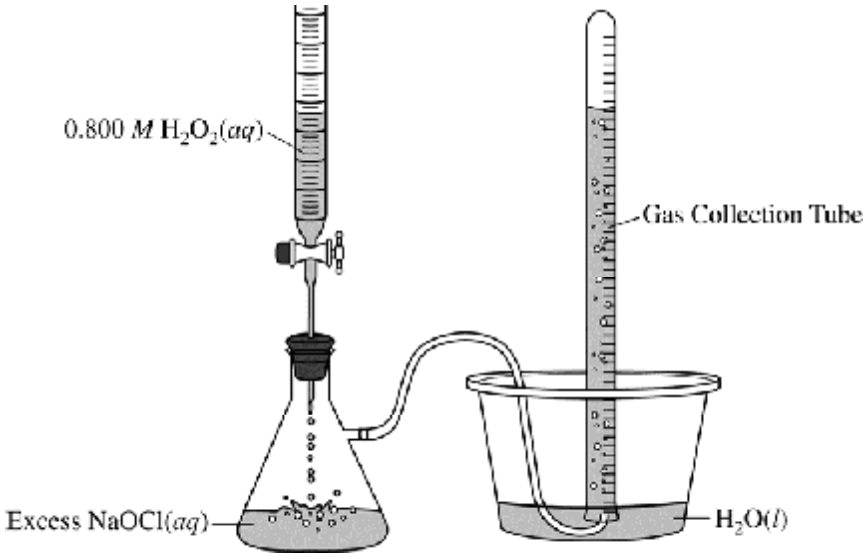
The temperature increases because the reaction is exothermic ($\Delta H^\circ < 0$).	1 point is earned for indicating an increase in temperature with a valid justification.

(d) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

$\Delta G^\circ = -RT \ln K$ $K = e^{\frac{-\Delta G^\circ}{RT}} = e^{\frac{-(-197{,}000 \text{ J/mol})}{(8.314 \text{ J/(mol·K)})(298 \text{ K})}} = e^{79.5} = 3 \times 10^{34}$	1 point is earned for the correct value of K with evidence of calculation.

The student decides to produce 40.0 mL of $O_2(g)$ at a pressure of 0.988 atm and a temperature of 298 K using the reaction represented above. The student uses the equipment shown below. The student sets up a 250 mL Erlenmeyer flask fitted with a one-hole stopper. The flask is connected to a 50 mL gas-collection tube that initially is completely filled with water.

Question 2 (continued)

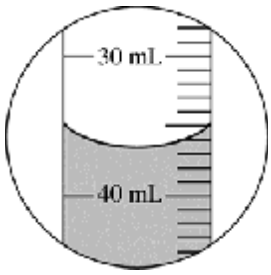


(e) Calculate the volume of 0.800 M $H_2O_2(aq)$ that the student should add to excess $NaOCl(aq)$ to produce 40.0 mL of $O_2(g)$ at 0.988 atm and 298 K.

$PV = nRT$ $n = \frac{PV}{RT} = \frac{(0.988\ \text{atm})(0.0400\ \text{L})}{(0.08206\ \text{L atm mol}^{-1}\ \text{K}^{-1})(298\ \text{K})} = 0.00162\ \text{mol}\ O_2$ $0.00162\ \text{mol}\ O_2 \times \frac{1\ \text{mol}\ H_2O_2}{1\ \text{mol}\ O_2} = 0.00162\ \text{mol}\ H_2O_2$ needed $0.00162\ \text{mol}\ H_2O_2 \times \frac{\text{L}}{0.800\ \text{mol}\ H_2O_2} = 0.00202\ \text{L}$	1 point is earned for calculating the number of moles of O_2 needed. 1 point is earned for calculating the volume of H_2O_2 solution that should be added.

Question 2 (continued)

(f) The student added the amount of $H_2O_2(aq)$ calculated in part (e) to excess $NaOCl(aq)$. However, instead of producing 40.0 mL of $O_2(g)$, the volume indicated in the diagram below was produced.



(i) Based on the diagram above, what volume of gas was produced?

36.5 mL (values within ± 0.4 of 36.5 are acceptable)	1 point is earned for the correct reading of the meniscus level to **three** significant figures.

(ii) Assuming that all the gas in the tube is $O_2(g)$, calculate the percent yield of $O_2(g)$.

