CollegeBoard

AP® Chemistry Practice Exam

From the 2016 Administration

NOTE: This is a modified version of the 2016 AP Chemistry Exam.

Contents

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

Exam Instructions

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

AP® Chemistry Exam

Regularly Scheduled Exam Date: Monday morning, May 2, 2016

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

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

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

What Proctors Need to Bring to This Exam

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

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

Students are not allowed to use calculators in Section I of the AP Chemistry Exam. However, students are permitted to use four-function, scientific, or graphing calculators to answer questions in Section II. Before starting the exam administration, make sure that each student has an appropriate calculator and that any student with a graphing calculator has a model from the approved list on page 47 of the *2015-16 AP Coordinator's Manual*. See pages 44–47 of the *AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide, or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 45 of the *AP Coordinator's Manual*.

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

If you are giving the regularly scheduled exam, say:

It is Monday morning, May 2, 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 19, 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 *2015-16 Bulletin for AP Students and Parents*. You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

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

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

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

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

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

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

Are there any questions? . . .

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

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 questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .

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

SECTION II: Free Response

After the break, say:

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

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

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

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

Read the last statement. . . .

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

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

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

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

Read Item 4. . . .

Are there any questions? . . .

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

Read the information on the back cover of the exam booklet. Do not open the 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 60 of the *2015-16 AP Coordinator's Manual* for complete details). Then say:

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

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

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

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

If you are giving the regularly scheduled exam, say:

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

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

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

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

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

Then say:

You are now dismissed.

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

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

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

Student Answer Sheet for the Multiple-Choice Section

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

AP Answer Sheet 2016

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

CollegeBoard

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

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

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

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

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

C. YOUR AP NUMBER

D. EXAM DATE Month Day

E. EXAM START TIME AM PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

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

785208

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 2 Option 2

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE | School Name | City | State | Country

K. DATE OF BIRTH

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

Day | Year

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE

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

College Name | City | State | Country

N. CURRENT GRADE LEVEL

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

O. STUDENT SEARCH SERVICE®

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

Would you like us to supply your information?

Yes No

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

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COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

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

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

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

◯ Yes ◯ No

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

◯ Yes ◯ No

QUESTIONS 1–75

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

COMPLETE MARK ● **EXAMPLES OF INCOMPLETE MARKS**

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

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

ETS USE ONLY

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

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

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

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

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

QUESTIONS 121–126

For Students Taking AP Biology

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

121 122 123 124 125 126

QUESTIONS 131–142

For Students Taking AP Physics 1 or AP Physics 2

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

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

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

R. YOUR MAILING ADDRESS

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

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

AK	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

U. EMAIL ADDRESS

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

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. RACIAL/ETHNIC GROUP

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

(You may mark all that apply.)

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

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

b. What is your race?

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

Y. PARENTAL EDUCATION LEVEL

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

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

T. STUDENT IDENTIFIER (Student ID Number)

Section I: Multiple-Choice Questions

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

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

AP® Chemistry Exam

SECTION I: Multiple Choice

2016

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
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 4MBP4-S

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

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

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

AP® CHEMISTRY EQUATIONS AND CONSTANTS

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

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

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy
ν = frequency
λ = wavelength

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

EQUILIBRIUM

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

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

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

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

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

$= K_a \times K_b$

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

$14 = pH + pOH$

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

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

Equilibrium Constants

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

KINETICS

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

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

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

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

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

Molarity, M = moles of solute per liter of solution

$$A = abc$$

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

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

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

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

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

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

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

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

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

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

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

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

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

CHEMISTRY

Section I

50 Questions

Time—90 minutes

CALCULATORS ARE NOT ALLOWED FOR SECTION I.

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

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

1. In which of the following liquids do the intermolecular forces include dipole-dipole forces?

   (A) $F_2(l)$
   (B) $CH_4(l)$
   (C) $CF_4(l)$
   (D) $CH_2F_2(l)$

2. Which of the following best helps explain why an increase in temperature increases the rate of a chemical reaction?

   (A) At higher temperatures, reactions have a lower activation energy.
   (B) At higher temperatures, reactions have a higher activation energy.
   (C) At higher temperatures, every collision results in the formation of product.
   (D) At higher temperatures, high-energy collisions happen more frequently.

3. A sample of a hard, solid binary compound at room temperature did not conduct electricity as a pure solid but became highly conductive when dissolved in water. Which of the following types of interactions is most likely found between the particles in the substance?

   (A) Ionic bonds
   (B) Metallic bonds
   (C) Covalent bonds
   (D) Hydrogen bonds

$$N_2(g) + 3\ H_2(g) \rightleftarrows 2\ NH_3(g) \qquad \Delta H < 0$$

4. $NH_3(g)$ was synthesized at 200°C in the presence of a powdered $Os(s)$ catalyst, leading to the equilibrium system represented above. Which of the following changes would result in more $NH_3(g)$ in the mixture after equilibrium is reestablished?

   (A) Replacing the powdered $Os(s)$ with a solid cube of $Os(s)$ of the same total mass
   (B) Increasing the temperature of the system to 250°C at constant pressure
   (C) Removing some $H_2(g)$
   (D) Adding some $N_2(g)$

5. Which of the following arranges the molecules N_2, O_2, and F_2 in order of their bond enthalpies, from least to greatest?

   (A) $F_2 < O_2 < N_2$
   (B) $O_2 < N_2 < F_2$
   (C) $N_2 < O_2 < F_2$
   (D) $N_2 < F_2 < O_2$

GO ON TO THE NEXT PAGE.

Ion	Ionic Radius (pm)
Li^+	60
Na^+	95
Ca^{2+}	99
In^{3+}	81

6. Based on Coulomb's law and the information in the table above, which of the following cations is most likely to have the weakest interaction with an adjacent water molecule in an aqueous solution?

   (A) Li^+
   (B) Na^+
   (C) Ca^{2+}
   (D) In^{3+}

Element	Electronegativity
H	2.1
C	2.5
S	2.5
F	4.0
Cl	3.0
Si	1.8

7. On the basis of the information above, which of the following arranges the binary compounds in order of increasing bond polarity?

   (A) $CH_4 < SiCl_4 < SF_4$
   (B) $CH_4 < SF_4 < SiCl_4$
   (C) $SF_4 < CH_4 < SiCl_4$
   (D) $SiCl_4 < SF_4 < CH_4$

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$X(g) \rightarrow X^{+}(g) + e^{-}$ $\quad IE_1 = 740$ kJ/mol

$X^{+}(g) \rightarrow X^{2+}(g) + e^{-}$ $\quad IE_2 = 1450$ kJ/mol

$X^{2+}(g) \rightarrow X^{3+}(g) + e^{-}$ $\quad IE_3 = 7730$ kJ/mol

8. For element X represented above, which of the following is the most likely explanation for the large difference between the second and third ionization energies?

   (A) The effective nuclear charge decreases with successive ionizations.
   (B) The shielding of outer electrons increases with successive ionizations.
   (C) The electron removed during the third ionization is, on average, much closer to the nucleus than the first two electrons removed were.
   (D) The ionic radius increases with successive ionizations.

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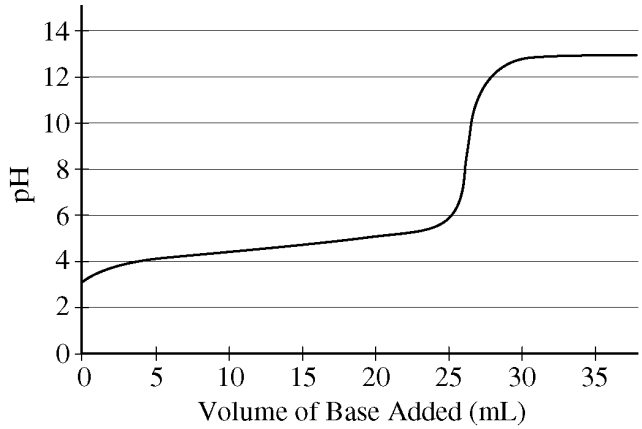

9. A student performs an acid-base titration and plots the experimental results in the graph above. Which of the following statements best explains the experimental findings?

   (A) A strong acid was titrated with a strong base, as evidenced by the equivalence point at pH = 7.

   (B) A strong acid was titrated with a strong base, as evidenced by the equivalence point at pH > 7.

   (C) A weak acid was titrated with a strong base, as evidenced by the equivalence point at pH > 7.

   (D) A weak acid was titrated with a weak base, as evidenced by the equivalence point at pH approximately 7.

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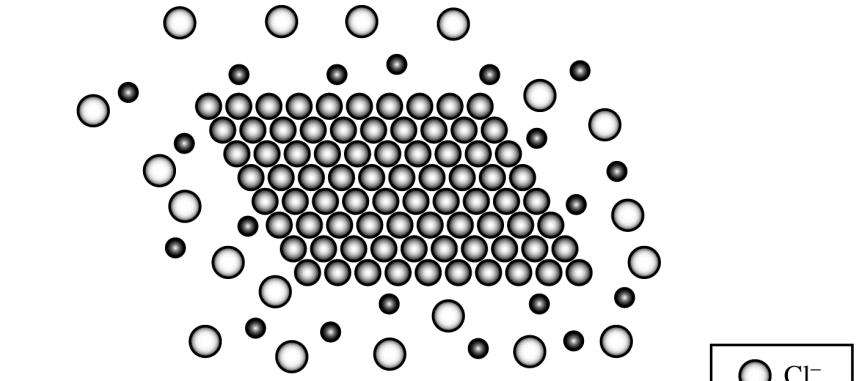

Figure 1

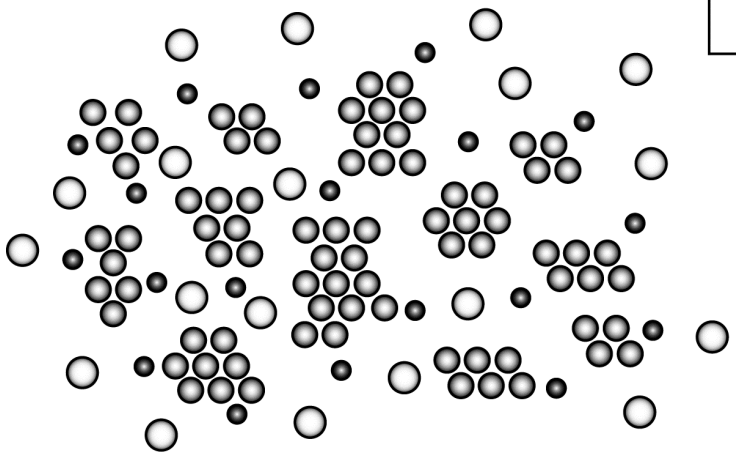

Figure 2

10. Two samples of Mg(*s*) of equal mass were placed in equal amounts of HCl(*aq*) contained in two separate reaction vessels. Particle representations of the mixing of Mg(*s*) and HCl(*aq*) in the two reaction vessels are shown in Figure 1 and Figure 2 above. Water molecules are not included in the particle representations. Which of the reactions will initially proceed faster, and why?

