AP Chemistry Summer Assignments

There is considerable breadth and depth in the AP chemistry course – yet our time frame (early September to early May) is relatively condensed. Therefore, I strongly suggest completing the following work over the summer prior to our first day of AP Chemistry next year.

#1 – Complete/understand chapters 1,2,3,4,19 in your Zumdahl text.
These chapters are a mostly a review of honors chemistry, but it is important you bring a working knowledge of this content to the first day of class. Andy Allan's website (www.sciencegeek.net/APchemistry/index.shtml) can be of great assistance. I suggest doing the following with each chapter.

- Read/study the chapter (including all sample exercises) in text.
- Copy (and study) the "notes" for each chapter from Mr. Allan's website. These "notes" provide a summary of key ideas for each chapter.
- Complete "interactive practice exercises" for each section as needed. ("Interactive practice exercises" are also on Mr. Allan's website.)
- Complete "interactive review exercises" for each chapter. Study/repeat "interactive review exercises" until you are at least 85% (preferably 90%) accurate. (Yes, "interactive review exercises" are also on Mr. Allan's website.)
- Nuclear Chemistry chapter is interesting and important --- but not a big part of AP exam.

Mr. Allan's website is based on the Zumdahl text – however, it's an older version of the Zumdahl text. Content is very similar (if not identical) for most parts. There are occasional added, dropped, or reordered sections / chapters. (i.e. - nuclear chem is chap 19 in our text and chap 18 on science geek)

#2 – Memorize formulas, charges and names of common ions (yellow sheets)
On the first day of the school year, you will be given a **quiz** on these ions. You will be asked to:
• write the names of these ions when given the formula and charge
• write the formula and charge when given the names
Attached is a list of the ions that you must know on the first day. This list also has, on the back, some suggestions for making the process of memorization easier. For instance, many of you will remember that most of the monatomic ions have charges that are directly related to their placement on the periodic table. There are naming patterns that greatly simplify the learning of the polyatomic ions as well. Attached is a sheet of flashcards for the polyatomic ions that you must learn. I suggest that you cut them out and begin memorizing them immediately. Use the hints on the common ions sheet to help you reduce the amount of memorizing that you must do. Do not let the fact that there are no flashcards for monatomic ions suggest to you that the monatomic ions are not important. They are every bit as important as the polyatomic ions. If you have trouble identifying the charge of monatomic ions (or the naming system) then I suggest that you make yourself some flashcards for those as well. Use every modality possible as you try to learn these – speak them, write them, visualize them. There are some fun "concentration" games for learning these in Mr. Allan's practice exercises for chapter 2.

#3 – Complete the Practice Exam
60 multiple choice and 7 free response
Do your best at answering these questions. (I wouldn't be concerned about time constraints at this point.) Then look at the answer keys for each section. Study the rationale for each multiple choice and free response answer.
Don't panic if you can't answer many of the questions yet. However, realize there is a great deal of work ahead of you – so get started.

Information from College Board

I suggest going on-line (Google college board AP chemistry) to learn more about the AP Chemistry exam
--- exam format, length of each exam section, content tested in each section, percent breakdown of content by topic , calculator use, sample problems, etc.
--- access to past AP Chemistry exams
(FYI - Current 60 MC and 7 FR format began with the 2014 exam. It was 75 MC and 6 FR prior to 2014)
AP Chemistry Exam 2016 is most likely scheduled for Monday, May 2 at 7:30 a.m.

Textbooks

You will be issued a textbook to use over the summer. Texts are 4 years old --- keep them in good condition. Texts are bar coded --- you are responsible for this ~$150 learning aid. Currently, we have a very small excess of texts compared to number of students enrolled. However, this could easily change --- making texts the limiting reagent in the student / textbook equation. If you decide over the summer that AP Chemistry is not for you at this time --- please return your text. I may ask you to share a book with a book buddy.

Buddy System

Collaborate on what you are learning with a buddy. If pairing works well for electrons, it may work for you as well. And the Pauli Exclusion Principle does not need to be applied here --- study groups of more than 2 are welcome and encouraged.

Topics (Zumdahl Chapter) - Tentative Schedule

Chemical Foundations (1) – Sept
Atomic Structure (2) / Nuclear (19) – Sept
Stoichiometry (3) – Sept
Chemical Reactions (4) –Sept
Gases (5) – Sept/Oct
Thermodynamics (6) - Oct
Atomic Structure / Periodicity (7) – Oct
Bonding (8,9) – Oct/Nov
Organic (22) - Nov
Liquids and Solids (10) – Nov
Solutions (11) – Nov/Dec
Kinetics (12) – Dec
Equilibrium (13,16) – Dec/Jan
Acids and Bases (14,15) - Feb
Thermo – Free Energy (17) - Mar
Electrochemistry (18) - Mar
Review – Apr/May
AP Exam – Monday, May 4th
Lab/Project Emphasis – May/June

Moodle Site

My moodle site for AP Chemistry 2014-15 is available to you. Although there will be changes in 2015-16, it will provide you with a good look at the fundamental structure of the course.
Access this site at http://learn.district196.org . Choose High School /Eastview / AP Chemistry. (Currently it's an open site – anyone may log in as a guest.)

Last Words

I look forward to seeing you at the beginning of the next school year. Please send me an e-mail if you need to contact me during the summer. (Usually I will check my school e-mail at least one time each week during the summer.)
Happy studying,
Mr. Meyer
steve.meyer@district196.org

Common Ions and Their Charges

A mastery of the common ions, their formulas and their charges, is essential to success in AP Chemistry. You are expected to know all of these ions on the first day of class, when I will give you a quiz on them. You will always be allowed a periodic table, which makes indentifying the ions on the left "automatic." For tips on learning these ions, see the opposite side of this page.

From the table:	
Cations	**Name**
H^+	Hydrogen
Li^+	Lithium
Na^+	Sodium
K^+	Potassium
Rb^+	Rubidium
Cs^+	Cesium
Be^{2+}	Beryllium
Mg^{2+}	Magnesium
Ca^{2+}	Calcium
Ba^{2+}	Barium
Sr^{2+}	Strontium
Al^{3+}	Aluminum
Anions	**Name**
H^-	Hydride
F^-	Fluoride
Cl^-	Chloride
Br^-	Bromide
I^-	Iodide
O^{2-}	Oxide
S^{2-}	Sulfide
Se^{2-}	Selenide
N^{3-}	Nitride
P^{3-}	Phosphide
As^{3-}	Arsenide
Type II Cations	**Name**
Fe^{3+}	Iron(III)
Fe^{2+}	Iron(II)
Cu^{2+}	Copper(II)
Cu^+	Copper(I)
Co^{3+}	Cobalt(III)
Co^{2+}	Cobalt(II)
Sn^{4+}	Tin(IV)
Sn^{2+}	Tin(II)
Pb^{4+}	Lead(IV)
Pb^{2+}	Lead(II)
Hg^{2+}	Mercury(II)

Ions to Memorize	
Cations	**Name**
Ag^+	Silver
Zn^{2+}	Zinc
Hg_2^{2+}	Mercury(I)
NH_4^+	Ammonium
Anions	**Name**
NO_2^-	Nitrite
NO_3^-	Nitrate
SO_3^{2-}	Sulfite
SO_4^{2-}	Sulfate
HSO_4^-	Hydrogen sulfate (bisulfate)
OH^-	Hydroxide
CN^-	Cyanide
PO_4^{3-}	Phosphate
HPO_4^{2-}	Hydrogen phosphate
$H_2PO_4^-$	Dihydrogen phosphate
NCS^-	Thiocyanate
CO_3^{2-}	Carbonate
HCO_3^-	Hydrogen carbonate (bicarbonate)
ClO^-	Hypochlorite
ClO_2^-	Chlorite
ClO_3^-	Chlorate
ClO_4^-	Perchlorate
BrO^-	Hypobromite
BrO_2^-	Bromite
BrO_3^-	Bromate
BrO_4^-	Perbromate
IO^-	Hypoiodite
IO_2^-	iodite
IO_3^-	iodate
IO_4^-	Periodate
$C_2H_3O_2^-$	Acetate
MnO_4^-	Permanganate
$Cr_2O_7^{2-}$	Dichromate
CrO_4^{2-}	Chromate
O_2^{2-}	Peroxide
$C_2O_4^{2-}$	Oxalate
NH_2^-	Amide
BO_3^{3-}	Borate
$S_2O_3^{2-}$	Thiosulfate

Tips for Learning the Ions

"From the Table"

These are ions can be organized into two groups.

1. Their place on the table suggests the charge on the ion, since the neutral atom gains or loses a predictable number of electrons in order to obtain a noble gas configuration. This was a focus in first year chemistry, so if you are unsure what this means, get help BEFORE the start of the year.
   a. All Group 1 Elements (alkali metals) lose one electron to form an ion with a 1+ charge
   b. All Group 2 Elements (alkaline earth metals) lose two electrons to form an ion with a 2+ charge
   c. Group 13 metals like aluminum lose three electrons to form an ion with a 3+ charge
   d. All Group 17 Elements (halogens) gain one electron to form an ion with a 1- charge
   e. All Group 16 nonmetals gain two electrons to form an ion with a 2- charge
   f. All Group 15 nonmetals gain three electrons to form an ion with a 3- charge

   Notice that cations keep their name (sodium ion, calcium ion) while anions get an "-ide" ending (chloride ion, oxide ion).

2. Metals that can form more than one ion will have their positive charge denoted by a roman numeral in parenthesis immediately next to the name of the

Polyatomic Anions

Most of the work on memorization occurs with these ions, but there are a number of patterns that can greatly reduce the amount of memorizing that one must do.