$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} = \frac{36.5\text{ mL}}{40.0\text{ mL}} \times 100 = 91.3\%$	1 point is earned for the correct percent yield.

(iii) Is the assumption that all the gas in the tube is $O_2(g)$ correct? Explain.

No, the gas also contains water vapor and air that was originally in the flask.	1 point is earned for the correct answer with a valid explanation. (Only **one** of the two extra gases is required for the point.)

(g) To account for the percent yield being less than 100 percent, the student claims that the reaction reached equilibrium before the expected amount of $O_2(g)$ was produced. Considering your answer to part (d) above, do you agree or disagree with the student's claim? Justify your answer.

Disagree. The very large value of K implies that the reaction goes essentially to completion, so essentially all of the H_2O_2 reacts to form O_2.	1 point is earned for an appropriate conclusion and valid justification based on the value of K in part (d).

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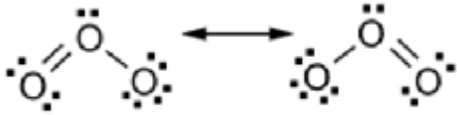
Question 3

Answer the following questions about ozone.

(a) The O_3 molecule has a central oxygen atom bonded to two outer oxygen atoms that are not bonded to one another. In the box below, draw the Lewis electron-dot diagram of the O_3 molecule. Include all valid resonance structures.

	1 point is earned for a diagram that includes all 18 valence electrons and obeys the octet rule. 1 point is earned for showing correct application of resonance.

(b) Based on the diagram you drew in part (a), what is the shape of the ozone molecule?

The ozone molecule has a bent shape.	1 point is earned for the shape based on student's Lewis diagram.

Ozone decomposes according to the reaction represented below.

$$2\ O_3(g) \rightarrow 3\ O_2(g) \qquad \Delta H^\circ = -285\ \text{kJ/mol}_{rxn}$$

(c) The bond enthalpy of the oxygen-oxygen bond in O_2 is 498 kJ/mol. Based on the enthalpy of the reaction represented above, what is the average bond enthalpy, in kJ/mol, of an oxygen-oxygen bond in O_3?

$\Delta H^\circ = \Sigma\ (\text{bond enthalpies})_{reactants} - \Sigma\ (\text{bond enthalpies})_{products}$ Four equivalent bonds are broken in two O_3 molecules. Three oxygen-oxygen bonds are formed in three O_2 molecules. Let x = the bond enthalpy in ozone, therefore $4x - 3(498\ \text{kJ/mol}) = -285\ \text{kJ/mol}_{rxn}$ $x = 302$ kJ/mol	1 point is earned for the correct determination of the number of bonds broken in the reactants and the number of bonds formed in the products. 1 point is earned for the calculation of the energy of the bonds in O_3 consistent with bond counting, the bond energy of O_2, and the ΔH°_{rxn}.

Ozone can oxidize $HSO_3^-(aq)$, as represented by the equation below.

$$HSO_3^-(aq) + O_3(aq) \rightarrow HSO_4^-(aq) + O_2(g)$$

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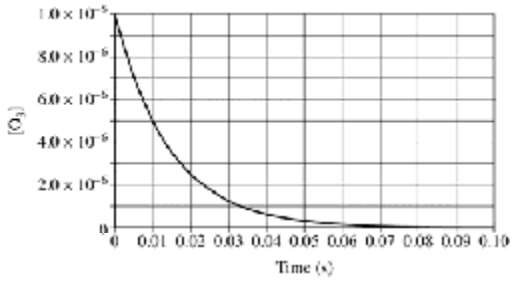
Question 3 (continued)

A solution is prepared in which the initial concentration of $HSO_3^-(aq)$ (6.4×10^{-4} M) is much larger than that of $O_3(aq)$ (1.0×10^{-5} M). The concentration of $O_3(aq)$ is monitored as the reaction proceeds, and the data are plotted in the graph below.



(d) The data are consistent with the following rate law: rate = $k_1[O_3]$.

(i) Based on the graph on the previous page, determine the half-life of the reaction.

Half-life = 0.010 s	1 point is earned for the correct answer.

(ii) Determine the value of the rate constant, k_1, for the rate law. Include units with your answer.