    (A) The reaction in Figure 1, because the atoms of Mg are more concentrated than those in Figure 2

    (B) The reaction in Figure 1, because the Mg(*s*) in Figure 1 has a larger mass than the Mg(*s*) in Figure 2

    (C) The reaction in Figure 2, because more Mg atoms are exposed to HCl(*aq*) in Figure 2 than in Figure 1

    (D) The reaction in Figure 2, because the Mg(*s*) in Figure 2 has less surface area than the Mg(*s*) in Figure 1

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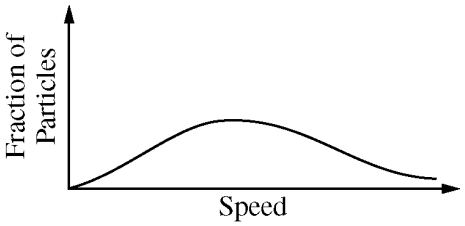
11. A 23.0 g sample of a compound contains 12.0 g of C, 3.0 g of H, and 8.0 g of O. Which of the following is the empirical formula of the compound?

(A) CH_3O
(B) C_2H_6O
(C) $C_3H_9O_2$
(D) $C_4H_{12}O_2$

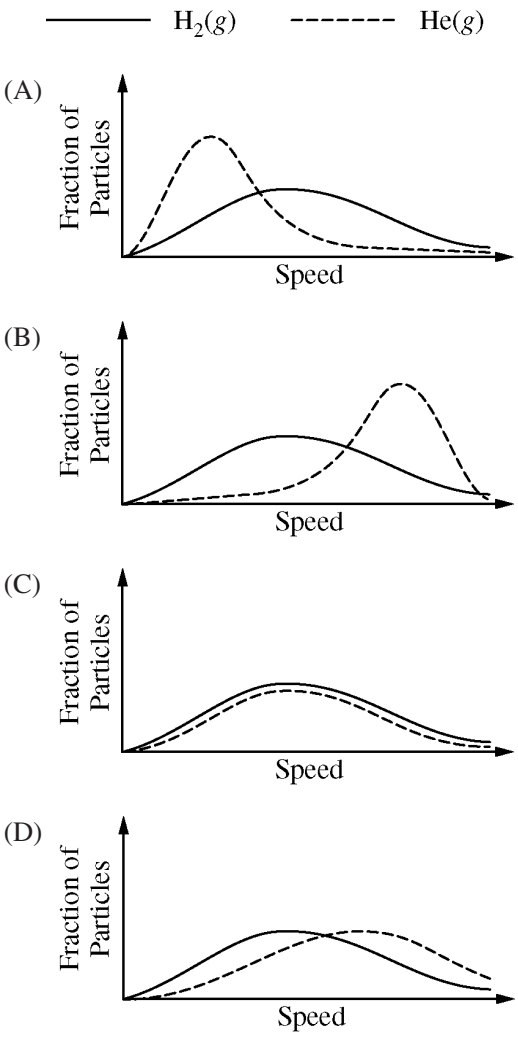
Compound	K_{sp}
$PbCl_2$	1.2×10^{-5}
CuCl	1.6×10^{-7}
AgCl	1.8×10^{-10}
Hg_2Cl_2	1.4×10^{-18}

12. Based on the K_{sp} values in the table above, a saturated solution of which of the following compounds has the highest $[Cl^-]$?

(A) $PbCl_2$
(B) CuCl
(C) AgCl
(D) Hg_2Cl_2



13. The distribution of speeds of $H_2(g)$ molecules at 273 K and 1 atm is shown in the diagram above. Which of the following best shows the speed distribution of $He(g)$ atoms under the same conditions of temperature and pressure?



Questions 14-15 refer to the following information.

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g) \qquad E^\circ = 0.55\ V$$

The equation and standard cell potential for the decomposition of $H_2O_2(aq)$ in acidic solution at 25°C is given above. The reduction half-reactions for the process are listed below.

$$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \qquad E^\circ = 1.23\ V$$

$$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq) \qquad E^\circ = ?$$

$$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq)$$

14. What is the standard reduction potential for the half-reaction represented above?

(A) −1.78 V
(B) −0.68 V
(C) +0.68 V
(D) +1.78 V

15. Which of the following is true for the decomposition of $H_2O_2(aq)$?

(A) $\Delta G^\circ > 0$ and $K_{eq} > 1$
(B) $\Delta G^\circ > 0$ and $K_{eq} < 1$
(C) $\Delta G^\circ < 0$ and $K_{eq} > 1$
(D) $\Delta G^\circ < 0$ and $K_{eq} < 1$

GO ON TO THE NEXT PAGE.

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

16. Which of the following will most likely increase the rate of the reaction represented above?

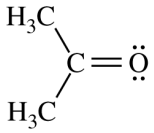
(A) Decreasing the temperature of the reaction system

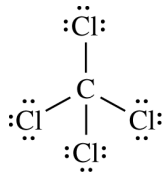
(B) Adding a heterogeneous catalyst to the reaction system

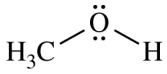
(C) Increasing the volume of the reaction vessel using a piston

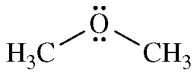
(D) Removing some $H_2(g)$ from the reaction system

17. Which of the following molecules is least soluble in water?

(A) 

(B) 

(C) 

(D) 

18. At room temperature $I_2(s)$ is a molecular solid. Which of the following provides a characteristic of $I_2(s)$ with a correct explanation?

(A) It has a high melting point because it has weak intermolecular forces.

(B) It is hard because it forms a three-dimensional covalent network.

(C) It is not a good conductor of electricity because its valence electrons are localized in bonding and nonbonding pairs.

(D) It is very soluble in water because its molecules are polar.

	Molar Mass (g/mol)	Boiling Point (°C)
$CS_2(l)$	76	46.5
$CCl_4(l)$	154	76.7

19. Based on the information in the table above, which liquid, $CS_2(l)$ or $CCl_4(l)$, has the higher equilibrium vapor pressure at 25°C, and why?

(A) $CS_2(l)$, because it has stronger London dispersion forces

(B) $CS_2(l)$, because it has weaker London dispersion forces

(C) $CCl_4(l)$, because it has stronger London dispersion forces

(D) $CCl_4(l)$, because it has weaker London dispersion forces

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

20. Based on the information given above, which of the following is the strongest acid?

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

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

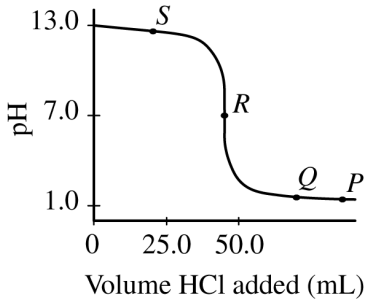
21. A student performed an analysis to determine the amount of $AgNO_3(aq)$ in a solution. Excess $NaCl(aq)$ was added to the solution, and the $Ag^+(aq)$ precipitated as $AgCl(s)$. The precipitate was collected by gravity filtration and dried in an oven. Three trials were performed, and in each case, according to the instructor, the mass of precipitate recovered was 5 percent higher than the actual mass of $AgCl(s)$ that should have formed. Which of the following could account for the error?

(A) The pores in the filter paper were too large.
(B) Not all of the precipitate was transferred to the filter paper.
(C) The $NaCl(aq)$ solution was too concentrated.
(D) The precipitate was not rinsed with deionized water before drying.

Questions 22-25 refer to the following information.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

To determine the concentration of a $NaOH(aq)$ solution, a student titrated a 50. mL sample with 0.10 *M* $HCl(aq)$. The reaction is represented by the equation above. The titration is monitored using a pH meter, and the experimental results are plotted in the graph below.



22. At the point labeled *R* on the pH curve, which of the following ions are present in the reaction mixture at a concentration greater than 0.01 *M* ?

    (A) Na^+ and Cl^- only
    (B) Na^+, Cl^-, and H^+ only
    (C) Na^+, Cl^-, and OH^- only
    (D) Na^+, Cl^-, H^+, and OH^-

23. One student titrated the $NaOH(aq)$ with 1.0 *M* $HCl(aq)$ instead of 0.10 *M* $HCl(aq)$. How would the student's titration curve differ from the original curve?

    (A) The initial pH would be 11 instead of 13.
    (B) The pH at the equivalence point would be 5 instead of 7.
    (C) The pH far beyond the equivalence point would be higher than in the original curve.
    (D) The pH far beyond the equivalence point would be lower than in the original curve.

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Trial	Volume of 0.10 *M* HCl	Volume of 0.10 *M* NaOH	Amount of Heat Released
1	50. mL	50. mL	X
2	100. mL	50. mL	Y

24. A student conducted an experiment to determine ΔH°_{rxn} for the reaction between HCl(*aq*) and NaOH(*aq*). The student ran two trials using the volumes of HCl(*aq*) and NaOH(*aq*) indicated in the table above, and determined the amount of heat released. Which of the following best explains the relationship between X and Y?

    (A) Y = 2X, because the volume of HCl(*aq*) used in trial 2 is twice the volume used in trial 1.

    (B) Y = X, because the number of moles of acid and base reacting with each other is the same in both trials.

    (C) $Y = \frac{2X}{3}$, because the heat is distributed over more particles in trial 2 than in trial 1.

    (D) The relationship between X and Y cannot be predicted.

25. A student mixes a 10.0 mL sample of 1.0 *M* NaOH(*aq*) with a 10.0 mL sample of 1.0 *M* HCl(*aq*) in a polystyrene container. The temperature of the solutions before mixing was 20.0°C. If the final temperature of the mixture is 26.0°C, what is the experimental value of ΔH°_{rxn} ? (Assume that the solution mixture has a specific heat of 4.2 J/(g·K) and a density of 1.0 g/mL.)