1. "ate" anions have one more oxygen then the "ite" ion, but the same charge. If you memorize the "ate" ions, then you should be able to derive the formula for the "ite" ion and vice-versa.
   a. sulfate is SO_4^{2-}, so sulfite has the same charge but one less oxygen (SO_3^{2-})
   b. nitrate is NO_3^-, so nitrite has the same charge but one less oxygen (NO_2^-)

2. If you know that a sufate ion is SO_4^{2-} then to get the formula for hydrogen sulfate ion, you add a hydrogen ion to the front of the formula. Since a hydrogen ion has a 1+ charge, the net charge on the new ion is less negative by one.
   a. Example:

PO_4^{3-}	→	HPO_4^{2-}	→	$H_2PO_4^-$
phosphate		hydrogen phosphate		dihydrogen phosphate

3. Learn the hypochlorite → chlorite → chlorate → perchlorate series, and you also know the series containing iodite/iodate as well as bromite/bromate.
   a. The relationship between the "ite" and "ate" ion is predictable, as always. Learn one and you know the other.
   b. The prefix "hypo" means "under" or "too little" (think "hypodermic", "hypothermic" or "hypoglycemia")
      i. Hypochlorite is "under" chlorite, meaning it has one less oxygen
   c. The prefix "hyper" means "above" or "too much" (think "hyperkinetic")
      i. the prefix "per" is derived from "hyper" so perchlorate (hyperchlorate) has one more oxygen than chlorate.
   d. Notice how this sequence increases in oxygen while retaining the same charge:

ClO^-	→	ClO_2^-	→	ClO_3^-	→	ClO_4^-
hypochlorite		chlorite		chlorate		perchlorate

Sulfite	Sulfate	Hydrogen sulfate
Phosphate	Dihydrogen Phosphate	Hydrogen Phosphate
Nitrite	Nitrate	Ammonium
Thiocyanate	Carbonate	Hydrogen carbonate
Borate	Chromate	Dichromate
Permanganate	Oxalate	Amide
Hydroxide	Cyanide	Acetate
Peroxide	Hypochlorite	Chlorite
Chlorate	Perchlorate	Thiosulfate

HSO_4^-	SO_4^{2-}	SO_3^{2-}
HPO_4^{2-}	$H_2PO_4^-$	PO_4^{3-}
NH_4^+	NO_3^-	NO_2^-
HCO_3^-	CO_3^{2-}	NCS^- SCN^-
$Cr_2O_7^{2-}$	CrO_4^{2-}	BO_3^{3-}
NH_2^-	$C_2O_4^{2-}$	MnO_4^-
$C_2H_3O_2^-$ CH_3COO^-	CN^-	OH^-
ClO_2^-	ClO^-	O_2^{2-}
$S_2O_3^{2-}$	ClO_4^-	ClO_3^-

CHEMISTRY
Section I
60 Multiple-Choice Questions
(Time—90 minutes)
YOU MAY NOT USE YOUR CALCULATOR FOR 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.

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

1. Complete combustion of a sample of a hydrocarbon in excess oxygen produces equimolar quantities of carbon dioxide and water. Which of the following could be the molecular formula of the compound?

(A) C_2H_2
(B) C_2H_6
(C) C_4H_8
(D) C_6H_6

Substance	Equilibrium Vapor Pressure at 20°C (torr)
$C_6H_6(l)$	75
$C_2H_5OH(l)$	44
$CH_3OH(l)$	92
$C_2H_6O_2(l)$	0.06

2. Based on the data in the table above, which of the following liquid substances has the weakest intermolecular forces?

(A) $C_6H_6(l)$
(B) $C_2H_5OH(l)$
(C) $CH_3OH(l)$
(D) $C_2H_6O_2(l)$

Ion	Ionic Radius (pm)
Zn^{2+}	74
Ca^{2+}	100
Ba^{2+}	135

3. Based on the data in the table above, which of the following correctly predicts the relative strength of the attraction of Zn^{2+}, Ca^{2+}, and Ba^{2+} ions to water molecules in a solution, from strongest to weakest, and provides the correct reason?

(A) $Zn^{2+} > Ca^{2+} > Ba^{2+}$ because the smaller ions have a stronger coulombic attraction to water
(B) $Zn^{2+} > Ca^{2+} > Ba^{2+}$ because the smaller ions are more electronegative
(C) $Ba^{2+} > Ca^{2+} > Zn^{2+}$ because the larger ions are more polarizable
(D) $Ba^{2+} > Ca^{2+} > Zn^{2+}$ because the larger ions are less electronegative

4. Zn(*s*) is used to reduce other compounds in chemical reactions. If a chemist needs a substance that is more effective in its reducing ability, which of the following species would be the best choice?

(A) Na
(B) H^+
(C) K^+
(D) Cl^-

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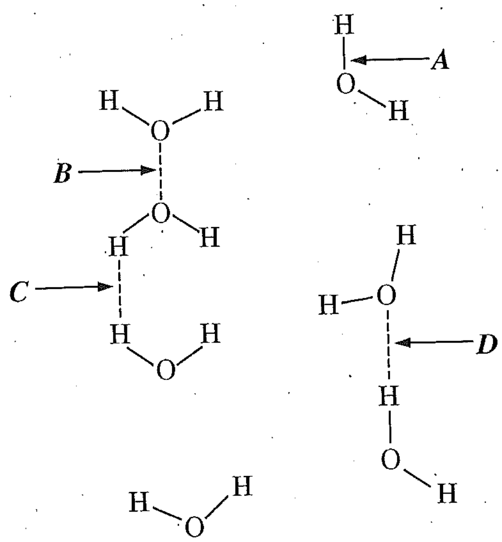

5. In the diagram above, which of the labeled arrows identifies hydrogen bonding in water?

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

6. A kinetics experiment is set up to collect the gas that is generated when a sample of chalk, consisting primarily of solid $CaCO_3$, is added to a solution of ethanoic acid, CH_3COOH. The rate of reaction between $CaCO_3$ and CH_3COOH is determined by measuring the volume of gas generated at 25°C and 1 atm as a function of time. Which of the following experimental conditions is most likely to increase the rate of gas production?

(A) Decreasing the volume of ethanoic acid solution used in the experiment
(B) Decreasing the concentration of the ethanoic acid solution used in the experiment
(C) Decreasing the temperature at which the experiment is performed
(D) Decreasing the particle size of the $CaCO_3$ by grinding it into a fine powder

$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g)$$

7. At 450°C, 2.0 moles each of $H_2(g)$, $I_2(g)$, and $HI(g)$ are combined in a 1.0 L rigid container. The value of K_c at 450°C is 50. Which of the following will occur as the system moves toward equilibrium?

(A) More $H_2(g)$ and $I_2(g)$ will form.
(B) More $HI(g)$ will form.
(C) The total pressure will decrease.
(D) No net reaction will occur, because the number of molecules is the same on both sides of the equation.

Practice Exam

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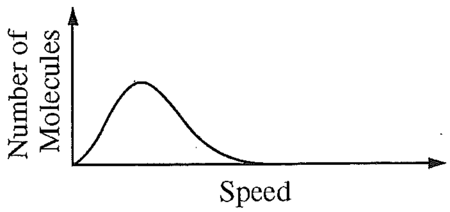
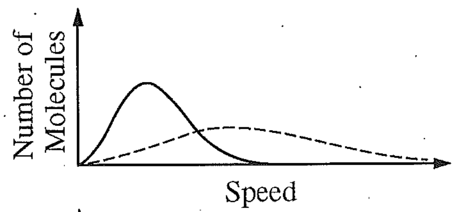
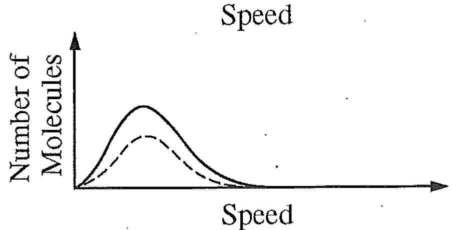
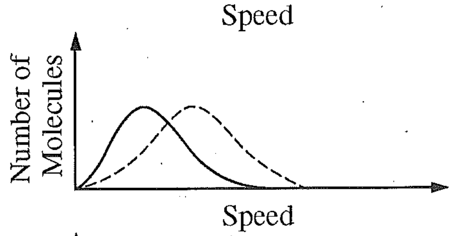
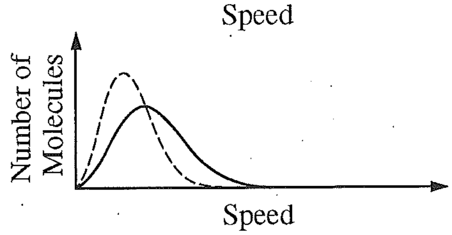


8. The graph above shows the speed distribution of molecules in a sample of a gas at a certain temperature. Which of the following graphs shows the speed distribution of the same molecules at a lower temperature (as a dashed curve) ?

(A) 

(B) 

(C) 

(D) 

9. A 100 g sample of a metal was heated to 100°C and then quickly transferred to an insulated container holding 100 g of water at 22°C. The temperature of the water rose to reach a final temperature of 35°C. Which of the following can be concluded?

(A) The metal temperature changed more than the water temperature did; therefore the metal lost more thermal energy than the water gained.
(B) The metal temperature changed more than the water temperature did, but the metal lost the same amount of thermal energy as the water gained.
(C) The metal temperature changed more than the water temperature did; therefore the heat capacity of the metal must be greater than the heat capacity of the water.
(D) The final temperature is less than the average starting temperature of the metal and the water; therefore the total energy of the metal and water decreased.

