Chapter II: The 2008 AP Chemistry Exam

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- The Exam

Exam Content and Format

The 2008 AP Chemistry Exam is 3 hours and 5 minutes in length and has two sections:

- A 90-minute multiple-choice section consisting of 75 questions that account for 50 percent of the final score.
- A 95-minute free-response section consisting of 6 required questions that account for 50 percent of the final score.

2008 AP Chemistry Exam Format

Multiple Choice (Section I)

75 questions — 90 minutes

Free Response (Section II)

Part A

3 questions — 55 minutes
(3 required problems)

Part B

3 questions — 40 minutes
(3 required questions)

Giving a Practice Exam

The following pages contain the instructions as they appeared in the 2008 *AP Examination Instructions* for administering the AP Chemistry Exam. Following these instructions are a blank 2008 answer sheet and the 2008 AP Chemistry Exam. If you plan to use this released exam to test your students, you may wish to use these instructions to create an exam situation that closely resembles an actual administration. If so, read only the indented, boldface directions to the students; all other instructions are for the person administering the exam and need not be read aloud. Some instructions, such as those referring to the date, the time, and page numbers, are no longer relevant and should be ignored. Note: the term "grades," which appears in the exam and exam instructions that follow, refers to AP Exam scores of 1, 2, 3, 4, or 5.

Another publication you might find useful is the *Packet of 10*—ten copies of the 2008 AP Chemistry Exam, each with a blank answer sheet. You can order this packet online at the College Board Store (store.collegeboard.com).

Instructions for Administering the Exam
(from the 2008 *AP Examination Instructions* book)

Students are permitted to use calculators to answer some of the questions on the AP Chemistry Exam. Before starting the exam administration, refer to the calculator policy for Chemistry on pages 62–63 of the 2008 *AP Coordinator's Manual.* If a student does not have an appropriate calculator, 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 sign the release statement on page 62 of the 2008 *AP Coordinator's Manual.*

During the administration of Section II, Part A only, 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.** Calculators with QWERTY keyboards are prohibited.

SECTION I: Multiple-Choice Questions

! 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. When you have completed the General Instructions, say:

> **It is Tuesday morning, May 13, 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 2007-08 *Bulletin for AP Students and Parents*. You may now open 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. Read the statements on the front cover of Section I and look up when you have finished. . . .**
>
> **Now 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? . . .**

Answer any questions. Then say:

> **Now turn to the back cover and read it completely. Look up when you have finished. . . .**
>
> **Are there any questions? . . .**

Answer any questions. Then say:

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

Answer any questions. Then say:

> **You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses on your answer sheet, one response per question. Completely fill in the ovals. There are more answer ovals on the answer sheet than there are questions, so you will have unused ovals when you**

reach the end. Your answer sheet will be scored by machine; any stray marks or smudges could be read as answers. 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? . . .

Answer all questions regarding procedure. Then say:

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 ________. You and your proctors should make sure students are marking their answers in pencil on their answer sheets, and that they are not looking at their shrinkwrapped Section II booklets. After 1 hour and 30 minutes, say:

Stop working. Close your booklet and put your answer sheet on your desk, face up, with the fold to your left. I will now collect your answer sheet.

After you have collected an answer sheet from each student, say:

Take your seals and press one on each area of your exam booklet marked "PLACE SEAL HERE." Fold them over the open edges and press them to the back cover. When you have finished, place the booklet on your desk with the cover face up and the fold to your left. . . .

I will now collect your Section I booklet.

As you collect the sealed Section I booklets, check to be sure that each student has signed the front cover. 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 break. Everything you placed under your chair at the beginning of the exam must remain there. You are not allowed to consult teachers, other students, or textbooks about the exam materials during the break. You may not make phone calls, send text messages, check e-mail, access a computer, calculator, cell phone, PDA, MP3 player, e-mail/messaging device, or any other electronic or communication device. Remember, you are not allowed to discuss the multiple-choice section of this exam with <u>anyone at any time</u>. Failure to adhere to any of these rules could result in invalidation of your grade. Please leave your shrinkwrapped Section II package on top of your desk during the break. You may get up, talk, go to the restroom, or get a drink. Are there any questions? . . .

Answer all questions regarding procedure. Then say:

Let's begin our break. Testing will resume at ________.

SECTION II: Free-Response Questions

After the break, say:

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

You may now open the shrinkwrapped Section II package. . . .

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

Now place an AP number label on the shaded box. If you don't place an AP number label on this box, it may be impossible to identify your booklet, which could delay or jeopardize your AP grade. 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 conditions stated on the front cover. . . .

Turn to the back cover and read Item 1 under "Important Identification Information." Print your identification information in the boxes. Note that you must print the first two letters of your LAST name and the first letter of your FIRST name. Look up when you have finished. . . .

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

Read Item 3 and copy the school code you printed on the front of your Student Pack into the boxes. . . .

Read Item 4. . . .

Are there any questions? . . .

Answer all questions regarding procedure. Then say:

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

While Student Packs are being collected, read the "At a Glance" column and the instructions on the back cover of the pink booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .

Collect the Student Packs. Then say:

Are there any questions? . . .

Answer all questions regarding procedure. Then say:

Section II has two parts. You are responsible for pacing yourself, and may proceed freely from one question to the next within each part. Write your answers legibly using either 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. Do not begin Part B or remove the green insert in the center of the pink booklet until you are told to do so. Calculators are allowed for Part A. You may get your calculators from under your chair and place them on your desk. . . .

You have 55 minutes to complete Part A. You must answer Questions 1, 2, and 3. If you need more paper during the exam, raise your hand. At the top of each extra piece of paper you use, be sure to write your AP number and the number of the question you are working on. Do not begin Part B or remove the green insert from the booklet at this time. Are there any questions? . . .

Answer any questions. Then say:

Open the Section II booklet and begin Part A.

Note Start Time here ________. Note Stop Time here ________. You and your proctors should make sure students are writing their answers in their pink Section II booklets and that they are not working on Part B. Pages in Part B are easily identifiable by a row of large bold letter B's at the top of each page. Proctors should also make sure that calculators' infrared ports are not facing each other and that students are not sharing calculators. After 45 minutes, say:

There are 10 minutes remaining in Part A.

After 10 minutes, say:

Stop working on Part A. Calculators are not allowed for Part B. Please put your calculators back under your chair. . . .

Now tear out the green insert that is in the center of the pink booklet. In the upper right-hand corner of the cover, print your name, your teacher's name, and your school's name. . . .

Read the information on the front cover of the green insert. Look up when you have finished. . . .

You have 40 minutes to complete Part B. You must answer Questions 4, 5, and 6. If you need more paper during the exam, raise your hand. At the top of each piece of paper you use, be sure to write your AP number and the number of the question you are working on. If you finish Part B before time is called, you may go back to Part A, but you may NOT use your calculators. You may use the green insert for scratch paper, but you MUST write your answers in the pink booklet. Are there any questions? . . .

Answer any questions. Then say:

You may begin Part B.

Note Start Time here ________. Note Stop Time here ________. You and your proctors should make sure students are writing their answers in their pink Section II booklets, not in their green inserts, and that they are not using calculators. After 30 minutes, say:

There are 10 minutes remaining in Part B.

After 10 minutes, say:

Stop working and close your exam booklet and green insert. Now put your pink booklet and your green insert on your desk, face up, with the folds to your left. Remain in your seat, without talking, while the exam materials are collected. . . .

Collect a pink Section II booklet and a green insert from every student. **Check the front cover of each pink booklet to ensure that the student has placed an AP number label on the shaded box, and printed his or her initials and today's date. Check that the student has completed**

the "Important Identification Information" area on the back cover, and that answers have been written in the pink booklet and not in the green insert. The green inserts must be stored securely for no fewer than two school days. After the two-day holding time, the green inserts may be given to the appropriate AP teacher(s) for return to the students. When all exam materials have been collected and accounted for, say:

> **Your teacher will return your green insert to you in about two days. You may not discuss the free-response questions with anyone until that time. Remember that the multiple-choice questions may <u>never</u> be discussed or shared in any way at any time. You should receive your grade report in the mail about the third week of July. You are now dismissed.**

Exam materials should be put in locked storage until they are returned to the AP Program after your school's last administration. Before storing materials, check your list of students who are eligible for fee reductions and fill in the appropriate oval on their registration answer sheets. To receive a separate *AP Instructional Planning Report* or student grade roster for each AP class taught, fill in the appropriate oval in the "School Use Only" section of the answer sheet. See "Post-Exam Activities" in the 2008 *AP Coordinator's Manual.*

USE PENCIL ONLY FOR THE ENTIRE ANSWER SHEET.

CollegeBoard AP

Answer Sheet for May 2008, Form 4EBP

PLACE YOUR AP® NUMBER LABEL OR WRITE YOUR AP NUMBER HERE AT EVERY EXAM.

NAME AND EXAM AREA – COMPLETE THIS AREA AT EVERY EXAM.

To maintain the security of the exam and the validity of my AP grade, 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 the completion of the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the 2007-08 *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.

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

Legal Last Name—first 15 letters | Legal First Name—first 12 letters | MI

C. YOUR AP NUMBER

D. ADMIN. DAY IN MAY

E. TIME OF DAY

6 AM, 7 AM, 8 AM, 9 AM, 10 AM, 11 AM, 12 PM, 1 PM, 2 PM, 3 PM, 4 PM, 5 PM

F. AP EXAM I AM TAKING USING THIS ANSWER SHEET

Print exam name: ______________________ Print form code (e.g., 4EBP-R) from M-C booklet: ________

Fill in the oval below that corresponds to the exam that you are taking.

07 U.S. History 4EBP-Q	43 European History	78 Physics B
07 U.S. History 4EBP-R	48 French Language	80 Physics C: Mech.
13 Art History	51 French Literature	82 Physics C: E & M
14 Art: Studio Drawing	53 Geography: Human	85 Psychology
15 Art: Studio 2-D Design	55 German Language	87 Spanish Language
16 Art: Studio 3-D Design	57 Gov. & Pol.: U.S.	89 Spanish Literature
20 Biology	58 Gov. & Pol.: Comp.	90 Statistics
25 Chemistry	60 Latin: Vergil	93 World History
28 Chinese Lang. & Culture	61 Latin Literature	
31 Computer Science A	62 Italian Lang. & Culture	
33 Computer Science AB	64 Japanese Lang. & Culture	
34 Economics: Micro	66 Calculus AB 4EBP-Q	
35 Economics: Macro	66 Calculus AB 4EBP-R	
36 Eng. Language & Comp.	68 Calculus BC 4EBP-Q	
37 Eng. Literature & Comp.	68 Calculus BC 4EBP-R	
40 Environmental Science	75 Music Theory	

G. ONLINE PROVIDER CODE

H. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER

S

743180

STUDENT INFORMATION AREA—COMPLETE THIS AREA ONLY ONCE.

I. SEX

1 Male
2 Female

J. CURRENT GRADE LEVEL

1 Not yet in 9th grade
2 9th grade
3 10th grade
4 11th grade
5 12th grade
6 No longer in high school

K. DATE OF BIRTH

Month | Day | Year

01 Jan., 02 Feb., 03 Mar., 04 Apr., 05 May, 06 June, 07 July, 08 Aug., 09 Sept., 10 Oct., 11 Nov., 12 Dec.

L. SOCIAL SECURITY NUMBER (Optional, but preferred)

M. ETHNICITY/RACE

1 American Indian or Alaska Native
2 Asian, Asian American, or Pacific Islander
3 Black or African American
4 Mexican or Mexican American
5 Puerto Rican
6 Other Hispanic, Latino, or Latin American
7 White
8 Other

N. EXPECTED DATE OF COLLEGE ENTRANCE

F Fall
W Winter/Spring
S Summer
U Undecided

0 2008
1 2009
2 2010
3 2011

O. WHAT LANGUAGE DO YOU KNOW BEST?

1 English
2 English and another language about the same
3 Another language

P. Complete ONLY if you are a SOPHOMORE or a JUNIOR.

I want the College Board to send information about me to colleges, universities, and government scholarship programs interested in students like me.

Yes No

Q. PARENTAL EDUCATION LEVEL

Father / Male Guardian | Mother / Female Guardian

- Grade school
- Some high school
- High school diploma or equivalent
- Business or trade school
- Some college
- Associate or two-year degree
- Bachelor's or four-year degree
- Some graduate or professional school
- Graduate or professional degree

SCHOOL USE ONLY

Instructional Planning Report/Student Grade Roster: 1 2 3 4 5 6 7 8 9

Fee Reduction Granted: Option 1 Option 2

ETS USE ONLY

Exam 1 2 | Exam 1 2

62699 • 00657 • TF127E3600 Q3121/06-09 mh07270

CollegeBoard AP

R. This section is for the survey questions in the AP Student Pack. **(Do not put responses to exam questions in this section.)** Be sure each mark is dark and completely fills the oval.

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

Do not complete this section unless instructed to do so.

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

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

Indicate your answers to the exam questions in this section. If a question has only four answer options, do not mark option E. Your answer sheet will be scored by machine. Use only No. 2 pencils to mark your answers on pages 2 and 3 (one response per question). After you have determined your response, be sure to completely fill in the oval corresponding to the number of the question you are answering. Stray marks and smudges could be read as answers, so erase carefully and completely. Any improper gridding may affect your grade. Answers written in the multiple-choice booklet will not be scored.

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

FOR QUESTIONS 76-151, SEE PAGE 3.

DO NOT WRITE IN THIS AREA.

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

76 A B C D E
77 A B C D E
78 A B C D E
79 A B C D E
80 A B C D E
81 A B C D E
82 A B C D E
83 A B C D E
84 A B C D E
85 A B C D E
86 A B C D E
87 A B C D E
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147 A B C D E
148 A B C D E
149 A B C D E
150 A B C D E
151 A B C D E

ETS USE ONLY			
	R	W	FS
PT1			
PT2			
PT3			
PT4			
TOT			
EQ			
TA1			
TA2			

DO NOT WRITE IN THIS AREA.

PAGE 4

HOME ADDRESS AND SCHOOL AREA—COMPLETE THIS AREA ONLY ONCE

T. YOUR MAILING ADDRESS

- Your grade report will be mailed to this address in July.
- Using the abbreviations given in your AP Student Pack, print your address in the boxes below. If your international address does not fit, see item V, below.
- Indicate a space in your address by leaving a blank box — do not grid that column. Only one oval is to be filled in for each column.

Street

City

STATE

1	AL	28	NE
2	AK	29	NV
3	AZ	30	NH
4	AR	31	NJ
5	CA	32	NM
6	CO	33	NY
7	CT	34	NC
8	DE	35	ND
9	DC	36	OH
10	FL	37	OK
11	GA	38	OR
12	HI	39	PA
13	ID	40	RI
14	IL	41	SC
15	IN	42	SD
16	IA	43	TN
17	KS	44	TX
18	KY	45	UT
19	LA	46	VT
20	ME	47	VA
21	MD	48	WA
22	MA	49	WV
23	MI	50	WI
24	MN	51	WY
25	MS	52	Puerto Rico
26	MO		
27	MT	53	Other

ZIP OR POSTAL CODE

U. COUNTRY CODE

W. TELEPHONE NUMBER

Area Code

INTERNATIONAL TELEPHONE

If your international telephone number is longer than 10 digits, write the entire number below.

FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

V. If the address gridded above is not complete enough for delivery of your grade report, please fill in this oval and print your complete address below. ⟶ ○

Address

Address

City

State or Province

Country

ZIP or Postal Code

X. SCHOOL YOU ATTEND

School Code

School Name, City, and State

← Make sure you have correctly entered your School Code, filled in the appropriate ovals, and completed the information below.

School Name

City

State

Y. COLLEGE TO RECEIVE YOUR AP GRADE REPORT

College Code

College Name and Address

Using the College Code list in the AP Student Pack, indicate the **one** college that you want to receive your AP Grade Report by writing in the college code number, gridding the appropriate ovals, and completing the information below.

College Name

City

State

CollegeBoard
Advanced Placement Program

Student Performance Q&A:

2008 AP® Chemistry Free-Response Questions

The following comments on the 2008 free-response questions for AP® Chemistry were compiled by the Chief Reader, Eleanor Siebert of Mount St. Mary's College in Los Angeles, California. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

What was the intent of this question?

This question was designed to probe student understanding of gases and gaseous equilibria. Part (a) required students to write the expression for K_p. In part (b) students were asked to determine the number of moles of $CO_2(g)$ given the volume, pressure, and temperature. This determination required the use of the ideal gas law. In part (c)(i) students had to select the correct data from the table and use Dalton's law of partial pressures to determine the pressure of $CO(g)$ at equilibrium. In part (c)(ii) students were asked to determine the value of K_p using equilibrium pressures. In part (d) they had to explain the effect of a catalyst on the total pressure of gases at equilibrium. In part (e) students were given a new set of initial conditions and asked to determine the direction the reaction would proceed to reach equilibrium.

How well did students perform on this question?

Generally, students performed in the middle range on this question. The mean score was 4.17 out of 9 possible points. Students often earned points in parts (b), (c)(ii), and (d). The most frequently earned point was in part (d), while the most frequently missed points were for part (e). Students often exhibited a better conceptual knowledge of gases than mathematical skills when using data.

What were common student errors or omissions?

Common student errors in part (a) included failing to express K_p in terms of pressure (typically substituting concentration) or copying the expression $K_p = K_c(RT)^{\Delta n}$ from the "Advanced Placement Chemistry Equations and Constants" sheet in the exam booklet and attempting to use it.

In parts (b) and (c) students often failed to recognize the significance of initial versus equilibrium pressures for their calculations. Also, students often made algebraic errors. In part (c)(i) students were frequently confused about when to use the stoichiometric relationship between the gases given in the reaction.

In part (e) students often did not use a calculation in the justification even though they were asked to do so; they also frequently used stoichiometric reasoning and/or Le Chatelier's principle instead of comparing the reaction quotient, Q, to K_p.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Teachers should ask students to write equilibrium expressions in their classroom assessments. They should also ask students to distinguish between a K_c expression and a K_p expression. The use of simulated lab data as a follow-up to labs may help students better distinguish between initial values of measurements and equilibrium values.
- Teachers should work with students to help them develop a qualitative and quantitative ability to justify predictions.
- Finally, teachers should stress to their students that they should read all of the parts of a question thoroughly and answer the question as it was written.

Question 2

What was the intent of this question?

This question assessed student knowledge and skills relating to gravimetric analysis, which is included in several of the laboratory experiments recommended in the *AP Chemistry Course Description*. In parts (a) through (c) students were asked to analyze and interpret a data table. They had to explain how they correctly determined that all the water of hydration had been driven off from a sample of a hydrate; calculate an appropriate formula for the hydrate; and determine the effect of an error in laboratory procedure on the calculation of the mass of water released upon heating. Parts (d) and (e) required students to describe a quantitative laboratory procedure to determine the mass of a precipitate from a mixture and then calculate the number of moles and percent by mass of a component of the mixture.

How well did students perform on this question?

Overall, students did reasonably well when answering this question. The mean score was 4.15 out of 10 possible points, and the distribution of scores was relatively even.

Students were generally successful on parts (a) and (b)(i), and responses that earned 1 to 2 points usually garnered them here. Part (b)(ii) proved a bit more challenging, as students frequently used an incorrect mass to calculate the number of moles of water of hydration and determine the formula.

In part (c) students usually recognized that the laboratory procedure error described would result in a calculation of too large a mass of water; however, many had difficulty providing an appropriate justification and consequently failed to earn the point.

In part (d) most students described a quantitative laboratory procedure for the isolation of a precipitate, but many did not elaborate sufficiently to earn full credit. While most students recognized filtration as the method of choice, they often did not include the necessary step of drying the precipitate prior to weighing, nor did they explain the need to determine the mass of the precipitate by difference. A significant proportion of students misinterpreted the intent of the question; these students attempted a mathematical explanation of the steps necessary to calculate the mass of $AgCl$ from the data.

In part (e)(i) students were generally successful with the calculation of the moles of $MgCl_2$; however, many used an incorrect value for the total mass of the sample in part (e)(ii) and so did not earn the final point.

What were common student errors or omissions?

(a) Students most frequently answered this part correctly. Common errors were:

- A description or restatement of the data provided, without explanation
- An unclear explanation of the term "constant mass"
- A description of the data as having high accuracy and/or precision

(b)(i) Students frequently answered this part correctly as well. Common errors were:

- Calculating an incorrect mass of water from the data (students often reversed the water and $MgCl_2$)
- Subtraction errors
- Failing to round the final answer appropriately and reporting an answer with the wrong number of significant figures

(b)(ii) Two points were available for this question, and students often earned one point for applying a mole ratio to end up with a hydrated formula. Common errors were:

- Using an incorrect mass to determine the moles of $MgCl_2$
- Failing to recognize that a mole ratio was required and applying the number of moles of water to the formula
- Misunderstanding the meaning of the term "formula" (some students tried to provide a balanced equation for a reaction between H_2O and $MgCl_2$ instead)

(c) Many students were able to correctly identify the effect of the error but unable to supply an appropriate justification. Common errors were:

- Confusion between the terms "hydrate" and "water"
- Not understanding that the hydrate was a solid and that water would not also "splash out"

(d) This was the most difficult part of the question for students. Common errors were:

- Omitting at least one of the required three steps (filtering, drying, or weighing the precipitate by difference)
- Stating only the need to weigh or mass the precipitate
- Not describing the steps in sufficient detail
- Referencing the hydrate procedure from the first part of the question

(e)(i) Many students earned at least one point in this part. Common errors were:

- Miscalculation of the molar mass of $AgCl$
- Failure to recognize the $1:2$ stoichiometric ratio between $MgCl_2$ and $AgCl$
- Not answering the question and calculating the mass of $MgCl_2$
- Using an incorrect mass of the sample from another part of the question
- Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures

(e)(ii) Many students answered this question correctly. Common errors were:

- Using an incorrect value for the total mass of the sample
- Trying to calculate a percent error rather than the percent by mass
- Calculating the mass of $MgCl_2$ but not using it to calculate the percent by mass
- Failing to round the final answer appropriately and reporting an answer with an incorrect number of significant figures

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Have students perform the recommended laboratory experiments.
- Provide opportunities for students to engage in guided-inquiry experiments. Students need to practice the analysis of data collected in tabular form and also be able to recognize when data are valid.
- Give students laboratory experiences in which technique is important, as was the case in part (d). Students rarely mentioned that the precipitate should be washed and rinsed to remove the other soluble salts.
- Remind students that significant figures are important in calculations, and review the rules for addition and subtraction.
- Deemphasize the use of algorithms for numerical calculations. Students are often able to solve gravimetric stoichiometry problems but are unaware of the intermediate values calculated.

Question 3

What was the intent of this question?

This question tested a diverse set of student skills. Parts (a) and (b) were intended to assess the ability of students to understand the relationship among standard reduction potentials of half-reactions and the cell potential, and the relationship between the cell potential and the change in Gibbs free energy of the reaction. Part (c) assessed students' ability to relate the change in entropy of the reaction to the phases of reactants and products given in the balanced equation. Parts (d), (e), and (f) required students to answer questions related to the kinetics of a different reaction; calculate reaction orders from experimental data; write a rate law that was consistent with the orders; and determine a rate constant. Those parts of the question were intended to assess the students' understanding of kinetics and the meaning of reaction orders, and their ability to write and interpret a rate law.

How well did students perform on this question?

Because this question assessed a broad range of skills, the range of student performance was also quite broad. The mean score was 3.65 out of 9 possible points. Surprisingly, the modal score was 0, with 18 percent of the responses failing to earn any points and another 6 percent of papers left completely blank. Those students who were able to earn points on the question performed fairly well, and the distribution of scores from 1 through 9 was relatively even. Many students earned all of the points available on parts (a) through (c) but earned no points on parts (d) through (f), or vice versa; this suggests that one or more of the topics had likely been omitted or covered superficially in the students' courses.