    (A) $-50.\ \text{kJ/mol}_{rxn}$

    (B) $-25\ \text{kJ/mol}_{rxn}$

    (C) $-5.0 \times 10^4\ \text{kJ/mol}_{rxn}$

    (D) $-5.0 \times 10^2\ \text{kJ/mol}_{rxn}$

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$$2\ NO_2(g)\ +\ F_2(g)\ \rightarrow\ 2\ NO_2F(g)$$

26. The rate law for the reaction represented by the equation above is rate = $k\ [NO_2][F_2]$. Which of the following could be the first elementary step of a two-step mechanism for the reaction if the first step is slow and the second step is fast?

(A) $F_2(g)\ \rightarrow\ 2\ F(g)$

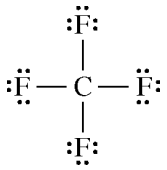
(B) $NO_2(g)\ +\ F_2(g)\ \rightarrow\ NO_2F(g)\ +\ F(g)$

(C) $NO_2(g)\ +\ F(g) \rightarrow\ NO_2F(g)$

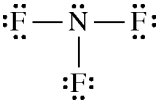
(D) $2\ NO_2(g)\ +\ F_2(g)\ \rightarrow\ 2\ NO_2F(g)$

27. Which of the following Lewis electron-dot diagrams represents the molecule that contains the smallest bond angle?

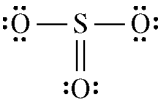
(A)



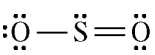
(B)

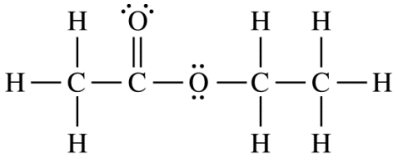


(C)

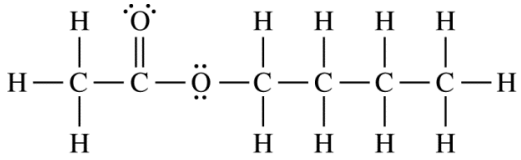


(D)





Ethyl Acetate



Butyl Acetate

28. A mixture containing equal numbers of moles of ethyl acetate and butyl acetate was separated using distillation. Based on the diagrams shown above, which of the following identifies the substance that would be initially present in higher concentration in the distillate and correctly explains why that occurs?

(A) Ethyl acetate, because it has fewer C–C bonds to break
(B) Ethyl acetate, because it has a shorter carbon chain and weaker London dispersion forces
(C) Butyl acetate, because it has more C–C bonds to break
(D) Butyl acetate, because it has a longer carbon chain and weaker dipole-dipole attractions

GO ON TO THE NEXT PAGE.

Questions 29-31 refer to the investigation described below.

$$\underset{\textit{violet}}{C_{25}H_{30}N_3^+(aq)} + OH^-(aq) \rightarrow \underset{\textit{colorless}}{C_{25}H_{30}N_3OH(aq)}$$

The reaction between $C_{25}H_{30}N_3^+(aq)$ and $OH^-(aq)$, as represented above, is first order with respect to $C_{25}H_{30}N_3^+(aq)$ in the presence of excess $OH^-(aq)$. A 10.0 mL sample of 0.10 *M* NaOH(*aq*) is mixed with a 10.0 mL sample of 2.5×10^{-5} *M* $C_{25}H_{30}N_3^+(aq)$. A 5.0 mL sample of the mixture is quickly transferred to a clean cuvette and placed in a spectrophotometer, and the progress of the reaction is measured. The data are given in the table below.

Time (s)	0	30	60	90	120	150	180	210	240	270	300
Absorbance	0.62	0.54	0.47	0.41	0.36	0.31	0.27	0.23	0.20	0.17	0.15

29. Approximately how long did it take for 75 percent of the initial amount of $C_{25}H_{30}N_3^+(aq)$ to react?

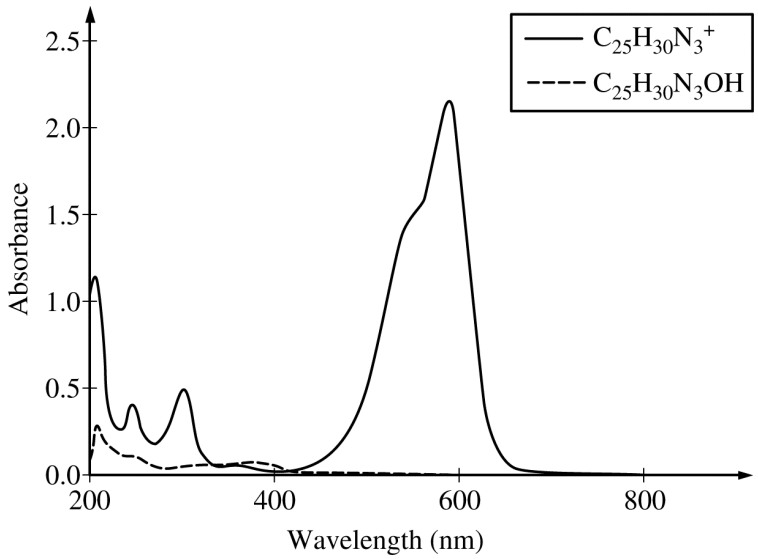
(A) 75 s
(B) 225 s
(C) 300 s
(D) 600 s

30. What would be the effect on the reaction rate if the solution of $C_{25}H_{30}N_3^+(aq)$ is diluted by a factor of two?

(A) It would be higher.
(B) It would be lower.
(C) It would not change.
(D) It would initially be higher but then rapidly decrease.

GO ON TO THE NEXT PAGE.

31. To choose a wavelength to analyze the progress of the reaction, a student records the absorbance spectra of both $C_{25}H_{30}N_3^+(aq)$ and $C_{25}H_{30}N_3OH(aq)$ in the range of 200-800 nm. The two spectra are presented in the graph below.



The student wants to use the spectrophotometer to measure $[C_{25}H_{30}N_3^+]$ with the greatest sensitivity as the reaction progresses. Which of the following indicates the best wavelength setting and explains why it is best?

(A) 205 nm, because the colorless form of the molecule will absorb significantly at this wavelength
(B) 205 nm, because both forms of the molecule will absorb significantly at this wavelength
(C) 590 nm, because only the violet form of the molecule will absorb significantly at this wavelength
(D) 590 nm, because this wavelength falls in the violet region of the visible light spectrum

$$CO(g) + H_2O(g) \rightleftarrows CO_2(g) + H_2(g) \qquad K_c = 1.5 \times 10^3$$

32. A 2.0 mol sample of $CO(g)$ and a 2.0 mol sample of $H_2O(g)$ are introduced into a previously evacuated 100. L rigid container, and the temperature is held constant as the reaction represented above reaches equilibrium. Which of the following is true at equilibrium?

(A) $[H_2O] > [CO]$ and $[CO_2] > [H_2]$
(B) $[H_2O] > [H_2]$
(C) $[CO_2] > [CO]$
(D) $[CO] = [H_2O] = [CO_2] = [H_2]$

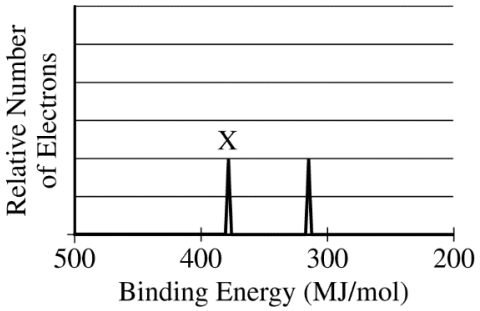
Compound	K_{sp} at 298 K
Ag_2SO_4	1×10^{-5}
$PbSO_4$	1×10^{-8}

33. A 1.0 L solution of $AgNO_3(aq)$ and $Pb(NO_3)_2(aq)$ has a Ag^+ concentration of 0.020 *M* and a Pb^{2+} concentration of 0.0010 *M*. A 0.0010 mol sample of $K_2SO_4(s)$ is added to the solution. Based on the information in the table above, which of the following will occur? (Assume that the volume change of the solution is negligible.)

(A) No precipitate will form.
(B) Only $Ag_2SO_4(s)$ will precipitate.
(C) Only $PbSO_4(s)$ will precipitate.
(D) Both $Ag_2SO_4(s)$ and $PbSO_4(s)$ will precipitate.

34. The pH of a 0.01 *M* $HNO_2(aq)$ solution is in which of the following ranges? (For $HNO_2(aq)$, $K_a = 4.0 \times 10^{-4}$)

(A) Between 1 and 2
(B) Between 2 and 3
(C) Between 4 and 5
(D) Between 6 and 7



35. The photoelectron spectra of the 1*s* electrons of two isoelectronic species, Ca^{2+} and Ar, are shown above. Which of the following correctly identifies the species associated with peak X and provides a valid justification?

(A) Ar, because it has completely filled energy levels
(B) Ar, because its radius is smaller than the radius of Ca^{2+}
(C) Ca^{2+}, because its nuclear mass is greater than that of Ar
(D) Ca^{2+}, because its nucleus has two more protons than the nucleus of Ar has

36. A vessel contains Ar(*g*) at a high pressure. Which of the following statements best helps to explain why the measured pressure is significantly greater than the pressure calculated using the ideal gas law?

(A) The molar mass of Ar is relatively large.
(B) A significant number of Ar_2 molecules form.
(C) The attractive forces among Ar atoms cause them to collide with the walls of the container with less force.
(D) The combined volume of the Ar atoms is too large to be negligible compared with the total volume of the container.

GO ON TO THE NEXT PAGE.

Questions 37-39 refer to the following information.

When water is added to a mixture of $Na_2O_2(s)$ and $S(s)$, a redox reaction occurs, as represented by the equation below.

$$2\ Na_2O_2(s) + S(s) + 2\ H_2O(l) \rightarrow 4\ NaOH(aq) + SO_2(aq) \qquad \Delta H^\circ_{298} = -610\ \text{kJ/mol}_{rxn}\ ;\ \Delta S^\circ_{298} = -7.3\ \text{J/(K}\cdot\text{mol}_{rxn})$$

37. Two trials are run, using excess water. In the first trial, 7.8 g of $Na_2O_2(s)$ (molar mass 78 g/mol) is mixed with 3.2 g of $S(s)$. In the second trial, 7.8 g of $Na_2O_2(s)$ is mixed with 6.4 g of $S(s)$. The $Na_2O_2(s)$ and $S(s)$ react as completely as possible. Both trials yield the same amount of $SO_2(aq)$. Which of the following identifies the limiting reactant and the heat released, q, for the two trials at 298 K?