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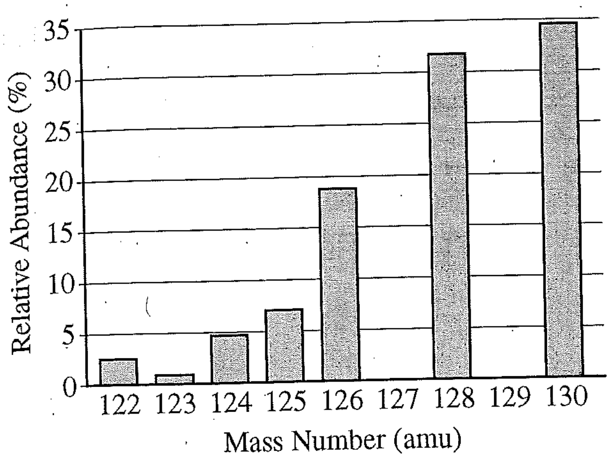

10. The elements I and Te have similar average atomic masses. A sample that was believed to be a mixture of I and Te was run through a mass spectrometer, resulting in the data above. All of the following statements are true. Which one would be the best basis for concluding that the sample was pure Te?

(A) Te forms ions with a −2 charge, whereas I forms ions with a −1 charge.
(B) Te is more abundant than I in the universe.
(C) I consists of only one naturally occurring isotope with 74 neutrons, whereas Te has more than one isotope.
(D) I has a higher first ionization energy than Te does.

$$H_2C_2O_4(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + HC_2O_4^-(aq)$$
$$HC_2O_4^-(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_2O_4^{2-}(aq)$$
$$H_2O(l) + H_2O(l) \rightleftarrows H_3O^+(aq) + OH^-(aq)$$

11. All the reactions represented above occur in an aqueous solution of oxalic acid. Which of the following represent a Brønsted-Lowry conjugate acid-base pair?

(A) $H_2C_2O_4(aq)$ and $C_2O_4^{2-}(aq)$
(B) $HC_2O_4^-(aq)$ and $C_2O_4^{2-}(aq)$
(C) $HC_2O_4^-(aq)$ and $H_2O(aq)$
(D) $H_3O^+(aq)$ and $OH^-(aq)$

Practice Exam

GO ON TO THE NEXT PAGE.

12. Which of the following reactions is not thermodynamically favored at low temperatures but becomes favored as the temperature increases?

	Reaction	$\Delta H°$ (kJ/mol$_{rxn}$)	$\Delta S°$ (J/(mol$_{rxn}$·K))
(A)	$2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$	−566	−173
(B)	$2\ H_2O(g) \rightarrow 2\ H_2(g) + O_2(g)$	484	90.0
(C)	$2\ N_2O(g) \rightarrow 2\ N_2(g) + O_2(g)$	−164	149
(D)	$PbCl_2(s) \rightarrow Pb^{2+}(aq) + 2\ Cl^{-}(aq)$	23.4	−12.5

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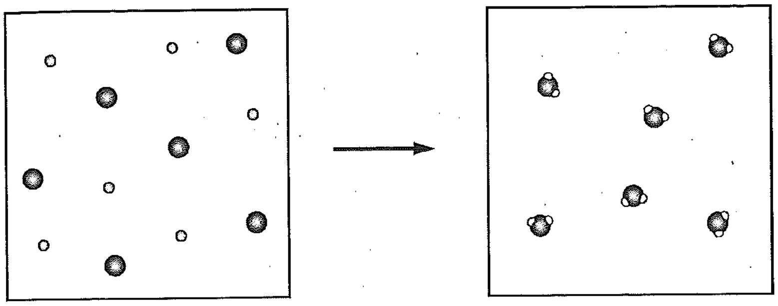
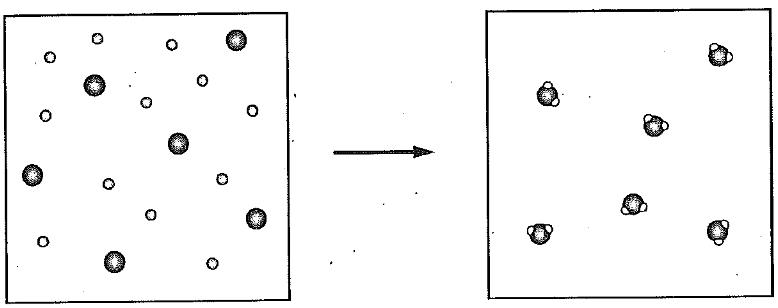
13. Which of the following particulate diagrams best shows the formation of water vapor from hydrogen gas and oxygen gas in a rigid container at 125°C ?

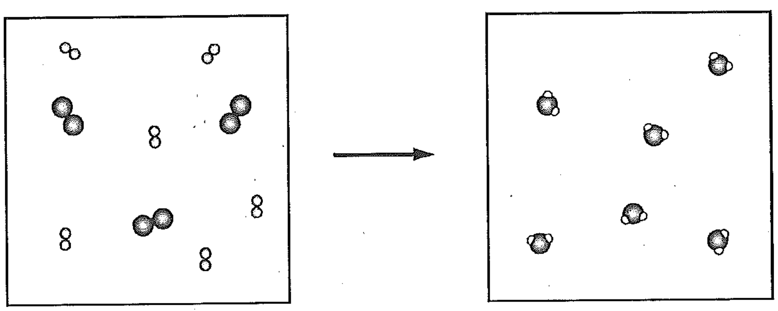
(A)



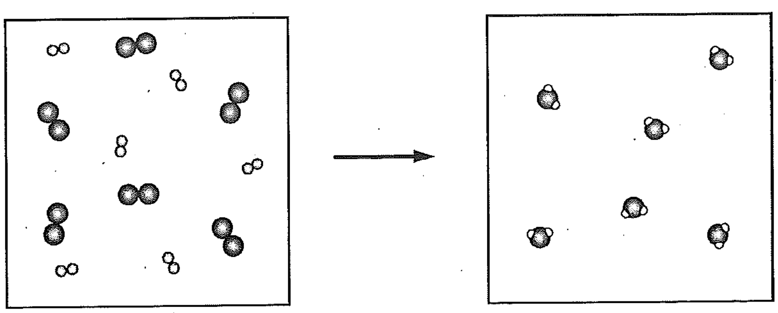
(B)



(C)



(D)



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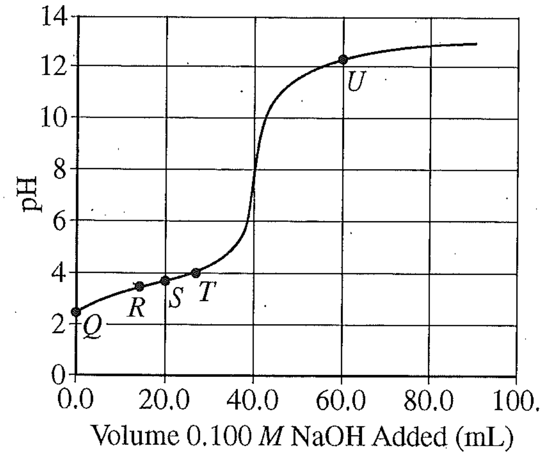
Questions 14-17 refer to the following.

pH VERSUS VOLUME TITRANT ADDED



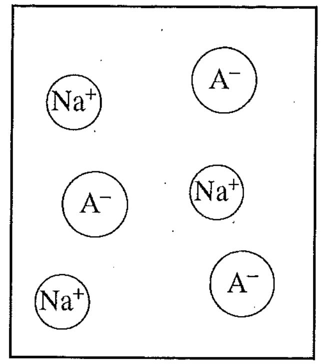
A 50.0 mL sample of an acid, HA, of unknown molarity is titrated, and the pH of the resulting solution is measured with a pH meter and graphed as a function of the volume of 0.100 *M* NaOH added.

14. At point *R* in the titration, which of the following species has the highest concentration?

(A) HA
(B) A^-
(C) H_3O^+
(D) OH^-

15. Which of the following is the best particulate representation of the species (other than H_2O) that are present in significant concentrations in the solution at point *U* in the titration?

(A)



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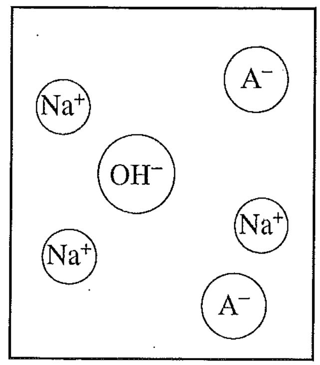
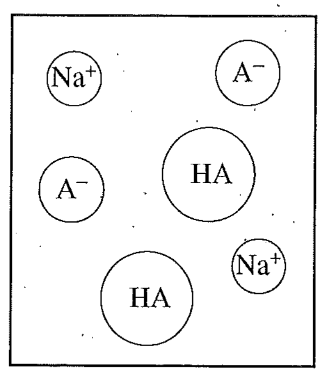
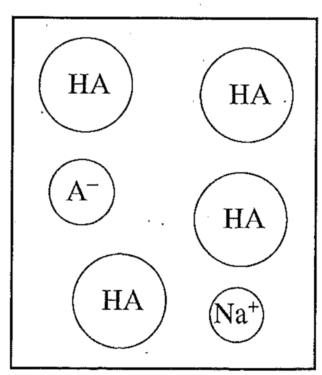


(C)



(D)



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16. At which point on the titration curve is $[A^-]$ closest to twice that of [HA] ?

(A) *R*
(B) *S*
(C) *T*
(D) *U*

17. A student carries out the same titration, but uses an indicator instead of a pH meter. If the indicator changes color slightly past the equivalence point, what will the student obtain for the calculated concentration of the acid?

(A) Slightly less than 0.0800 *M*
(B) Slightly more than 0.0800 *M*
(C) Slightly less than 0.125 *M*
(D) Slightly more than 0.125 *M*

Practice Exam

GO ON TO THE NEXT PAGE.

Questions 18-20 refer to three gases in identical rigid containers under the conditions given in the table below.