What were common student errors or omissions?

In part (a) the most common answer was obtained by simply subtracting the values of $E°$ given, obtaining +0.28 V rather than the correct +0.96 V. Because the unit (V) was provided in the values, responses that omitted the unit still earned the point.

In part (b) common errors included:

- Identifying an incorrect number of electrons transferred in the reaction, with common errors of $n = 5$ (sum of electrons in each half-reaction) and $n = 22$ (sum of coefficients in balanced equation)
- Using $E°$ for one of the half-reactions (answer carried down from part [a] rather than the cell potential given)
- Giving incorrect or inconsistent units or omitting units altogether
- Omitting the algebraic sign of $\Delta G°$

In part (c) many students attempted to determine the +/– sign of $\Delta S°$ from the relationship $\Delta G° = \Delta H° - T\Delta S°$ and then use the value of $\Delta G°$ obtained in part (b). A small fraction of responses determined the incorrect sign of $\Delta S°$ by considering the total number of moles of products versus reactants and failing to look carefully at the phases.

In part (d) many students performed well, but common errors included:

- Incorrect algebra (e.g., $3^n = 9 \Rightarrow n = 3$)
- Failure to provide justification

In part (e) common errors included:

- Omission of rate constant
- Exponents that were inconsistent with values obtained in part (d)
- Writing an equilibrium expression rather than a rate law

In part (f) those students who wrote a well-formed rate law in part (e) also did well here. The most common errors included:

- Failing to include units or including incorrect units (e.g., $M\ s^{-1}$)
- Substituting inconsistent value from the experimental data
- Poor algebra and an inability to use scientific notation
- Confusion between the rate of reaction and the rate constant, k

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Student performance on tasks like part (a) might be improved by encouraging students to write an equation that relates the cell potential to those of the half-reactions.
- Emphasize “ballpark” values and the physical meaning of numerical quantities (e.g., students should recognize that $-360{,}000$ kJ mol^{-1} is an absurdly large value for the $\Delta G°$ of a chemical reaction).
- Give students practice writing and interpreting rate laws, with particular emphasis on units of reaction rates, rate constants, rates of formation, and concentrations.
- Emphasize the precise use of symbols and notation (e.g., mol versus m versus M, k versus K, parentheses versus brackets, and the appropriate use of superscripts and subscripts).

Question 4

What was the intent of this question?

This question was intended to assess students’ ability to write both molecular and net-ionic equations and to recognize when each is appropriate. Various aspects of the question were intended to reinforce knowledge gleaned from the classroom and from experience in the laboratory.

How well did students perform on this question?

Students displayed a wide range of knowledge and skills in their responses to this question. The mean score was 6.81 out of 15 possible points. Scores covered the range from 0 to 15, with close to a perfect bell-shaped distribution curve. The most common scores were 4, 5, and 6, and there were relatively few blank papers.

What were common student errors or omissions?

Common student errors included:

- Showing insoluble substances, or substances stated to be solid or gaseous, in ionized form
- Showing gaseous forms as if in aqueous solution
- Including spectator ions in the same form on both sides of the equation
- Not balancing equations so that coefficients are in terms of lowest whole numbers
- Not canceling reagents that appear on both sides of the equation
- Confusing the terms “colorless” and “clear” ($CuSO_4$, for example, forms a clear but colored solution)
- Mistaking common formulas (e.g., writing “HCl_2” rather than “HCl,” or “2Cl” rather than “Cl_2”)
- Using inexact language (e.g., “phenolphthalein will show its basic color” rather than “phenolphthalein turns pink in basic solution”)
- Reading the prompt inexactly (e.g., not writing the formula of a complex ion when directed to do so)
- Balancing by stoichiometry of atoms but not by charge
- Omitting an explanation or justification following an assertion in parts (a)(ii), (b)(ii), and (c)(ii)
- Writing more than one answer in the provided answer box

- Placing charges within formulas (e.g., "$H^{1+}Cl^{1-}$" rather than "HCl")
- Adding inappropriate products just to "balance" the equation
- Adding and omitting randomly the charges on species in the written reaction

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Give students practice with writing net-ionic equations. Emphasize fundamental knowledge and skills regarding equation writing, including elemental forms and common ions, especially polyatomic anions. Student responses often showed errors in the systematic presentation of chemical species, including soluble versus insoluble salts, strong versus weak acids or bases, and gaseous versus aqueous states. Some students also had difficulty with the art of balancing equations, neglecting to conserve either mass or charge.

- Encourage students to write balanced net-ionic equations to describe their work in the laboratory. A student who has performed an acid-base titration with phenolphthalein as an indicator is unlikely to forget the characteristic pink color of the indicator as the solution becomes basic at the titration's endpoint. Similarly, a student who has created a precipitate of $Al(OH)_3$ by adding strong base drop-wise to a solution containing aluminum(III) cation is apt to remember the excitement of redissolving that precipitate by continuing to add drops of strong base to form a complex ion. A student who has oxidized $HCl(g)$ with $O_2(g)$ in the lab is not following safe lab practices, but that student should have been taught that HCl is not ionized in the gaseous state.

- Remind students to refer to the resources available to them during the exam, specifically the "Periodic Table of the Elements" and "Standard Reduction Potentials in Aqueous Solution at 25°C" pages in the exam booklet, for memory prompts about the behavior of elements and common ions.

- Provide students with opportunities to practice writing about chemistry. Precise language is important. For example, many responses for part (a)(ii) were unclear as to whether the added acid reacted with the complex or the hydroxide ions from the ionized NaOH. Many descriptions of LeChâtelier shifts or limiting reactants were vague. A good observation in the lab is not "it changed color" but specifically what the color change was. It is not sufficient to say "the acid reacted with the ions." What ions? What reaction occurred? Instead, specify why the added acid affected the concentration of the complex ion. Pronouns should have unambiguous antecedents; sentences that might have made sense if written as "the acid reacts with the base and tends to neutralize the solution" were too often seen as a statement such as "it reacts with it and tends to neutralize it."

Question 5

What was the intent of this question?

This question was designed to assess student understanding of the structure and properties of atoms and molecules. In parts (a) through (c) students had to demonstrate their understanding of ionization energy and provide explanations for its variance among different atoms. In parts (d) through (f) students were required to sketch Lewis electron-dot diagrams, identify molecular shape and hybridization, and predict molecular polarity.

How well did students perform on this question?

The mean score was 3.92 out of 9 possible points, with scores of 4 and 5 both being modal. This question had a wide bell-shaped distribution of scores.

What were common student errors or omissions?

In part (a) the correct chemical equation was seldom obtained. Some responses attempted to develop a mathematical equation involving the given value of the first ionization energy.

In parts (b) and (c) the explanations that were to be made on the basis of nuclear charge and atomic size instead often involved discussions of periodic trends, electron configuration, or electronegativity.

In part (d) most students drew correct Lewis electron-dot diagrams. Performance varied when students attempted to use these diagrams to reason out the shape, the central atom hybridization, and then molecular polarity.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

- Students need to be able to discuss the factors determining the trends of atomic properties. They must also understand the difference between periodic trends and the explanation for what is responsible for such trends.
- Some students need help in distinguishing between the first-ionization energy and electron affinity.
- Students need to practice the reasoning sequence employed in understanding molecular structure: complete a Lewis electron-dot diagram, use this to determine the electron-pair orientation and thus the molecular shape, and then use the shape to find the central atom hybridization and molecular polarity. The role of symmetry in determining polarity needs to be stressed.

Question 6

What was the intent of this question?

This question explored the importance of intermolecular interactions in phase changes and dissolution. To earn full credit, a student had to identify the relevant forces involved in each process. In part (a) students had to explain that pyridine's ability to hydrogen bond with water distinguishes its aqueous solubility from that of benzene. In part (b) students had to recognize that while ethanol and dimethyl ether (structural isomers) have similar dispersion forces, the hydrogen bonding between ethanol molecules leads to a higher boiling point. Part (c) required students to contrast the melting points of a network covalent solid (in which strong covalent bonds are broken in the melting transition) and a molecular solid (in which only relatively weak intermolecular attractions must be overcome). In part (d) students had to recognize that the London/dispersion interactions between Cl_2 molecules must be greater than the total intermolecular forces between HCl molecules, and then attribute the difference to the larger number of electrons in the Cl_2 molecules.

How well did students perform on this question?

Students did poorly on this question. The mean score was only 1.86 out of 8 possible points. Both the median and modal scores were 1. Answers revealed a widespread misunderstanding concerning the differences between the interactions between molecules and the bonds that hold atoms together.

What were common student errors or omissions?

In all parts of the question, many students showed uncertainty about the distinctions between molecules and atoms, and between intermolecular forces and covalent (intramolecular) bonds. Many responses contained the ambiguous phrase "the forces holding the molecules together" or similar constructions, and it was difficult for Readers to determine whether the students intended to refer to inter- or intramolecular forces.

Part (a): Many students said that pyridine molecules "dissociated" or "came apart" when they dissolved in water, while the benzene bonds were so strong that they could not come apart. Students often attributed the solubility of pyridine to the solubility of ammonium or nitrate compounds. Appropriate discussions of the nature of the interaction between pyridine and water were rare; the adage that "like dissolves like" was used by a vast majority of the students, but it did not by itself earn credit because it was not an explanation or a discussion of the interaction between either of the solutes and water.

Part (b): The fundamental error made in a plurality (if not a majority) of the responses was that the covalent bonds within dimethyl ether and ethanol must be broken for the material to boil. A very common answer indicated that the C–C bond in ethanol was stronger than the C–O bonds in dimethyl ether, so that more energy was needed to break apart ethanol. A variation on this theme was to say that ethanol's oxygen was easier (or harder) to remove than the (protected, less-conspicuous, or less-exposed) oxygen in the center of dimethyl ether.

Students frequently identified the (covalent) O–H bond in ethanol as a hydrogen bond, and they cited the ease of breaking the O–H bond in ethanol as the reason for the difference in boiling points (indeed, students often identified any covalent bond to hydrogen as a hydrogen bond). Students often referred to ethanol's hydrogen bonding as "the strongest bond," stronger than any of dimethyl ether's covalent bonds. Dimethyl ether was almost uniformly (and incorrectly) classified as nonpolar, and many students attempted incorrect explanations of boiling point differences based on the apparent linearity of dimethyl ether or the length of the hydrocarbon chain in ethanol.

Part (c): A very common error based the difference in melting points on the covalent bond orders in Lewis electron-dot diagrams for SO_2 and SiO_2 molecules. Comparison of covalent and ionic bond strengths was another common approach. Differences in electronegativities among the three elements (S, Si, O) were frequently cited, as were their relative positions on the periodic table. The properties of elemental S, Si, and O were also repeatedly invoked.

Many responses displayed the misunderstanding that "network covalent bonds are stronger than regular covalent bonds," rather than comparing the network covalent bond strength in SiO_2 to the strength of the intermolecular forces between SO_2 molecules.

Students often classified SiO_2 as an ionic compound, and many responses referred to Si as a transition metal.

Part (d): It was apparent that many students are fundamentally confused about the difference between intramolecular Cl–Cl and H–Cl bonds and the intermolecular interactions between Cl_2 and HCl molecules. Responses often attributed double bonds to Cl_2 (and HCl), and comparisons between the triple (or quadruple) bond in Cl_2 and the double bond in HCl were common. The Cl_2 molecule was often said to be polar, while HCl was nonpolar. Students often attributed some property (or properties) to Cl_2 because "it is diatomic." Students often cited periodic trends or positions of H and Cl on the periodic table.

Students interchangeably identified Cl_2 and HCl as ionic, polar, or nonpolar and as having ionic bonding, covalent bonding, hydrogen bonding, dipole-dipole, ion-dipole, and dispersion forces. Any selection of these forces, in any combination or order, could be found as students tried to justify the difference in boiling points. Responses frequently tried to invoke the dissociation of HCl as a strong acid to explain its low boiling point.

Based on your experience of student responses at the AP Reading, what message would you like to send to teachers that might help them to improve the performance of their students on the exam?

Students have clearly been exposed to the material covered in this question. While they used the correct vocabulary, they generally used it incorrectly. The correct phrase "network covalent bonds" appeared in answers to part (c), for example, but the subsequent prose showed that students did not know what it meant. The bonds between atoms in molecules must be distinguished from the interactions that keep the molecules attracted to each other. The forces within a molecule are different from the forces between them. Phrases like "the intermolecular forces within the molecule" illuminate a major misunderstanding that must be addressed. The phrase "the forces holding molecules together" (and similar constructions) is ambiguous and should be avoided in favor of clear language, such as "forces between molecules" and "forces within molecules."

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2008 Scoring Guidelines

Question 1

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some $C(s)$ remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

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

$K_p = \dfrac{(P_{CO})^2}{P_{CO_2}}$	One point is earned for the correct expression.

(b) Calculate the number of moles of $CO_2(g)$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

$n = \dfrac{PV}{RT} = \dfrac{(5.00\text{ atm})(2.00\text{ L})}{(0.0821\ \frac{\text{L atm}}{\text{mol K}})(1{,}160\text{ K})} = 0.105\text{ mol}$	One point is earned for the correct setup. One point is earned for the correct answer.

(c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $CO_2(g)$ is 1.63 atm. Calculate

(i) the partial pressure of $CO(g)$, and

$P_{CO_2} + P_{CO} = P_{total}$ $P_{CO} = P_{total} - P_{CO_2} = 8.37\text{ atm} - 1.63\text{ atm} = 6.74\text{ atm}$	One point is earned for the correct answer supported by a correct method.

Question 1 (continued)

(ii) the value of the equilibrium constant, K_p .

$K_p = \dfrac{(P_{CO})^2}{P_{CO_2}} = \dfrac{(6.74\text{ atm})^2}{1.63\text{ atm}} = 27.9$	One point is earned for a correct setup that is consistent with part (a). One point is earned for the correct answer according to the setup.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

The total pressure of the gases at equilibrium with a catalyst present would be equal to the total pressure of the gases without a catalyst. Although a catalyst would cause the system to reach the same equilibrium state more quickly, it would not affect the extent of the reaction, which is determined by the value of the equilibrium constant, K_p.	One point is earned for the correct answer with justification.

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(s), plus CO(g) and CO_2(g), each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of CO_2(g) will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

$Q = \dfrac{(P_{CO})^2}{P_{CO_2}} = \dfrac{(2.00\text{ atm})^2}{2.00\text{ atm}} = 2.00 < K_p\ (= 27.9)$, therefore P_{CO_2} will decrease as the system approaches equilibrium.	One point is earned for a correct calculation involving Q or ICE calculation. One point is earned for a correct conclusion based on the calculation.

Question 2

Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

No additional mass was lost during the third heating, indicating that all the water of hydration had been driven off.	One point is earned for the correct explanation.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

mass of H_2O lost $= 25.825 - 23.977 = 1.848$ g *OR* $25.825 - 23.976 = 1.849$ g $1.848 \text{ g } H_2O \times \dfrac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1026 \text{ mol } H_2O$	One point is earned for calculating the correct number of moles of water.

(ii) determine the formula of the hydrated compound.

mass of anhydrous $MgCl_2 = 23.977 - 22.347 = 1.630$ g $1.630 \text{ g } MgCl_2 \times \dfrac{1 \text{ mol } MgCl_2}{95.20 \text{ g } MgCl_2} = 0.01712 \text{ mol } MgCl_2$ $\dfrac{0.1026 \text{ mol } H_2O}{0.01712 \text{ mol } MgCl_2} = 5.993 \approx 6 \text{ mol } H_2O \text{ per mol } MgCl_2$ $\Rightarrow$ formula is $MgCl_2 \cdot 6H_2O$	One point is earned for calculating the correct number of moles of anhydrous $MgCl_2$. One point is earned for writing the correct formula (with supporting calculations).

Question 2 (continued)

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

The calculated mass (or moles) of water lost by the hydrate will be too large because the mass of the solid that was lost will be assumed to be water when it actually included some $MgCl_2$ as well.	One point is earned for the correct answer with justification.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

Add excess $AgNO_3$. - Separate the AgCl precipitate (by filtration). - Wash the precipitate and dry the precipitate completely. - Determine the mass of AgCl by difference.	Two points are earned for <u>all three major steps</u>: filtering the mixture, drying the precipitate, and determining the mass by difference. One point is earned for any two steps.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

$5.48 \text{ g AgCl} \times \frac{1 \text{ mol AgCl}}{143.32 \text{ g AgCl}} = 0.0382 \text{ mol AgCl}$	One point is earned for calculating the number of moles of AgCl.
$0.0382 \text{ mol AgCl} \times \frac{1 \text{ mol Cl}}{1 \text{ mol AgCl}} \times \frac{1 \text{ mol } MgCl_2}{2 \text{ mol Cl}} = 0.0191 \text{ mol } MgCl_2$	One point is earned for conversion to moles of $MgCl_2$.

(ii) The percent by mass of $MgCl_2$ in the original mixture

$0.0191 \text{ mol } MgCl_2 \times \frac{95.20 \text{ g } MgCl_2}{1 \text{ mol } MgCl_2} = 1.82 \text{ g } MgCl_2$ $\frac{1.82 \text{ g } MgCl_2}{2.94 \text{ g sample}} \times 100\% = 61.9\% \text{ } MgCl_2 \text{ by mass}$	One point is earned for calculating the correct percentage.

Question 3

Answer the following questions related to chemical reactions involving nitrogen monoxide, $NO(g)$.

The reaction between solid copper and nitric acid to form copper(II) ion, nitrogen monoxide gas, and water is represented by the following equation.

$$3\,Cu(s) + 2\,NO_3^-(aq) + 8\,H^+(aq) \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 4\,H_2O(l) \qquad E° = +0.62\text{ V}$$

(a) Using the information above and in the table below, calculate the standard reduction potential, $E°$, for the reduction of NO_3^- in acidic solution.

Half-Reaction	Standard Reduction Potential, $E°$
$Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$	+0.34 V
$NO_3^-(aq) + 4\,H^+(aq) + 3\,e^- \rightarrow NO(g) + 2\,H_2O(l)$	?

$E°_{rxn} = E°_{NO_3^-} - E°_{Cu^{2+}} = E°_{NO_3^-} - 0.34\text{ V} = 0.62\text{ V}$ $\Rightarrow E°_{NO_3^-} = 0.62\text{ V} + 0.34\text{ V} = 0.96\text{ V}$	One point is earned for the correct calculation of the standard reduction potential.

(b) Calculate the value of the standard free energy change, $\Delta G°$, for the overall reaction between solid copper and nitric acid.

$\Delta G° = -n\mathcal{F}E° = -(6)(96{,}500\text{ C mol}^{-1})(0.62\text{ V})$ $= -360{,}000\text{ J mol}^{-1} = -360\text{ kJ mol}^{-1}$	One point is earned for the correct value of n, the number of moles of electrons. One point is earned for calculating the correct value of $\Delta G°$, with correct sign and consistent units.

(c) Predict whether the value of the standard entropy change, $\Delta S°$, for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

$\Delta S° > 0$. Even though there is a loss of 7 moles of ions in solution, the value of $\Delta S°$ for the overall reaction will be greater than zero because two moles of NO gas will be produced (there are no gaseous reactants).	One point is earned for the correct answer with a justification that is based on the gaseous state of one of the products.

Question 3 (continued)

Nitrogen monoxide gas, a product of the reaction above, can react with oxygen to produce nitrogen dioxide gas, as represented below.

$$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$$

A rate study of the reaction yielded the data recorded in the table below.

Experiment	Initial Concentration of NO (mol L^{-1})	Initial Concentration of O_2 (mol L^{-1})	Initial Rate of Formation of NO_2 (mol L^{-1} s^{-1})
1	0.0200	0.0300	8.52×10^{-2}
2	0.0200	0.0900	2.56×10^{-1}
3	0.0600	0.0300	7.67×10^{-1}

(d) Determine the order of the reaction with respect to each of the following reactants. Give details of your reasoning, clearly explaining or showing how you arrived at your answers.

(i) NO

Comparing experiments 1 and 3, the tripling of the initial concentration of NO while the initial concentration of oxygen remained constant at 0.0300 mol L^{-1} resulted in a nine-fold increase in the initial rate of formation of NO_2. Since $9 = 3^2$, the reaction is second order with respect to NO.	One point is earned for the correct answer with justification.

(ii) O_2

Comparing experiments 1 and 2, the tripling of the initial concentration of O_2 while the initial concentration of NO remained constant at 0.0200 mol L^{-1} resulted in a tripling in the initial rate of formation of NO_2. Since $3 = 3^1$, the reaction is first order with respect to O_2.	One point is earned for the correct answer with justification.

(e) Write the expression for the rate law for the reaction as determined from the experimental data.

rate $= k\,[NO]^2[O_2]$	One point is earned for the correct expression for the rate law.

Question 3 (continued)

(f) Determine the value of the rate constant for the reaction, clearly indicating the units.

Because the coefficient for NO_2 in the balanced equation is 2, the rate of the reaction is defined as $\frac{1}{2}$ the rate of the appearance of NO_2. From part (e) above, $k = \dfrac{\text{reaction rate}}{[NO]^2[O_2]}$ $= \dfrac{\left(\frac{1}{2}\right)(\text{rate of formation of } NO_2)}{[NO]^2[O_2]}$ Substituting data from experiment 1, $k = \dfrac{\left(\frac{1}{2}\right)\left(8.52 \times 10^{-2} \text{ mol L}^{-1}\text{ s}^{-1}\right)}{(0.0200 \text{ mol L}^{-1})^2(0.0300 \text{ mol L}^{-1})}$ $= 3.55 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$	One point is earned for calculating the correct value of the rate constant. One point is earned for including the correct units.

<u>Note:</u> a rate constant value of $7.10 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$ earns the point if the rate of reaction is assumed to be the same as the rate of formation of NO_2.

Question 4

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation: $Al(OH)_3 + OH^- \rightarrow [Al(OH)_4]^-$ $Al(OH)_3 + 3\ OH^- \rightarrow [Al(OH)_6]^{3-}$ $Al^{3+} + 4\ OH^- \rightarrow [Al(OH)_4]^-$ $Al^{3+} + 6\ OH^- \rightarrow [Al(OH)_6]^{3-}$	One point is earned for the correct reactants. Two points are earned for a correct product. One point is earned for balancing the equation.

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

The $[Al(OH)_4]^-$ will decrease because … (If equilibrium exists), the H^+ added would react with the OH^- in solution, reducing the $[OH^-]$ and shifting the equilibrium toward the reactants, thus reducing the concentration of the complex ion. *OR* (If the reaction has gone to completion), the H^+ added would react with the $[Al(OH)_4]^-$, thus reducing the concentration. $[Al(OH)_4]^- + H^+ \rightarrow Al(OH)_3 + H_2O$	One point is earned for a correct answer with an explanation.

Question 4 (continued)

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation $4\ HCl + O_2 \rightarrow 2\ H_2O + 2\ Cl_2$ Some other acceptable equations and products: $4\ HCl + 3\ O_2 \rightarrow 2\ H_2O + 4\ ClO$ $4\ HCl + 5\ O_2 \rightarrow 2\ H_2O + 4\ ClO_2$ $4\ HCl + 7\ O_2 \rightarrow 2\ H_2O + 4\ ClO_3$ $2\ HCl + O_2 \rightarrow 2\ HClO$ $HCl + O_2 \rightarrow HClO_2$ $2\ HCl + 3\ O_2 \rightarrow 2\ HClO_3$ $HCl + 2\ O_2 \rightarrow HClO_4$	One point is earned for the correct reactants. Two points are earned for the correct products. One point is earned for balancing the equation.