	Limiting Reactant	q
(A)	S	30. kJ
(B)	S	61 kJ
(C)	Na_2O_2	30. kJ
(D)	Na_2O_2	61 kJ

38. Atoms of which element are reduced in the reaction?

(A) S; each atom loses four electrons
(B) Na in Na_2O_2; each atom loses one electron
(C) O in Na_2O_2; each atom gains one electron
(D) O in H_2O; each atom gains one electron

39. Which of the following statements about the thermodynamic favorability of the reaction at 298 K is correct?

(A) It is thermodynamically unfavorable.
(B) It is thermodynamically favorable and is driven by ΔS° only.
(C) It is thermodynamically favorable and is driven by ΔH° only.
(D) It is thermodynamically favorable and is driven by both ΔH° and ΔS°.

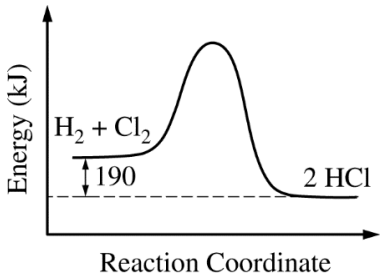
GO ON TO THE NEXT PAGE.

Bond	Bond Energy (kJ/mol)
H–H	430
Cl–Cl	240
H–Cl	430

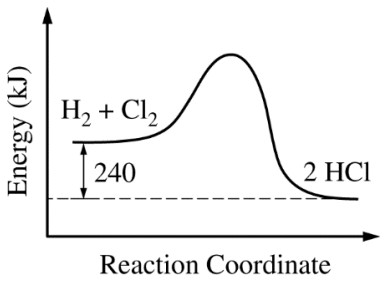
40. Based on the bond energies shown in the table above, which of the following diagrams best represents the change in energy as the reaction represented below proceeds?

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

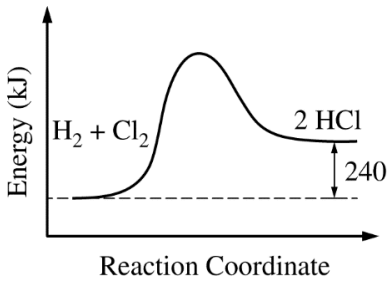
(A)



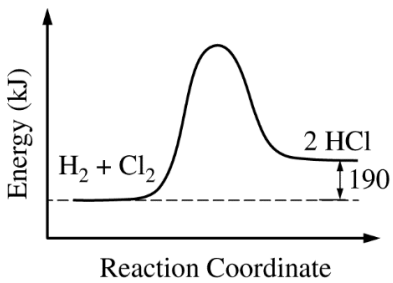
(B)



(C)



(D)



	Ionization Energy (kJ/mol)
First	577
Second	1,816
Third	2,745
Fourth	11,577
Fifth	14,482

41. Based on the ionization energies of element X given in the table above, which of the following is most likely the empirical formula of an oxide of element X?

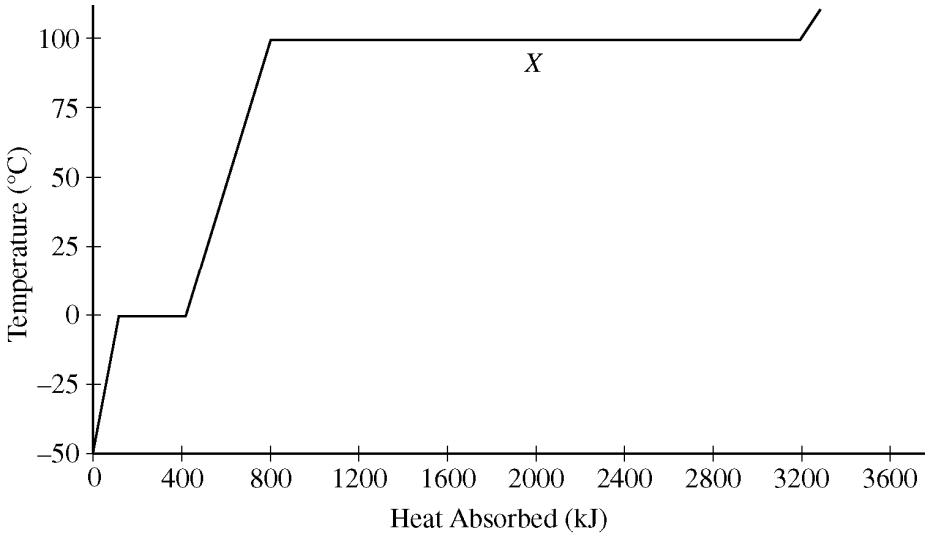
(A) XO_2
(B) X_2O
(C) X_2O_3
(D) X_2O_5

GO ON TO THE NEXT PAGE.

$$2\ H_2S(g) + CH_4(g) \rightleftarrows CS_2(g) + 4\ H_2(g) \qquad K_c = 3.4 \times 10^{-4}$$

42. A 0.10 mol sample of each of the four species in the reaction represented above is injected into a rigid, previously evacuated 1.0 L container. Which of the following species will have the highest concentration when the system reaches equilibrium?

(A) $H_2S(g)$
(B) $CH_4(g)$
(C) $CS_2(g)$
(D) $H_2(g)$



43. At 1.0 atm a sample of ice is heated to liquid water and then to water vapor. The heating curve is shown in the graph above. Which of the following lists the signs for the changes in enthalpy and entropy for the process corresponding to segment *X*, going from left to right?

	$\Delta H°$	$\Delta S°$
(A)	Positive	Negative
(B)	Positive	Positive
(C)	Negative	Negative
(D)	Negative	Positive

GO ON TO THE NEXT PAGE.

Questions 44-47 refer to the following.

$$CH_3OH(g) \rightarrow CO(g) + 2\,H_2(g) \qquad \Delta H^\circ = +91 \text{ kJ/mol}_{rxn}$$

The reaction represented above goes essentially to completion. The reaction takes place in a rigid, insulated vessel that is initially at 600 K.

44. What happens to the temperature of the contents of the vessel as the reaction occurs?

(A) The temperature must increase, because according to Le Châtelier's principle, an increase in temperature causes more products to form.
(B) The temperature must decrease, because the reaction takes place at a temperature above room temperature.
(C) The temperature must decrease, because the reaction is endothermic.
(D) The temperature does not change, because the vessel is insulated.

45. A sample of $CH_3OH(g)$ is placed in the previously evacuated vessel with a pressure of P_1 at 600 K. What is the final pressure in the vessel after the reaction is complete and the contents of the vessel are returned to 600 K?

(A) $\frac{P_1}{9}$
(B) $\frac{P_1}{3}$
(C) P_1
(D) $3P_1$

46. What can be inferred about ΔS° for the reaction at 600 K?

(A) It must be positive, since the reaction is thermodynamically unfavorable at 600 K.
(B) It must be negative, since there are more moles of products than reactants.
(C) It must be positive, since ΔG° is negative and ΔH° is positive.
(D) It must be negative, since ΔG° is positive and ΔH° is positive.

47. Which of the following statements about the bonds in the reactants and products is most accurate?

(A) The sum of the bond enthalpies of the bonds in the reactant is greater than the sum of the bond enthalpies of the bonds in the products.
(B) The sum of the bond enthalpies of the bonds in the reactant is less than the sum of the bond enthalpies of the bonds in the products.
(C) The length of the bond between carbon and oxygen in CH_3OH is shorter than the length of the bond between carbon and oxygen in CO.
(D) All of the bonds in the reactant and products are polar.

GO ON TO THE NEXT PAGE.

Acid	Concentration	pH
X	0.005 *M*	2.3
Y	2.0 *M*	2.8
Z	3.0 *M*	2.8

48. Which of the following correctly ranks the three monoprotic acids listed in the table above from the weakest to the strongest?

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

Element	Known Oxides
H	H_2O, H_2O_2
Li	Li_2O, Li_2O_2
Na	Na_2O, Na_2O_2, NaO_2
K	K_2O, K_2O_2, KO_2

49. Based on the information above and periodic trends, which of the following is the best hypothesis regarding the oxide(s) formed by Rb?

(A) Rb will form only Rb_2O.
(B) Rb will form only RbO_2.
(C) Rb will form only Rb_2O and Rb_2O_2.
(D) Rb will form Rb_2O, Rb_2O_2, and RbO_2.

$$Fe(s) + 2\,HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$$

50. When a student adds 30.0 mL of 1.00 *M* HCl to 0.56 g of powdered Fe, a reaction occurs according to the equation above. When the reaction is complete at 273 K and 1.0 atm, which of the following is true?

(A) HCl is in excess, and 0.100 mol of HCl remains unreacted.
(B) HCl is in excess, and 0.020 mol of HCl remains unreacted.
(C) 0.015 mol of $FeCl_2$ has been produced.
(D) 0.22 L of H_2 has been produced.

GO ON TO THE NEXT PAGE.

END OF SECTION I

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

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

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

Section II: Free-Response Questions

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

AP® Chemistry Exam

SECTION II: Free Response

2016

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

At a Glance

Total Time
1 hour, 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 4MBP4-S

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

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

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

AP® CHEMISTRY EQUATIONS AND CONSTANTS

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

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

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy
ν = frequency
λ = wavelength

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

EQUILIBRIUM

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

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

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

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

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

$= K_a \times K_b$

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

$14 = pH + pOH$

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

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

Equilibrium Constants

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

KINETICS

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

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

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

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

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

Molarity, M = moles of solute per liter of solution

$$A = abc$$

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

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

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

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

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

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

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

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

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

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

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

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

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

CHEMISTRY

Section 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.

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s) \qquad \Delta H^\circ_{rxn} = -63.7 \text{ kJ/mol}_{rxn}$$

1. Calcium oxide, $CaO(s)$, has been proposed as a substance that can be used to heat water quickly for portable heating packs or for cooking. When placed in water, $CaO(s)$ reacts as shown by the equation above.

   (a) A student wants to design a heating pad that could heat a 150.0 g sample of water from 25.0°C to 60.0°C.

   (i) Calculate the amount of heat, in joules, that the water must absorb for its temperature to change by this amount. (Assume that the specific heat capacity of the water is 4.18 J/(g·°C).)

   (ii) Calculate the minimum mass of $CaO(s)$ that the student would need to use in order to cause this temperature change.