Container	A	B	C
Gas	Methane	Ethane	Butane
Formula	CH_4	C_2H_6	C_4H_{10}
Molar mass (g/mol)	16	30.	58
Temperature (°C)	27	27	27
Pressure (atm)	2.0	4.0	2.0

18. The average kinetic energy of the gas molecules is

(A) greatest in container A
(B) greatest in container B
(C) greatest in container C
(D) the same in all three containers

19. The density of the gas, in g/L, is

(A) greatest in container A
(B) greatest in container B
(C) greatest in container C
(D) the same in all three containers

20. If the pressure of each gas is increased at constant temperature until condensation occurs, which gas will condense at the lowest pressure?

(A) Methane
(B) Ethane
(C) Butane
(D) All the gases will condense at the same pressure.

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21. The mass percent of carbon in pure glucose, $C_6H_{12}O_6$, is 40.0 percent. A chemist analyzes an impure sample of glucose and determines that the mass percent of carbon is 38.2 percent. Which of the following impurities could account for the low mass percent of carbon in the sample?

(A) Water, H_2O
(B) Ribose, $C_5H_{10}O_5$
(C) Fructose, $C_6H_{12}O_6$, an isomer of glucose
(D) Sucrose, $C_{12}H_{22}O_{11}$

22. Caffeine ($C_8H_{10}N_4O_2$) is a weak base with a K_b value of 4×10^{-4}. The pH of a 0.01 M solution of caffeine is in the range of

(A) 2–3
(B) 5–6
(C) 7–8
(D) 11–12

23. Lewis electron-dot diagrams for CO_2 and SO_2 are given above. The molecular geometry and polarity of the two substances are

(A) the same because the molecular formulas are similar
(B) the same because C and S have similar electronegativity values
(C) different because the lone pair of electrons on the S atom make it the negative end of a dipole
(D) different because S has a greater number of electron domains (regions of electron density) surrounding it than C has

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

24. Consider the following mechanism for the reaction represented above.

Step 1: $2\,NO \rightleftarrows N_2O_2$ (*fast reversible*)

Step 2: $N_2O_2 + O_2 \rightarrow 2\,NO_2$ (*slow*)

Which of the following statements is true?

(A) Step 1 represents a unimolecular reaction.
(B) Increasing the concentration of NO will decrease the overall rate of the reaction.
(C) Raising the temperature will have no effect on the numerical value of the rate constant.
(D) The rate law that is consistent with the mechanism is $rate = k[NO]^2[O_2]$.

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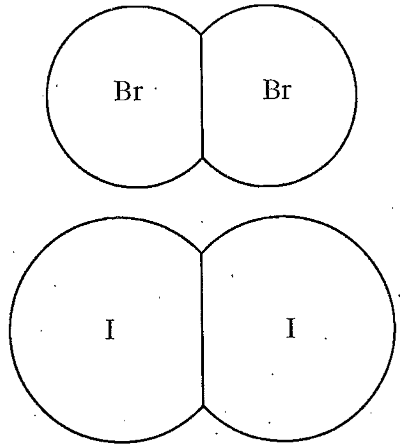


25. The diagram above shows molecules of Br_2 and I_2 drawn to the same scale. Which of the following is the best explanation for the difference in the boiling points of liquid Br_2 and I_2, which are 59°C and 184°C, respectively?

(A) Solid iodine is a network covalent solid, whereas solid bromine is a molecular solid.

(B) The covalent bonds in I_2 molecules are weaker than those in Br_2 molecules.

(C) I_2 molecules have electron clouds that are more polarizable than those of Br_2 molecules, thus London dispersion forces are stronger in liquid I_2.

(D) Bromine has a greater electronegativity than iodine, thus there are stronger dipole-dipole forces in liquid bromine than in liquid iodine.

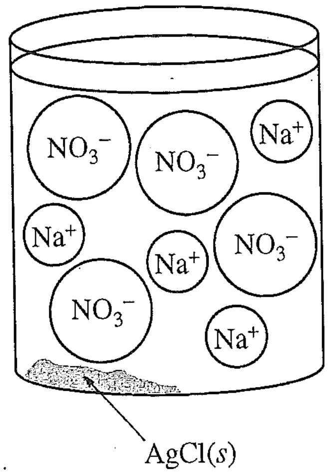
Practice Exam

GO ON TO THE NEXT PAGE.

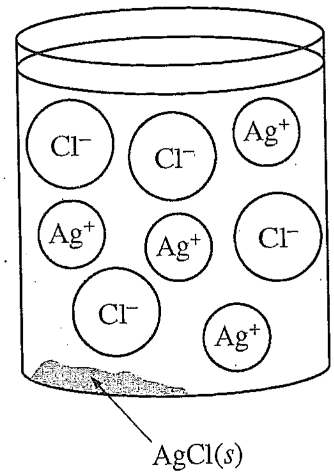
$$Ag^{+}(aq) + Cl^{-}(aq) \rightleftarrows AgCl(s)$$

28. A student mixes dilute $AgNO_3(aq)$ with excess $NaCl(aq)$ to form $AgCl(s)$, as represented by the net ionic equation above. Which of the diagrams below best represents the ions that are present in significant concentrations in the solution? (K_{sp} for AgCl is 1.8×10^{-10}.)

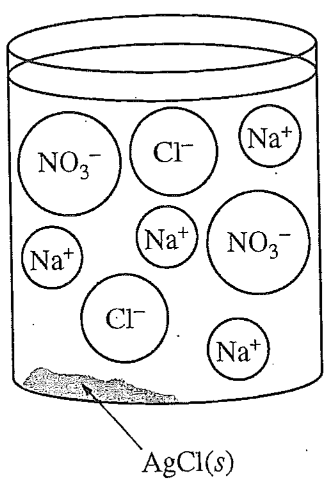
(A)



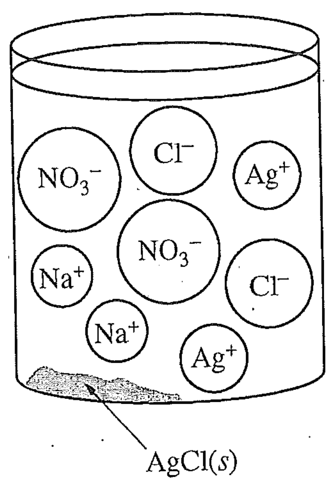
(B)

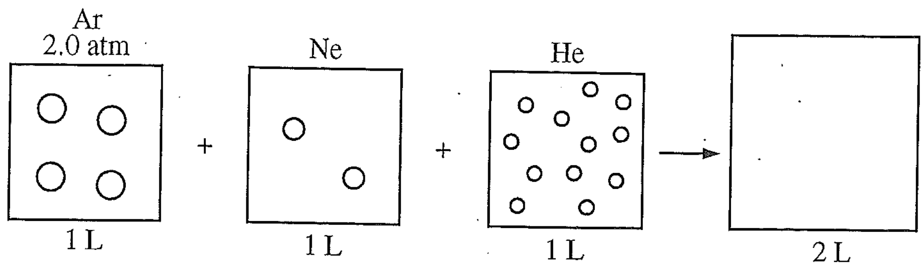


(C)



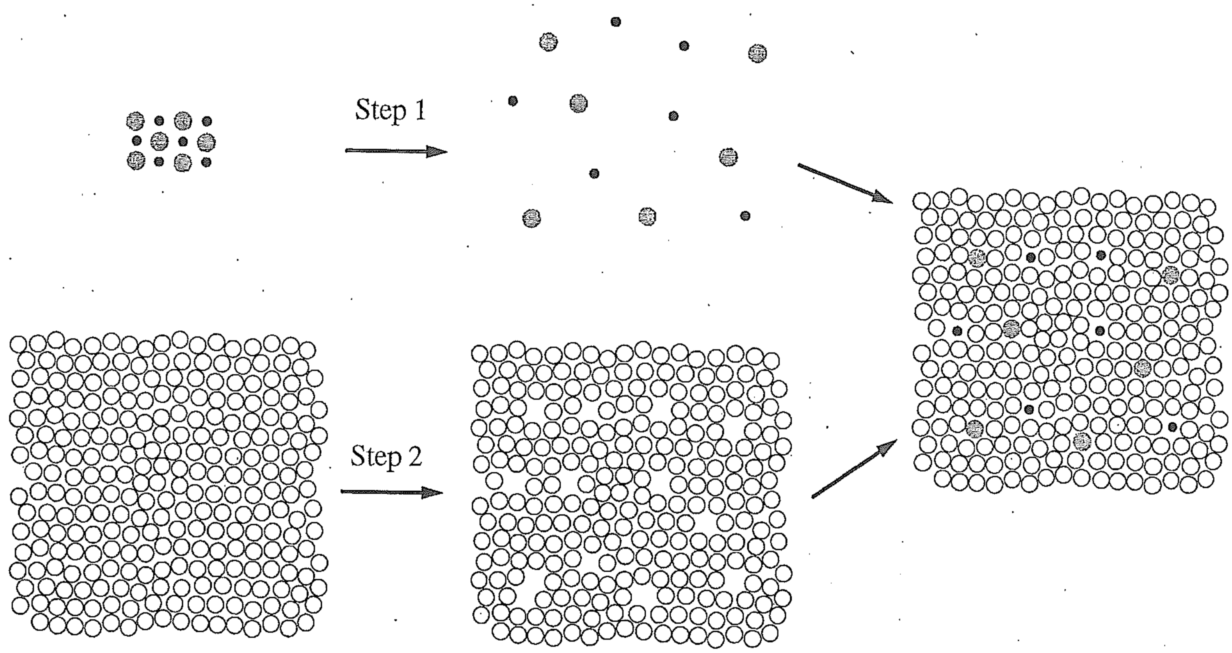
(D)





26. The figure above represents three sealed 1.0 L vessels, each containing a different inert gas at 298 K. The pressure of Ar in the first vessel is 2.0 atm. The ratio of the numbers of Ar, Ne, and He atoms in the vessels is 2:1:6, respectively. After all the gases are combined in a previously evacuated 2.0 L vessel, what is the total pressure of the gases at 298 K?