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

O_2 would be in excess because of the stoichiometry of the reaction; 4 moles of HCl are consumed for 1 mole of O_2. (It takes only 0.75 mole of O_2 to react with 3 moles of HCl, leaving an excess of 2.25 moles of O_2.) For other acceptable equations and products, the excess reactant must be based on the stoichiometry of the reaction given by the student.	One point is earned for a correct answer that is based on the balanced chemical equation and that has an appropriate justification.

Question 4 (continued)

(c) Solid potassium oxide is added to water.

(i) Balanced equation: $K_2O + H_2O \rightarrow 2\ K^+ + 2\ OH^-$	One point is earned for the correct reactants. Two points are earned for the correct products. One point is earned for balancing the equation.

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

The solution would turn pink because the production of OH^- makes the solution basic. In basic solutions, phenolphthalein turns pink.	One point is earned for the correct answer with an explanation.

Question 5

Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy ($kJ\ mol^{-1}$)
F	1,681.0
O	1,313.9
Xe	?

(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 $kJ\ mol^{-1}$.

$F(g) \rightarrow F^{+}(g) + e^{-}$	One point is earned for the correct equation. (Phase designations are not required.)

(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

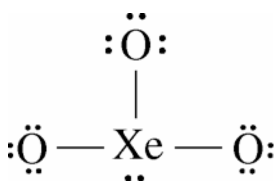
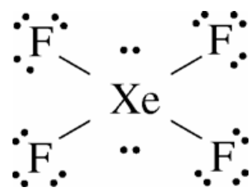
In both cases the electron removed is from the same energy level (2*p*), but fluorine has a greater effective nuclear charge due to one more proton in its nucleus (the electrons are held more tightly and thus take more energy to remove).	One point is earned for recognizing that the effective nuclear charge of F is greater than that of O.

(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

The first ionization energy of Xe should be less than the first ionization energy of F. To ionize the F atom, an electron is removed from a 2*p* orbital. To ionize the Xe atom, an electron must be removed from a 5*p* orbital. The 5*p* is a higher energy level and is farther from the nucleus than 2*p*, hence it takes less energy to remove an electron from Xe.	One point is earned for a prediction based on size and/or energy level.

Question 5 (continued)

(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3	XeF_4	
		One point is earned for each correct Lewis electron-dot diagram. Omission of lone pairs of electrons on the O or F atoms results in a one-time, 1-point deduction.

(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

(i) The geometric shape of the XeO_3 molecule

Trigonal pyramidal	One point is earned for a shape that is consistent with the Lewis electron-dot diagram.

(ii) The hybridization of the valence orbitals of xenon in XeF_4

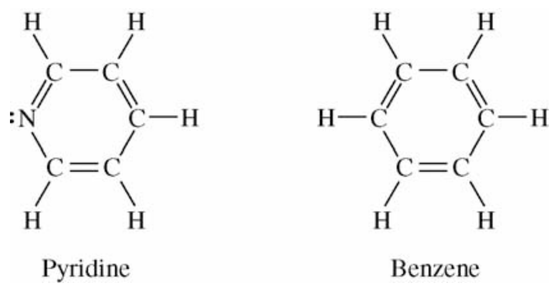
sp^3d^2	One point is earned for the hybridization consistent with the Lewis electron-dot diagram.

(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

The XeO_3 molecule would be polar because it contains three polar $Xe-O$ bonds that are asymmetrically arranged around the central Xe atom (i.e., the bond dipoles do not cancel but add to a net molecular dipole with the Xe atom at the positive end).	One point is earned for the answer that is consistent with the shape indicated in part (e)(i). One point is earned for an explanation correctly related to the shape in part (e)(i).

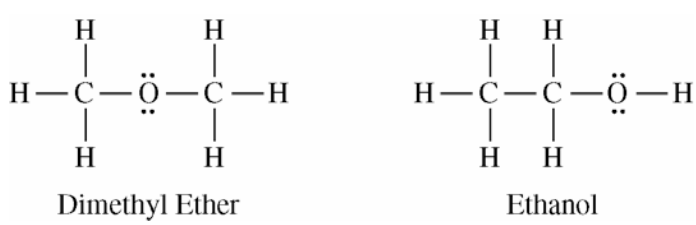
Question 6

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.



Pyridine is polar (and capable of forming hydrogen bonds with water), while the nonpolar benzene is not capable of forming hydrogen bonds. Pyridine will dissolve in water because of the strong hydrogen bonds (or dipole-dipole intermolecular interactions) that exist between the lone pair of electrons on pyridine's nitrogen atom and the solvent water molecules. No such strong intermolecular interaction can exist between benzene and water, so benzene is insoluble in water.	One point is earned for identifying a relevant structural difference between pyridine and benzene. One point is earned for indicating that pyridine is soluble in water because pyridine can form strong dipole-dipole interactions (or hydrogen bonds) with water, while benzene cannot.

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Question 6 (continued)

The intermolecular forces of attraction among molecules of dimethyl ether consist of London (dispersion) forces and weak dipole-dipole interactions. In addition to London forces and dipole-dipole interactions that are comparable in strength to those in dimethyl ether, ethanol can form hydrogen bonds between the H of one molecule and the O of a nearby ethanol molecule. Hydrogen bonds are particularly strong intermolecular forces, so they require more energy to overcome during the boiling process. As a result, a higher temperature is needed to boil ethanol than is needed to boil dimethyl ether.	One point is earned for recognizing that ethanol molecules can form intermolecular hydrogen bonds, whereas dimethyl ether molecules do not form intermolecular hydrogen bonds. One point is earned for recognizing that, compared to the energy required to overcome the weaker intermolecular forces in liquid dimethyl ether, more energy is required to overcome the stronger hydrogen bonds in liquid ethanol, leading to a higher boiling point.

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss <u>both</u> of the substances in your answer.

In the solid phase, SO_2 consists of discrete molecules with dipole-dipole and London (dispersion) forces among the molecules. These forces are relatively weak and are easily overcome at a relatively low temperature, consistent with the low melting point of SO_2.	One point is earned for recognizing that SO_2 is a molecular solid with only weak dipole-dipole and London forces among SO_2 molecules.
In solid SiO_2, a network of Si and O atoms, linked by strong covalent bonds, exists. These covalent bonds are much stronger than typical intermolecular interactions, so very high temperatures are needed to overcome the covalent bonds in SiO_2. This is consistent with the very high melting point for SiO_2.	One point is earned for recognizing that SiO_2 is a covalent network solid, and that strong covalent bonds must be broken for SiO_2 to melt.

Question 6 (continued)

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

The intermolecular forces in liquid Cl_2 are London (dispersion) forces, whereas the intermolecular forces in liquid HCl consist of London forces and dipole-dipole interactions. Since the boiling point of Cl_2 is higher than the boiling point of HCl, the London forces among Cl_2 molecules must be greater than the London and dipole-dipole forces among HCl molecules. The greater strength of the London forces between Cl_2 molecules occurs because Cl_2 has more electrons than HCl, and the strength of the London interaction is proportional to the total number of electrons.	One point is earned for recognizing that the London forces among Cl_2 molecules must be larger than the intermolecular forces (London and dipole-dipole) among HCl molecules. One point is earned for recognizing that the strength of the London forces among molecules is proportional to the total number of electrons in each molecule.

The 2008 AP® Chemistry Released Exam

Contains:

- Multiple-Choice Questions, Answer Key, and Diagnostic Guide
- Free-Response Questions with:
  - Scoring Guidelines
  - Sample Student Responses
  - Scoring Commentary
- Statistical Information About Student Performance on the 2008 Exam

Materials included in this Released Exam may not reflect the current AP Course Description and exam in this subject, and teachers are advised to take this into account as they use these materials to support their instruction of students. For up-to-date information about this AP course and exam, please download **the official AP Course Description from the AP Central® Web site at apcentral.collegeboard.com.**

Chapter I: The AP® Process

- What Is the Purpose of the AP® Chemistry Exam?
- Who Develops the Exam?
- How Is the Exam Developed?
  - Section I—Multiple Choice
  - Section II—Free Response
- Question Types
  - Multiple Choice
  - Free Response
- Scoring the Exam
  - Who Scores the AP Chemistry Exam?
  - Ensuring Accuracy
  - How the Scoring Guidelines Are Created
  - Training Readers to Apply the Scoring Guidelines
  - Maintaining the Scoring Guidelines
- Preparing Students for the Exam
  - Essential Features of Student Responses

This chapter will give you a brief overview of the development and scoring processes for the AP Chemistry Exam. You can find more detailed information at AP Central® (apcentral.collegeboard.com).

What Is the Purpose of the AP Chemistry Exam?

The AP Chemistry Exam is designed to allow students to demonstrate their knowledge of chemistry at the level of a two-semester college general chemistry course. A qualifying score on the AP Chemistry Exam thus allows some students, as first-year college students, to undertake second-year work in the chemistry sequence at their institution or to take courses in other fields where general chemistry is a prerequisite. For other students, a qualifying score may be used to fulfill a requirement for a laboratory-science course.

Who Develops the Exam?

The AP Chemistry Development Committee, working with Assessment Specialists at ETS, develops the exam. This committee is appointed by the College Board and is composed of six teachers from secondary schools, colleges, and universities in the United States. The members provide different perspectives: high school teachers offer valuable advice regarding realistic expectations when matters of content coverage, skills required, and clarity of phrasing are addressed. College and university faculty members ensure that the questions are at the appropriate level of difficulty for students planning to continue their studies at colleges and universities. Committee members typically serve for one to four years.

The Chief Reader also aids in the development process. The Chief Reader, a college chemistry professor responsible for supervising the scoring of the free-response questions at the AP Reading, attends every committee meeting to ensure that the free-response questions selected for the exam can be scored reliably. The expertise of the Chief Reader and the committee members who have scored exams in past years is notable: they bring to bear their valuable experience from past AP Readings and suggest changes to improve the quality and the performance of the questions.

How Is the Exam Developed?

The Development Committee sets the exam specifications, determining what will be tested and how it will be tested. It also determines the appropriate level of difficulty for the exam, based on its understanding of the level of competence required for success in general chemistry courses in colleges and universities. Each AP Chemistry Exam is the result of several stages of development that together span two or more years.

Section I—Multiple Choice

1. Development Committee members and other college faculty and AP teachers write and submit multiple-choice questions directed to the topics outlined in the *AP Chemistry Course Description.*
2. ETS Assessment Specialists perform a series of reviews to ensure that the multiple-choice questions are worded clearly and concisely.
3. Pretests are assembled from the reviewed questions, and these pretests undergo another internal review by ETS Assessment Specialists to ensure that the questions are clear and unambiguous, that each question has only one correct answer, and that the difficulty level of the questions is appropriate.
4. The pretests are then administered in general chemistry classes at several colleges and universities, and data on the difficulty of each question is gathered. This information is used in assembling the draft exam according to the specifications set by the Development Committee.

5. The committee members thoroughly review the draft exam in various stages of its development, revising any problematic questions until they are satisfied with the result.

Section II—Free Response

1. Well in advance of the exam administration, the members of the Development Committee write free-response questions for the exam. These are assembled into a free-response question pool.
2. From this pool, the committee members select an appropriate combination of questions for a particular exam. They review and revise these questions at all stages of development of that exam to ensure that they are of the highest possible quality. They consider, for example, whether the questions will offer an appropriate level of difficulty and whether the questions will elicit answers that will allow Readers, the high school and college chemistry teachers who score the free-response questions, to discriminate among the responses along the scoring scale used for the different questions. An ideal question enables the stronger students to demonstrate their accomplishments while revealing the limitations of less proficient students.

Question Types

The 2008 AP Chemistry Exam contains a 90-minute multiple-choice section consisting of 75 questions and a 95-minute free-response section consisting of 6 required questions. The two sections are designed to complement each other and to measure a wide range of skills.

Multiple-choice questions are useful for measuring a student's level of competence in a variety of contexts. In addition, they have three other strengths:

1. They are highly reliable. Reliability, or the likelihood that students of similar ability levels taking a different form of the exam will receive the same scores, is controlled more effectively with multiple-choice questions than with free-response questions.
2. They allow the Development Committee to include a selection of questions at various levels of difficulty, thereby ensuring that the measurement of differences in students' achievement is optimized. For AP Exams, the most important distinctions are between students earning the scores of 2 and 3 and those earning scores of 3 and 4. These distinctions are usually best accomplished by using many questions of middle difficulty.
3. They allow comparison of the ability level of the current students with those from another year. A number of questions from an earlier exam are included in the current one, allowing comparisons to be made between the scores of the earlier group of students and those of the current group. This information, along with other data, is used to establish AP scores that reflect the competence demanded by the Advanced Placement Program® and that can be legitimately compared with scores from earlier years.

Free-response questions on the AP Chemistry Exam are a more appropriate tool for evaluating a student's ability to solve complex problems and to explain concepts clearly.

The free-response and multiple-choice sections are designed to complement each other and to meet the overall course objectives and exam specifications. After each exam administration, the questions in each section are analyzed both individually and collectively, and the findings are used to improve the following year's exam.

Scoring the Exam

Who Scores the AP Chemistry Exam?

The multiple-choice answer sheets are machine scored. The teachers who score the free-response section of the AP Chemistry Exam are known as Readers. The majority of these Readers are experienced faculty members who teach either a high school AP Chemistry course or an equivalent course at a college or university. Great care is taken to obtain a broad and balanced group of Readers. Among the factors considered before appointing someone to the role are school locale and setting (urban, rural, and so on), as well as the potential Reader's gender, ethnicity, and years of teaching experience. University and high school chemistry teachers who are interested in applying to be a Reader at a future AP Reading can complete and submit an online application via AP Central (apcentral.collegeboard.com/reader) or request more information by e-mailing apreader@ets.org.

In June 2008, approximately 270 chemistry teachers and professors gathered at the University of Nebraska in Lincoln to participate in the scoring session for the 2008 AP Chemistry Exam. Some of the most experienced members of this group were invited to serve as Question Leaders and Table Leaders, and they arrived at the Reading early to help prepare for the scoring session. The remaining Readers were divided into groups, with each group advised and supervised by a Question Leader or Table Leader. Under the guidance of the Chief Reader, Question Leaders and Table Leaders assisted in establishing scoring guidelines, selecting sample student responses that exemplified the guidelines, and preparing for Reader training. All of the free-response questions on the 2008 AP Chemistry Exam were evaluated by the Readers at this single, central scoring session under the supervision of the Chief Reader.

Ensuring Accuracy

The primary goal of the scoring process is to have all Readers score a problem or essay accurately, consistently, fairly, and with the same guidelines as the other Readers. This goal is achieved through the creation of detailed scoring guidelines, the thorough training of all Readers, and the various checks and balances that are applied throughout the AP Reading.

How the Scoring Guidelines Are Created

1. As the questions are being developed and reviewed, the Development Committee and the Chief Reader discuss the scoring of the free-response questions to ensure that the questions can be scored validly and reliably. They provide preliminary guidance regarding the scoring of the various free-response questions.
2. Before the Reading, the Chief Reader produces a draft of the scoring guidelines for each free-response question. The Question Leaders and Table Leaders review the scoring guidelines, and the Chief Reader revises them accordingly.
3. During the pre-Reading period before the Readers arrive, the Chief Reader, Question Leaders, and Table Leaders review the scoring guidelines and test them by applying them to actual student responses. The guidelines are then revised and adjusted, as necessary, to reflect the full range of actual responses that will be encountered by the Readers.
4. Once the scoring of student responses begins, no substantive changes are made to the guidelines, though more details and examples may be added. Given the expertise of the Chief Reader and the analysis of many student responses by Question Leaders and Table Leaders in the pre-Reading period, nearly all student responses can be evaluated using these guidelines. Each Question Leader devotes a great deal of time and effort during the first day of the Reading to teaching the Readers the scoring guidelines for that particular question and to ensuring that all Readers who evaluate student responses for that question understand the scoring standards and can apply them accurately and consistently.

Training Readers to Apply the Scoring Guidelines

Because Reader training is so vital in ensuring that students receive an AP score that accurately reflects their performance, the process is thorough:

1. On the first day of the Reading, the Chief Reader provides an overview of the exam and the scoring process to the entire group of Readers. The Readers then break into smaller groups, with each group working on a particular question for which it receives specific training.
2. Each Question Leader, assisted by his or her Table Leaders, directs a discussion of the assigned question, commenting on the question requirements and student performance expectations. The scoring guidelines for the question are explained and thoroughly discussed.
3. The Readers are trained to apply the scoring guidelines by reading and evaluating samples of student answers that were selected at the pre-Reading session as clear examples of the various score points and the kinds of responses that Readers are likely to encounter. Leaders explain why the responses received particular scores. Then more responses, including those more subtle or complex, are read in order to train Readers on the finer points of applying the scoring guidelines.
4. When the Question Leader and Table Leaders are convinced that the Readers thoroughly understand the scoring guidelines and can apply them accurately and consistently, the actual scoring of student responses begins.
5. Throughout the course of the Reading, Readers are told to discuss with their Table Leader any student response that does not fit the scoring guidelines.

Maintaining the Scoring Guidelines

Throughout the Reading, Question Leaders and Table Leaders continue to reinforce the use of the scoring guidelines by asking their groups to review sample responses that have already been discussed as clear examples of particular scores, or to score new samples and discuss those scores with them. This procedure helps the Readers adhere to the standards of the group and helps to ensure that a student response will get the same score whether it is evaluated at the beginning, middle, or end of the Reading.

A potential problem is that a Reader could unintentionally score a student response higher or lower than it deserves because that same student performed well or poorly on other questions. The following steps are taken to prevent this so-called halo effect:

- A different Reader scores each question in a given exam booklet.
- The student's identity is unknown to the Reader. Thus, each Reader can evaluate student responses without being prejudiced by knowledge about individual students.
- No marks of any kind are made on the students' papers. The Readers record the scores on a form that is identified only by the student's AP number. Readers are unable to see the scores that have been given to other responses in the exam booklet.

Here are some other methods that help ensure that everyone is adhering closely to the scoring guidelines:

- Table Leaders backread (reread) and score a subset of the student responses from each of the Readers in that Leader's group. The two scores are compared, and the Leader and the Reader discuss any discrepancies. This approach allows Leaders to guide their Readers toward appropriate and consistent interpretations of the scoring guidelines.
- The Chief Reader and Leaders monitor use of the full range of the scoring scale for the group and for each Reader by periodically checking data on score distributions.

Preparing Students for the Exam

Most students preparing to take the AP Chemistry Exam are in the final stages of their pre-university training and have completed two courses in chemistry, with AP Chemistry as the second course, that included instruction in the topic areas outlined in the *AP Chemistry Course Description*. This preparation should include ample hands-on laboratory experience, as well as practice in solving problems and expressing ideas with clarity and logic. Students who take the AP Chemistry Exam will be expected to demonstrate a depth of understanding of fundamentals and competence in dealing with problems and calculations.

Essential Features of Student Responses

AP teachers should devote some course time to reviewing strategies for responding to free-response questions. It is important for students to know that they should clearly show their work in all calculations, include units where appropriate, and pay attention to the proper use of significant figures in order to earn as much credit as possible on quantitative questions (problems). Also, they should know that it is helpful to the Readers scoring the responses if students call attention to their final answers by drawing a circle or box around them. For essays, students should make sure they understand what is being asked and respond appropriately. Most importantly, students should learn that the best strategy for good free-response writing is to read and understand the question, focus on developing a response to what is asked, and then to write the answer clearly and legibly.

Chapter III: Answers to the 2008 AP Chemistry Exam

- Section I: Multiple Choice
  - Section I Answer Key and Percent Answering Correctly
  - Analyzing Your Students' Performance on the Multiple-Choice Section
  - Diagnostic Guide for the 2008 AP Chemistry Exam
- Section II: Free Response
  - Comments from the Chief Reader
  - Scoring Guidelines, Sample Student Responses, and Commentary

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions, the percent of AP students who answered each question correctly by AP score, and the total percent answering correctly.

Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
1	A	87	82	77	70	54	72
2	E	94	85	75	65	45	70
3	C	89	81	69	58	37	63
4	C	91	76	66	58	46	65
5	E	95	86	76	65	42	69
6	B	74	45	32	25	22	38
7	A	91	79	69	62	51	68
8	E	85	67	51	38	25	50
9	E	90	79	67	55	35	62
10	C	69	52	41	33	21	41
11	A	56	36	29	26	23	33
12	C	93	79	62	45	25	57
13	A	81	57	39	26	16	41
14	C	71	47	32	21	13	34
15	B	99	96	91	83	52	80
16	E	87	72	58	47	37	58
17	A	91	75	56	40	24	54
18	C	85	72	63	57	43	62
19	C	99	95	89	78	48	78
20	E	87	66	48	33	16	46
21	B	95	88	79	68	42	71
22	C	75	50	36	26	19	39
23	B	97	92	87	80	64	82
24	B	98	94	89	80	60	82
25	A	98	95	93	89	71	87

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
26	D	87	65	45	31	21	47
27	D	91	81	73	64	48	69
28	C	96	91	84	76	52	77
29	B	82	65	48	31	18	46
30	B	77	63	54	48	37	54
31	C	90	81	70	59	39	65
32	C	73	53	37	26	14	38
33	A	93	77	58	41	26	56
34	D	94	89	85	80	61	80
35	C	86	71	57	46	33	56
36	A	71	45	29	22	17	35
37	A	81	61	45	32	17	44
38	D	96	90	81	70	47	73
39	E	82	71	64	54	35	58
40	A	67	40	27	22	19	33
41	E	84	66	53	43	29	52
42	E	69	44	25	13	5	29
43	C	83	67	54	41	28	52
44	B	82	61	46	36	25	48
45	D	90	75	61	48	30	57
46	A	93	84	71	55	26	61
47	B	49	34	27	23	18	29
48	B	91	80	70	59	38	64
49	E	81	66	53	41	24	50
50	E	80	50	30	17	8	34

continued on the next page

Section I Answer Key and Percent Answering Correctly *(continued)*

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
51	C	73	51	37	25	15	37
52	C	69	51	39	30	23	40
53	D	88	77	67	58	42	64
54	D	54	26	15	10	9	21
55	E	94	87	80	68	35	69
56	A	78	52	38	29	21	41
57	A	74	51	35	22	11	36
58	D	67	42	30	22	14	33
59	B	63	43	31	22	14	32
60	B	68	42	28	21	15	33
61	D	58	39	30	24	19	32
62	B	47	38	32	29	22	32
63	B	80	55	36	23	12	38

Item No.	Correct Answer	Percent Correct by Score					Total Percent Correct
		5	4	3	2	1	
64	D	72	44	28	20	13	33
65	C	62	52	45	39	29	43
66	E	80	64	53	44	32	52
67	B	49	22	13	10	11	20
68	B	56	30	18	14	11	24
69	A	81	63	47	36	23	47
70	B	92	85	78	73	60	76
71	C	75	59	47	35	23	45
72	E	74	57	46	37	24	45
73	E	44	24	19	17	14	23
74	B	69	33	13	7	9	24
75	B	79	56	40	29	16	41

Analyzing Your Students' Performance on the Multiple-Choice Section

If you give your students the 2008 exam for practice, you may want to analyze the results to find overall strengths and weaknesses in their understanding of AP Chemistry. The following diagnostic worksheet will help you do this. You are permitted to photocopy and distribute it to your students for completion.

1. In each section, students should insert a check mark for each correct answer.
2. Add together the total number of correct answers for each section.
3. To compare the student's number of correct answers for each section with the average number correct for that section, copy the number of correct answers to the "Number Correct" table at the end of the Diagnostic Guide.

In addition, under each item, the percent of AP students who answered correctly is shown, so students can analyze their performance on individual items. This information will be helpful in deciding how students should plan their study time. Please note that one item may appear in several different categories, as questions can cover different topics.