$t_{1/2} = \frac{0.693}{k_1} \Rightarrow k_1 = \frac{0.693}{t_{1/2}} = \frac{0.693}{0.010\text{ s}} = 69\text{ s}^{-1}$	1 point is earned for the correct value. 1 point is earned for the correct unit.

(iii) Considering the relative concentrations of the reactants, briefly explain why the data in the graph are also consistent with the following rate law: rate = $k_2[O_3][HSO_3^-]$.

The data are consistent with rate = $k_2[O_3][HSO_3^-]$ because $[HSO_3^-]$ remains essentially constant during the experiment. ($[HSO_3^-]$ can be contained in the rate constant k_1.)	1 point is earned for a correct explanation.

(iv) Briefly describe an experiment that could provide evidence to support the rate law given in part (d)(iii).

Repeat the experiment with a different initial concentration of HSO_3^-. (If the change in the rate of the reaction is directly proportional to the change in $[HSO_3^-]$, then the reaction is first order with respect to HSO_3^-.)	1 point is earned for describing a valid experiment.

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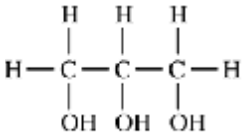
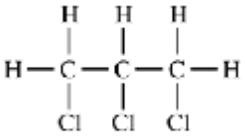
Question 4



Glycerol

Boiling point 290°C



Trichloropropane

Boiling point 157°C

The structural formulas of glycerol and trichloropropane are given above. Both compounds are liquids at 25°C.

(a) For each compound, identify all types of intermolecular forces present in the liquid. Explain why glycerol has the higher boiling point in terms of the relative strengths of the intermolecular forces.

Each substance has intermolecular London dispersion forces and dipole-dipole forces. Glycerol also has hydrogen bonding. The presence of hydrogen bonding in glycerol results in the total intermolecular forces in glycerol being stronger than the total intermolecular forces in trichloropropane.	1 point is earned for identifying the IMFs in <u>each</u> liquid. 1 point is earned for a correct explanation.

(b) Glycerol (molar mass 92.09 g/mol) has been suggested for use as an alternative fuel. The enthalpy of combustion, ΔH°_{comb}, of glycerol is −1654 kJ/mol. What mass of glycerol would need to be combusted to heat 500.0 g of water from 20.0°C to 100.0°C ? (The specific heat capacity of water is 4.184 J/(g·°C). Assume that all the heat released by the combustion reaction is absorbed by the water.)

$q_{H_2O} = mc\Delta T = (500.0\text{ g}) \times (4.184\text{ J/(g·°C)}) \times (100.0\text{°C} - 20.0\text{°C})$ $= 167{,}000\text{ J} = 167\text{ kJ}$ $-q_{H_2O} = q_{comb}$ $-167\text{ kJ} \times \frac{1\text{ mol glycerol}}{-1654\text{ kJ}} \times \frac{92.09\text{ g glycerol}}{1\text{ mol glycerol}} = 9.30\text{ g glycerol}$	1 point is earned for a correct calculation of q. 1 point is earned for the correct mass of glycerol.

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Question 5

Overall reaction: $Pb(s) + PbO_2(s) + 2\ H^+(aq) + 2\ HSO_4^-(aq) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$

Cathode half-cell reaction: $PbO_2(s) + 3\ H^+(aq) + HSO_4^-(aq) + 2\ e^- \rightarrow PbSO_4(s) + 2\ H_2O(l)$

The equations above represent reactions associated with the operation of a lead storage battery. The first is the overall reaction that occurs as the battery produces an electrical current, and the second is the half-reaction that occurs at the cathode.

(a) Determine the oxidation number of sulfur in the overall reaction.

+6	1 point is earned for the correct answer.

(b) Write the equation for the half-reaction that occurs at the anode as the battery operates.

$Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2\ e^-$	1 point is earned for a correct equation.

After the battery has operated for some time, it can be recharged by applying a current to reverse the overall reaction.

(c) Calculate the time, in seconds, needed to regenerate 100. g of $Pb(s)$ in the battery by applying a current of 5.00 amp.