(A) 3.0 atm
(B) 4.5 atm
(C) 9.0 atm
(D) 18 atm



27. The dissolution of an ionic solute in a polar solvent can be imagined as occurring in three steps, as shown in the figure above. In step 1, the separation between ions in the solute is greatly increased, just as will occur when the solute dissolves in the polar solvent. In step 2, the polar solvent is expanded to make spaces that the ions will occupy. In the last step, the ions are inserted into the spaces in the polar solvent. Which of the following best describes the enthalpy change, ΔH, for each step?

(A) All three steps are exothermic.
(B) All three steps are endothermic.
(C) Steps 1 and 2 are exothermic, and the final step is endothermic.
(D) Steps 1 and 2 are endothermic, and the final step is exothermic.

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Questions 29-33 refer to the following.

$$PCl_5(g) \rightleftarrows PCl_3(g) + Cl_2(g)$$

$PCl_5(g)$ decomposes into $PCl_3(g)$ and $Cl_2(g)$ according to the equation above. A pure sample of $PCl_5(g)$ is placed in a rigid, evacuated 1.00 L container. The initial pressure of the $PCl_5(g)$ is 1.00 atm. The temperature is held constant until the $PCl_5(g)$ reaches equilibrium with its decomposition products. The figures below show the initial and equilibrium conditions of the system.

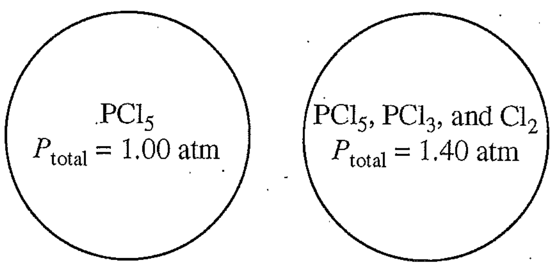

Figure 1: Initial Figure 2: Equilibrium

29. Which of the following is the most likely cause for the increase in pressure observed in the container as the reaction reaches equilibrium?

(A) A decrease in the strength of intermolecular attractions among molecules in the flask
(B) An increase in the strength of intermolecular attractions among molecules in the flask
(C) An increase in the number of molecules, which increases the frequency of collisions with the walls of the container
(D) An increase in the speed of the molecules that then collide with the walls of the container with greater force

30. As the reaction progresses toward equilibrium, the rate of the forward reaction

(A) increases until it becomes the same as the reverse reaction rate at equilibrium
(B) stays constant before and after equilibrium is reached
(C) decreases to become a constant nonzero rate at equilibrium
(D) decreases to become zero at equilibrium

31. If the decomposition reaction were to go to completion, the total pressure in the container would be

(A) 1.4 atm
(B) 2.0 atm
(C) 2.8 atm
(D) 3.0 atm

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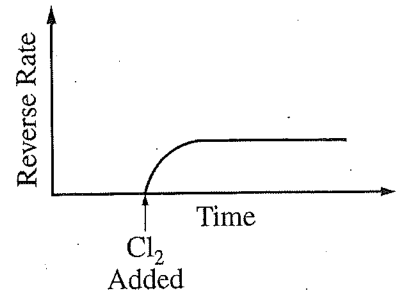
32. Which of the following statements about K_p, the equilibrium constant for the reaction, is correct?

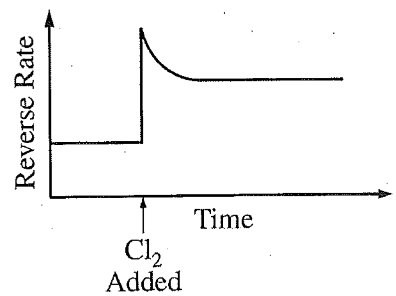
(A) $K_p > 1$
(B) $K_p < 1$
(C) $K_p = 1$
(D) It cannot be determined whether $K_p > 1$, $K_p < 1$, or $K_p = 1$ without additional information.

33. Additional $Cl_2(g)$ is injected into the system at equilibrium. Which of the following graphs best shows the rate of the reverse reaction as a function of time? (Assume that the time for injection and mixing of the additional $Cl_2(g)$ is negligible.)

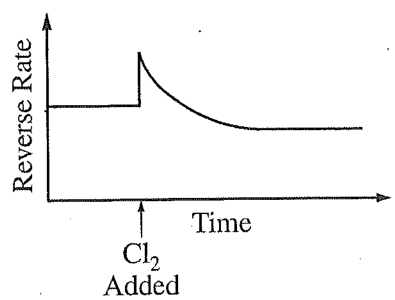
(A)



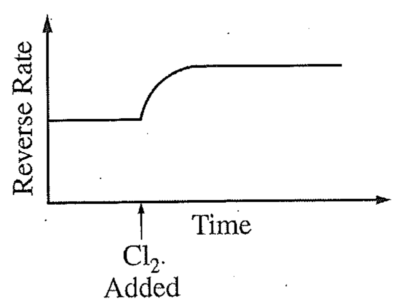
(B)



(C)



(D)



Questions 34-38

$$K(s) + \frac{1}{2} Cl_2(g) \rightarrow KCl(s) \qquad \Delta H° = -437 \text{ kJ/mol}_{rxn}$$

The elements K and Cl react directly to form the compound KCl according to the equation above. Refer to the information above and the table below to answer the questions that follow.

Process	$\Delta H°$ (kJ/mol_{rxn})
$K(s) \rightarrow K(g)$	v
$K(g) \rightarrow K^+(g) + e^-$	w
$Cl_2(g) \rightarrow 2\ Cl(g)$	x
$Cl(g) + e^- \rightarrow Cl^-(g)$	y
$K^+(g) + Cl^-(g) \rightarrow KCl(s)$	z

34. How much heat is released or absorbed when 0.050 mol of $Cl_2(g)$ is formed from $KCl(s)$?

(A) 87.4 kJ is released
(B) 43.7 kJ is released
(C) 43.7 kJ is absorbed
(D) 87.4 kJ is absorbed

35. What remains in the reaction vessel after equal masses of $K(s)$ and $Cl_2(g)$ have reacted until either one or both of the reactants have been completely consumed?

(A) KCl only
(B) KCl and K only
(C) KCl and Cl_2 only
(D) KCl, K, and Cl_2

36. Which of the values of $\Delta H°$ for a process in the table is (are) less than zero (i.e., indicate(s) an exothermic process) ?

(A) z only
(B) y and z only
(C) x, y, and z only
(D) w, x, y, and z

37. It is observed that the reaction producing KCl from its elements goes essentially to completion. Which of the following is a true statement about the thermodynamic favorability of the reaction?

(A) The reaction is favorable and driven by an enthalpy change only.
(B) The reaction is unfavorable and driven by an entropy change only.
(C) The reaction is favorable and driven by both enthalpy and entropy changes.
(D) The reaction is unfavorable due to both enthalpy and entropy changes.

$$Cl_2(g) + 2\,e^- \rightarrow 2\,Cl^-(g)$$

38. Which of the following expressions is equivalent to $\Delta H°$ for the reaction represented above?

(A) $x + y$

(B) $x - y$

(C) $x + 2y$

(D) $\frac{x}{2} - y$

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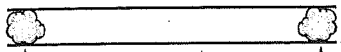

39. The experimental apparatus represented above is used to demonstrate the rates at which gases diffuse. When the cotton balls are placed in the ends of a tube at the same time, the gases diffuse from each end and meet somewhere in between, where they react to form a white solid. Which of the following combinations will produce a solid closest to the center of the tube?

(A) HCl and CH_3NH_2

(B) HCl and NH_3

(C) HBr and CH_3NH_2

(D) HBr and NH_3

40. Silicon crystals are semiconductors. Which of the following is a correct reason for the increase in the conductivity of Si crystals when a small fraction of Si atoms are replaced with those of a different element?

(A) P atoms introduce additional mobile negative charges.
(B) P atoms introduce additional mobile positive charges.
(C) Ge atoms have more electrons than Si atoms have.
(D) Ge atoms are much smaller than Si atoms.

41. N_2 molecules absorb ultraviolet light but not visible light. I_2 molecules absorb both visible and ultraviolet light. Which of the following statements explains the observations?

(A) More energy is required to make N_2 molecules vibrate than is required to make I_2 molecules vibrate.
(B) More energy is required to remove an electron from an I_2 molecule than is required to remove an electron from a N_2 molecule.
(C) Visible light does not produce transitions between electronic energy levels in the N_2 molecule but does produce transitions in the I_2 molecule.
(D) The molecular mass of I_2 is greater than the molecular mass of N_2.

Element	Metallic Radius (pm)	Melting Point (°C)	Common Oxidation State
Au	144	1064	1+, 3+
Cu	128	1085	1+, 2+
Ag	144	961	1+

42. To make Au stronger and harder, it is often alloyed with other metals, such as Cu and Ag. Consider two alloys, one of Au and Cu and one of Au and Ag, each with the same mole fraction of Au. If the Au/Cu alloy is harder than the Au/Ag alloy, then which of the following is the best explanation based on the information in the table above?

(A) Cu has two common oxidation states, but Ag has only one.
(B) Cu has a higher melting point than Au has, but Ag has a lower melting point than Au has.
(C) Cu atoms are smaller than Ag atoms, thus they interfere more with the displacement of atoms in the alloy.
(D) Cu atoms are less polarizable than are Au or Ag atoms, thus Cu has weaker interparticle forces.