Diagnostic Guide for the 2008 AP Chemistry Exam

Structure of Matter (Average number correct = 7.3)

Question #	7	19	20	21	22	24	27	28	56	57	63	71	75
Correct/Incorrect													
Percent of Students Answering Correctly	*68*	*78*	*46*	*71*	*39*	*82*	*69*	*77*	*41*	*36*	*38*	*45*	*41*

States of Matter (Average number correct = 6.7)

Question #	9	25	29	38	42	43	45	46	51	52	54	58	69	73
Correct/Incorrect														
Percent of Students Answering Correctly	*62*	*87*	*46*	*73*	*29*	*52*	*57*	*61*	*37*	*40*	*21*	*33*	*47*	*23*

Reactions, Rates, Thermodynamics, and Equilibrium (Average number correct = 14.9)

Question #	4	5	6	10	11	12	13	14	15	16	17	18	26	31	32	33
Correct/Incorrect																
Percent of Students Answering Correctly	*65*	*69*	*38*	*41*	*33*	*57*	*41*	*34*	*80*	*58*	*54*	*62*	*47*	*65*	*38*	*56*

Question #	34	35	36	41	44	48	50	55	59	60	64	66	67	68	74
Correct/Incorrect															
Percent of Students Answering Correctly	*80*	*56*	*35*	*52*	*48*	*64*	*34*	*69*	*32*	*33*	*33*	*52*	*20*	*24*	*24*

Descriptive Chemistry and Laboratory (Average number correct = 9.0)

Question #	1	2	3	8	23	30	37	39	40	47	49	53	61	62	65	70	72
Correct/Incorrect																	
Percent of Students Answering Correctly	*72*	*70*	*63*	*50*	*82*	*54*	*44*	*58*	*33*	*29*	*50*	*64*	*32*	*32*	*43*	*76*	*45*

Quantitative* (Average number correct = 6.0)

Question #	26	29	31	32	33	36	38	42	46	54	55	58	74
Correct/Incorrect													
Percent of Students Answering Correctly	*47*	*46*	*65*	*38*	*56*	*35*	*73*	*29*	*61*	*21*	*69*	*33*	*24*

*Questions involving very simple numbers or requiring simple quantitative reasoning are not included in this table.

Diagnostic Guide for the 2008 AP Chemistry Exam *(continued)*

Number Correct

	Structure of Matter	States of Matter	Reactions, Rates, Thermodynamics, and Equilibrium	Descriptive Chemistry and Laboratory	Quantitative
Number of Questions	13	14	31	17	13
Average Number Correct	7.3 (56.2%)	6.7 (47.9%)	14.9 (48.1%)	9.0 (52.9%)	6.0 (46.2%)
My Number Correct					

Section II: Free Response

Comments from the Chief Reader

Eleanor Siebert
Mount St. Mary's College
Los Angeles, California

The questions in the free-response section of the 2008 AP Chemistry Exam tested student understanding of many important concepts in several of the major content areas of college general chemistry courses. The questions consisted of an equilibrium problem involving gases, a laboratory problem on gravimetric analysis, a problem involving electrochemistry and kinetics, a chemical reactions question, an atomic structure/chemical bonding question, and a question relating properties of substances to structure and intermolecular forces. These questions gave students the opportunity to demonstrate their depth of understanding of fundamentals, as well as their ability to solve problems, think critically, and express ideas clearly and logically.

In terms of percentage of available points earned, students, in general, did best on questions 1 and 4 and least well on question 6. Overall, the exam was about as difficult as in the previous few years.

Scoring Guidelines, Sample Student Responses, and Commentary

The answers presented on the following pages are actual student responses to the free-response questions on the 2008 AP Chemistry Exam. The students gave permission to have their work reproduced at the time they took the exam. These responses were read and scored by the Table Leaders and Readers assigned to each particular question during the AP Reading in June 2008. The actual scores that these student responses earned, as well as a brief explanation of why, are indicated.

Chapter IV: Statistical Information

- Table 4.1—Section II Scores
- Table 4.2—Scoring Worksheet
- Table 4.3—Score Distributions
- Table 4.4—Section I Scores and AP Scores
- How AP Scores Are Determined
- College Comparability Studies
- Reminders for All Score Report Recipients
- Reporting AP Scores
- Purpose of AP Scores

This chapter presents statistical information about overall student performance on the 2008 AP Chemistry Exam.

Table 4.1 shows and summarizes score distributions for each of the free-response questions. The scoring worksheet presented in Table 4.2 provides step-by-step instruction for calculating AP section and composite scores and converting composite scores to AP Exam scores. Table 4.3 includes distributions for the overall exam scores. The score distributions conditioned on multiple-choice performance presented in Table 4.4 are useful in estimating a student's AP Exam score given only the student's multiple-choice score.

College comparability studies, which are conducted to collect information for setting AP score cut-points, are briefly discussed in this chapter. In addition, the purpose and intended use of AP Exams are reiterated to promote appropriate interpretation and use of the AP Exam and exam results.

Table 4.1—Section II Scores

The following table shows the score distributions for AP students on each free-response question from the 2008 AP Chemistry Exam.

Score	Question 1		Question 2		Question 3	
	No. of Students	% at Score	No. of Students	% at Score	No. of Students	% at Score
10			2,983	3.1		
9	5,746	6.0	5,209	5.4	4,077	4.3
8	5,308	5.5	8,716	9.1	7,695	8.0
7	9,533	9.9	7,958	8.3	9,238	9.6
6	13,459	14.0	7,668	8.0	9,492	9.9
5	12,114	12.6	9,291	9.7	9,550	10.0
4	10,839	11.3	9,105	9.5	9,089	9.5
3	10,354	10.8	10,308	10.7	7,627	8.0
2	8,630	9.0	12,014	12.5	7,887	8.2
1	6,888	7.2	12,765	13.3	8,451	8.8
0	11,571	12.1	7,974	8.3	16,831	17.5
No Response	1,536	1.6	1,987	2.1	6,041	6.3
Total Students	95,978		95,978		95,978	
Mean	4.18		4.15		3.66	
Standard Deviation	2.69		2.92		2.93	
Mean as % of Maximum Score	46%		42%		41%	

Table 4.1—Section II Scores *(continued)*

Score	Question 4		Question 5		Question 6	
	No. of Students	% at Score	No. of Students	% at Score	No. of Students	% at Score
15	3,148	3.3				
14	3,652	3.8				
13	3,611	3.8				
12	3,809	4.0				
11	4,680	4.9				
10	5,807	6.1				
9	6,917	7.2	1,698	1.8		
8	7,870	8.2	4,774	5.0	332	0.4
7	8,377	8.7	8,445	8.8	1,579	1.7
6	8,684	9.1	12,005	12.5	2,968	3.1
5	8,770	9.1	13,818	14.4	4,952	5.2
4	8,696	9.1	13,576	14.1	7,500	7.8
3	7,613	7.9	12,855	13.4	11,469	12.0
2	6,169	6.4	11,262	11.7	16,242	16.9
1	4,166	4.3	8,191	8.5	25,699	26.8
0	2,784	2.9	6,414	6.7	19,354	20.2
No Response	1,225	1.3	2,940	3.1	5,883	6.1
Total Students	95,978		95,978		95,978	
Mean	6.82		3.93		1.86	
Standard Deviation	3.97		2.37		1.80	
Mean as % of Maximum Score	45%		44%		23%	

Table 4.2—Scoring Worksheet

Section I: Multiple Choice

[__________ − (1/4 × __________)] × 1.0000 = __________

Number Correct (out of 75)	Number Wrong	Weighted Section I Score (If less than zero, enter zero; do not round)

Section II: Free Response

Question 1	______ (out of 9)	× 1.6666 =	______ (Do not round)
Question 2	______ (out of 10)	× 1.5000 =	______ (Do not round)
Question 3	______ (out of 9)	× 1.6666 =	______ (Do not round)
Question 4	______ (out of 15)	× .5000 =	______ (Do not round)
Question 5	______ (out of 9)	× 1.2500 =	______ (Do not round)
Question 6	______ (out of 8)	× 1.4062 =	______ (Do not round)
		Sum =	______ Weighted Section II Score (Do not round)

AP Score Conversion Chart Chemistry

Composite Score Range	AP Score
96–150	5
75–95	4
55–74	3
41–54	2
0–40	1

Composite Score

__________ + __________ = __________

Weighted Section I Score	Weighted Section II Score	Composite Score (Round to nearest whole number)

Table 4.3—Score Distributions

More than 55 percent of the AP students who took this exam earned a qualifying score of 3 or above.

	Exam Score	Number of Students	Percent at Score
Extremely well qualified	5	17,136	17.85
Well qualified	4	16,804	17.51
Qualified	3	19,307	20.12
Possibly qualified	2	13,855	14.44
No recommendation	1	28,876	30.09
Total Number of Students		95,978	
Mean Score		2.79	
Standard Deviation		1.48	

Table 4.4—Section I Scores and AP Scores

For a given range of multiple-choice scores, this table shows the percentage of students receiving each AP score. If you have calculated the multiple-choice score **(Weighted Section I Score)** by using the formula shown in Table 4.2, you can use this table to figure out the most likely score that the student would receive based only on that multiple-choice score.

	AP Score					
Multiple-Choice Score	1	2	3	4	5	Total
63 to 75	0.0%	0.0%	0.0%	0.3%	99.7%	4.5%
51 to 62	0.0%	0.0%	0.3%	11.7%	88.0%	11.3%
39 to 50	0.0%	0.3%	14.1%	66.6%	19.0%	18.4%
26 to 38	2.0%	21.60%	61.0%	15.5%	0.0%	25.4%
14 to 25	58.2%	34.1%	7.7%	0.0%	0.0%	25.9%
0 to 13	99.5%	0.5%	0.0%	0.0%	0.0%	14.6%
Total	30.1%	14.4%	20.1%	17.5%	17.9%	100.0%

How AP Scores Are Determined

As described in Chapter II, the AP Chemistry Exam has two sections. Section I has 75 multiple-choice questions and a score range from a minimum possible score of 0 to a maximum possible score of 75 points. Section II contains 6 free-response questions; scores range from a minimum possible score of 0 to a maximum possible score of 9 points for questions 1, 3, and 5; 0 to 10 points for question 2; 0 to 15 points for question 4; and 0 to 8 points for question 6.

The scores on the different parts of the exam are combined to produce a composite score that ranges from a minimum possible score of 0 to a maximum possible score of 150 points. In calculating the composite scores, scores on different parts are multiplied by weights.

Composite scores are not released to students, schools, or colleges. Instead, the composite scores are converted to scores on an AP 5-point scale, and it is these scores that are reported. The process of calculating the composite score and converting it to an AP Exam score involves a number of steps that are shown in the Scoring Worksheet (Table 4.2) and described in detail here.

1. **The score on Section I is calculated.** In calculating the score for Section I, a fraction of the number of wrong answers is subtracted from the number of right answers. With this adjustment to the number of right answers, students are not likely to benefit from random guessing. The value of the fraction is 1/4 for the five-choice questions in the AP Chemistry Exam. The maximum possible weighted score on Section I is 75 points, and it accounts for 50 percent of the maximum composite score.
2. **The score on Section II is calculated.** The raw scores on the 6 essay questions are multiplied by weights determined such that questions 1 through 3 each contribute 10 percent, question 4 contributes 5 percent, and questions 5 and 6 each contribute 7.5 percent to the maximum composite score. The weighted scores on the questions in Section II are summed to give the total weighted score for Section II. The maximum possible weighted score on Section II is 75 points, and it accounts for 50 percent of the maximum possible composite score.
3. **AP Exam scores are calculated.** Composite scores are calculated by adding the weighted Section I and weighted Section II scores together. The AP Exam scores are calculated by comparing the composite scores to the four composite cut-scores selected during the score-setting process. A variety of information is available during the score-setting process to help determine the cut-scores corresponding to each AP score:
   - Statistical information based on test score equating
   - College/AP score comparability studies, if available
   - The Chief Reader's observations of students' free-response performance
   - The distribution of scores on different parts of the exam
   - AP score distributions from the past three years

See Table 4.3 for the score distributions for the 2008 AP Chemistry Exam.

If you are interested in more detailed information about this process, please visit AP Central (apcentral.collegeboard.com). There you will also find information about how the AP Exams are developed, how validity and reliability studies are conducted, and other data on all AP subjects.

College Comparability Studies

The Advanced Placement Program has conducted college grade comparability studies in all AP subjects. These studies have compared the performance of AP students with that of college students in related courses who have taken the AP Exam at the end of their course. In general, AP cut-points are selected so that the lowest AP 5 is equivalent to the average A in college, the lowest AP 4 is equivalent to the average B, and the lowest AP 3 is equivalent to the average C (see below).

AP Score	Average College Grade
5	
	A
4	
	B
3	
	C
2	
	D
1	

Research studies conducted by colleges and universities and by the AP Program indicate that AP students generally receive higher grades in advanced courses than do students who have taken the regular first-year courses at the institution. Colleges and universities are encouraged to periodically undertake such studies to establish appropriate policy for accepting AP scores and ensure that admissions and placement standards remain valid. It is critical to verify that admissions and placement measures established for a previous class continue for future classes. Summaries of several studies are available at AP Central. Also on the College Board Web site is the free Admitted Class

Evaluation Service™ (http://professionals.collegeboard.com/higher-ed/validity) that can predict how admitted college students will perform at a particular institution generally and how successful they can be in specific classes.

Reminders for All Score Report Recipients

AP Exams are designed to provide accurate assessments of achievement. However, any exam has limitations, especially when used for purposes other than those intended. Presented here are some suggestions for teachers to aid in the use and interpretation of AP scores:

- AP Exams in different subjects are developed and evaluated independently of each other. They are linked only by common purpose, format, and method of reporting results. Therefore, comparisons should not be made between scores on different AP Exams. An AP score in one subject may not have the same meaning as the same AP score in another subject, just as national and college standards vary from one discipline to another.
- Score reports are confidential. Everyone who has access to AP scores should be aware of the confidential nature of the scores and agree to maintain their security. In addition, school districts and states should not release data about high school performance without the school's permission.
- AP Exams are not designed as instruments for teacher or school evaluation. Many factors influence AP Exam performance in a particular course or school in any given year. Thus, differences in AP Exam performance should be carefully studied before being attributed to the teacher or school.
- Where evaluation of AP students, teachers, or courses is desired, local evaluation models should be developed. An important aspect of any evaluation model is the use of an appropriate method of comparison or frame of reference to account for yearly changes in student composition and ability, as well as local differences in resources, educational methods, and socioeconomic factors.
- The AP Instructional Planning Report is sent to schools automatically and can be a useful diagnostic tool in reviewing course results. This report identifies areas of strength and weakness for the students in each AP course. The information may also provide teachers with guidance for course emphasis and student evaluation.
- Many factors can influence exam results. AP Exam performance can be affected by the degree of agreement between a course and the course defined in the relevant AP Course Description, use of different instructional methods, differences in emphasis or preparation on particular parts of the exam, differences in curriculum, or differences in student background and preparation in comparison with the national group.

Reporting AP Scores

The results of AP Exams are disseminated in several ways to students, their secondary schools, and the colleges they select:

- College and student score reports contain a cumulative record of all scores earned by the student on AP Exams during the current or previous years. These reports are sent in July. (School score reports are sent shortly thereafter.)
- Group results for AP Exams are available to AP teachers in the AP Instructional Planning Report mentioned previously. This report provides useful information comparing local student performance with that of the total group of students taking an exam, as well as details on different subsections of the exam.

Several other reports produced by the AP Program provide summary information on AP Exams:

- State, National, and Canadian Reports show the distribution of scores obtained on each AP Exam for all students and for subsets of students broken down by gender and by ethnic group.
- The Program also produces a one-page summary of AP score distributions for all exams in a given year.

For information on any of the above, please call AP Services at 609 771-7300 or e-mail apexams@info.collegeboard.org.

Purpose of AP Scores

AP scores are intended to allow participating colleges and universities to award college credit, advanced placement, or both to qualified students. In general, an AP score of 3 or higher indicates sufficient mastery of course content to allow placement in the succeeding college course, or credit for and exemption from a college course comparable to the AP course. Students seeking credit through their AP scores should note that each college, not the AP Program or the College Board, determines the nature and extent of its policies for awarding advanced placement, credit, or both. Because policies regarding AP scores vary, students should consult the AP policy of individual colleges and universities. Students can find information in a college's catalog or Web site, or by using the AP Credit Policy search at www.collegeboard.com/ap/creditpolicy.

Question 1

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some $C(s)$ remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

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

$K_p = \dfrac{(P_{CO})^2}{P_{CO_2}}$	One point is earned for the correct expression.

(b) Calculate the number of moles of $CO_2(g)$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

$n = \dfrac{PV}{RT} = \dfrac{(5.00\text{ atm})(2.00\text{ L})}{(0.0821\ \frac{\text{L atm}}{\text{mol K}})(1{,}160\text{ K})} = 0.105\text{ mol}$	One point is earned for the correct setup. One point is earned for the correct answer.

(c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $CO_2(g)$ is 1.63 atm. Calculate

(i) the partial pressure of $CO(g)$, and

$P_{CO_2} + P_{CO} = P_{total}$ $P_{CO} = P_{total} - P_{CO_2} = 8.37\text{ atm} - 1.63\text{ atm} = 6.74\text{ atm}$	One point is earned for the correct answer supported by a correct method.

Question 1 (continued)

(ii) the value of the equilibrium constant, K_p .

$K_p = \dfrac{(P_{CO})^2}{P_{CO_2}} = \dfrac{(6.74 \text{ atm})^2}{1.63 \text{ atm}} = 27.9$	One point is earned for a correct setup that is consistent with part (a). One point is earned for the correct answer according to the setup.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

The total pressure of the gases at equilibrium with a catalyst present would be equal to the total pressure of the gases without a catalyst. Although a catalyst would cause the system to reach the same equilibrium state more quickly, it would not affect the extent of the reaction, which is determined by the value of the equilibrium constant, K_p.	One point is earned for the correct answer with justification.

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(s), plus CO(g) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

$Q = \dfrac{(P_{CO})^2}{P_{CO_2}} = \dfrac{(2.00 \text{ atm})^2}{2.00 \text{ atm}} = 2.00 < K_p \ (= 27.9)$, therefore P_{CO_2} will decrease as the system approaches equilibrium.	One point is earned for a correct calculation involving Q or ICE calculation. One point is earned for a correct conclusion based on the calculation.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

1A

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(*s*), plus CO(*g*) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a) $K_p = \frac{P_{CO}^2}{P_{CO_2}}$

b) Use the gas law $PV = nRT$

$5.00\,atm \cdot 2.00\,L = n \cdot 0.0821\,L\,atm\,mol^{-1}K^{-1} \cdot 1160\,K$

(solve) $\frac{5.00\,atm \cdot 2.00\,L}{0.0821\,L\,atm\,mol^{-1}k^{-1} \cdot 1160\,K} = n$

$n = .105\,mol$

c) i. full pressure is 8.37 atm subtract $CO_2(g)$ partial pressure to find CO(g) partial pressure

$8.37\,atm - 1.63\,atm = 6.74\,atm$

CO(g) partial pressure = 6.74 atm

ii. $K_p = \frac{(6.74\,atm)^2}{1.63\,atm}$ $K_p = 27.9$

d) the solid catalyst would cause more CO(g) to be produced therefore raising the final pressure.

e) the pressure of $CO_2(g)$ will decrease as the new system approches equilibrium.

$K_p = 27.9$ $Q = \frac{(2.0\,atm)^2}{2.0\,atm}$ $Q = 2$

$Q < K$ therefore we ~~ta~~ need more products and the pressure of CO(g) will increase and the $CO_2(g)$ will decrease

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

1B, 1

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(*s*), plus CO(*g*) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a) $K_p = \frac{[CO]^2}{[CO_2]}$

b) $t=0$, $P = 5.00$ atm

$PV = nRT$

$(5.00\text{ atm})(2.00\text{ L}) = n \cdot 0.0821 \cdot 1{,}160$

$n = 0.105$ mol

c) i) $P_T = P_{CO_2} + P_{CO}$

$8.37 = 1.63 + P_{CO}$

$\boxed{P_{CO} = 6.74}$

ii) $K_p = \frac{[6.74]^2}{[1.63]} = \boxed{27.87}$

d) If a suitable solid catalyst were added, the final pressure at equilibrium would be equal to the final pressure at equilibrium without the catalyst (assuming that the volume of the catalyst is negligible). This is because a catalyst only speeds up a reaction and help the system reach equilibrium faster; it does not affect the final pressure or concentration at equilibrium.

e) The partial pressure of CO_2 as it approaches equilibrium will increase since the container begins with CO_2. Since $K_p \propto \frac{1}{[CO_2]}$, K_p will decrease and the partial pressure of CO_2 will increase.

GO ON TO THE NEXT PAGE.

1B2

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

because not as much CO_2 will react to form CO.

GO ON TO THE NEXT PAGE.

1C

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(s), plus CO(g) and CO_2(g), each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of CO_2(g) will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a. $\frac{[CO]^2}{[C][CO_2]} = k_p$

b. $k_p = 5.00 = k_c(.0821 \frac{L\,atm}{mol\,k})(1160k)^{2-1}$

$k_c = 5.00^{atm}/(.0821 \frac{L\,atm}{mol\,k})(1160k)^1$

$k_c = .0525 \frac{L}{mol} \cdot 2L$

$CO_2 = .105$ mol

c. i $P_1 + P_2 + P_n \ldots = P_T$

$P_1 = CO_{2(g)}$ $P_2 = CO_{(g)}$ $P_T = 8.37$

$P_1 = 1.63$ atm $P_T - P_1 = P_2$

$8.37atm - 1.63atm = P_2 = CO_{(g)} = 6.74$

ii $k_p = \frac{6.74^2}{1.63} = 27.9$

d. they would be less than because the reaction would get to equilibrium faster so less gas pressure would found.

e. It would decrease because it is a 2 to 1 mole ratio so the partial pressure of $CO_{2(g)}$ will go down

Question 1

Overview

This question was designed to probe student understanding of gases and gaseous equilibria. Part (a) required students to write the expression for K_p . In part (b) students were asked to determine the number of moles of $CO_2(g)$ given the volume, pressure, and temperature. This determination required the use of the ideal gas law. In part (c)(i) students had to select the correct data from the table and use Dalton's law of partial pressures to determine the pressure of CO(g) at equilibrium. In part (c)(ii) students were asked to determine the value of K_p using equilibrium pressures. In part (d) they had to explain the effect of a catalyst on the total pressure of gases at equilibrium. In part (e) students were given a new set of initial conditions and asked to determine the direction the reaction would proceed to reach equilibrium.

Sample: 1A
Score: 8

This response earned 8 out of 9 points: 1 for part (a), 2 for part (b), 1 for part (c)(i), 2 for part (c)(ii), and 2 for part (e). The point was not earned in part (d) because the response states that the pressure would increase.

Sample: 1B
Score: 6

The point was not earned in part (a) because the equilibrium-constant expression is given in terms of concentrations rather than pressures. The points were not earned in part (e) because the question states that the prediction needs to be justified with a calculation.

Sample: 1C
Score: 3

The point was not earned in part (a) because the equilibrium-constant expression is given in terms of concentrations rather than pressures (also, the concentration of solid carbon is included in the expression). The points were not earned in part (b) because there is an attempt to solve for the number of moles of CO_2 using the relationship between K_c and K_p . Note that the correct numerical value is obtained fortuitously with the assumed K_p = 5.00 atm and n = 1. The points were earned in parts (c)(i) and (c)(ii). The point was not earned in part (d) because the response states that the pressure would be less. The points were not earned in part (e) because the question states that the prediction needs to be justified with a calculation, and the response uses incorrect reasoning (the 2 to 1 mole ratio) to try to justify the correct prediction of a decrease in the partial pressure of CO_2 .