   (b) The student hypothesizes that the design of the heating pad could be changed to enable it to heat 150.0 g of water from 25.0°C to 90.0°C by using a greater mass of $CaO(s)$.

   (i) Use the data in the table below to determine the standard entropy change, ΔS°_{rxn}, in J/(K·mol$_{rxn}$) for the reaction.

Substance	Absolute Entropy at 25°C (J/(K·mol))
$CaO(s)$	83
$H_2O(l)$	70.
$Ca(OH)_2(s)$	40.

   (ii) Is the reaction thermodynamically favorable at 90.0°C? Justify your answer with a calculation. (Assume that both ΔS°_{rxn} and ΔH°_{rxn} are constant between 25.0°C and 90.0°C.)

GO ON TO THE NEXT PAGE.

The student learns that the $Ca(OH)_2$ produced from the reaction is relatively insoluble and that it dissolves in water according to the equation below.

$$Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2\ OH^-(aq)$$

(c) The student prepares a saturated solution of $Ca(OH)_2$ and determines that the $[Ca^{2+}]$ is 0.011 *M*. Calculate the value of K_{sp} for $Ca(OH)_2$.

The student wishes to significantly increase the molar solubility of the $Ca(OH)_2(s)$ and has access to the following substances.

15 mL of distilled water	15 mL of 1.0 *M* $KOH(aq)$
15 mL of 1.0 *M* $CaCl_2(aq)$	15 mL of 1.0 *M* $HCl(aq)$

(d) Which substance, when added to the $Ca(OH)_2$ mixture, would increase the molar solubility most significantly? Justify your choice based on concepts of chemical equilibrium, such as Le Châtelier's principle.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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

2. $NaHCO_3(s)$ (baking soda) decomposes upon heating to produce $Na_2CO_3(s)$ and two gaseous products, as shown by the equation above.

   (a) A student claims that the reaction is an oxidation-reduction reaction because the oxidation number of carbon changes. Do you agree with the claim? In your answer include the oxidation number of carbon in each of the three carbon-containing species in the reaction.

   The student conducts an experiment to determine the composition of a mixture of $NaHCO_3$ (molar mass 84.01 g/mol) and Na_2CO_3 (molar mass 105.99 g/mol). The student places a sample of the mixture into a preweighed test tube that is attached to a container that holds a drying agent. The student heats the test tube strongly with a Bunsen burner for 10 minutes, during which time all of the water produced by the reaction is captured by the drying agent. The following table shows the data the student recorded during the experiment.

Mass of empty test tube	15.825 g
Mass of test tube and mixture before heating	17.648 g
Mass of drying agent before reaction	2.134 g
Mass of drying agent and water after reaction	2.303 g

   (b) Calculate the number of moles of $NaHCO_3(s)$ present in the mixture in the test tube before the reaction was initiated.

   (c) Determine the mass percent of $NaHCO_3(s)$ in the mixture.

   (d) If the student spills some of the mixture out of the test tube after weighing the test tube and mixture and before heating, how would this error affect the mass percent of $NaHCO_3$ calculated in part (c) ? Justify your answer.

   When a sample of pure Na_2CO_3 is placed in distilled water, the student observes that the pH of the solution increases significantly. This process is represented by the balanced net-ionic equation shown below.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftarrows HCO_3^{-}(aq) + OH^{-}(aq)$$

   (e) The student prepares a 0.10 M $Na_2CO_3(aq)$ solution and measures the pH of the solution to be 11.65.

      (i) Calculate $[OH^-]$ in the $Na_2CO_3(aq)$ solution.

      (ii) Write the expression for K_b for the carbonate ion.

      (iii) Calculate the value of K_b for the carbonate ion.

   The student adds some 1.0 M $Sr(NO_3)_2(aq)$ to the 0.10 M $Na_2CO_3(aq)$ and observes the formation of a precipitate.

   (f) Write the balanced net-ionic equation for the reaction between $Sr(NO_3)_2$ and Na_2CO_3 that produces the precipitate.

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PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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$$H_3BO_3(aq) + 4\ HF(g) \rightarrow H_3O^+(aq) + BF_4^-(aq) + 2\ H_2O(l)$$

3. Tetrafluoroboric acid is a strong acid with the formula HBF_4. The acid can be prepared by reacting the weak acid H_3BO_3 (molar mass 61.83 g/mol) with HF according to the equation above.

   (a) To prepare a solution of $BF_4^-(aq)$, $HF(g)$ is bubbled into a solution containing 50.0 g of H_3BO_3 in a 1 L reaction vessel.

   (i) Calculate the maximum number of moles of $BF_4^-(aq)$ that can be produced.

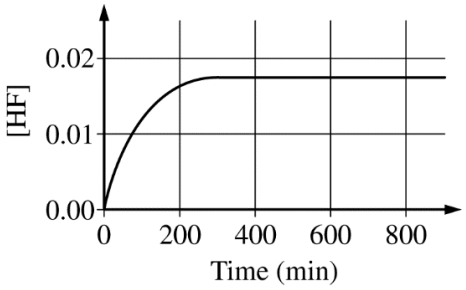
   (ii) Calculate the number of liters of $HF(g)$, measured at 273 K and 1.00 atm, that will be consumed if all the H_3BO_3 reacts.

   (iii) Will the pH of the solution increase, decrease, or remain the same during the course of the reaction? Justify your answer.

   In another experiment, a 0.150 *M* $BF_4^-(aq)$ solution is prepared by dissolving $NaBF_4(s)$ in distilled water. The $BF_4^-(aq)$ ions in the solution slowly react with $H_2O(l)$ in the reversible reaction represented below.

$$BF_4^-(aq) + H_2O(l) \rightleftarrows BF_3OH^-(aq) + HF(aq)$$

   The concentration of HF is monitored over time, as shown in the graph below.



   [HF] reaches a constant value of 0.0174 *M* when the reaction reaches equilibrium. For the forward reaction, the rate law is $rate = k_f[BF_4^-]$. The value of the rate constant k_f was experimentally determined to be $9.00 \times 10^{-4}\ min^{-1}$.

   (b) Calculate the rate of the forward reaction after 600. minutes. Include units with your answer.

   The rate law for the reverse reaction is $rate = k_r[BF_3OH^-][HF]$.

   (c) A student claims that the initial rate of the reverse reaction is equal to zero. Do you agree or disagree with this claim? Justify your answer in terms of the rate law for the reverse reaction.

   (d) At equilibrium the forward and reverse reaction rates are equal. Calculate the value of the rate constant for the reverse reaction.

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PAGE FOR ANSWERING QUESTION 3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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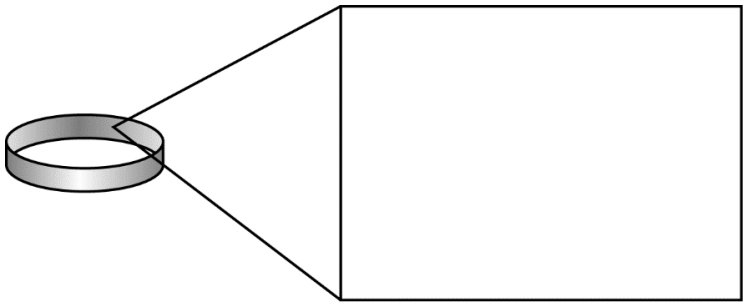
Element	Atomic Radius (pm)
Au	135
Pd	140

4. White gold is a common alloy of gold and palladium that is often used in jewelry. The atomic radii of the metals are given in the table above.

   (a) A particular ring is made from an alloy that is 75 mole percent gold and 25 mole percent palladium. Using the box below, draw a particle-level diagram of the solid alloy consisting of 12 atoms with a representative proportion of atom types. Your diagram should clearly indicate whether the alloy is interstitial or substitutional. Use empty circles for gold and shaded circles for palladium.



White-gold jewelry is often coated with rhodium to modify the color and durability.

   (b) A student hypothesizes that placing the ring in a 1.0 *M* solution of $Rh(NO_3)_3(aq)$ will result in a reaction in which Rh metal is deposited on the white-gold ring. Based on the information in the table below, calculate $E°$ for the reactions that may occur between ions in the solution and atoms in the ring, and indicate whether or not the student's hypothesis is correct.

Half-Reaction	$E°$ (V)
$Au^{3+}(aq) + 3\,e^- \rightarrow Au(s)$	1.50
$Pd^{2+}(aq) + 2\,e^- \rightarrow Pd(s)$	0.92
$Rh^{3+}(aq) + 3\,e^- \rightarrow Rh(s)$	0.76

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ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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Element	First Ionization Energy (J/mol)
Na	4.95×10^5
K	4.19×10^5

5. The first ionization energies for Na and K are given in the table above. Na metal reacts vigorously with water to form hydrogen gas and a metal hydroxide. K metal reacts vigorously as well, but it bursts into a violet-colored flame.

   (a) Write the electron configuration for a K^+ ion.

   (b) Based on principles of atomic structure, explain why the first ionization energy of K is lower than the first ionization energy of Na.

   (c) A student hypothesizes that the flame is violet colored because violet light consists of photons that have the energy needed to ionize K atoms. The wavelength of the violet light is measured to be 423 nm.

      (i) Calculate the energy, in J, of one photon of violet light with a wavelength of 423 nm.