Practice Exam

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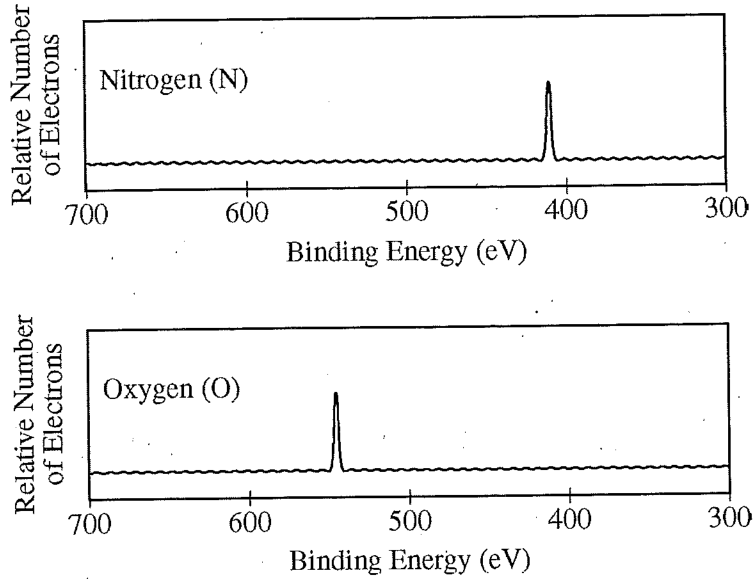

43. The photoelectron spectra above show the energy required to remove a 1*s* electron from a nitrogen atom and from an oxygen atom. Which of the following statements best accounts for the peak in the upper spectrum being to the right of the peak in the lower spectrum?

(A) Nitrogen atoms have a half-filled *p* subshell.
(B) There are more electron-electron repulsions in oxygen atoms than in nitrogen atoms.
(C) Electrons in the *p* subshell of oxygen atoms provide more shielding than electrons in the *p* subshell of nitrogen atoms.
(D) Nitrogen atoms have a smaller nuclear charge than oxygen atoms.

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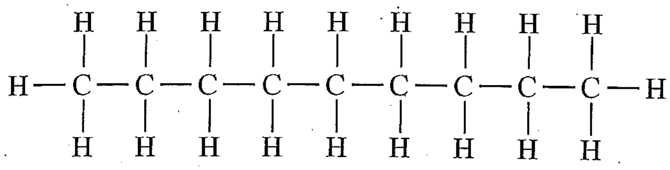
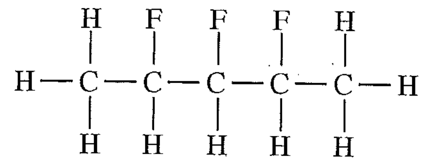


Nonane



2,3,4-trifluoropentane

44. Consider the molecules represented above and the data in the table below.

Compound	Molecular Formula	Molar Mass (g/mol)	Boiling Point (°C)
Nonane	C_9H_{20}	128	151
2,3,4-trifluoropentane	$C_5H_9F_3$	126	89

Nonane and 2,3,4-trifluoropentane have almost identical molar masses, but nonane has a significantly higher boiling point. Which of the following statements best helps explain this observation?

(A) The C–F bond is easier to break than the C–H bond.
(B) The C–F bond is more polar than the C–H bond.
(C) The carbon chains are longer in nonane than they are in 2,3,4-trifluoropentane.
(D) The carbon chains are farther apart in a sample of nonane than they are in 2,3,4-trifluoropentane.

Questions 45-47 refer to galvanic cells made from different combinations of the three half-cells described below.

Half-cell 1: strip of Al(*s*) in 1.00 *M* $Al(NO_3)_3(aq)$
Half-cell 2: strip of Cu(*s*) in 1.00 *M* $Cu(NO_3)_2(aq)$
Half-cell 3: strip of Fe(*s*) in 1.00 *M* $Fe(NO_3)_2(aq)$

Galvanic Cell	Half-cells	Cell Reaction	E°_{cell} (V)
X	1 and 2	$2\ Al(s) + 3\ Cu^{2+}(aq) \rightarrow 2\ Al^{3+}(aq) + 3\ Cu(s)$	2.00
Y	1 and 3	$2\ Al(s) + 3\ Fe^{2+}(aq) \rightarrow 2\ Al^{3+}(aq) + 3\ Fe(s)$	1.22
Z	2 and 3	$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$	?

45. What is the standard cell potential of galvanic cell Z?

(A) 0.26 V
(B) 0.78 V
(C) 2.34 V
(D) 3.22 V

46. In galvanic cells Y and Z, which of the following takes place in half-cell 3 ?

(A) Reduction occurs in both cell Y and cell Z.
(B) Oxidation occurs in both cell Y and cell Z.
(C) Reduction occurs in cell Y, and oxidation occurs in cell Z.
(D) Oxidation occurs in cell Y, and reduction occurs in cell Z.

47. If the half-cell containing 1.00 *M* $Fe(NO_3)_2(aq)$ in galvanic cells Y and Z is replaced with a half-cell containing 5.00 *M* $Fe(NO_3)_2(aq)$, what will be the effect on the cell voltage of the two galvanic cells?

(A) The voltage will increase in both cells.
(B) The voltage will decrease in both cells.
(C) The voltage will increase in cell Y and decrease in cell Z.
(D) The voltage will decrease in cell Y and increase in cell Z.

GO ON TO THE NEXT PAGE.

Questions 48-52 refer to the following.

Concentration (M)	pH of Acid 1	pH of Acid 2	pH of Acid 3	pH of Acid 4
0.010	3.44	2.00	2.92	2.20
0.050	3.09	1.30	2.58	1.73
0.10	2.94	1.00	2.42	1.55
0.50	2.69	0.30	2.08	1.16
1.00	2.44	0.00	1.92	0.98

The pH of solutions of four acids prepared at various concentrations were measured and recorded in the table above. The four acids are, in no particular order, chlorous, hydrochloric, lactic, and propanoic.

48. For which acid is the value of the acid-dissociation constant, K_a, the smallest?

(A) Acid 1
(B) Acid 2
(C) Acid 3
(D) Acid 4

49. Which of the four acids listed in the table is hydrochloric acid?

(A) Acid 1
(B) Acid 2
(C) Acid 3
(D) Acid 4

50. Of the following species, which has the greatest concentration in a 1.0 M solution of acid 1 at equilibrium?

(A) OH^-
(B) H_3O^+
(C) Acid 1
(D) The conjugate base of acid 1

51. If equal volumes of the four acids at a concentration of 0.50 M are each titrated with a strong base, which will require the greatest volume of base to reach the equivalence point?

(A) Acid 1
(B) Acid 2
(C) Acid 3
(D) All the acids will require the same volume of base to reach the equivalence point.

52. A 25 mL sample of a 1.0 M solution of acid 1 is mixed with 25 mL of 0.50 M NaOH. Which of the following best explains what happens to the pH of the mixture when a few drops of 1.0 M HNO_3 are added?

(A) The pH of the mixture increases sharply, because HNO_3 is a strong acid.
(B) The pH of the mixture decreases sharply, because H_3O^+ ions were added.
(C) The pH of the mixture stays about the same, because the conjugate base of acid 1 reacts with the added H_3O^+ ions.
(D) The pH of the mixture stays about the same, because the OH^- ions in the solution react with the added H_3O^+ ions.

Practice Exam

GO ON TO THE NEXT PAGE.

Step 1: $Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$

Step 2: $ClO(g) + O(g) \rightarrow Cl(g) + O_2(g)$

53. A proposed mechanism for destruction of ozone gas in the stratosphere is represented above. Which of the following is evidence that the mechanism is occurring?

(A) The presence of $Cl(g)$ increases the rate of the overall reaction.

(B) The presence of $Cl(g)$ decreases the rate of the overall reaction.

(C) The presence of $Cl(g)$ increases the equilibrium constant of the overall reaction.

(D) The presence of $Cl(g)$ decreases the equilibrium constant of the overall reaction.

GO ON TO THE NEXT PAGE.

	NaF	MgO
Boiling Point (°C)	1695	3600

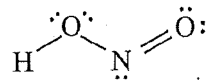
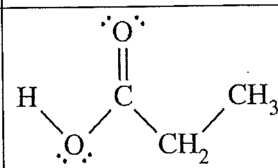
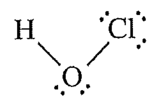
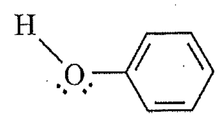
	Na^+	Mg^{2+}	F^-	Cl^-	O^{2-}
Ionic Radius (pm)	76	72	133	181	140

54. Based on the data in the tables above, which of the following statements provides the best prediction for the boiling point of NaCl ?

(A) NaCl will have a lower boiling point than NaF because the coulombic attractions are weaker in NaCl than in NaF.
(B) NaCl will have a boiling point between that of NaF and MgO because the covalent character of the bonds in NaCl is intermediate between that of MgO and NaF.
(C) NaCl will have a higher boiling point than MgO because the ions are spaced farther apart in NaCl.
(D) NaCl will have a higher boiling point than MgO because the energy required to transfer electrons from the anion to the cation is larger in NaCl than in MgO.

Practice Exam

GO ON TO THE NEXT PAGE.

Acid	Structure	K_a
HNO_2		4.0×10^{-4}
$HC_3H_5O_2$		1.3×10^{-5}
HClO		3.0×10^{-8}
HOC_6H_5		1.6×10^{-10}

55. The table above shows the values of K_a for four weak acids. Which of the following pairs of chemical species, when combined in equimolar amounts, results in a buffer with a pH closest to 7.5 ?