Question 2

Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

No additional mass was lost during the third heating, indicating that all the water of hydration had been driven off.	One point is earned for the correct explanation.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

mass of H_2O lost $= 25.825 - 23.977 = 1.848$ g *OR* $25.825 - 23.976 = 1.849$ g $1.848\text{ g } H_2O \times \dfrac{1\text{ mol } H_2O}{18.02\text{ g } H_2O} = 0.1026\text{ mol } H_2O$	One point is earned for calculating the correct number of moles of water.

(ii) determine the formula of the hydrated compound.

mass of anhydrous $MgCl_2 = 23.977 - 22.347 = 1.630$ g $1.630\text{ g } MgCl_2 \times \dfrac{1\text{ mol } MgCl_2}{95.20\text{ g } MgCl_2} = 0.01712\text{ mol } MgCl_2$ $\dfrac{0.1026\text{ mol } H_2O}{0.01712\text{ mol } MgCl_2} = 5.993 \approx 6\text{ mol } H_2O\text{ per mol } MgCl_2$ $\Rightarrow$ formula is $MgCl_2 \cdot 6H_2O$	One point is earned for calculating the correct number of moles of anhydrous $MgCl_2$. One point is earned for writing the correct formula (with supporting calculations).

Question 2 (continued)

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

The calculated mass (or moles) of water lost by the hydrate will be too large because the mass of the solid that was lost will be assumed to be water when it actually included some $MgCl_2$ as well.	One point is earned for the correct answer with justification.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the $AgCl$ precipitate.

Add excess $AgNO_3$. - Separate the AgCl precipitate (by filtration). - Wash the precipitate and dry the precipitate completely. - Determine the mass of AgCl by difference.	Two points are earned for <u>all three major steps</u>: filtering the mixture, drying the precipitate, and determining the mass by difference. One point is earned for any two steps.

(e) The student determines the mass of the $AgCl$ precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

$5.48\text{ g AgCl} \times \frac{1\text{ mol AgCl}}{143.32\text{ g AgCl}} = 0.0382\text{ mol AgCl}$ $0.0382\text{ mol AgCl} \times \frac{1\text{ mol Cl}}{1\text{ mol AgCl}} \times \frac{1\text{ mol MgCl}_2}{2\text{ mol Cl}} = 0.0191\text{ mol MgCl}_2$	One point is earned for calculating the number of moles of AgCl. One point is earned for conversion to moles of $MgCl_2$.

(ii) The percent by mass of $MgCl_2$ in the original mixture

$0.0191\text{ mol MgCl}_2 \times \frac{95.20\text{ g MgCl}_2}{1\text{ mol MgCl}_2} = 1.82\text{ g MgCl}_2$ $\frac{1.82\text{ g MgCl}_2}{2.94\text{ g sample}} \times 100\% = 61.9\%\text{ MgCl}_2\text{ by mass}$	One point is earned for calculating the correct percentage.

2A1

2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the $AgCl$ precipitate.

(e) The student determines the mass of the $AgCl$ precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

(a) the mass of the sample did not change significantly between the second and third heatings

(b) initial mass of sample: 25.825g − 22.347g = 3.478g

mass of sample after heating: 23.977g − 22.347g = 1.630g

mass of water evaporated: 3.478g − 1.630g = 1.848g

i) molar mass of water = 18.02g/mol

$1.848\text{g } H_2O \cdot \frac{1\text{mol } H_2O}{18.02\text{g } H_2O} = \boxed{.1026\text{mol } H_2O}$

 2A2

(b) ii) molar mass of $MgCl_2$ = 95.20 g/mol

$$1.630\,g\,MgCl_2 \cdot \frac{1\,mol\,MgCl_2}{95.20\,g\,MgCl_2} = .01712\,mol\,MgCl_2$$

$$\frac{.1026\,mol\,H_2O}{.01712\,mol\,MgCl_2} = \frac{5.991\,mol\,H_2O}{mol\,MgCl_2}$$

$\therefore \boxed{MgCl_2 \cdot 6H_2O}$

(c) the calculated mass of water lost will be greater than the actual mass lost because the mass of whatever solid spattered will also be subtracted from the original sample

(d)
- 2.94 g sample dissolved in water
- add excess $AgNO_3$ ~~• mass the empty filter~~
- once precipitate is formed, filter the solution
- pour through filter several times to be sure
- let the filter dry
- find the mass of filter and precipitate
- subtract mass of filter

(e) i) molar mass of AgCl = 143.42 g/mol

$$5.48\,g\,AgCl \cdot \frac{1\,mol\,AgCl}{143.42\,g\,AgCl} = .0382\,mol\,AgCl$$

mol Cl^- = mol AgCl = .0382 mol

mol $MgCl_2$ = $\frac{1}{2}$ mol Cl^- = $\frac{1}{2}$(.0382 mol) = $\boxed{.0191\,mol\,MgCl_2}$

ii) $$.0191\,mol\,MgCl_2 \cdot \frac{95.20\,g\,MgCl_2}{1\,mol\,MgCl_2} = 1.82\,g\,MgCl_2$$

$$\frac{1.82\,g\,MgCl_2}{2.94\,g} \cdot 100\% = \boxed{61.9\%}$$

GO ON TO THE NEXT PAGE.

2. Answer the following questions relating to gravimetric analysis.

2B1

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

A) The difference in mass of the container + sample gets smaller after each successive heating. The majority of the water was eliminated after the first heating (1.843 g worth), while the next heating lowered the mass by .006g + the following showed a slight increase.

 2B2

B) i) mass lost after heating 1 : 1.843 g

" heating 2 : .006 g

total mass lost : 1.849 g

$1.849g\ H_2O \cdot \frac{1\ mol\ H_2O}{18.016g\ H_2O} = \boxed{.1026\ mol\ H_2O}$

ii) mass sample : 25.825 g − 22.347 g = 3.478

less mass H_2O lost : 1.629 g = mass $MgCl_2$

$1.629g\ MgCl_2 \cdot \frac{1\ mol\ MgCl_2}{95.20g\ MgCl_2} = .01711\ mol\ MgCl_2$

$\frac{.1026\ mol\ H_2O}{.01711\ mol\ MgCl_2} = 5.996$, so there are ≈6 mol H_2O for each mol $MgCl_2$

$\boxed{\therefore \text{The formula is } MgCl_2 \cdot 6H_2O}$

C) As the solid spatters out, the sample will appear to have lost more water mass than it has Because the assumption is that the change in mass is due to water loss, students will conclude that the hydrate has lost more water.

D) Determine the mol Cl in the solution by calculating the ratio of moles $MgCl_2$ to KNO_3. Use this value to calculate the % of the mass $MgCl_2$ to KNO_3. From there, perform stoichiometry, determining first the moles $MgCl_2$ present + using this value to determine how many moles Cl_2 are present.

 2B3

E) i) $5.48\text{ g AgCl} \cdot \frac{1\text{ mol AgCl}}{143.32\text{ g AgCl}} \cdot \frac{1\text{ mol MgCl}_2}{2\text{ mol AgCl}} = \boxed{.0191\text{ mol MgCl}_2}$

ii) $.0191\text{ mol MgCl}_2 \cdot \frac{95.02\text{ g MgCl}_2}{1\text{ mol MgCl}_2} = 1.81\text{ g MgCl}_2$

$$\text{mass \%} = \frac{\text{g MgCl}_2}{\text{g total}} \cdot 100$$
$$= \frac{1.81\text{ g}}{2.94\text{ g}} \cdot 100$$
$$= \boxed{61.6\%\text{ MgCl}_2}$$

GO ON TO THE NEXT PAGE.

2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot n\,H_2O$. The student collects the data shown in the following table.

2C1

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

a) If the mass of the sample and container stops decreasing after the heating, the water has all been evaporated and what is left does not change mass with temperature increase.

b) i) (initial mass - container) - (mass after 3rd heating - container)

$= (3.478) - (1.63) = 1.848\text{ g } H_2O$ lost

$1.848\text{ g } H_2O \times \frac{1\text{ mol } H_2O}{18\text{ g } H_2O}$ $\boxed{0.103 \text{ moles of } H_2O \text{ lost}}$

GO ON TO THE NEXT PAGE.

 2C2

b) (i) $3.478g\ MgCl_2 \cdot nH_2O \left(\frac{1\ mol\ MgCl_2 \cdot nH_2O}{(95.2 + n(18))g\ MgCl_2 \cdot nH_2O}\right)\left(\frac{n\ mol\ H_2O}{1\ mol\ MgCl_2 \cdot nH_2O}\right) =$ 0.103 moles

$\frac{3.478(n)}{95.2 + n(18)} = 0.103$

$3.478n = 9.774 + 1.848n$

$1.63n = 9.774$

$n = 5.996 \approx 6$

$\boxed{MgCl_2 \cdot 6\ H_2O}$

c) Since some of the solid splattered out of the crucible, the mass of the water lost is now inflated to a much too great number. When the student sees that a certain mass has been lost from the heating, he or she will assume it is water that was lost. As a result, the mass of the water and therefore the moles of water in the formula too big.

d) $AgNO_{3(s)} + MgCl_2 \longrightarrow AgCl + MgNO_{3(aq)}$
$Mg^{2+} + 2Cl^{-}(aq)$

$AgNO_3 + 2Cl^- \longrightarrow AgCl + NO_3^-$

To determine the mass of AgCl precipitate, the amount of $AgNO_3$ added should first be known. Then the mixture of $MgCl_2$ and KNO_3 is added. The mass is then converted to moles through Cl ratios.

e) (i) $5.48g\ AgCl \left(\frac{1\ mol\ AgCl}{(107.87 + 35.45)g\ AgCl}\right)\left(\frac{1\ mol\ Cl}{1\ mol\ AgCl}\right)\left(\frac{2\ mol\ Cl}{1\ mol\ Cl}\right)\left(\frac{1\ mol\ MgCl_2}{1\ mol\ Cl}\right) =$

(ii) $0.076\ moles\ MgCl_2 \left(\frac{24.3 + (35.45)2}{1\ mol\ MgCl_2}\right)$ $7.28g\ MgCl_2$ $\boxed{0.076\ moles\ MgCl_2}$

$\boxed{93.2\%}$

 GO ON TO THE NEXT PAGE.

Question 2

Overview

This question assessed student knowledge and skills relating to gravimetric analysis, which is included in several of the laboratory experiments recommended in the *AP Chemistry Course Description*. In parts (a) through (c) students were asked to analyze and interpret a data table. They had to explain how they correctly determined that all the water of hydration had been driven off from a sample of a hydrate; calculate an appropriate formula for the hydrate; and determine the effect of an error in laboratory procedure on the calculation of the mass of water released upon heating. Parts (d) and (e) required students to describe a quantitative laboratory procedure to determine the mass of a precipitate from a mixture and then calculate the number of moles and percent by mass of a component of the mixture.

Sample: 2A
Score: 10

This response earned all 10 points: 1 for part (a), 1 for part (b)(i), 2 for part (b)(ii), 1 for part (c), 2 for part (d), 2 for part (e)(i), and 1 for part (e)(ii).

Sample: 2B
Score: 8

In part (d) no points were earned because the necessary steps were not described.

Sample: 2C
Score: 6

In part (d) no points were earned because the necessary steps were not described. In part (e)(i) 1 point was earned for dividing by the molar mass of AgCl, but the other point was not earned owing to the misapplication of the mole ratio in the calculation. In part (e)(ii) no point was earned. Although the answer brought down from part (e)(i) was multiplied by the correct molar mass, that product was not subsequently divided by 2.94 g, the mass of the original sample.

Question 3

Answer the following questions related to chemical reactions involving nitrogen monoxide, $NO(g)$.

The reaction between solid copper and nitric acid to form copper(II) ion, nitrogen monoxide gas, and water is represented by the following equation.

$$3\ Cu(s) + 2\ NO_3^-(aq) + 8\ H^+(aq) \rightarrow 3\ Cu^{2+}(aq) + 2\ NO(g) + 4\ H_2O(l) \qquad E° = +0.62\ V$$

(a) Using the information above and in the table below, calculate the standard reduction potential, $E°$, for the reduction of NO_3^- in acidic solution.

Half-Reaction	Standard Reduction Potential, $E°$
$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$	+0.34 V
$NO_3^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow NO(g) + 2\ H_2O(l)$	?

$E_{rxn} = E_{NO_3} - E_{Cu^{2+}} = E_{NO_3} - 0.34\ V = 0.62\ V$ $\Leftarrow\ E_{NO_3} = 0.62\ V + 0.34\ V = 0.96\ V$	One point is earned for the correct calculation of the standard reduction potential.

(b) Calculate the value of the standard free energy change, $\Delta G°$, for the overall reaction between solid copper and nitric acid.

$\Delta G° = -n\mathcal{F}E° = -(6)(96{,}500\ C\ mol^{-1})(0.62\ V)$ $= -360{,}000\ J\ mol^{-1} = -360\ kJ\ mol^{-1}$	One point is earned for the correct value of n, the number of moles of electrons. One point is earned for calculating the correct value of $\Delta G°$, with correct sign and consistent units.

(c) Predict whether the value of the standard entropy change, $\Delta S°$, for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

$\Delta S° > 0$. Even though there is a loss of 7 moles of ions in solution, the value of $\Delta S°$ for the overall reaction will be greater than zero because two moles of NO gas will be produced (there are no gaseous reactants).	One point is earned for the correct answer with a justification that is based on the gaseous state of one of the products.

Question 3 (continued)

Nitrogen monoxide gas, a product of the reaction above, can react with oxygen to produce nitrogen dioxide gas, as represented below.

$$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$$

A rate study of the reaction yielded the data recorded in the table below.

Experiment	Initial Concentration of NO (mol L^{-1})	Initial Concentration of O_2 (mol L^{-1})	Initial Rate of Formation of NO_2 (mol L^{-1} s^{-1})
1	0.0200	0.0300	8.52×10^{-2}
2	0.0200	0.0900	2.56×10^{-1}
3	0.0600	0.0300	7.67×10^{-1}

(d) Determine the order of the reaction with respect to each of the following reactants. Give details of your reasoning, clearly explaining or showing how you arrived at your answers.

(i) NO

Comparing experiments 1 and 3, the tripling of the initial concentration of NO while the initial concentration of oxygen remained constant at 0.0300 mol L^{-1} resulted in a nine-fold increase in the initial rate of formation of NO_2. Since $9 = 3^2$, the reaction is second order with respect to NO.	One point is earned for the correct answer with justification.

(ii) O_2

Comparing experiments 1 and 2, the tripling of the initial concentration of O_2 while the initial concentration of NO remained constant at 0.0200 mol L^{-1} resulted in a tripling in the initial rate of formation of NO_2. Since $3 = 3^1$, the reaction is first order with respect to O_2.	One point is earned for the correct answer with justification.

(e) Write the expression for the rate law for the reaction as determined from the experimental data.

rate $= k[NO]^2[O_2]$	One point is earned for the correct expression for the rate law.

Question 3 (continued)

(f) Determine the value of the rate constant for the reaction, clearly indicating the units.

Because the coefficient for NO_2 in the balanced equation is 2, the rate of the reaction is defined as $\frac{1}{2}$ the rate of the appearance of NO_2. From part (e) above, $k = \dfrac{\text{reaction rate}}{[NO]^2[O_2]}$ $= \dfrac{\left(\frac{1}{2}\right)(\text{rate of formation of } NO_2)}{[NO]^2[O_2]}$ Substituting data from experiment 1, $k = \dfrac{\left(\frac{1}{2}\right)\left(8.52 \times 10^{-2} \text{ mol L}^{-1}\text{ s}^{-1}\right)}{(0.0200 \text{ mol L}^{-1})^2 (0.0300 \text{ mol L}^{-1})}$ $= 3.55 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$	One point is earned for calculating the correct value of the rate constant. One point is earned for including the correct units.

<u>Note:</u> a rate constant value of $7.10 \times 10^3 \text{ L}^2 \text{ mol}^{-2} \text{ s}^{-1}$ earns the point if the rate of reaction is assumed to be the same as the rate of formation of NO_2.

 3A

(a) $2(NO_3^- + 4H^+ + \cancel{3e^-} \rightarrow NO + 2H_2O)$ $\quad \mathcal{E}^\circ = x\ V$

$(Cu_{(s)} \rightarrow Cu^{2+} + 2e^-)3$ $\quad \mathcal{E}^\circ = -0.34V$

$3Cu + 2NO_3^- + 8H^+ \rightarrow 3Cu^{2+} + 2NO + 4H_2O$ $\quad \mathcal{E}^\circ = 0.62V$

$(x - 0.34)V = 0.62V$

$x = \boxed{0.96\ V}$

(b) $\Delta G^\circ = -nF^\circ \cdot \mathcal{E}^\circ$

$= -6\,\cancel{mole}\,e^- \cdot \frac{96500\,C}{1\,\cancel{mole}\,e^-} \cdot 0.62\,\frac{J}{C} \cdot \frac{kJ}{10^3 J} = \boxed{-360\,KJ}$

(c) ΔS° is greater than 0 because the reaction becomes more disordered on product sign since gas and liquid, which are more disorganized than solid and aqueous, are produced

(d) (i) $\frac{Rate_3}{Rate_1} = \frac{k[NO]^x[O_2]^y}{k[NO]^x[O_2]^y}$ $\quad \frac{7.67\times10^{-1} M/s}{8.52\times10^{-2} M/s} = \frac{\cancel{k}[0.0600]^x\cancel{[0.0300]^y}}{\cancel{k}[0.0200]^x\cancel{[0.0300]^y}}$

$\boxed{Rate = k[NO]^2}$ $\quad 9.00 = 3^x \quad x = 2$

NO is second order

(ii) $\frac{Rate_2}{Rate_1} = \frac{k[NO]^x[O_2]^y}{k[NO]^x[O_2]^y}$ $\quad \frac{2.56\times10^{-1} M/s}{8.52\times10^{-2} M/s} = \frac{\cancel{k}\cancel{[0.0200]^x}[0.0900]^y}{\cancel{k}\cancel{[0.0200]^x}[0.0300]^y}$

$\boxed{Rate = k[O_2]^1}$ $\quad 3.00 = 3^y \quad y = 1$

O_2 is first order.

(e) $\boxed{Rate = k[NO]^2[O_2]^1}$

(f) $8.52\times10^{-2}\,M/s = k(0.0200M)^2(0.0300M)^1$

$\boxed{k = 7.10\times10^3 \frac{1}{M^2 \cdot s}}$

 3B

(a) $E^\circ_{cell} = E_{reduction} - E_{oxidation}$

$+.62 = (x) - (.34)$

$E^\circ = +.96\ V$

(b) $\Delta G = -nFE^\circ$

$\Delta G = (96,500\ \frac{c}{mol})(+.62)(-6)$

$\Delta G = -358980\ J$

(c) The ΔS for the overall reaction is less than zero because ΔG is $-$.

NO:

(d) (i) $\frac{8.52\times10^{-2} = .02^x}{7.67\times10^{-1} = .06^x}$

$.33^x = .111$

$x = 2$

NO's order of reaction is 2, because when it's concentration changed (+ O_2's concentration didn't) from experiment 1 to 3, the rates changed also to mathematically (see above) result in a 2nd order reaction.

(ii) $\frac{.03^x = 8.52\times10^{-2}}{.09^x = 2.56\times10^{-1}}$

$.33^x = .33$

$x = 1$ } O_2's order of reaction is 1, because when it's concentration changed from experiment 1 to 2 (+ NO's concentration didn't), the rates changed to mathematically result in a 1st order reaction.

(e) rate $= k[NO]^2[O_2]$

(f) $8.52\times10^{-2}\ \frac{mol}{Ls} = (k)(.02\ \frac{mol}{L})^2(.03\ \frac{mol}{L})$

$k = 142\ \frac{L}{mol^2 s^2}$

3C

3. $(Cu^{2+} + 2e^- \rightarrow Cu)3$ $3(+0.34V)$

$(NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O)2$

$3Cu + 2NO_3^- + 8H^+ \rightarrow 3Cu^{2+} + 2NO + 4H_2O$ $E° = +.62V$

a)

$0.62V - 3(0.34) = \frac{-0.4\ V}{2} = -0.2V$

b) $\Delta G° = -n\mathcal{F}E°$

$= -6\mathcal{F}(.62\ V)$

$\Delta G° = -358.9\ kJ/mol$

$= -360\ kJ/mol$

c) $\Delta S° > 0$ because the spontaneity is increasing (exothermic)

d) i) 2nd order

ii) 1st order $\frac{R}{[NO]^2[O_2]} = k$ for all 3 exp.

e) $rate = k[NO]^2[O_2]$

f) $\frac{8.52 \times 10^{-2}\ mol/L \cdot s}{(.02\ mol/L)^2(.03\ mol/L)} = 7100\ s^{-1}$

Question 3

Overview

This question tested a diverse set of student skills. Parts (a) and (b) were intended to assess the ability of students to understand the relationship among standard reduction potentials of half-reactions and the cell potential, and the relationship between the cell potential and the change in Gibbs free energy of the reaction. Part (c) assessed students' ability to relate the change in entropy of the reaction to the phases of reactants and products given in the balanced equation. Parts (d), (e), and (f) required students to answer questions related to the kinetics of a different reaction; calculate reaction orders from experimental data; write a rate law that was consistent with the orders; and determine a rate constant. Those parts of the question were intended to assess the students' understanding of kinetics and the meaning of reaction orders, and their ability to write and interpret a rate law.

Sample: 3A
Score: 9

This response earned all 9 points: 1 for part (a), 2 for part (b), 1 for part (c), 1 for part (d)(i), 1 for part (d)(ii), 1 for part (e), and 2 for part (f).

Sample: 3B
Score: 6

The point was not earned in part (c) because S° is greater, not less, than 0. No points were earned in part (f); although correct values are substituted into the rate law from part (e), both the value and the units in the final answer are incorrect.

Sample: 3C
Score: 4

The point was not earned in part (a) because the value calculated for E° is incorrect. Both points were earned in part (b). In part (c) the response correctly indicates that the value of S° is greater than 0, but the point was not earned because the justification is insufficient. No points were earned in parts (d)(i) or (d)(ii) because the response does not show or explain how the orders of the reaction with respect to each reactant are determined. However, the point was earned in part (e) for providing a rate law consistent with the orders given in parts (d)(i) and (d)(ii). In part (f) 1 point was earned for calculating the value of the rate constant, but the second point was not earned because the units are incorrect.

Question 4

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation: $Al(OH)_3 + OH^- \rightarrow [Al(OH)_4]^-$ $Al(OH)_3 + 3\ OH^- \rightarrow [Al(OH)_6]^{3-}$ $Al^{3+} + 4\ OH^- \rightarrow [Al(OH)_4]^-$ $Al^{3+} + 6\ OH^- \rightarrow [Al(OH)_6]^{3-}$	One point is earned for the correct reactants. Two points are earned for a correct product. One point is earned for balancing the equation.

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

The $[Al(OH\ _4]^-$ will decrease because … (If equilibrium exists), the H^+ added would react with the OH^- in solution, reducing the $[OH^-]$ and shifting the equilibrium toward the reactants, thus reducing the concentration of the complex ion. *OR* (If the reaction has gone to completion), the H^+ added would react with the $[Al(OH)_4]^-$, thus reducing the concentration. $[Al(OH)_4]^- + H^+ \rightarrow Al(OH)_3 + H_2O$	One point is earned for a correct answer with an explanation.

Question 4 (continued)

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation $4\,HCl + O_2 \rightarrow 2\,H_2O + 2\,Cl_2$ Some other acceptable equations and products: $4\,HCl + 3\,O_2 \rightarrow 2\,H_2O + 4\,ClO$ $4\,HCl + 5\,O_2 \rightarrow 2\,H_2O + 4\,ClO_2$ $4\,HCl + 7\,O_2 \rightarrow 2\,H_2O + 4\,ClO_3$ $2\,HCl + O_2 \rightarrow 2\,HClO$ $HCl + O_2 \rightarrow HClO_2$ $2\,HCl + 3\,O_2 \rightarrow 2\,HClO_3$ $HCl + 2\,O_2 \rightarrow HClO_4$	One point is earned for the correct reactants. Two points are earned for the correct products. One point is earned for balancing the equation.