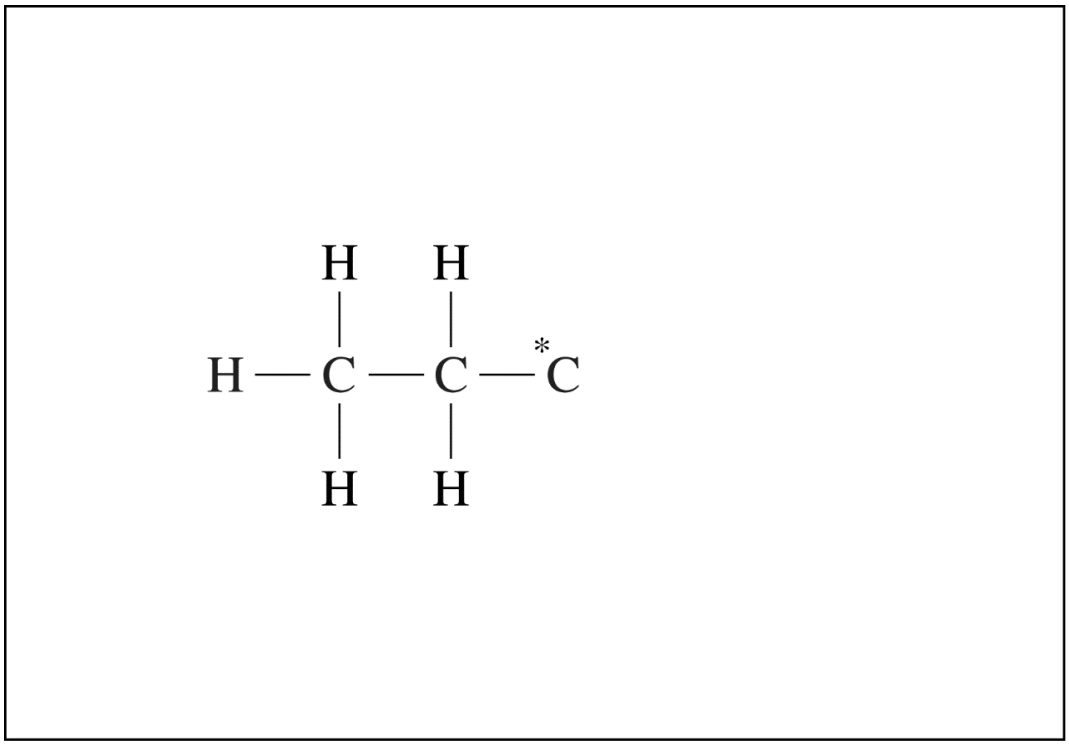
      (ii) Is the energy of one photon of the violet light sufficient to cause the ionization of a K atom? Justify your answer.

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

GO ON TO THE NEXT PAGE.

6. Propanoic acid, C_2H_5COOH, is an organic acid that is a liquid at room temperature.

(a) An incomplete Lewis diagram for the propanoic acid molecule is provided in the box below. Complete the diagram, showing how the remaining atoms in the molecule are arranged around the carbon atom marked with an asterisk (*). Your structure should minimize formal charge and include any lone pairs of electrons.



(b) Identify the hybridization of the carbon atom marked with the asterisk.

(c) Propanoic acid has a lower boiling point than butanoic acid, C_3H_7COOH.

(i) Identify all the types of intermolecular forces present among the molecules in propanoic acid.

(ii) Which of the types of intermolecular forces that you identified in part (c)(i) is most responsible for the difference in boiling points of the two acids?

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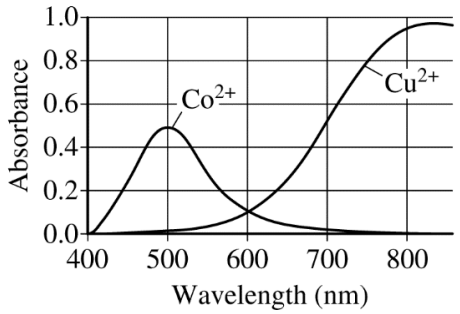
ADDITIONAL PAGE FOR ANSWERING QUESTION 6

7. A student has 100. mL of 0.400 *M* $CuSO_4(aq)$ and is asked to make 100. mL of 0.150 *M* $CuSO_4(aq)$ for a spectrophotometry experiment. The following laboratory equipment is available for preparing the solution: centigram balance, weighing paper, funnel, 10 mL beaker, 150 mL beaker, 50 mL graduated cylinder, 100 mL volumetric flask, 50 mL buret, and distilled water.

   (a) Calculate the volume of 0.400 *M* $CuSO_4(aq)$ required for the preparation.

   (b) Briefly describe the essential steps to most accurately prepare the 0.150 *M* $CuSO_4(aq)$ from the 0.400 *M* $CuSO_4(aq)$ using the equipment listed above.

   The student plans to conduct a spectrophotometric analysis to determine the concentration of $Cu^{2+}(aq)$ in a solution. The solution has a small amount of $Co(NO_3)_2(aq)$ present as a contaminant. The student is given the diagram below, which shows the absorbance curves for aqueous solutions of $Co^{2+}(aq)$ and $Cu^{2+}(aq)$.



   (c) The spectrophotometer available to the student has a wavelength range of 400 nm to 700 nm. What wavelength should the student use to minimize the interference from the presence of the $Co^{2+}(aq)$ ions?

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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: D
Question 2: D
Question 3: A
Question 4: D
Question 5: A
Question 6: B
Question 7: A
Question 8: C
Question 9: C
Question 10: C
Question 11: B
Question 12: A
Question 13: A
Question 14: C
Question 15: C
Question 16: B
Question 17: B
Question 18: C
Question 19: B
Question 20: A
Question 21: D
Question 22: A
Question 23: D
Question 24: B
Question 25: A
Question 26: B
Question 27: B
Question 28: B
Question 29: C
Question 30: B
Question 31: C
Question 32: C
Question 33: C
Question 34: B
Question 35: D
Question 36: D
Question 37: C
Question 38: C
Question 39: C
Question 40: A
Question 41: C
Question 42: A
Question 43: B
Question 44: C
Question 45: D
Question 46: C
Question 47: A
Question 48: D
Question 49: D
Question 50: D

Free-Response Scoring Guidelines

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

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Question 1

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s) \qquad \Delta H^\circ_{rxn} = -63.7 \text{ kJ/mol}_{rxn}$$

Calcium oxide, $CaO(s)$, has been proposed as a substance that can be used to heat water quickly for portable heating packs or for cooking. When placed in water, $CaO(s)$ reacts as shown by the equation above.

(a) A student wants to design a heating pad that could heat a 150.0 g sample of water from 25.0°C to 60.0°C.

(i) Calculate the amount of heat, in joules, that the water must absorb for its temperature to change by this amount. (Assume that the specific heat capacity of the water is 4.18 J/(g·°C).)

$q = mc\Delta T$ $= 150.0 \text{ g} \times 4.18 \text{ J/(g·°C)} \times (60.0°\text{C} - 25.0°\text{C})$ $= 2.19 \times 10^4 \text{ J}$	1 point is earned for the correct answer.

(ii) Calculate the minimum mass of $CaO(s)$ that the student would need to use in order to cause this temperature change.

$(2.19 \times 10^4 \text{ J}) \times \frac{1 \text{ mol}_{rxn}}{6.37 \times 10^4 \text{ J}} \times \frac{1 \text{ mol CaO}}{1 \text{ mol}_{rxn}} \times \frac{56.08 \text{ g CaO}}{1 \text{ mol CaO}} = 19.3 \text{ g}$	1 point is earned for calculation of moles of CaO from energy change (can be implicit). 1 point is earned for the correct mass of CaO.

(b) The student hypothesizes that the design of the heating pad could be changed to enable it to heat 150.0 g of water from 25.0°C to 90.0°C by using a greater mass of $CaO(s)$.

(i) Use the data in the table below to determine the standard entropy change, ΔS°_{rxn}, in $\text{J/(K·mol}_{rxn})$ for the reaction.

Substance	Absolute Entropy at 25°C (J/(K·mol))
$CaO(s)$	83
$H_2O(l)$	70.
$Ca(OH)_2(s)$	40.

$\Delta S^\circ_{rxn} = \Sigma S^\circ$ products $- \Sigma S^\circ$ reactants $= 40. \text{ J/(K·mol)} - [83 \text{ J/(K·mol)} + 70. \text{ J/(K·mol)}]$ $= -113 \text{ J/(K·mol}_{rxn})$	1 point is earned for the correct answer.

Question 1 (continued)

(ii) Is the reaction thermodynamically favorable at 90.0°C? Justify your answer with a calculation.
(Assume that both ΔS°_{rxn} and ΔH°_{rxn} are constant between 25.0°C and 90.0°C.)

Yes, because ΔG° is negative. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ $= -63.7 \text{ kJ/mol}_{rxn} - 363 \text{ K } (-113 \text{ J/(K·mol}_{rxn})) \times \frac{1 \text{ kJ}}{1000 \text{ J}}$ $= -22.7 \text{ kJ/mol}_{rxn}$	1 point is earned for indicating that the reaction is thermodynamically favorable. 1 point is earned for the calculation of ΔG°.

The student learns that the $Ca(OH)_2$ produced from the reaction is relatively insoluble and that it dissolves in water according to the equation below.

$$Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2\ OH^-(aq)$$

(c) The student prepares a saturated solution of $Ca(OH)_2$ and determines that the $[Ca^{2+}]$ is 0.011 *M*. Calculate the value of K_{sp} for $Ca(OH)_2$.

$[OH^-] = 2 \times [Ca^{2+}] = 2\ (0.011\ M) = 0.022\ M$ $K_{sp} = [Ca^{2+}]\ [OH^-]^2$ $= (0.011)(0.022)^2 = 5.3 \times 10^{-6}$	1 point is earned for the correct $[OH^-]$ (or implicit recognition that $[OH^-] = 2\ [Ca^{2+}]$). 1 point is earned for the correct value of K_{sp}.

The student wishes to significantly increase the molar solubility of the $Ca(OH)_2(s)$ and has access to the following substances.

15 mL of distilled water	15 mL of 1.0 *M* KOH(*aq*)
15 mL of 1.0 *M* $CaCl_2(aq)$	15 mL of 1.0 *M* HCl(*aq*)

(d) Which substance, when added to the $Ca(OH)_2$ mixture, would increase the molar solubility most significantly? Justify your choice based on concepts of chemical equilibrium, such as Le Châtelier's principle.

HCl The H^+ from the HCl reacts with OH^-, decreasing $[OH^-]$. The loss of OH^- results in non-equilibrium conditions in the $Ca(OH)_2$ dissolution. More $Ca(OH)_2$ must dissolve to increase $[OH^-]$, increasing the molar solubility as Q approaches K and the system returns to equilibrium.	1 point is earned for choosing HCl. 1 point is earned for the justification.

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Question 2

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

$NaHCO_3(s)$ (baking soda) decomposes upon heating to produce $Na_2CO_3(s)$ and two gaseous products, as shown by the equation above.

(a) A student claims that the reaction is an oxidation-reduction reaction because the oxidation number of carbon changes. Do you agree with the claim? In your answer include the oxidation number of carbon in each of the three carbon-containing species in the reaction.

No. The oxidation number of carbon is +4 in each of the three carbon-containing species.	1 point is earned for the oxidation number and correct conclusion.