$100.\text{ g Pb} \times \frac{1\text{ mol Pb}}{207.2\text{ g}} = 0.483\text{ mol Pb}$ $0.483\text{ mol Pb} \times \frac{2\text{ mol } e^-}{1\text{ mol Pb}} = 0.966\text{ mol } e^-$ $0.966\text{ mol } e^- \times \frac{96{,}485\text{ C}}{1\text{ mol } e^-} = 93{,}200\text{ C}$	1 point is earned for the correct number of moles of electrons (may be implicit).
$I = \frac{q}{t} \Rightarrow t = \frac{q}{I}$ $\frac{93{,}200\text{ C}}{5.00\text{ amp}} \times \frac{1\text{ amp}}{1\text{ C/s}} = 18{,}600\text{ s}$	1 point is earned for the correct time based on the moles of electrons.

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Question 6

Answer the following questions about the solubility of $AgCl(s)$. The value of K_{sp} for $AgCl(s)$ is 1.8×10^{-10}.

(a) Calculate the value of $[Ag^+]$ in a saturated solution of $AgCl$ in distilled water.

$K_{sp} = [Ag^+][Cl^-]$ Let $x = [Ag^+] = [Cl^-]$ Then $1.8 \times 10^{-10} = (x)(x) \Rightarrow x = \sqrt{1.8 \times 10^{-10}}$ $x = [Ag^+] = 1.3 \times 10^{-5}\ M$	1 point is earned for the correct K_{sp} expression and indication that the two ions have equal concentrations. 1 point is earned for correct calculation of the value of $[Ag^+]$.

(b) The concentration of $Cl^-(aq)$ in seawater is $0.54\ M$.

(i) Calculate the molar solubility of $AgCl(s)$ in seawater.

$1.8 \times 10^{-10} = [Ag^+] \times (0.54) \Rightarrow [Ag^+] = 3.3 \times 10^{-10}\ M$	1 point is earned for the correct answer with supporting work.

(ii) Explain why $AgCl(s)$ is less soluble in seawater than in distilled water.

An increased $[Cl^-]$ will decrease the solubility of $AgCl(s)$ since the K_{sp} is a product of the $[Ag^+]$ and $[Cl^-]$. (This is an example of the common ion effect.)	1 point is earned for a correct explanation.

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Question 7

A new element with atomic number 116 was discovered in 2000. In 2012 it was named livermorium, Lv. Although Lv is radioactive and short-lived, its chemical properties and reactivity should follow periodic trends.

(a) Write the electron configuration for the valence electrons of Lv in the ground state.

$7s^2\ 7p^4$	1 point is earned for the correct configuration.

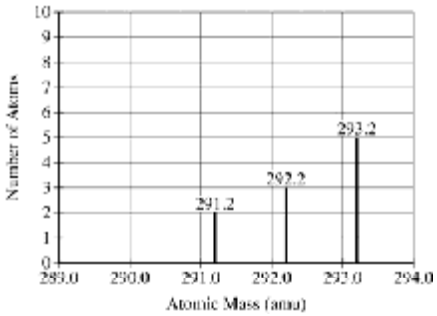
(b) According to periodic properties, what would be the most likely formula for the product obtained when Lv reacts with $H_2(g)$?

LvH_2 (or H_2Lv)	1 point is earned for the correct formula.

(c) The first ionization energy of polonium, Po, is 812 kJ/mol. Is the first ionization energy of Lv expected to be greater than, less than, or equal to that of Po? Justify your answer in terms of Coulomb's law.

Less than that of Po. The two atoms have comparable effective nuclear charges, but the valence electrons in Lv would be at a greater distance from the nucleus than those in Po. By Coulomb's law, the attractive force between the valence electrons and the nucleus decreases by the inverse square of the distance between them.	1 point is earned for a correct prediction <u>with</u> a valid justification.

(d) Shown below is a hypothetical mass spectrum for a sample of Lv containing 10 atoms.



Using the information in the graph, determine the average atomic mass of Lv in the sample to four significant figures.

Average atomic mass $= \frac{2}{10}(291.2) + \frac{3}{10}(292.2) + \frac{5}{10}(293.2) = 292.5$ amu	1 point is earned for the correct average atomic mass.