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

O_2 would be in excess because of the stoichiometry of the reaction; 4 moles of HCl are consumed for 1 mole of O_2. (It takes only 0.75 mole of O_2 to react with 3 moles of HCl, leaving an excess of 2.25 moles of O_2.) For other acceptable equations and products, the excess reactant must be based on the stoichiometry of the reaction given by the student.	One point is earned for a correct answer that is based on the balanced chemical equation and that has an appropriate justification.

Question 4 (continued)

(c) Solid potassium oxide is added to water.

(i) Balanced equation: $K_2O + H_2O \rightarrow 2\ K^+ + 2\ OH^-$	One point is earned for the correct reactants. Two points are earned for the correct products. One point is earned for balancing the equation.

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

The solution would turn pink because the production of OH^- makes the solution basic. In basic solutions, phenolphthalein turns pink.	One point is earned for the correct answer with an explanation.

 4A1

CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$$Mg + 2Ag^{+} \longrightarrow Mg^{2+} + 2Ag$$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation:

$$3OH^{-} + Al(OH)_3 \longrightarrow [Al(OH)_6]^{3-}$$

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

The concentration of complex ion will decrease. The acid will decrease the concentration of OH^-, so the reaction will shift to the left, and less complex ion is produced.

4A2

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation:

$4HCl + O_2 \rightarrow 2H_2O + 2Cl_2$

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

There will be excess O_2. To react 3 moles of HCl completely, only 0.75 moles O_2 are needed. Since there are 3 moles of O_2 present, there will be 2.25 moles in excess

(c) Solid potassium oxide is added to water.

(i) Balanced equation:

$K_2O + H_2O \rightarrow 2K^+ + 2OH^-$

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

If phenolphthalein is added, the solution will turn pink. Phenolphthalein turns pink in the presence of a base such as KOH.

YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE GRADED.

CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$$Mg + 2\,Ag^{+} \longrightarrow Mg^{2+} + 2\,Ag$$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation:

$$Na^{+} + 4OH^{-} + Al^{+} \Rightarrow NaAlO_2 + 2\,H_2O$$

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

Decrease the H^{+} would bond with OH^{-} ions shifting equilibrium to the reactants side

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation:

$4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

O_2 gass when 1mole of HCl is used $\frac{1}{4}$ mole of O_2 is used therefore HCl will be the limiting reactant.

(c) Solid potassium oxide is added to water.

(i) Balanced equation:

$K_2O + H_2O \rightarrow K^+ + 2OH$

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

It would turn pink because it is basic.

YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE GRADED.

$HCl + O_2 \rightarrow Cl_2 + H_2O$

~~At Na KO + H2O → Na+ +~~

$K_2O + H_2O \rightarrow K^+ + 2OH$

B B B B B B B B B B B B B B 4C1

CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$$Mg + 2\,Ag^+ \longrightarrow Mg^{2+} + 2\,Ag$$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation:

$$2Al(OH)_3 \rightarrow 3O_2 + 2[AlH_3]^+$$

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

The concentration would stay the same.

GO ON TO THE NEXT PAGE.

 4C2

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation:

$2HCl + O_2 \rightarrow HOH + 2Cl^-$

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

No reactant would be in excess because the hydrogen chloride gas would be completely oxidized.

(c) Solid potassium oxide is added to water.

(i) Balanced equation:

$K_2O + H_2O \rightarrow 2OH^- + 2K^+$

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

The solution would turn pink because when metal oxides are placed in water they form basic solutions.

YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE GRADED.

Question 4

Overview

This question was intended to assess students' ability to write both molecular and net-ionic equations and to recognize when each is appropriate. Various aspects of the question were intended to reinforce knowledge gleaned from the classroom and from experience in the laboratory.

Sample: 4A
Score: 15

This response earned all 15 points: 4 for part (a)(i), 1 for part (a)(ii), 4 for part (b)(i), 1 for part (b)(ii), 4 for part (c)(i), and 1 for part (c)(ii).

Sample: 4B
Score: 9

No points were earned in part (a)(i). Na^+ should not be included as a reactant, and the aluminum ion has an incorrect charge. No complex ion is shown as a product, and the equation is mass balanced but not charge balanced. The point was earned in part (a)(ii); this response shows understanding of the effect of removing hydroxide ions and so earned credit. All points were earned in parts (b)(i) and (b)(ii). In part (c)(i) 1 point was earned for the reactants, but only 1 of the 2 product points was earned because of the lack of a charge on OH. The balancing point was not earned; the equation is not balanced for mass or charge. The point was earned in part (c)(ii).

Sample: 4C
Score: 7

No points were earned in part (a)(i). The reactant point was not earned because OH is not included. The product points were not earned because no acceptable complex ion is given. The equation is not balanced for charge, so the balancing point was not earned. The point was not earned in part (a)(ii). In part (b)(i) the reactant point was earned. Only 1 of the 2 product points was earned; HOH (H_2O) is an acceptable product, but Cl is not. The balancing point was not earned; neither mass nor charge is balanced. In part (b)(ii) the response is not consistent with the equation given in part (b)(i), so the point was not earned. All the points were earned in parts (c)(i) and (c)(ii).

Question 5

Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy (kJ mol^{-1})
F	1,681.0
O	1,313.9
Xe	?

(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 kJ mol [1].

$F(g) \rightarrow F^{+}(g) + e^{-}$	One point is earned for the correct equation. (Phase designations are not required.)

(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

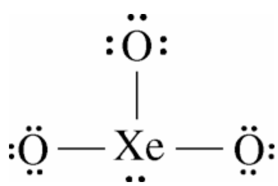
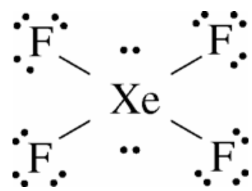
In both cases the electron removed is from the same energy level ($2p$), but fluorine has a greater effective nuclear charge due to one more proton in its nucleus (the electrons are held more tightly and thus take more energy to remove).	One point is earned for recognizing that the effective nuclear charge of F is greater than that of O.

(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

The first ionization energy of Xe should be less than the first ionization energy of F. To ionize the F atom, an electron is removed from a $2p$ orbital. To ionize the Xe atom, an electron must be removed from a $5p$ orbital. The $5p$ is a higher energy level and is farther from the nucleus than $2p$, hence it takes less energy to remove an electron from Xe.	One point is earned for a prediction based on size and/or energy level.

Question 5 (continued)

(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3	XeF_4	
		One point is earned for each correct Lewis electron-dot diagram. Omission of lone pairs of electrons on the O or F atoms results in a one-time, 1-point deduction.

(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

(i) The geometric shape of the XeO_3 molecule

Trigonal pyramidal	One point is earned for a shape that is consistent with the Lewis electron-dot diagram.

(ii) The hybridization of the valence orbitals of xenon in XeF_4

sp^3d^2	One point is earned for the hybridization consistent with the Lewis electron-dot diagram.

(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

The XeO_3 molecule would be polar because it contains three polar Xe – O bonds that are asymmetrically arranged around the central Xe atom (i.e., the bond dipoles do not cancel but add to a net molecular dipole with the Xe atom at the positive end).	One point is earned for the answer that is consistent with the shape indicated in part (e)(i). One point is earned for an explanation correctly related to the shape in part (e)(i).

B B B B B B B B B

5A1

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy (kJ mol^{-1})
F	1,681.0
O	1,313.9
Xe	?

(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 kJ mol^{-1}.

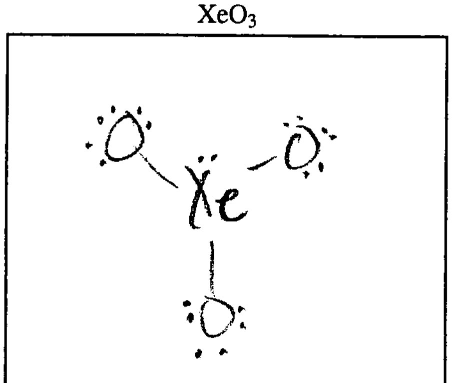
(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

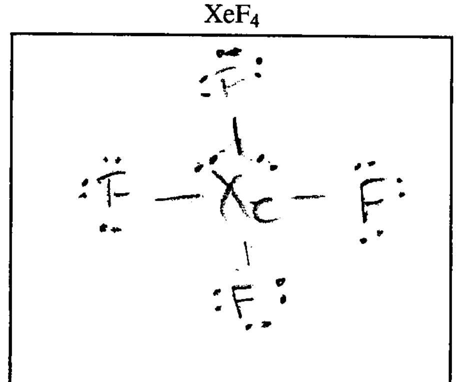
(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

$6+6+6 = 18 + 8 = 26 - 6 = 20$ $\quad$ $8 + 28 = 36 - 8 = 28$

XeO_3



XeF_4



(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

(i) The geometric shape of the XeO_3 molecule

(ii) The hybridization of the valence orbitals of xenon in XeF_4 S

(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

GO ON TO THE NEXT PAGE.

5A2

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

a) $F = F^{+} + e^{-}$ $\Delta H = 1{,}681.0$ kJ/mol

b) For Fluorine, it takes more energy to remove the first electron (first ionization energy) because Fluorine has a very high electronegativity and holds on to its electrons very strongly. Oxygen has a slightly lower electronegativity. Also, Fluorine is closer to fulfilling the octet rule than Oxygen so it does not want to lose any electrons

c) it is less because the electron would come from an orbital farther from the nucleus so it is held weaker

e) i) trigonal pyramid

ii) sp^3d^2

f) polar, not balanced, unequal sharing of electrons, not symmetrical

GO ON TO THE NEXT PAGE.

B B B B B B B B B

5B 1

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy ($kJ\ mol^{-1}$)
F	1,681.0
O	1,313.9
Xe	?

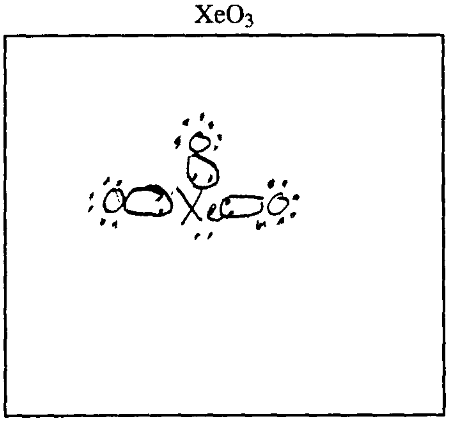
(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 $kJ\ mol^{-1}$.

(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

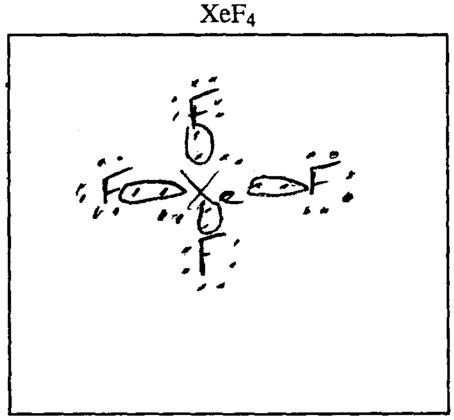
(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3



XeF_4



(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

(i) The geometric shape of the XeO_3 molecule

(ii) The hybridization of the valence orbitals of xenon in XeF_4

(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

5B2

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

a) $F + 1681.6 kJ mol^{-1} = F^{+} + 1e^{-}$

b) Ionization energy is the energy required to remove one electron from the valence shell of an atom. Also, it must be considered that each atom is looking for a valence shell of 8 electrons proven by the octet rule. Therefore, F wants to gain 1 and O wants to gain 2, so neither want to lose an electron. However, O will lose one easier than F because it needs to gain more to be an Octet. Also, Each of the O + F atoms are held together with the nucleaus. Because F has a stronger positive charge it will hold the negative charge particles or electrons tighter.

c) It will be even greater because Xe is found at its octet or stable stage where it wants to react with absolutely nothing.

e) i) Trigonal Planar
ii) sp^3d^2

f) it will be Polar because of the lone electron pair,

5C

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy ($kJ\ mol^{-1}$)
F	1,681.0
O	1,313.9
Xe	?

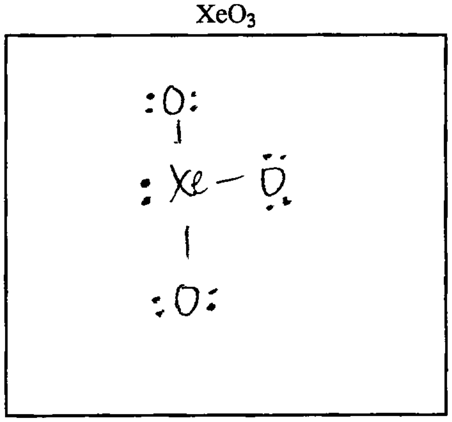
(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 $kJ\ mol^{-1}$.

(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

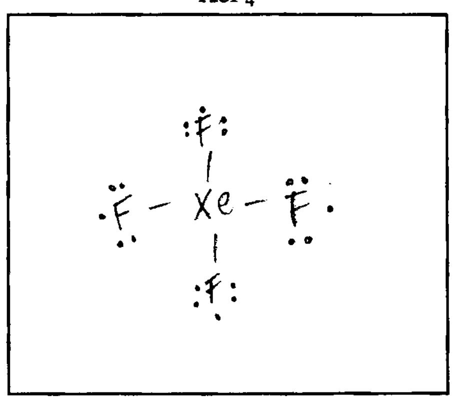
(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3



XeF_4



(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

(i) The geometric shape of the XeO_3 molecule

(ii) The hybridization of the valence orbitals of xenon in XeF_4

(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

GO ON TO THE NEXT PAGE.

5C2

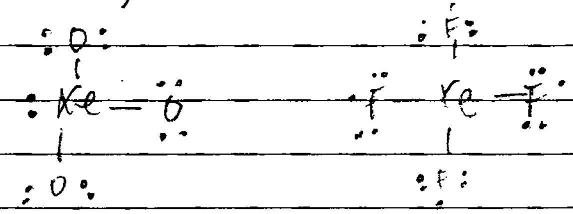
ADDITIONAL PAGE FOR ANSWERING QUESTION 5

a) F^-

b) The ionization energy of F is greater than O because it is more stable than O. Across a period, the ionization energy increases as well. F has 7 valence electrons and O has 6. F has more stability and is more unwilling to give up elections because it is trying to reach an octect.

c) the ionization energy of Xenon will be greater because it is stable and has a full octect.

d) XeO_2 XeF_4



e) (i) trigonal pyramidal
(ii) s^2p^2

f) non-polar because it has a lone pair

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Question 5

Overview

This question was designed to assess student understanding of the structure and properties of atoms and molecules. In parts (a) through (c) students had to demonstrate their understanding of ionization energy and provide explanations for its variance among different atoms. In parts (d) through (f) students were required to sketch Lewis electron-dot diagrams, identify molecular shape and hybridization, and predict molecular polarity.

Sample: 5A
Score: 8

This response earned 8 out of 9 points: 1 for part (a), 1 for part (c), 2 for part (d), 1 for part (e)(i), 1 for part (e)(ii), and 2 for part (f). The point was not earned in part (b); explanations based on electronegativity did not earn credit.

Sample: 5B
Score: 5

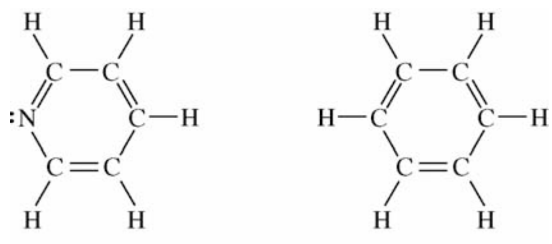
The point was earned in part (a). The point was earned in part (b) for the reference to a "stronger positive charge"; other factors discussed are not relevant but do not negate the credit earned for the response. The answer to part (c) is not correct. Both points were earned in part (d); students generally did well in this part. The answer to part (e)(i) is not correct. The point was earned in part (e)(ii). The answer to part (f) must be consistent with the response given in part (e)(i); no credit was earned in part (f) because "Polar" is not consistent with "Trigonal Planar."

Sample: 5C
Score: 1

The response to part (a) is not correct. The answer to part (b) does not address the effective nuclear charge, so the point was not earned. The answer to part (c) is incorrect. Neither point was earned in part (d); the Lewis electron-dot diagram for XeO_3 is missing one lone pair of electrons on each O atom, and electrons are also missing in the diagram for XeF_4. Part (e)(i) earned 1 point for being consistent with the Lewis electron-dot diagram for XeO_3 given in part (d). The answer to part (e)(ii) is not correct. The answer to part (f) is not correct for a trigonal-pyramidal-shaped molecule.

Question 6

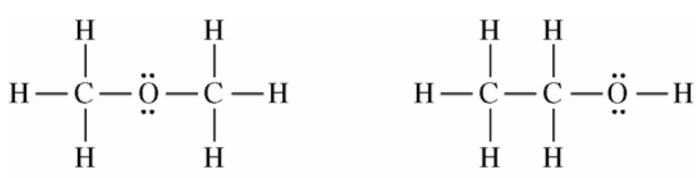
(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.



Pyridine Benzene

Pyridine is polar (and capable of forming hydrogen bonds with water), while the nonpolar benzene is not capable of forming hydrogen bonds. Pyridine will dissolve in water because of the strong hydrogen bonds (or dipole-dipole intermolecular interactions) that exist between the lone pair of electrons on pyridine's nitrogen atom and the solvent water molecules. No such strong intermolecular interaction can exist between benzene and water, so benzene is insoluble in water.	One point is earned for identifying a relevant structural difference between pyridine and benzene. One point is earned for indicating that pyridine is soluble in water because pyridine can form strong dipole-dipole interactions (or hydrogen bonds) with water, while benzene cannot.

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether Ethanol

Question 6 (continued)

The intermolecular forces of attraction among molecules of dimethyl ether consist of London (dispersion) forces and weak dipole-dipole interactions. In addition to London forces and dipole-dipole interactions that are comparable in strength to those in dimethyl ether, ethanol can form hydrogen bonds between the H of one molecule and the O of a nearby ethanol molecule. Hydrogen bonds are particularly strong intermolecular forces, so they require more energy to overcome during the boiling process. As a result, a higher temperature is needed to boil ethanol than is needed to boil dimethyl ether.	One point is earned for recognizing that ethanol molecules can form intermolecular hydrogen bonds, whereas dimethyl ether molecules do not form intermolecular hydrogen bonds. One point is earned for recognizing that, compared to the energy required to overcome the weaker intermolecular forces in liquid dimethyl ether, more energy is required to overcome the stronger hydrogen bonds in liquid ethanol, leading to a higher boiling point.

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss <u>both</u> of the substances in your answer.

In the solid phase, SO_2 consists of discrete molecules with dipole-dipole and London (dispersion) forces among the molecules. These forces are relatively weak and are easily overcome at a relatively low temperature, consistent with the low melting point of SO_2.	One point is earned for recognizing that SO_2 is a molecular solid with only weak dipole-dipole and London forces among SO_2 molecules.
In solid SiO_2, a network of Si and O atoms, linked by strong covalent bonds, exists. These covalent bonds are much stronger than typical intermolecular interactions, so very high temperatures are needed to overcome the covalent bonds in SiO_2. This is consistent with the very high melting point for SiO_2.	One point is earned for recognizing that SiO_2 is a covalent network solid, and that strong covalent bonds must be broken for SiO_2 to melt.

Question 6 (continued)

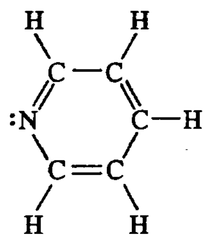
(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

The intermolecular forces in liquid Cl_2 are London (dispersion) forces, whereas the intermolecular forces in liquid HCl consist of London forces and dipole-dipole interactions. Since the boiling point of Cl_2 is higher than the boiling point of HCl, the London forces among Cl_2 molecules must be greater than the London and dipole-dipole forces among HCl molecules. The greater strength of the London forces between Cl_2 molecules occurs because Cl_2 has more electrons than HCl, and the strength of the London interaction is proportional to the total number of electrons.	One point is earned for recognizing that the London forces among Cl_2 molecules must be larger than the intermolecular forces (London and dipole-dipole) among HCl molecules. One point is earned for recognizing that the strength of the London forces among molecules is proportional to the total number of electrons in each molecule.

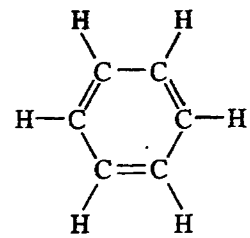
6A.

6. Answer the following questions by using principles of molecular structure and intermolecular forces.

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.



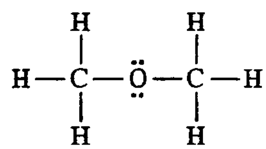
Pyridine



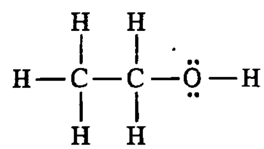
Benzene

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.

$|\bar{O} - \bar{S} = O\rangle$



Dimethyl Ether



Ethanol

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

6.a) Pyridine is soluble in water because it is polar: the unshared pair of electrons on the Nitrogen atom will attract the positive end of a water molecule. Benzene, however, is a nonpolar atom and will not attract molecules in this way. Although the H-C bond is somewhat polar, the entire molecule is symmetrical, so the molecule as a whole is nonpolar.

GO ON TO THE NEXT PAGE.

6A2

b) Ethanol has a higher boiling point because -
- the Ethanol molecule has hydrogen bonding which makes it very polar and more attractive to itself
- the dimethyl Ether molecule exhibits no hydrogen bonding, so its intermolecular forces are weaker, making its boiling point lower

c) SiO_2 has a higher melting point than SO_2 because -
- SiO_2 is a covalent network compound with strong bonds - SiO_2 is glass, rock etc.
- SO_2 forms covalent bonds also, but it is a molecular compound attached to itself only through dipole-dipole intermolecular forces rather than through more covalent bonds like SiO_2

d) The boiling point of Cl_2 is higher than HCl because -
- Cl_2's electron cloud is larger than HCl's, making its london dispersion intermolecular forces stronger because the molecule is more polarizable.
- HCl exhibits weak dipole-dipole forces which are not as strong as the London dispersion forces present in Cl_2

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 6B

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

a) In pyridine, the unshared electron pair on the N allows the pyridine to interact with the water and therefore dissolve. Benzene has no unshared electron pairs anywhere, it does not interact with water and is insoluble

b) In Dimethyl Ether, the only intermolecular forces are dispersion, very weak forces. Ethanol has hydrogen-bond intermolecular forces, which are much stronger. As a result, ethanol holds together better and boils at a higher temperature

c) SiO_2 is a network covalent structure. SiO_2 molecules form a very solid latticework that is very difficult to break. SO_2 is a much simpler compound that does not form this kind of network. It is easier to break the molecules apart, so it has a lower melting point than SiO_2.

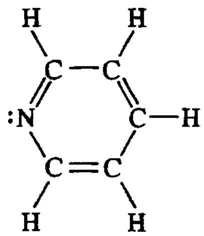
d) HCl interacts with other HCl molecules through dipole-dipole forces. These are weak forces and easy to break. As a result, it has a fairly low boiling point. Cl_2 molecules interact with dispersion forces which are also weak, but not as weak as the dipole-dipole forces in HCl. Therefore, Cl_2 has a higher boiling point than HCl.

GO ON TO THE NEXT PAGE.

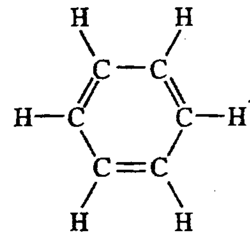
6C 1

6. Answer the following questions by using principles of molecular structure and intermolecular forces.

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.