The student conducts an experiment to determine the composition of a mixture of $NaHCO_3$ (molar mass 84.01 g/mol) and Na_2CO_3 (molar mass 105.99 g/mol). The student places a sample of the mixture into a preweighed test tube that is attached to a container that holds a drying agent. The student heats the test tube strongly with a Bunsen burner for 10 minutes, during which time all of the water produced by the reaction is captured by the drying agent. The following table shows the data the student recorded during the experiment.

Mass of empty test tube	15.825 g
Mass of test tube and mixture before heating	17.648 g
Mass of drying agent before reaction	2.134 g
Mass of drying agent and water after reaction	2.303 g

(b) Calculate the number of moles of $NaHCO_3(s)$ present in the mixture in the test tube before the reaction was initiated.

$2.303\ g - 2.134\ g = 0.169\ g\ H_2O$ $0.169\ g\ H_2O \times \frac{1\ mol\ H_2O}{18.02\ g\ H_2O} \times \frac{2\ mol\ NaHCO_3}{1\ mol\ H_2O}$ $= 0.0188\ mol\ NaHCO_3$	1 point is earned for the calculation of the mass of H_2O from the experimental data. 1 point is earned for the calculation of the number of moles of $NaHCO_3$.

(c) Determine the mass percent of $NaHCO_3(s)$ in the mixture.

$0.0188\ mol\ NaHCO_3 \times \frac{84.01\ g\ NaHCO_3}{1\ mol\ NaHCO_3} = 1.58\ g\ NaHCO_3$ $\frac{1.58\ g}{(17.648\ g - 15.825\ g)} \times 100 = 86.7\%$	1 point is earned for the number of grams of $NaHCO_3$. 1 point is earned for the mass percent.

Question 2 (continued)

(d) If the student spills some of the mixture out of the test tube after weighing the test tube and mixture and before heating, how would this error affect the mass percent of $NaHCO_3$ calculated in part (c)? Justify your answer.

The calculated mass percent would be smaller than the actual value. Less water would be collected, so there would appear to be less $NaHCO_3$ in the sample.	1 point is earned for the correct answer and justification.

When a sample of pure Na_2CO_3 is placed in distilled water, the student observes that the pH of the solution increases significantly. This process is represented by the balanced net-ionic equation shown below.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftarrows HCO_3^{-}(aq) + OH^{-}(aq)$$

(e) The student prepares a 0.10 M $Na_2CO_3(aq)$ solution and measures the pH of the solution to be 11.65.

(i) Calculate $[OH^-]$ in the $Na_2CO_3(aq)$ solution.

pOH = 14.00 − 11.65 = 2.35 $[OH^-] = 10^{-2.35} = 4.5 \times 10^{-3}$ M	1 point is earned for the correct concentration.

(ii) Write the expression for K_b for the carbonate ion.

$K_b = \dfrac{[HCO_3^-][OH^-]}{[CO_3^{2-}]}$	1 point is earned for the correct expression.

(iii) Calculate the value of K_b for the carbonate ion.

$K_b = \dfrac{(4.5 \times 10^{-3}) \times (4.5 \times 10^{-3})}{0.10 - (4.5 \times 10^{-3})} \approx \dfrac{(4.5 \times 10^{-3})^2}{(0.10)} = 2.0 \times 10^{-4}$	1 point is earned for the correct value.

The student adds some 1.0 M $Sr(NO_3)_2(aq)$ to the 0.10 M $Na_2CO_3(aq)$ and observes the formation of a precipitate.

(f) Write the balanced net-ionic equation for the reaction between $Sr(NO_3)_2$ and Na_2CO_3 that produces the precipitate.

$Sr^{2+} + CO_3^{2-} \rightarrow SrCO_3$	1 point is earned for the correct equation.

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2016 SCORING GUIDELINES

Question 3

$$H_3BO_3(aq) + 4\ HF(g) \rightarrow H_3O^+(aq) + BF_4^-(aq) + 2\ H_2O(l)$$

Tetrafluoroboric acid is a strong acid with the formula HBF_4. The acid can be prepared by reacting the weak acid H_3BO_3 (molar mass 61.83 g/mol) with HF according to the equation above.

(a) To prepare a solution of $BF_4^-(aq)$, $HF(g)$ is bubbled into a solution containing 50.0 g of H_3BO_3 in a 1 L reaction vessel.

(i) Calculate the maximum number of moles of $BF_4^-(aq)$ that can be produced.

$50.0\ \text{g}\ H_3BO_3 \times \frac{1\ \text{mol}\ H_3BO_3}{61.83\ \text{g}} \times \frac{1\ \text{mol}\ BF_4^-}{1\ \text{mol}\ H_3BO_3}$ $= 0.809\ \text{mol}\ BF_4^-$	1 point is earned for the number of moles.

(ii) Calculate the number of liters of $HF(g)$, measured at 273 K and 1.00 atm, that will be consumed if all the H_3BO_3 reacts.

$0.809\ \text{mol} \times 4 = 3.24\ \text{mol}$ $PV = nRT$ $V = \frac{nRT}{P} = \frac{(3.24\ \text{mol})(0.08206\ \text{L atm mol}^{-1}\ \text{K}^{-1})(273\ \text{K})}{(1.00\ \text{atm})}$ $= 72.6\ \text{L}$ OR $0.809\ \text{mol} \times 4 = 3.24\ \text{mol}$ $\frac{22.4\ \text{L}}{1\ \text{mol}} \times 3.24\ \text{mol} = 72.6\ \text{L}$	1 point is earned for calculation of number of moles of HF. 1 point is earned for the number of liters.

(iii) Will the pH of the solution increase, decrease, or remain the same during the course of the reaction? Justify your answer.

As the reaction proceeds, H_3O^+ is produced, so the pH will decrease.	1 point is earned for the correct choice and the justification.

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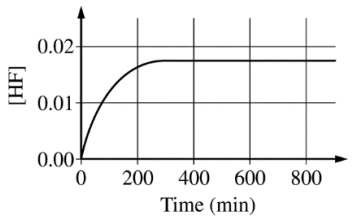
Question 3 (continued)

In another experiment, a 0.150 M $BF_4^-(aq)$ solution is prepared by dissolving $NaBF_4(s)$ in distilled water. The $BF_4^-(aq)$ ions in the solution slowly react with $H_2O(l)$ in the reversible reaction represented below.

$$BF_4^-(aq) + H_2O(l) \rightleftarrows BF_3OH^-(aq) + HF(aq)$$

The concentration of HF is monitored over time, as shown in the graph below.



[HF] reaches a constant value of 0.0174 M when the reaction reaches equilibrium. For the forward reaction, the rate law is $rate = k_f[BF_4^-]$. The value of the rate constant k_f was experimentally determined to be 9.00×10^{-4} min^{-1}.

(b) Calculate the rate of the forward reaction after 600. minutes. Include units with your answer.

$[BF_4^-] = 0.150\ M - 0.0174\ M = 0.133\ M$ $rate = (9.00 \times 10^{-4}\ min^{-1})(0.133\ M) = 1.20 \times 10^{-4}\ M\ min^{-1}$	1 point is earned for the molarity. 1 point is earned for the value of the rate. 1 point is earned for units.

The rate law for the reverse reaction is $rate = k_r[BF_3OH^-][HF]$.

(c) A student claims that the initial rate of the reverse reaction is equal to zero. Do you agree or disagree with this claim? Justify your answer in terms of the rate law for the reverse reaction.

Agree. The initial concentration of each product is zero, so the initial rate of the reverse reaction is zero.	1 point is earned for agreeing and for the justification.

(d) At equilibrium the forward and reverse reaction rates are equal. Calculate the value of the rate constant for the reverse reaction.

$rate = k_r[BF_3OH^-][HF]$ At equilibrium, $rate_{reverse} = rate_{forward} = 1.20 \times 10^{-4}\ M\ min^{-1}$ $k_r = \frac{rate}{[BF_3OH^-][HF]} = \frac{1.20 \times 10^{-4}\ M\ min^{-1}}{(0.0174\ M) \times (0.0174\ M)} = 0.396\ M^{-1}\ min^{-1}$	1 point is earned for appropriate numerical substitutions into the rate expression. 1 point is earned for the correct answer.

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Question 4

Element	Atomic Radius (pm)
Au	135
Pd	140

White gold is a common alloy of gold and palladium that is often used in jewelry. The atomic radii of the metals are given in the table above.

(a) A particular ring is made from an alloy that is 75 mole percent gold and 25 mole percent palladium. Using the box below, draw a particle-level diagram of the solid alloy consisting of 12 atoms with a representative proportion of atom types. Your diagram should clearly indicate whether the alloy is interstitial or substitutional. Use empty circles for gold and shaded circles for palladium.

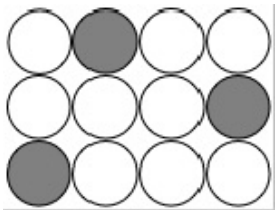

Diagram should show 12 circles in a regular array, 9 empty and 3 shaded.	1 point is earned for the correct number of each type of circle. 1 point is earned for showing an acceptable arrangement (i.e., regular array of circles of about the same size).

White-gold jewelry is often coated with rhodium to modify the color and durability.

(b) A student hypothesizes that placing the ring in a 1.0 M solution of $Rh(NO_3)_3(aq)$ will result in a reaction in which Rh metal is deposited on the white-gold ring. Based on the information in the table below, calculate $E°$ for the reactions that may occur between ions in the solution and atoms in the ring, and indicate whether or not the student's hypothesis is correct.

Half-Reaction	$E°$ (V)
$Au^{3+}(aq) + 3\ e^- \rightarrow Au(s)$	1.50
$Pd^{2+}(aq) + 2\ e^- \rightarrow Pd(s)$	0.92
$Rh^{3+}(aq) + 3\ e^- \rightarrow Rh(s)$	0.76

$Au + Rh^{3+} \rightarrow Au^{3+} + Rh$ $0.76\ V - 1.50\ V = -0.74\ V$ $3\ Pd + 2\ Rh^{3+} \rightarrow 3\ Pd^{2+} + 2\ Rh$ $0.76\ V - 0.92\ V = -0.16\ V$	1 point is earned for the $E°$ calculations.
The student's hypothesis is incorrect. (Both voltages are negative, so the reactions are not thermodynamically favorable under these conditions.)	1 point is earned for the claim.

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Question 5

Element	First-Ionization Energy (J/mol)
Na	4.95×10^5
K	4.19×10^5

The first-ionization energies for Na and K are given in the table above. Na metal reacts vigorously with water to form hydrogen gas and a metal hydroxide. K metal reacts vigorously as well, but it bursts into a violet-colored flame.