(A) HNO_2 and OH^-
(B) $HC_3H_5O_2$ and $C_3H_5O_2^-$
(C) HClO and ClO^-
(D) C_6H_5OH and $C_6H_5O^-$

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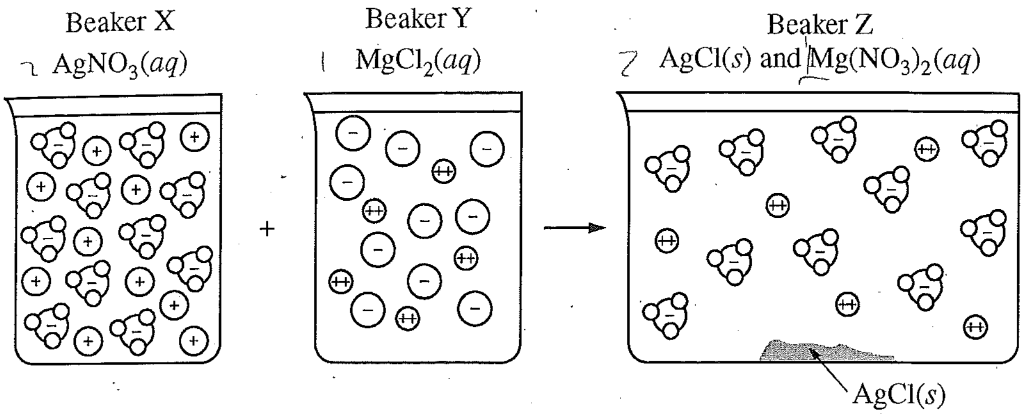

56. Beaker X and beaker Y each contain 1.0 L of solution, as shown above. A student combines the solutions by pouring them into a larger, previously empty beaker Z and observes the formation of a white precipitate. Assuming that volumes are additive, which of the following sets of solutions could be represented by the diagram above?

	Beaker X	Beaker Y	Beaker Z
(A)	2.0 *M* $AgNO_3$	2.0 *M* $MgCl_2$	4.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(B)	2.0 *M* $AgNO_3$	2.0 *M* $MgCl_2$	2.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(C)	2.0 *M* $AgNO_3$	1.0 *M* $MgCl_2$	1.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(D)	2.0 *M* $AgNO_3$	1.0 *M* $MgCl_2$	0.50 *M* $Mg(NO_3)_2$ and $AgCl(s)$

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$$2\,N_2O_5(g) \rightarrow 4\,NO_2(g) + O_2(g)$$

57. A sample of N_2O_5 was placed in an evacuated container, and the reaction represented above occurred. The value of $P_{N_2O_5}$, the partial pressure of $N_2O_5(g)$, was measured during the reaction and recorded in the table below.

Time (min)	$P_{N_2O_5}$ (atm)	$\ln(P_{N_2O_5})$	$\frac{1}{P_{N_2O_5}}$ (atm^{-1})
0	150	5.0	0.0067
100	75	4.3	0.013
200	38	3.6	0.027
300	19	2.9	0.053

Which of the following correctly describes the reaction?

(A) The decomposition of N_2O_5 is a zero-order reaction.

(B) The decomposition of N_2O_5 is a first-order reaction.

(C) The decomposition of N_2O_5 is a second-order reaction.

(D) The overall reaction order is 3.

Element	Atomic Radius	First Ionization Energy
Calcium	194 pm	590 kJ/mol
Potassium	—	—

58. Based on periodic trends and the data in the table above, which of the following are the most probable values of the atomic radius and the first ionization energy for potassium, respectively?

(A) 242 pm, 633 kJ/mol
(B) 242 pm, 419 kJ/mol
(C) 120 pm, 633 kJ/mol
(D) 120 pm, 419 kJ/mol

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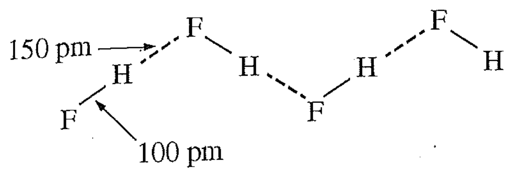


59. The figure above shows that in solid hydrogen fluoride there are two different distances between H atoms and F atoms. Which of the following best accounts for the two different distances?

(A) Accommodation of the necessary bond angles in the formation of the solid
(B) Difference in strength between covalent bonds and intermolecular attractions
(C) Different isotopes of fluorine present in the samples
(D) Uneven repulsions among nonbonding electron pairs

$$COCl_2(g) \rightleftarrows CO(g) + Cl_2(g)$$

60. $COCl_2(g)$ decomposes according to the equation above. When pure $COCl_2(g)$ is injected into a rigid, previously evacuated flask at 690 K, the pressure in the flask is initially 1.0 atm. After the reaction reaches equilibrium at 690 K, the total pressure in the flask is 1.2 atm. What is the value of K_p for the reaction at 690 K?

(A) 0.040
(B) 0.050
(C) 0.80
(D) 1.0

STOP

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK.

DO NOT TURN TO SECTION II UNTIL YOU ARE TOLD TO DO SO

Practice Exam

CHEMISTRY

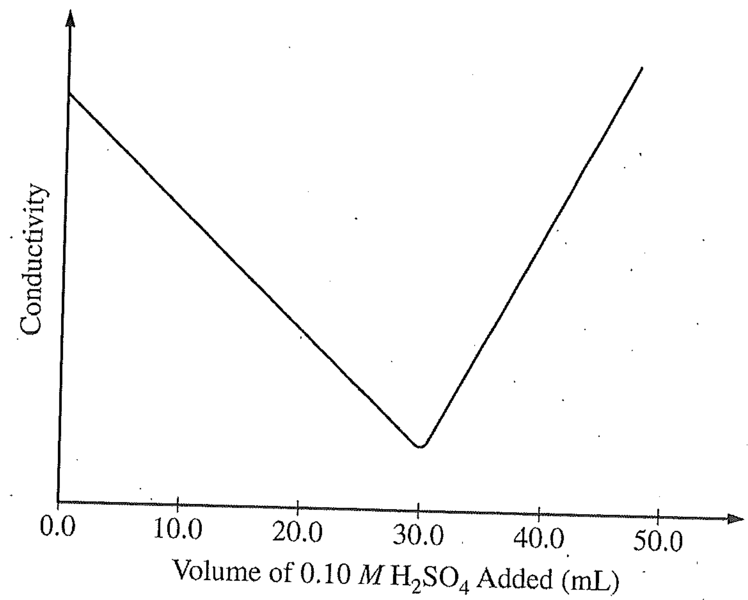
Section II

7 Constructed-Response Questions

(Time—90 minutes)

YOU MAY USE YOUR CALCULATOR FOR SECTION II

Directions: Questions 1, 2, and 3 are long constructed-response questions that should require about 20 minutes each to answer. Questions 4, 5, 6, and 7 are short constructed-response questions that should require about seven minutes each to answer. Read each question carefully and write your response in the space provided following each question. Your responses to these questions will be scored on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Specific answers are preferable to broad, diffuse responses. For calculations, 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.



1. A student performs an experiment in which the conductivity of a solution of $Ba(OH)_2$ is monitored as the solution is titrated with 0.10 M H_2SO_4. The original volume of the $Ba(OH)_2$ solution is 25.0 mL. A precipitate of $BaSO_4$ ($K_{sp} = 1.0 \times 10^{-10}$) formed during the titration. The data collected from the experiment are plotted in the graph above.

   (a) As the first 30.0 mL of 0.10 M H_2SO_4 are added to the $Ba(OH)_2$ solution, two types of chemical reactions occur simultaneously. On the lines provided below, write the balanced net-ionic equations for (i) the neutralization reaction and (ii) the precipitation reaction.

   (i) Equation for neutralization reaction: ____________________

   (ii) Equation for precipitation reaction: ____________________

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(b) The conductivity of the $Ba(OH)_2$ solution decreases as the volume of added 0.10 *M* H_2SO_4 changes from 0.0 mL to 30.0 mL.

(i) Identify the chemical species that enable the solution to conduct electricity as the first 30.0 mL of 0.10 *M* H_2SO_4 are added.

(ii) On the basis of the equations you wrote in part (a), explain why the conductivity decreases.

(c) Using the information in the graph, calculate the molarity of the original $Ba(OH)_2$ solution.

(d) Calculate the concentration of $Ba^{2+}(aq)$ in the solution at the equivalence point (after exactly 30.0 mL of 0.10 *M* H_2SO_4 are added).

(e) The concentration of $Ba^{2+}(aq)$ in the solution decreases as the volume of added 0.10 *M* H_2SO_4 increases from 30.0 mL to 31.0 mL. Explain.

Practice Exam

GO ON TO THE NEXT PAGE.

2. A student is given the task of determining the enthalpy of reaction for the reaction between HCl(*aq*) and NaOH(*aq*). The following materials are available.

1.00 *M* HCl(*aq*)
2.00 *M* HCl(*aq*)
insulated cups with covers
thermometer (± 0.1°C)

1.00 *M* NaOH(*aq*)
2.00 *M* NaOH(*aq*)
gloves
stirring rod

distilled water
goggles
lab coat

The student may select from the glassware listed in the table below.

Glassware Items	Precision
250 mL Erlenmeyer flasks	± 25 mL
100 mL beakers	± 10 mL
100 mL graduated cylinders	± 0.1 mL

(a) The student selects two 100 mL beakers, uses them to measure 50 mL each of 1.00 *M* HCl(*aq*) solution and 1.00 *M* NaOH(*aq*) solution, and measures an initial temperature of 24.5°C for each solution. Then the student pours the two solutions into an insulated cup, stirs the mixture, covers the cup, and records a maximum temperature of 29.9°C.

(i) Is the experimental design sufficient to determine the enthalpy of reaction to a precision of two significant figures? Justify your answer.

(ii) List two specific changes to the experiment that will allow the student to determine the enthalpy of reaction to a precision of three significant figures. Explain.

(b) A second student is given two solutions, 75.0 mL of 1.00 *M* HCl and 75.0 mL of 1.00 *M* NaOH, each at 25.0°C. The student pours the solutions into an insulated cup, stirs the mixture, covers the cup, and records the maximum temperature of the mixture.

(i) The student calculates the amount of heat evolved in the experiment to be 4.1 kJ. Calculate the student's experimental value for the enthalpy of reaction, in kJ/mol_{rxn}.