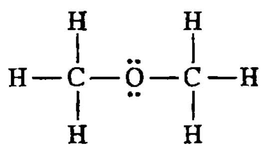


Pyridine

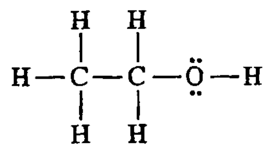


Benzene

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

a) The reason for pyridine being soluble is because it is polar due to its lone pair on the nitrogen. Also, water is polar, and like dissolves like, which allows for the polar pyridine to dissolve in the polar water. The reason for benzene not being soluble is it is non polar. Therefore, the non polar benzene cannot dissolve into the polar water

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6C2

B B B B B B B B B B B B B B

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

b) The dimethyl ether has a lower boiling point because it is nonpolar, which allows for the compound to be broken down more easily. the ethanol molecule has a higher boiling point because it is polar, which caused it to require more energy to seperate

c) SiO_2 melts at a higher temperature because it is the carbon family, which allows it to form covalent network solids, which are very strong. SO_2 melts at a lower temperature because it doesn't have these capabilities.

d) Cl_2 has a higher normal boiling point because it has a dipole - dipole bond. However, HCl only has hydrogen bonding and london dispersion forces which are much weaker and easily broken

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Question 6

Overview

This question explored the importance of intermolecular interactions in phase changes and dissolution. To earn full credit, a student had to identify the relevant forces involved in each process. In part (a) students had to explain that pyridine's ability to hydrogen bond with water distinguishes its aqueous solubility from that of benzene. In part (b) students had to recognize that while ethanol and dimethyl ether (structural isomers) have similar dispersion forces, the hydrogen bonding between ethanol molecules leads to a higher boiling point. Part (c) required students to contrast the melting points of a network covalent solid (in which strong covalent bonds are broken in the melting transition) and a molecular solid (in which only relatively weak intermolecular attractions must be overcome). In part (d) students had to recognize that the London/dispersion interactions between Cl_2 molecules must be greater than the total intermolecular forces between HCl molecules, and then attribute the difference to the larger number of electrons in the Cl_2 molecules.

Sample: 6A
Score: 8

This response earned all 8 points: 2 for part (a), 2 for part (b), 2 for part (c), and 2 for part (d). In part (a) pyridine is shown to be polar, whereas benzene is shown to be nonpolar, and the dipole-dipole interactions between pyridine's lone pair of electrons and the positive end of water's dipole is nicely described. In part (b) the mention of intermolecular hydrogen bonding between ethanol molecules is explicit. The response makes clear that these hydrogen bonds are stronger than the intermolecular interactions between dimethyl ether molecules. It is clear that interactions between molecules are being discussed, and 2 points were earned. In part (c) the difference in the types of intermolecular interactions (covalent network versus dipole-dipole) is clear, as is the fact that the covalent network bonds are stronger than the dipole-dipole forces, which earned 2 points. Part (d) earned 2 points by making clear the relationship between the strength of London/dispersion forces and the size of the electron cloud, as well as stating that the strength of the intermolecular interactions between Cl_2 molecules must be greater than the intermolecular forces between HCl molecules.

Sample: 6B
Score: 6

In part (a) the difference between the two solutes (nonpolar versus polar) is discussed, and the response briefly mentions that the solubility of pyridine is the result of the nature of its interactions with water molecules, so both points were earned. In part (b) the intermolecular hydrogen bonding between ethanol molecules is clearly indicated, as is the fact that weaker dipole-dipole interactions occur between dimethyl ether molecules. No deduction was made for omitting the dipole-dipole forces between dimethyl ether molecules, and both points were earned. In part (c) the SiO_2 is acceptably described ("network covalent structure" with a lattice that is "very difficult to break"), which earned 1 point, but the description of solid SO_2 is inadequate to earn the second point. The answer to part (d) earned 1 point by correctly attributing the higher boiling point for Cl_2 to stronger London/dispersion forces but does not connect the strength of the London force to the total number of electrons, so the second point was not earned.

Question 6 (continued)

Sample: 6C
Score: 2

In part (a) the response includes a discussion of the difference between the two solutes (nonpolar benzene versus polar pyridine) and thus earned 1 point. However, the response does not describe the nature of the interaction between either of the solutes and water, so the second point was not earned. The phrase "like dissolves like" is not a discussion of intermolecular interactions. In part (b) it is not clear whether the student is referring to intra- or intermolecular interactions, and no points were earned. The phrase "which allows for the compound to be broken down" (and many similar constructions by other students) implies that the dimethyl ether molecule breaks apart when heated; no points were earned for this type of response. In part (c) the description of the structure and the relative strength of the interactions in solid SiO_2 earned 1 point, but the response does not adequately deal with SO_2 and thus did not earn the second point. The answer in part (d) did not earn any points for the discussion of dipole-dipole bonds in Cl_2 and the weak hydrogen bonds in HCl.

AP® Chemistry Exam

SECTION I: Multiple-Choice Questions

2008

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
75
Percent of Total Grade
50%
Writing Instrument
Pencil required
Electronic Device
None allowed

Instructions

Section I of this exam contains 75 multiple-choice questions. Fill in only the ovals for numbers 1 through 75 of the answer sheet.

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 oval on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a	Ⓐ ● Ⓒ Ⓓ Ⓔ

(A) state
(B) city
(C) country
(D) continent
(E) village

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

About Guessing

Many students wonder whether or not to guess the answers to questions about which they are not certain. In this section of the exam, as a correction for random guessing, one-fourth of the number of questions you answer incorrectly will be subtracted from the number of questions you answer correctly. If you are not sure of the best answer but have some knowledge of the question and are able to eliminate one or more of the answer choices, your chance of answering correctly is improved, and it may be to your advantage to answer such a question.

Section I

MATERIAL IN THE FOLLOWING TABLE MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	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											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** 47.90	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** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	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** 95.94	43 **Tc** (98)	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** 121.75	52 **Te** 127.60	53 **I** 126.91	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** 183.85	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** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide 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** 173.04	71 **Lu** 174.97
†Actinide 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)

GO ON TO THE NEXT PAGE.

CHEMISTRY
Section I
Time—1 hour and 30 minutes
NO CALCULATOR MAY BE USED WITH SECTION I.

Note: For all questions, assume that the temperature is 298 K, the pressure is 1.00 atmosphere, and solutions are aqueous unless otherwise specified.

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

T =	temperature	L, mL =	liter(s), milliliter(s)
P =	pressure	g =	gram(s)
V =	volume	nm =	nanometer(s)
S =	entropy	atm =	atmosphere(s)
H =	enthalpy	mm Hg =	millimeters of mercury
G =	Gibbs free energy	J, kJ =	joule(s), kilojoule(s)
R =	molar gas constant	V =	volt(s)
n =	number of moles	mol =	mole(s)
M =	molar		
m =	molal		

Part A

Directions: Each set of lettered choices below refers to the numbered statements immediately following it. Select the one lettered choice that best fits each statement and then fill in the corresponding oval on the answer sheet. A choice may be used once, more than once, or not at all in each set.

Questions 1-3 refer to the following types of elements in the periodic table.

(A) Noble gases
(B) Alkali metals
(C) Halogens
(D) Transition elements
(E) Actinides

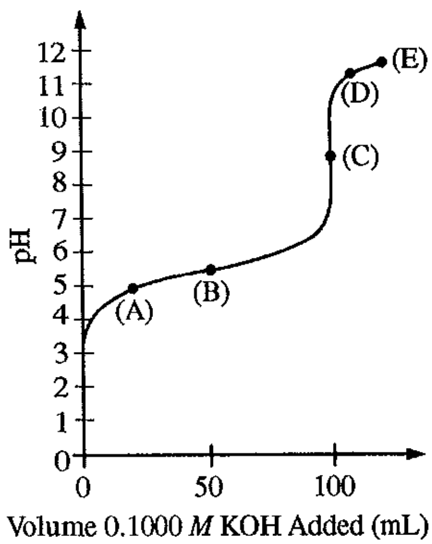
1. Are the most difficult to oxidize in a given period of the periodic table

2. Are always radioactive

3. Are the most likely to form anions

Questions 4-6

A solution of a weak monoprotic acid is titrated with a solution of a strong base, KOH. Consider the points labeled (A) through (E) on the titration curve that results, as shown below.



4. The point at which the moles of the added strong base are equal to the moles of the weak acid initially present

5. The point at which the pH is closest to that of the strong base being added

6. The point at which the concentrations of the weak acid and its conjugate base are approximately equal

Questions 7-9 refer to the following pure substances, which are gases at 25°C and 1 atmosphere.

(A) $NH_3(g)$
(B) $BH_3(g)$
(C) $H_2(g)$
(D) $H_2S(g)$
(E) $HBr(g)$

7. Has molecules with a pyramidal shape

8. Is a strong electrolyte in aqueous solution

9. Is the slowest to effuse through a small opening at 25°C and 1 atm

Questions 10-11 refer to the following.

(A) Activation energy
(B) Enthalpy of formation
(C) Entropy
(D) Gibbs free energy
(E) Lattice energy

10. Quantity that would be zero for a pure, perfect crystal at 0 K

11. Quantity typically determined by measuring the rate of a reaction at two or more different temperatures

Questions 12-14 refer to the following combinations of enthalpy changes (ΔH) and entropy changes (ΔS) for chemical reactions.

(A) $\Delta H > 0,\ \Delta S > 0$
(B) $\Delta H > 0,\ \Delta S < 0$
(C) $\Delta H < 0,\ \Delta S > 0$
(D) $\Delta H < 0,\ \Delta S < 0$
(E) $\Delta H = 0,\ \Delta S < 0$

12. Must be true for a reaction that is spontaneous at all temperatures

13. True for the evaporation of water at 25°C and 1 atm

14. True for the combustion of liquid pentane, $C_5H_{12}(l)$, to form $H_2O(g)$ and $CO_2(g)$ at 1 atm

GO ON TO THE NEXT PAGE.

Questions 15-17 refer to the following reactions.

(A) $2\,Mg(s) + O_2(g) \rightarrow 2\,MgO(s)$
(B) $Pb^{2+}(aq) + CrO_4^{2-}(aq) \rightarrow PbCrO_4(s)$
(C) $SO_3(g) + 2\,H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$
(D) $2\,H_2O(g) \rightarrow 2\,H_2(g) + O_2(g)$
(E) $Ag^+(aq) + 2\,NH_3(aq) \rightarrow [Ag(NH_3)_2]^+(aq)$

15. A precipitation reaction

16. A Lewis acid-base reaction that produces a coordination complex

17. An oxidation-reduction reaction that is also a synthesis reaction

Part B

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

$$2\,KClO_3(s) \xrightarrow[MnO_2]{\Delta} 2\,KCl(s) + 3\,O_2(g)$$

18. According to the equation above, how many moles of potassium chlorate, $KClO_3$, must be decomposed to generate 1.0 L of O_2 gas at standard temperature and pressure?

(A) $\frac{1}{3}\left(\frac{1}{22.4}\right)$ mol

(B) $\frac{1}{2}\left(\frac{1}{22.4}\right)$ mol

(C) $\frac{2}{3}\left(\frac{1}{22.4}\right)$ mol

(D) $\frac{3}{2}\left(\frac{1}{22.4}\right)$ mol

(E) $2\left(\frac{1}{22.4}\right)$ mol

19. Which of the following ions has the same number of electrons as Br^- ?

(A) Ca^{2+}
(B) K^+
(C) Sr^{2+}
(D) I^-
(E) Cl^-

20. In solid methane, the forces between neighboring CH_4 molecules are best characterized as

(A) ionic bonds
(B) covalent bonds
(C) hydrogen bonds
(D) ion-dipole forces
(E) London (dispersion) forces

21. Of the following electron configurations of neutral atoms, which represents an atom in an excited state?

(A) $1s^2\,2s^2\,2p^5$
(B) $1s^2\,2s^2\,2p^5\,3s^2$
(C) $1s^2\,2s^2\,2p^6\,3s^1$
(D) $1s^2\,2s^2\,2p^6\,3s^2\,3p^2$
(E) $1s^2\,2s^2\,2p^6\,3s^2\,3p^5$

22. Which of the following is a nonpolar molecule that contains polar bonds?

(A) F_2
(B) CHF_3
(C) CO_2
(D) HCl
(E) NH_3

23. The oxidation state that is common to aqueous ions of Fe, Mn, and Zn is

(A) +1
(B) +2
(C) +3
(D) +4
(E) +5

24. Which of the following shows the correct number of protons, neutrons, and electrons in a neutral cesium-134 atom?

	Protons	Neutrons	Electrons
(A)	55	55	55
(B)	55	79	55
(C)	55	79	79
(D)	79	55	79
(E)	134	55	134

GO ON TO THE NEXT PAGE.

25. The pressure, in atm, exerted by 1.85 mol of an ideal gas placed in a 3.00 L container at 35.0°C is given by which of the following expressions?

(A) $\frac{(1.85)(0.0821)(308)}{3.00}$ atm

(B) $\frac{(1.85)(35.0)}{(0.0821)(3.00)}$ atm

(C) $\frac{3.00}{(1.85)(0.0821)(308)}$ atm

(D) $\frac{(1.85)(8.314)(308)}{3.00}$ atm

(E) $\frac{(3.00)(1.85)}{(0.0821)(35.0)}$ atm

Experiment	$[X]_0$	$[Y]_0$	Initial Rate of Formation of Z (mol L^{-1} sec^{-1})
1	0.40	0.10	R
2	0.20	0.20	?

26. The table above shows the results from a rate study of the reaction $X + Y \rightarrow Z$. Starting with known concentrations of X and Y in experiment 1, the rate of formation of Z was measured. If the reaction was first order with respect to X and second order with respect to Y, the initial rate of formation of Z in experiment 2 would be

(A) $\frac{R}{4}$

(B) $\frac{R}{2}$

(C) R

(D) $2R$

(E) $4R$

27. Which of the following is a correctly balanced nuclear reaction?

(A) ${}^{238}_{92}U \rightarrow {}^{232}_{90}Th + {}^{4}_{2}He$

(B) ${}^{249}_{98}Cf + {}^{15}_{7}N \rightarrow {}^{260}_{105}Db + 3\,{}^{1}_{0}n$

(C) ${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{0}n$

(D) ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U$

(E) ${}^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{+1}\beta$

28. Which of the following molecules contains only single bonds?

(A) CH_3COOH
(B) $CH_3CH_2COOCH_3$
(C) C_2H_6
(D) C_6H_6
(E) HCN

29. What is the molality of a solution of phosphoric acid, H_3PO_4, that contains 24.5 g of phosphoric acid (molar mass 98.0 g) in 100. g of H_2O ?

(A) 0.245 m
(B) 2.50 m
(C) 4.00 m
(D) 25.0 m
(E) 40.0 m

	Mass (g)
Empty flask	18.990
Flask + liquid	39.493

30. The density of a pure liquid at 25°C was calculated by determining the mass and volume of a sample of the liquid. A student measured the mass of a clean, dry 25.00 mL volumetric flask, filled the flask to its calibration mark with the liquid, and then measured the mass of the flask and liquid. The recorded measurements are shown in the table above. On the basis of this information, to how many significant figures should the density of the liquid be reported?

(A) 3
(B) 4
(C) 5
(D) 6
(E) 8

31. A compound contains 30. percent sulfur and 70. percent fluorine by mass. The empirical formula of the compound is

(A) SF
(B) SF_2
(C) SF_4
(D) SF_6
(E) S_2F

32. Gaseous cyclobutene undergoes a first-order reaction to form gaseous butadiene. At a particular temperature, the partial pressure of cyclobutene in the reaction vessel drops to one-eighth its original value in 124 seconds. What is the half-life for this reaction at this temperature?

(A) 15.5 sec
(B) 31.0 sec
(C) 41.3 sec
(D) 62.0 sec
(E) 124 sec

33. If 0.40 mol of H_2 and 0.15 mol of O_2 were to react as completely as possible to produce H_2O, what mass of reactant would remain?

(A) 0.20 g of H_2
(B) 0.40 g of H_2
(C) 3.2 g of O_2
(D) 4.0 g of O_2
(E) 4.4 g of O_2

GO ON TO THE NEXT PAGE.

$$\ldots Ca_3(PO_4)_2(s) + \ldots H_3PO_4(l) \rightarrow \ldots Ca(H_2PO_4)_2(s)$$

34. When the equation above is balanced and all coefficients are reduced to lowest whole-number terms, what is the coefficient for $H_3PO_4(l)$?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g) \qquad \Delta H > 0$$

35. Which of the following changes to the equilibrium system represented above will increase the quantity of $HI(g)$ in the equilibrium mixture?

I. Adding $H_2(g)$
II. Increasing the temperature
III. Decreasing the pressure

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

36. How many carbon atoms are contained in 2.8 g of C_2H_4 ?

(A) 1.2×10^{23}
(B) 3.0×10^{23}
(C) 6.0×10^{23}
(D) 1.2×10^{24}
(E) 6.0×10^{24}

37. Which of the following elements combines with oxygen to form a covalent network solid?

(A) Si
(B) S
(C) C
(D) Mg
(E) Cs

38. How many mL of 10.0 *M* HCl are needed to prepare 500. mL of 2.00 *M* HCl ?

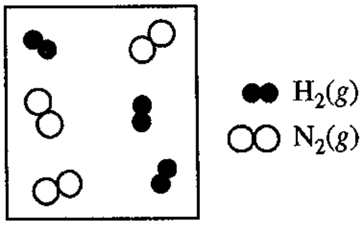
(A) 1.00 mL
(B) 10.0 mL
(C) 20.0 mL
(D) 100. mL
(E) 200. mL

39. A student mixes equal volumes of 1.0 *M* solutions of tin(II) chloride and copper(II) sulfate and observes that no precipitate forms. Then the student mixes equal volumes of 1.0 *M* solutions of zinc(II) sulfate and tin(II) fluoride and observes the formation of a precipitate. The formula of the precipitate must be

(A) SnF_2
(B) $SnSO_4$
(C) $Sn(SO_4)_2$
(D) ZnF
(E) ZnF_2

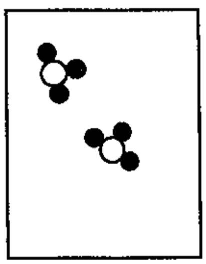
40. On the basis of strength of intermolecular forces, which of the following elements would be expected to have the highest melting point?

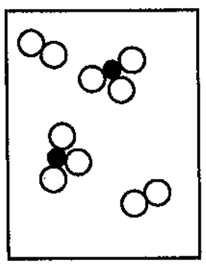
(A) Br_2
(B) Cl_2
(C) F_2
(D) Kr
(E) N_2



41. The diagram above represents $H_2(g)$ and $N_2(g)$ in a closed container. Which of the following diagrams would represent the results if the reaction shown below were to proceed as far as possible?

$$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g)$$

(A)


(B)


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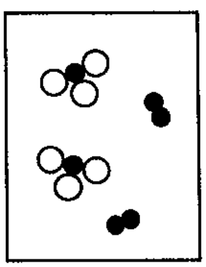

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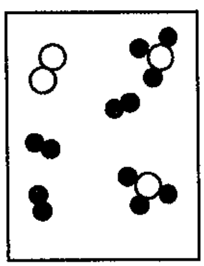
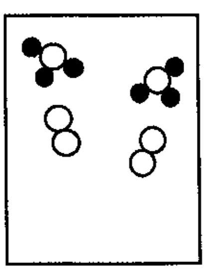


(E)


42. Equal masses of He and Ne are placed in a sealed container. What is the partial pressure of He if the total pressure in the container is 6 atm?

(A) 1 atm
(B) 2 atm
(C) 3 atm
(D) 4 atm
(E) 5 atm

43. A pure liquid in an open vessel boils at the temperature at which the

(A) molar entropy of the liquid becomes equal to that of the gas
(B) vapor pressure of the liquid becomes equal to the equilibrium pressure at the triple point
(C) vapor pressure of the liquid becomes equal to the atmospheric pressure on the surface of the liquid
(D) molar heat capacity of the liquid becomes equal to that of the gas
(E) average kinetic energy of the liquid molecules becomes equal to that of the gas molecules

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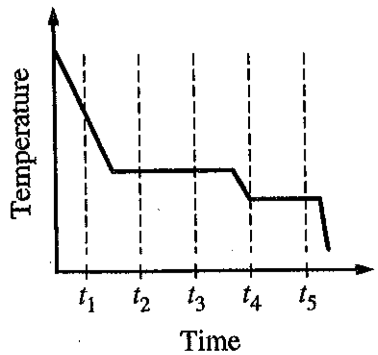
$$Cl_2(g) + 2\,I^-(aq) \rightarrow 2\,Cl^-(aq) + I_2(aq)$$

44. Which of the following best accounts for the fact that a galvanic cell based on the reaction represented above will generate electricity?

(A) Cl_2 can easily lose two electrons.
(B) Cl_2 is a stronger oxidizing agent than I_2.
(C) I atoms have more electrons than do atoms of Cl.
(D) I^- is a more stable species than I_2.
(E) $I_2(s)$ is more soluble than $Cl_2(g)$.



45. The cooling curve above shows how the temperature of a sample varies with time as the sample goes through phase changes. The sample starts as a gas, and heat is removed at a constant rate. At which time does the sample contain the most liquid?

(A) t_1
(B) t_2
(C) t_3
(D) t_4
(E) t_5

46. A solution is prepared by adding 16 g of CH_3OH (molar mass 32 g) to 90. g of H_2O (molar mass 18 g). The mole fraction of CH_3OH in this solution is closest to which of the following?

(A) 0.1
(B) 0.2
(C) 0.3
(D) 0.4
(E) 0.6

47. When diluting concentrated H_2SO_4, one should slowly add acid to a beaker of water rather than add water to a beaker of acid. The reason for this precaution is to ensure that

(A) there is complete ionization of the H_2SO_4
(B) there is a sufficient volume of water to absorb the heat released
(C) the water does not sink beneath the acid and remain unmixed
(D) the acid does not react with impurities in the dry beaker
(E) any SO_2 released quickly redissolves in the water

48. Which of the following is the conjugate acid of NH_2^- ?

(A) NH^{2-}
(B) NH_3
(C) H^+
(D) NH_4^+
(E) H_2O

49. Salts containing which of the following ions are generally insoluble in cold water?

(A) Acetate
(B) Ammonium
(C) Potassium
(D) Nitrate
(E) Phosphate

$$2\ MnO_4^-(aq) + 10\ Br^-(aq) + 16\ H^+(aq) \rightarrow 2\ Mn^{2+}(aq) + 5\ Br_2(aq) + 8\ H_2O(l)$$

50. How many electrons are transferred in the reaction represented by the balanced equation above?

(A) 2
(B) 4
(C) 5
(D) 8
(E) 10

---

51. Under which of the following conditions of temperature and pressure would 1.0 mol of the real gas $CO_2(g)$ behave most like an ideal gas?

	Temperature (K)	Pressure (atm)
(A)	100	0.1
(B)	100	100
(C)	800	0.1
(D)	800	1
(E)	800	100

52. Which of the following measures of concentration changes with temperature?

(A) Mass percentage
(B) Mole fraction
(C) Molarity
(D) Molality
(E) Parts per million by mass

GO ON TO THE NEXT PAGE.

53. A sample of 10.0 mol of butyric acid, $HC_4H_7O_2$, a weak acid, is dissolved in 1000. g of water to make a 10.0-molal solution. Which of the following would be the best method to determine the molarity of the solution? (In each case, assume that no additional information is available.)

(A) Titration of the solution with standard acid
(B) Measurement of the pH with a pH meter
(C) Determination of the freezing point of the solution
(D) Measurement of the total volume of the solution
(E) Measurement of the electrical conductivity of the solution

54. The nonvolatile compound ethylene glycol, $C_2H_6O_2$, forms nearly ideal solutions with water. What is the vapor pressure of a solution made from 1.00 mole of $C_2H_6O_2$ and 9.00 moles of H_2O if the vapor pressure of pure water at the same temperature is 25.0 mm Hg ?