(a) Write the electron configuration for a K^+ ion.

$1s^2\ 2s^2 2p^6\ 3s^2 3p^6$ OR [Ne] $3s^2 3p^6$	1 point is earned for the correct configuration.

(b) Based on principles of atomic structure, explain why the first ionization energy of K is lower than the first ionization energy of Na.

The valence electron in K is in a higher principal energy level and farther from the nucleus than the valence electron in Na, therefore the valence electron in K is easier to remove.	1 point is earned for a correct explanation.

(c) A student hypothesizes that the flame is violet colored because violet light consists of photons that have the energy needed to ionize K atoms. The wavelength of the violet light is measured to be 423 nm.

(i) Calculate the energy, in J, of one photon of violet light with a wavelength of 423 nm.

$c = \lambda\nu$ $\nu = \frac{c}{\lambda} = \frac{(2.998 \times 10^8\ \text{m s}^{-1})}{4.23 \times 10^{-7}\ \text{m}} = 7.09 \times 10^{14}\ \text{s}^{-1}$ $E = h\nu = (6.626 \times 10^{-34}\ \text{J s})(7.09 \times 10^{14}\ \text{s}^{-1})$ $= 4.70 \times 10^{-19}\ \text{J}$	1 point is earned for the correct answer.

(ii) Is the energy of one photon of the violet light sufficient to cause the ionization of a K atom? Justify your answer.

$4.19 \times 10^5\ \text{J/mol} \times \frac{1\ \text{mol}}{6.022 \times 10^{23}}$ $= 6.96 \times 10^{-19}\ \text{J}$ required to ionize one atom This is greater than the energy of one photon of violet light, so it is not sufficient.	1 point is earned for the correct energy and conclusion.

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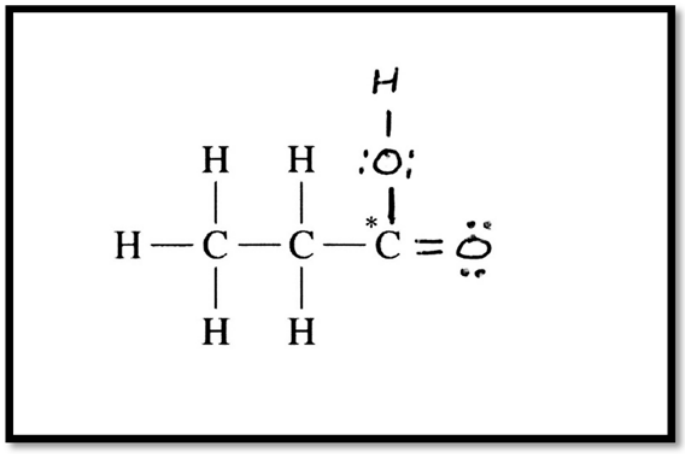
Question 6

Propanoic acid, C_2H_5COOH, is an organic acid that is a liquid at room temperature.

(a) An incomplete Lewis diagram for the propanoic acid molecule is provided in the box below. Complete the diagram, showing how the remaining atoms in the molecule are arranged around the carbon atom marked with an asterisk (*). Your structure should minimize formal charge and include any lone pairs of electrons.



There should be two O atoms attached to the C atom, one with a double bond and one with a single bond. The O atom attached with a single bond should have an H atom attached to it. Each O atom has two lone pairs of electrons. (Figure is required.)	1 point is earned for a correct structure.

(b) Identify the hybridization of the carbon atom marked with the asterisk.

sp^2	1 point is earned for the correct hybridization.

(c) Propanoic acid has a lower boiling point than butanoic acid, C_3H_7COOH.

(i) Identify all the types of intermolecular forces present among the molecules in propanoic acid.

London dispersion forces, dipole-dipole forces, and hydrogen bonding. (Identifying dipole-dipole forces is not required to earn the point.)	1 point is earned for identifying both London dispersion forces and hydrogen bonding.

(ii) Which of the types of intermolecular forces that you identified in part (c)(i) is most responsible for the difference in boiling points of the two acids?

London dispersion forces.	1 point is earned for the correct answer.

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Question 7

A student has 100. mL of 0.400 M $CuSO_4(aq)$ and is asked to make 100. mL of 0.150 M $CuSO_4(aq)$ for a spectrophotometry experiment. The following laboratory equipment is available for preparing the solution: centigram balance, weighing paper, funnel, 10 mL beaker, 150 mL beaker, 50 mL graduated cylinder, 100 mL volumetric flask, 50 mL buret, and distilled water.

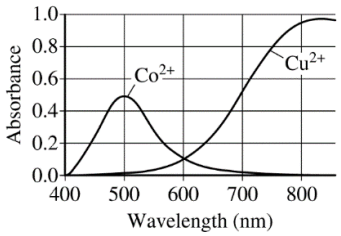
(a) Calculate the volume of 0.400 M $CuSO_4(aq)$ required for the preparation.

$M_1 V_1 = M_2 V_2$ $V_2 = \frac{(0.150\ M)(0.100\ \text{L})}{0.400\ M}$ $V_2 = 0.0375\ \text{L} \times \frac{1000\ \text{mL}}{1\ \text{L}} = 37.5\ \text{mL}$	1 point is earned for the correct volume.

(b) Briefly describe the essential steps to most accurately prepare the 0.150 M $CuSO_4(aq)$ from the 0.400 M $CuSO_4(aq)$ using the equipment listed above.

Use the buret to dispense 37.5 mL of $CuSO_4$ solution into the volumetric flask. Fill to the mark with distilled water.	1 point is earned for using the buret to measure 37.5 mL of 0.400 M $CuSO_4$ solution. 1 point is earned for adding the $CuSO_4$ solution to the volumetric flask and filling to the mark with distilled water.

The student plans to conduct a spectrophotometric analysis to determine the concentration of $Cu^{2+}(aq)$ in a solution. The solution has a small amount of $Co(NO_3)_2(aq)$ present as a contaminant. The student is given the diagram below, which shows the absorbance curves for aqueous solutions of $Co^{2+}(aq)$ and $Cu^{2+}(aq)$.



(c) The spectrophotometer available to the student has a wavelength range of 400 nm to 700 nm. What wavelength should the student use to minimize the interference from the presence of the $Co^{2+}(aq)$ ions?

700 nm (Any wavelength from 650 to 700 nm is acceptable.)	1 point is earned for a correct wavelength.

Scoring Worksheet

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

2016 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
45-63	3
28-44	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.

2016 AP Chemistry

Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
1	2.13	2B2	1.4	D	61
2	4.5	4B2	6.2	D	86
3	2.24	2D1	7.1	A	74
4	6.9	6B1	4.2	D	82
5	2.21, 5.8	2C4|5C2	1.4, 2.3, 7.1, 7.2	A	32
6	2.14	2B2	1.4	B	19
7	2.17	2C0	6.4	A	80
8	1.5	1B1	1.5	C	78
9	6.13	6C1	6.4	C	78
10	4.4	4A3|4B1|4B2	7.1	C	79
11	1.2	1A2	2.2	B	76
12	6.21	6C3	2.2, 2.3	A	76
13	5.2	5A1	1.1, 1.4	A	37
14	3.12	3C3	2.2, 2.3	C	58
15	6.25	6D1	2.3	C	54
16	4.1	4A1	4.2	B	81
17	2.15	2B3|5E1	6.2	B	68
18	2.32	2D4	6.2	C	58
19	2.16	2B3	6.2	B	50
20	6.16	6C1	2.2	A	64
21	1.19	1E2	6.4	D	62
22	6.13, 6.17	6C1	6.4	A	46
23	1.20	1E2|6C1	5.1	D	60
24	5.7	5B4	5.1	B	37
25	5.7	5B4	4.2	A	21
26	4.7	4C0	6.5	B	60
27	2.21	2C4	1.4	B	49
28	2.10	2A3	6.4	B	44
29	4.3	4A3	2.2	C	53
30	4.1	4A1	5.1	B	58
31	1.16	1D3	4.2	C	57
32	6.6	6A3	2.2, 6.4	C	56
33	6.21	6C3	2.2, 2.3	C	26
34	6.16	6C1	2.2	B	36
35	1.7	1B2	6.2	D	45
36	2.4	2A2	1.4	D	50
37	5.6	5B3	2.2, 2.3	C	36
38	3.8	3B3	6.1	C	47

2016 AP Chemistry

Question Descriptors and Performance Data

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
39	5.13	5E1|5E2	2.2, 2.3	C	42
40	5.8	5C2	7.1, 7.2	A	34
41	1.9	1C1	6.4	C	62
42	6.6	6A3	6.4	A	40
43	5.12	5E1|5E2	1.4	B	60
44	5.6	5B3	2.3	C	56
45	2.6	2A1|3A2	2.2, 2.3	D	44
46	5.13	5E2|5E3	6.4	C	59
47	5.8	5C2	7.1, 7.2	A	47
48	6.12	6C1	1.4	D	67
49	1.11	1C1	3.1	D	83
50	3.4	3A2	5.1	D	21

Free-Response Questions

Question	Learning Objectives	Essential Knowledge	Science Practice	Mean Score
1	5.6, 5.7, 5.13, 5.14, 6.22, and 6.23	5.B.3, 5.B.4, 5.E.2, 5.E.3, and 6.C.3	2.2, 2.3, 4.2, 5.1, 6.4	4.37
2	1.3, 3.1, 3.8, 6.5, and 6.16	1.A.2, 3A-3C, 3.B.3, 6.A.3 and 6.C.1	1.5, 2.2, 6.1, 6.4	4.82
3	2.6, 3.3, 4.1, 6.15 and 6.16	2.A.2, 3.A.2, 4.A.1, and 6.C.1	2.2, 2.3, 4.2, 5.1, 6.4	5.27
4	2.27 and 3.12	2.D.2 and 3.C.3	1.1, 2.2, 2.3, and 6.4	1.70
5	1.7 and 1.9	1.B.2, and 1.C.1	5.1, 6.2, and 6.4	1.32
6	2.11, 2.13, 2.16, and 2.21	2.B.1, 2.B.2, 2.B.3, and 2.C.4	1.4, 6.2, and 6.4	1.78
7	1.16 and 3.4	1.D.3 and 3.A.2	2.2, 4.2, 5.1, and 6.4	1.76

AP Chemistry

The College Board

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