Scoring Worksheet

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

2017 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
79-100	5
64-78	4
44-63	3
28-43	2
0-27	1

Question Descriptors and Performance Data

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

2017 AP Chemistry

Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practices	Key	% Correct
1	1.14	1D2	1.4, 1.5	B	61
2	2.1, 2.4	2A2	1.4, 6.4, 7.1	D	86
3	2.11	2B1	6.2, 6.4	A	74
4	2.18	2C1	6.1	A	82
5	1.16	1D3	4.2, 5.1	C	32
6	1.6	1B1	5.1	B	19
7	2.21	2C4	1.4	D	80
8	2.24	2D1	1.1, 6.2, 7.1	D	78
9	1.17, 3.1	1E1	1.5, 7.1	B	78
10	3.8	3B3	6.1	D	79
11	1.16	1D3	4.2, 5.1	C	76
12	1.2	1A2	2.2	B	76
13	4.1	4A1	4.2, 5.1	C	37
14	2.22	2D0	4.2, 6.4	D	58
15	2.13	2B2	1.4, 6.4	B	74
16	1.3	1A2	2.2, 6.1	D	84
17	1.3	1A2	2.2, 6.1	A	75
18	2.6	2A2	2.2, 2.3	C	75
19	1.7, 1.9	1B2|1C1	5.1, 6.2, 6.4	C	63
20	2.1, 2.16	2B3	6.2, 6.4, 7.1	D	71
21	2.15, 2.21	2B3|2C4	1.4, 6.2	C	74
22	6.6	6A3	2.2, 6.4	B	79
23	6.8	6B1	1.4, 6.4	B	91
24	6.8	6B1	1.4, 6.4	D	55
25	5.8	5C2	2.3, 7.1, 7.2	D	60
26	6.8	6B1	1.4, 6.4	A	67
27	2.25	2D2	1.4, 7.2	D	69
28	4.7	4C0	6.5	B	82
29	4.1, 4.4	4A1|4B1	4.2, 5.1, 7.1	C	74
30	2.21	2C4	1.4	D	60
31	3.12	3C3	2.2, 2.3, 6.4	B	62
32	4.8	4D1	1.5	B	72
33	6.8	6B1	1.4, 6.4	C	53
34	5.8, 5.12, 6.24	5C2|5E1|6C3	1.4, 2.3, 7.1, 7.2	A	70
35	1.20, 2.9	1E2|2A3	1.1, 1.4, 4.2, 5.1, 6.4	C	59
36	5.13	5E2	2.2, 2.3, 6.4	D	56
37	5.8	5C2	2.3, 7.1, 7.2	B	58
38	6.25	6D1	2.3	B	49

2017 AP Chemistry

Question Descriptors and Performance Data

Question	Learning Objective(s)	Essential Knowledge	Science Practice(s)	Key	% Correct
39	6.21	6C3	2.2, 2.3, 6.4	D	59
40	5.6	5B3	2.2, 2.3	B	66
41	6.4	6A3	2.2, 6.4	D	82
42	5.13, 6.25	5E2|6D1	2.2, 2.3, 6.4	D	67
43	5.6, 5.8	5B3|5C2	2.2, 2.3, 7.1, 7.2	A	74
44	1.11	1C1	3.1, 5.1	C	63
45	6.2	6A2	2.2	D	63
46	2.2	20	7.2	D	62
47	5.17	5E4	6.4	C	59
48	5.18	5E5	1.3, 7.2	D	38
49	6.20	6C2	6.4	D	28
50	3.10	3C1	1.4, 6.1	D	51

Free-Response Questions

Question	Learning Objective(s)	Essential Knowledge	Science Practice(s)	Mean Score
1	1.20, 3.2, 6.13	1.E.2, 3.A.1, 6.C.1	1.5, 4.2, 5.1, 6.4, 7.1	4.09
2	3.8, 3.9, 5.13, 5.14, 6.25	3.B.3, 5.E.2, 5.E.3, 6.D.1	2.2, 2.3, 4.2, 5.1, 6.1, 6.4	4.63
3	2.21, 4.1, 4.2, 4.3, 5.8	2.C.4, 4.A.1, 4.A.2, 4.A.3, 5.C.2	1.4, 2.1, 2.2, 2.3, 4.2, 5.1, 6.4, 7.1, 7.2	3.95
4	2.16, 5.6	2.B.3, 5.B.3	2.2, 2.3, 6.2	1.38
5	3.13	3.C.3	5.1	1.66
6	6.22, 6.23	6.C.3	2.2, 2.3, 5.1, 6.4	1.79
7	1.9, 1.14	1.C.1, 1.D.2	1.4, 1.5, 6.4	1.95

AP Chemistry

The College Board

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