(A) 2.50 mm Hg
(B) 7.50 mm Hg
(C) 12.5 mm Hg
(D) 22.5 mm Hg
(E) 27.5 mm Hg

$$2\,X(g) + Y(g) \rightleftarrows 3\,Z(g)$$

55. The reaction mixture represented above is at equilibrium at 298 K, and the molar concentrations are [X] = 2.0 *M*, [Y] = 0.5 *M*, and [Z] = 4.0 *M*. What is the value of the equilibrium constant for the reaction at 298 K ?

(A) 0.50
(B) 2.0
(C) 4.0
(D) 16
(E) 32

56. The London (dispersion) forces are weakest for which of the following gases under the same conditions of temperature and pressure?

(A) H_2
(B) O_2
(C) Xe
(D) F_2
(E) N_2

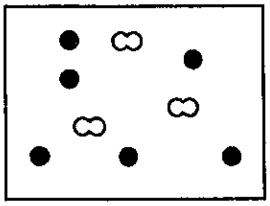
$$H—C{\equiv}C—H$$

57. What is the hybridization of the carbon atoms in a molecule of ethyne, represented above?

(A) *sp*
(B) sp^2
(C) sp^3
(D) dsp^2
(E) d^2sp

58. A 360. mg sample of aspirin, $C_9H_8O_4$, (molar mass 180. g), is dissolved in enough water to produce 200. mL of solution. What is the molarity of aspirin in a 50. mL sample of this solution?

(A) 0.0800 *M*
(B) 0.0400 *M*
(C) 0.0200 *M*
(D) 0.0100 *M*
(E) 0.00250 *M*



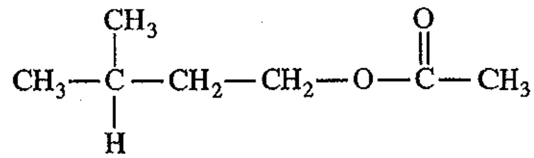
NO_2 = ●
N_2O_4 = ∞

59. The diagram above represents a mixture of $NO_2(g)$ and $N_2O_4(g)$ in a 1.0 L container at a given temperature. The two gases are in equilibrium according to the equation $2\,NO_2(g) \rightleftarrows N_2O_4(g)$. Which of the following must be true about the value of the equilibrium constant for the reaction at this temperature?

(A) $K = 0$
(B) $0 < K < 1$
(C) $K = 1$
(D) $K > 1$
(E) There is not enough information to determine the relative value of K.

60. When aqueous NH_3 is first added to a solution containing Ni^{2+}, a precipitate forms, but when an excess of aqueous NH_3 is added, the precipitate dissolves. Which of the following best explains why the precipitate dissolves?

(A) Ni^{2+} forms hydrogen bonds with NH_3.
(B) Ni^{2+} forms a complex ion with NH_3.
(C) Ni^{2+} acts as a Brønsted-Lowry base.
(D) Ni^{2+} is oxidized to Ni^{3+}.
(E) Ni^{2+} is reduced to Ni^{+}.



61. The structure of a molecule of "banana oil" is shown above. This organic compound is an example of

(A) an alcohol
(B) an amine
(C) a carboxylic acid
(D) an ester
(E) a ketone

62. Which of the following pieces of laboratory glassware should be used to most accurately measure out a 25.00 mL sample of a solution?

(A) 5 mL pipet
(B) 25 mL pipet
(C) 25 mL beaker
(D) 25 mL Erlenmeyer flask
(E) 50 mL graduated cylinder

63. Which of the following best helps to account for the fact that the F^- ion is smaller than the O^{2-} ion?

(A) F^- has a larger nuclear mass than O^{2-} has.
(B) F^- has a larger nuclear charge than O^{2-} has.
(C) F^- has more electrons than O^{2-} has.
(D) F^- is more electronegative than O^{2-} is.
(E) F^- is more polarizable than O^{2-} is.

64. Which of the following solutions has a pH greater than 7.0 ?

(A) 0.10 M KBr
(B) 0.10 M NH_4Cl
(C) 0.10 M $HC_2H_3O_2$
(D) 0.10 M NaF
(E) 0.10 M HI

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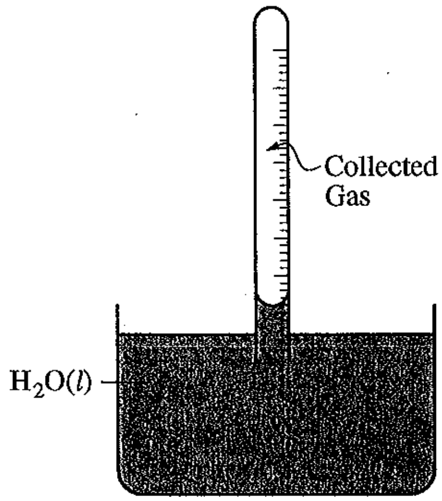


65. In a laboratory experiment, $H_2(g)$ is collected over water in a gas-collection tube as shown in the diagram above. The temperature of the water is 21°C and the atmospheric pressure in the laboratory is measured to be 772 torr. Before measuring the volume of gas collected in the tube, what step, if any, must be taken to make it possible to determine the total gas pressure inside the tube?

(A) Tilt the tube to the side enough to let some air in to break the partial vacuum in the tube.
(B) Lift the tube upward until it is just barely immersed in the water.
(C) Move the tube downward until the water level is the same inside and outside the tube.
(D) Adjust the temperature of the water to 25°C.
(E) No further steps need to be taken as long as the temperature of the water is known.

66. Factors that affect the rate of a chemical reaction include which of the following?

I. Frequency of collisions of reactant particles
II. Kinetic energy of collisions of reactant particles
III. Orientation of reactant particles during collisions

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

$$\ldots H^+(aq) + \ldots NO_2^-(aq) + \ldots Cr_2O_7^{2-}(aq) \rightarrow \ldots Cr^{3+}(aq) + \ldots NO_3^-(aq) + \ldots H_2O(l)$$

67. When the equation above is balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for $H_2O(l)$ is

(A) 2
(B) 4
(C) 5
(D) 6
(E) 8

---

68. The pH of a solution prepared by the addition of 10. mL of 0.002 *M* KOH(*aq*) to 10. mL of distilled water is closest to

(A) 12
(B) 11
(C) 10
(D) 4
(E) 3

69. At standard temperature and pressure, a 0.50 mol sample of H_2 gas and a separate 1.0 mol sample of O_2 gas have the same

(A) average molecular kinetic energy
(B) average molecular speed
(C) volume
(D) effusion rate
(E) density

70. Naturally produced amino acids typically contain all of the following elements EXCEPT

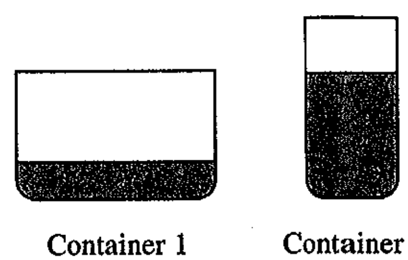
(A) nitrogen
(B) chlorine
(C) oxygen
(D) hydrogen
(E) carbon

71. Of the following single bonds, which is the LEAST polar?

(A) N–H
(B) H–F
(C) O–F
(D) I–F
(E) O–H

72. When mixed, each of the following pairs of reactants gives visible evidence of a chemical reaction EXCEPT

(A) $Na_2CO_3(s)$ + $HCl(aq)$
(B) $Zn(s)$ + $HCl(aq)$
(C) $Ba(NO_3)_2(aq)$ + $Na_2SO_4(aq)$
(D) $FeCl_3(aq)$ + $KOH(aq)$
(E) $NH_4Cl(aq)$ + $HCl(aq)$



73. The figure above shows two closed containers. Each contains the same volume of acetone in equilibrium with its vapor at the same temperature. The vapor pressure of the acetone is

(A) higher in container 1 because the surface area of the liquid is greater
(B) higher in container 1 because the volume of vapor is greater
(C) lower in container 1 because the level of the liquid is lower
(D) the same in both containers because the volume of the liquid is the same
(E) the same in both containers because the temperature is the same

74. An electric current of 1.00 ampere is passed through an aqueous solution of $Ni(NO_3)_2$. How long will it take to plate out exactly 1.00 mol of nickel metal, assuming 100 percent current efficiency?

(1 faraday = 96,500 coulombs = 6.02×10^{23} electrons)

(A) 386,000 sec
(B) 193,000 sec
(C) 96,500 sec
(D) 48,200 sec
(E) 24,100 sec

---

75. Which of the following molecules has an angular (bent) geometry that is commonly represented as a resonance hybrid of two or more electron-dot structures?

(A) CO_2
(B) O_3
(C) CH_4
(D) BeF_2
(E) OF_2

END OF SECTION I

AP® Chemistry Exam

SECTION II: Free-Response Questions

2008

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At a Glance

Total Time
1 hour, 35 minutes
Number of Questions
6
Percent of Total Grade
50%
Writing Instrument
Either pencil or pen with black or dark blue ink

Part A

Number of Questions
3
Time
55 minutes
Electronic Device
Calculator allowed
Percent of Section II Score
Question 1 — 20%
Question 2 — 20%
Question 3 — 20%

Part B

Number of Questions
3
Time
40 minutes
Electronic Device
None allowed
Percent of Section II Score
Question 4 — 10%
Question 5 — 15%
Question 6 — 15%

IMPORTANT Identification Information

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   First letter of your first name ☐
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Instructions

The questions for Part A and Part B are printed in the green insert and in this Section II booklet. You may not remove or open the insert during Part A; you will be instructed to open the insert when it is time to start Part B. You may use the insert to organize your answers and for scratch work but you must write your answers in the pink Section II booklet. No credit will be given for any work written in the insert. Pages containing a periodic table, reduction potentials, and lists containing equations and constants are printed in this booklet.

Write your answers to each question in the space provided for that question in the Section II booklet. Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be graded.

Manage your time carefully. The proctor will announce the time for Part A and Part B, but you may proceed freely from one question to the next within each part. Do not spend too much time on any one question. If you finish Part B before time is called, you may go back to Part A if you wish, but you may NOT use a calculator.

INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 34-36 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	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											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** 47.90	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** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	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** 95.94	43 **Tc** (98)	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** 121.75	52 **Te** 127.60	53 **I** 126.91	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** 183.85	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** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide 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** 173.04	71 **Lu** 174.97
†Actinide 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)

GO ON TO THE NEXT PAGE.

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E°$(V)
$F_2(g) + 2e^-$	$\rightarrow$	$2F^-$	2.87
$Co^{3+} + e^-$	$\rightarrow$	Co^{2+}	1.82
$Au^{3+} + 3e^-$	$\rightarrow$	$Au(s)$	1.50
$Cl_2(g) + 2e^-$	$\rightarrow$	$2Cl^-$	1.36
$O_2(g) + 4H^+ + 4e^-$	$\rightarrow$	$2H_2O(l)$	1.23
$Br_2(l) + 2e^-$	$\rightarrow$	$2Br^-$	1.07
$2Hg^{2+} + 2e^-$	$\rightarrow$	Hg_2^{2+}	0.92
$Hg^{2+} + 2e^-$	$\rightarrow$	$Hg(l)$	0.85
$Ag^+ + e^-$	$\rightarrow$	$Ag(s)$	0.80
$Hg_2^{2+} + 2e^-$	$\rightarrow$	$2Hg(l)$	0.79
$Fe^{3+} + e^-$	$\rightarrow$	Fe^{2+}	0.77
$I_2(s) + 2e^-$	$\rightarrow$	$2I^-$	0.53
$Cu^+ + e^-$	$\rightarrow$	$Cu(s)$	0.52
$Cu^{2+} + 2e^-$	$\rightarrow$	$Cu(s)$	0.34
$Cu^{2+} + e^-$	$\rightarrow$	Cu^+	0.15
$Sn^{4+} + 2e^-$	$\rightarrow$	Sn^{2+}	0.15
$S(s) + 2H^+ + 2e^-$	$\rightarrow$	$H_2S(g)$	0.14
$2H^+ + 2e^-$	$\rightarrow$	$H_2(g)$	0.00
$Pb^{2+} + 2e^-$	$\rightarrow$	$Pb(s)$	–0.13
$Sn^{2+} + 2e^-$	$\rightarrow$	$Sn(s)$	–0.14
$Ni^{2+} + 2e^-$	$\rightarrow$	$Ni(s)$	–0.25
$Co^{2+} + 2e^-$	$\rightarrow$	$Co(s)$	–0.28
$Cd^{2+} + 2e^-$	$\rightarrow$	$Cd(s)$	–0.40
$Cr^{3+} + e^-$	$\rightarrow$	Cr^{2+}	–0.41
$Fe^{2+} + 2e^-$	$\rightarrow$	$Fe(s)$	–0.44
$Cr^{3+} + 3e^-$	$\rightarrow$	$Cr(s)$	–0.74
$Zn^{2+} + 2e^-$	$\rightarrow$	$Zn(s)$	–0.76
$2H_2O(l) + 2e^-$	$\rightarrow$	$H_2(g) + 2OH^-$	–0.83
$Mn^{2+} + 2e^-$	$\rightarrow$	$Mn(s)$	–1.18
$Al^{3+} + 3e^-$	$\rightarrow$	$Al(s)$	–1.66
$Be^{2+} + 2e^-$	$\rightarrow$	$Be(s)$	–1.70
$Mg^{2+} + 2e^-$	$\rightarrow$	$Mg(s)$	–2.37
$Na^+ + e^-$	$\rightarrow$	$Na(s)$	–2.71
$Ca^{2+} + 2e^-$	$\rightarrow$	$Ca(s)$	–2.87
$Sr^{2+} + 2e^-$	$\rightarrow$	$Sr(s)$	–2.89
$Ba^{2+} + 2e^-$	$\rightarrow$	$Ba(s)$	–2.90
$Rb^+ + e^-$	$\rightarrow$	$Rb(s)$	–2.92
$K^+ + e^-$	$\rightarrow$	$K(s)$	–2.92
$Cs^+ + e^-$	$\rightarrow$	$Cs(s)$	–2.92
$Li^+ + e^-$	$\rightarrow$	$Li(s)$	–3.05

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$E = h\nu \qquad c = \lambda\nu$

$\lambda = \dfrac{h}{mv} \qquad p = mv$

$E_n = \dfrac{-2.178 \times 10^{-18}}{n^2}$ joule

E = energy
ν = frequency
λ = wavelength
p = momentum
v = velocity
n = principal quantum number
m = mass

Speed of light, $c = 3.0 \times 10^8$ m s^{-1}

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J K^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom = 96.5 kJ mol^{-1}

EQUILIBRIUM

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

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

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

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

$$14 = pH + pOH$$

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

$$pOH = pK_b + \log\frac{[HB^+]}{[B]}$$

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

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = moles product gas − moles reactant gas

Equilibrium Constants

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

THERMOCHEMISTRY/KINETICS

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

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

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

$$\Delta G° = \Delta H° - T\Delta S° = -RT\ln K = -2.303\,RT\log K = -n\mathcal{F}E°$$

$$\Delta G = \Delta G° + RT\ln Q = \Delta G° + 2.303\,RT\log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

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

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

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

$S°$ = standard entropy
$H°$ = standard enthalpy
$G°$ = standard free energy
$E°$ = standard reduction potential
T = temperature
n = moles
m = mass
q = heat
c = specific heat capacity
C_p = molar heat capacity at constant pressure
E_a = activation energy
k = rate constant
A = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, R = 8.31 J mol^{-1} K^{-1}
= 0.0821 L atm mol^{-1} K^{-1}
= 62.4 L torr mol^{-1} K^{-1}
= 8.31 volt coulomb mol^{-1} K^{-1}

GO ON TO THE NEXT PAGE.

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

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

$$P_{total} = P_A + P_B + P_C + ...$$

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

$$K = °C + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

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

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
D = density
m = mass
v = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
M = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
A = absorbance
a = molar absorptivity
b = path length
c = concentration
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
$E°$ = standard reduction potential
K = equilibrium constant

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}, \text{ where } a\,A + b\,B \rightarrow c\,C + d\,D$$

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

$$E_{cell} = E^\circ_{cell} - \frac{RT}{n\mathcal{F}}\ln Q = E^\circ_{cell} - \frac{0.0592}{n}\log Q \quad @\ 25°C$$

$$\log K = \frac{nE°}{0.0592}$$

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1} \text{K}^{-1}$
$= 62.4 \text{ L torr mol}^{-1} \text{K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1} \text{K}^{-1}$

Boltzmann's constant, $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

K_f for H_2O = $1.86 \text{ K kg mol}^{-1}$

K_b for H_2O = $0.512 \text{ K kg mol}^{-1}$

1 atm = 760 mm Hg
= 760 torr

STP = 0.00°C and 1.0 atm

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

GO ON TO THE NEXT PAGE.

CHEMISTRY
Section II
(Total time—95 minutes)

Part A
Time—55 minutes
YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

1. Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some $C(s)$ remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

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

(b) Calculate the number of moles of $CO_2(g)$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

(c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $CO_2(g)$ is 1.63 atm. Calculate

(i) the partial pressure of $CO(g)$, and

(ii) the value of the equilibrium constant, K_p.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of $C(s)$, plus $CO(g)$ and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

---

2. Answer the following questions relating to gravimetric analysis.

In the first of two experiments, a student is assigned the task of determining the number of moles of water in one mole of $MgCl_2 \cdot nH_2O$. The student collects the data shown in the following table.

Mass of empty container	22.347 g
Initial mass of sample and container	25.825 g
Mass of sample and container after first heating	23.982 g
Mass of sample and container after second heating	23.976 g
Mass of sample and container after third heating	23.977 g

(a) Explain why the student can correctly conclude that the hydrate was heated a sufficient number of times in the experiment.

(b) Use the data above to

(i) calculate the total number of moles of water lost when the sample was heated, and

(ii) determine the formula of the hydrated compound.

(c) A different student heats the hydrate in an uncovered crucible, and some of the solid spatters out of the crucible. This spattering will have what effect on the calculated mass of the water lost by the hydrate? Justify your answer.

In the second experiment, a student is given 2.94 g of a mixture containing anhydrous $MgCl_2$ and KNO_3. To determine the percentage by mass of $MgCl_2$ in the mixture, the student uses excess $AgNO_3(aq)$ to precipitate the chloride ion as $AgCl(s)$.

(d) Starting with the 2.94 g sample of the mixture dissolved in water, briefly describe the steps necessary to quantitatively determine the mass of the AgCl precipitate.

(e) The student determines the mass of the AgCl precipitate to be 5.48 g. On the basis of this information, calculate each of the following.

(i) The number of moles of $MgCl_2$ in the original mixture

(ii) The percent by mass of $MgCl_2$ in the original mixture

3. Answer the following questions related to chemical reactions involving nitrogen monoxide, $NO(g)$.

The reaction between solid copper and nitric acid to form copper(II) ion, nitrogen monoxide gas, and water is represented by the following equation.

$$3\ Cu(s) + 2\ NO_3^-(aq) + 8\ H^+(aq) \rightarrow 3\ Cu^{2+}(aq) + 2\ NO(g) + 4\ H_2O(l) \qquad E° = +0.62\ V$$

(a) Using the information above and in the table below, calculate the standard reduction potential, $E°$, for the reduction of NO_3^- in acidic solution.

Half-Reaction	Standard Reduction Potential, $E°$
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.34 V
$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$	?

(b) Calculate the value of the standard free energy change, $\Delta G°$, for the overall reaction between solid copper and nitric acid.

(c) Predict whether the value of the standard entropy change, $\Delta S°$, for the overall reaction is greater than 0, less than 0, or equal to 0. Justify your prediction.

Nitrogen monoxide gas, a product of the reaction above, can react with oxygen to produce nitrogen dioxide gas, as represented below.

$$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$$

A rate study of the reaction yielded the data recorded in the table below.

Experiment	Initial Concentration of NO (mol L^{-1})	Initial Concentration of O_2 (mol L^{-1})	Initial Rate of Formation of NO_2 (mol $L^{-1}\ s^{-1}$)
1	0.0200	0.0300	8.52×10^{-2}
2	0.0200	0.0900	2.56×10^{-1}
3	0.0600	0.0300	7.67×10^{-1}

(d) Determine the order of the reaction with respect to each of the following reactants. Give details of your reasoning, clearly explaining or showing how you arrived at your answers.

(i) NO

(ii) O_2

(e) Write the expression for the rate law for the reaction as determined from the experimental data.

(f) Determine the value of the rate constant for the reaction, clearly indicating the units.

STOP

If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.

CHEMISTRY
Part B
Time—40 minutes
NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$Mg + 2\,Ag^{+} \longrightarrow Mg^{2+} + 2\,Ag$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Aqueous sodium hydroxide is added to a saturated solution of aluminum hydroxide, forming a complex ion.

(i) Balanced equation:

(ii) If the resulting mixture is acidified, would the concentration of the complex ion increase, decrease, or remain the same? Explain.

(b) Hydrogen chloride gas is oxidized by oxygen gas.

(i) Balanced equation:

(ii) If three moles of hydrogen chloride gas and three moles of oxygen gas react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

(c) Solid potassium oxide is added to water.

(i) Balanced equation:

(ii) If a few drops of phenolphthalein are added to the resulting solution, what would be observed? Explain.

YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE GRADED.

Section II

Part B

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. Using principles of atomic and molecular structure and the information in the table below, answer the following questions about atomic fluorine, oxygen, and xenon, as well as some of their compounds.

Atom	First Ionization Energy (kJ mol^{-1})
F	1,681.0
O	1,313.9
Xe	?

(a) Write the equation for the ionization of atomic fluorine that requires 1,681.0 kJ mol^{-1}.

(b) Account for the fact that the first ionization energy of atomic fluorine is greater than that of atomic oxygen. (You must discuss both atoms in your response.)

(c) Predict whether the first ionization energy of atomic xenon is greater than, less than, or equal to the first ionization energy of atomic fluorine. Justify your prediction.

(d) Xenon can react with oxygen and fluorine to form compounds such as XeO_3 and XeF_4. In the boxes provided, draw the complete Lewis electron-dot diagram for each of the molecules represented below.

XeO_3

XeF_4

(e) On the basis of the Lewis electron-dot diagrams you drew for part (d), predict the following:

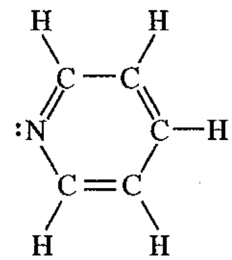
(i) The geometric shape of the XeO_3 molecule

(ii) The hybridization of the valence orbitals of xenon in XeF_4

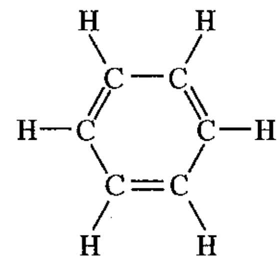
(f) Predict whether the XeO_3 molecule is polar or nonpolar. Justify your prediction.

6. Answer the following questions by using principles of molecular structure and intermolecular forces.

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.

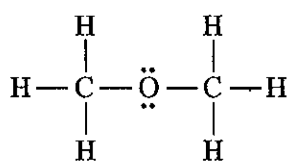


Pyridine

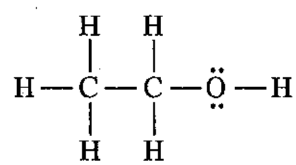


Benzene

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

STOP

END OF EXAM

IF YOU FINISH PART B OF SECTION II BEFORE TIME IS CALLED, YOU MAY RETURN TO PART A OF SECTION II IF YOU WISH, BUT YOU MAY NOT USE A CALCULATOR.