(ii) The student assumes that the thermometer and the calorimeter do not absorb energy during the reaction. Does this assumption result in a calculated value of the enthalpy of reaction that is higher than, lower than, or the same as it would have been had the heat capacities of the thermometer and calorimeter been taken into account? Justify your answer.

(iii) One assumption in interpreting the results of the experiment is that the reaction between HCl(*aq*) and NaOH(*aq*) goes to completion. Justify the validity of this assumption in terms of the equilibrium constant for the reaction.

(c) A third student calculates a value for the enthalpy of reaction that is significantly higher than the accepted value.

(i) Identify a specific error in procedure made by the student that will result in a calculated value for the enthalpy of reaction that is higher than the accepted value. (Vague statements like "human error" or "incorrect calculations" will not earn credit.)

(ii) Explain how the error that you identified in part (c)(i) leads to a calculated value for the enthalpy of reaction that is higher than the accepted value.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

Practice Exam

GO ON TO THE NEXT PAGE.

$$SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g)$$

3. A 4.32 g sample of liquid SO_2Cl_2 is placed in a rigid, evacuated 1.50 L reaction vessel. As the container is heated to 400. K, the sample vaporizes completely and starts to decompose according to the equation above. The decomposition reaction is endothermic.

   (a) If no decomposition occurred, what would be the pressure, in atm, of the $SO_2Cl_2(g)$ in the vessel at 400. K ?

   (b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ in the container at 400. K.

   (c) For the decomposition reaction at 400. K,

      (i) write the equilibrium-constant expression for K_p for the reaction, and

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

   (d) The temperature of the equilibrium mixture is increased to 425 K. Will the value of K_p increase, decrease, or remain the same? Justify your prediction.

   (e) In another experiment, the original partial pressures of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ are 1.0 atm each at 400. K. Predict whether the amount of $SO_2Cl_2(g)$ in the container will increase, decrease, or remain the same. Justify your prediction.

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

Practice Exam

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

4. It is proposed that the reaction represented above proceeds via the mechanism represented by the two element steps shown below.

Step I: $NO_2 + F_2 \rightarrow NO_2F + F$ *(slow)*

Step II: $NO_2 + F \rightleftarrows NO_2F$ *(fast reversible)*

(a) Step I of the proposed mechanism involves the collision between NO_2 and F_2 molecules. This step is slow even though such collisions occur very frequently in a mixture of $NO_2(g)$ and $F_2(g)$. Consider a specific collision between a molecule of NO_2 and a molecule of F_2.

(i) One factor that affects whether the collision will result in a reaction is the magnitude of the collision energy. Explain.

(ii) Identify and explain one other factor that affects whether the collision will result in a reaction.

(b) Consider the following potential rate laws for the reaction. Circle the rate law below that is consistent with the mechanism proposed above. Explain the reasoning behind your choice in terms of the details of the elementary steps of the mechanism.

rate = $k[NO_2]^2[F_2]$ rate = $k[NO_2][F_2]$

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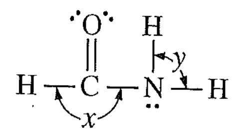
5. Methanamide, CH_3NO, is a liquid at 25°C.

(a) The complete Lewis electron-dot diagram for methanamide is shown below.



(i) In the molecule, angle x is not 180°. Estimate the observed angle. Justify your answer.

(ii) In the molecule, angle y is not 90°. Explain why in terms of electron domains (VSEPR model).

(b) Consider a molecule with the formula CH_2O_2. The structure of this molecule has a geometry around the carbon atom similar to the geometry around carbon in methanamide. In the box provided below, draw the complete Lewis electron-dot diagram for the molecule.

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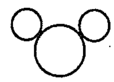
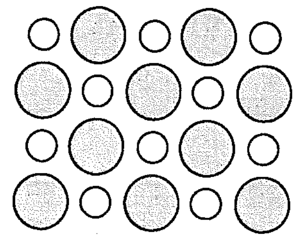


H_2O molecule

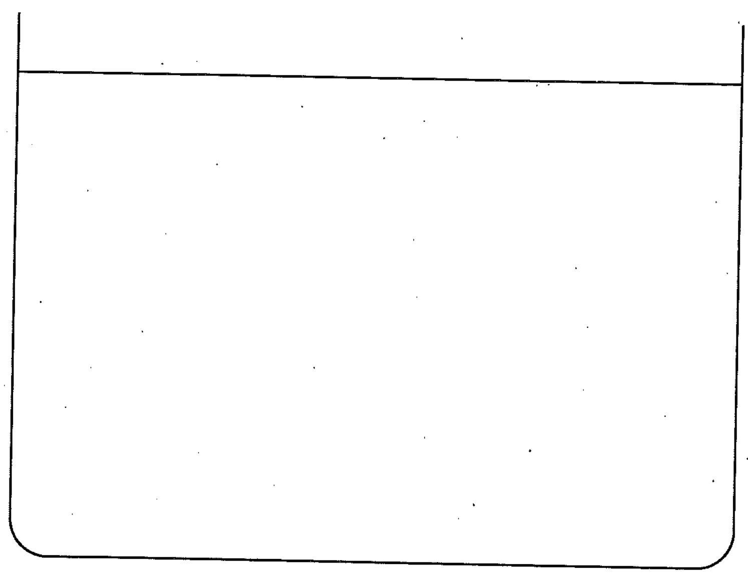


LiCl crystal

6. The structures of a water molecule and a crystal of LiCl(*s*) are represented above. A student prepares a 1.0 *M* solution by dissolving 4.2 g of LiCl(*s*) in enough water to make 100 mL of solution.

(a) In the space provided below, show the interactions of the components of LiCl(*aq*) by making a drawing tha represents the different particles present in the solution. Base the particles in your drawing on the particles shown in the representations above. Include only one formula unit of LiCl and no more than ten molecules of water. Your drawing must include the following details.

- identity of ions (symbol and charge)
- the arrangement and proper orientation of the particles in the solution



LiCl (*aq*)

(b) The student passes a direct current through the solution and observes that chlorine gas is produced at the anode. Identify the chemical species produced at the cathode and justify your answer using the information given in the table below.

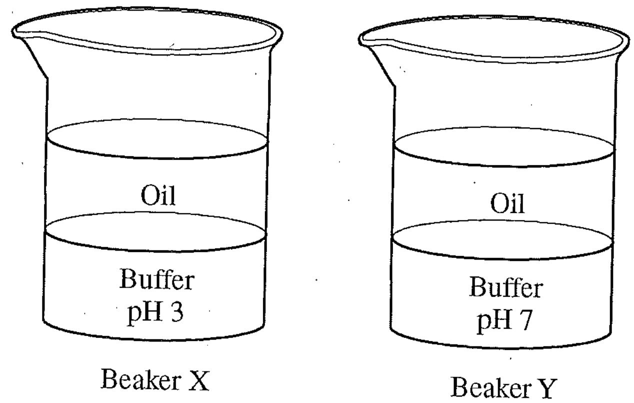
Half-reaction	Standard Reduction Potential at 25°C (V)
$Li^+(aq) + e^- \rightarrow Li(s)$	−3.05
$2\,H_2O(l) + 2\,e^- \rightarrow H_2(g) + 2\,OH^-(aq)$	−0.83

GO ON TO THE NEXT PAGE.

$$HIn(aq) + H_2O(l) \rightleftarrows In^-(aq) + H_3O^+(aq)$$

yellow *blue*

7. The indicator HIn is a weak acid with a pK_a value of 5.0. It reacts with water as represented in the equation above. Consider the two beakers below. Each beaker has a layer of colorless oil (a nonpolar solvent) on top of layer of aqueous buffer solution. In beaker X the pH of the buffer solution is 3, and in beaker Y the pH of the buffer solution is 7. A small amount of HIn is placed in both beakers. The mixtures are stirred well, and the oil and water layers are allowed to separate.



(a) What is the predominant form of HIn in the aqueous buffer in beaker Y, the acid form or the conjugate base form? Explain your reasoning.

(b) In beaker X the oil layer is yellow, whereas in beaker Y the oil layer is colorless. Explain these observations in terms of both acid-base equilibria and interparticle forces.

GO ON TO THE NEXT PAGE.

Notes on the Practice Exam

Introduction

This section provides a description of how the questions in the AP Practice Exam correspond to the components of the curriculum framework included in the *AP Chemistry Course and Exam Description*. For each of the questions in the AP Practice Exam, the targeted learning objectives, essential knowledge, and science practices from the curriculum framework are indicated.

In addition, the multiple-choice and free-response questions include the following features:

- For multiple-choice questions, the correct response is indicated with a justification for why it is correct. There are additional explanations that address why the other responses are incorrect.
- Free-response questions include scoring guidelines as well as descriptions of student responses that would represent "strong, good, and weak" levels. These scoring guidelines demonstrate how the essential knowledge and application of the science practices are assessed in each free-response question.

The AP Chemistry Exam is approximately 3 hours in length. There are two sections, each accounting for 50 percent of the student's exam score.

- Section I is 90 minutes in length and consists of 60 multiple-choice questions.
- Section II is 90 minutes in length and consists of three long free-response questions and four short free-response questions.

Section	Question Type	Number of Questions	Timing
I	Multiple-Choice	60	90 minutes
II	Long Free-Response	3	90 minutes
	Short Free-Response	4	

All of the questions on the exam are designed to measure the student's understanding of the big ideas, enduring understandings, and essential knowledge, and the student's application of this understanding through the science practices.

Practice Exam

Multiple-Choice Section

In Section I, there are 60 multiple-choice questions. These questions represent the knowledge and skills students should know, understand, and be able to apply. Students will be given a periodic table and an equations and constants list to use during this section.

Information for Multiple-Choice Questions 1–60

Question 1

Essential Knowledge	1.A.3 The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively.

(A)	This option is incorrect. The balanced chemical equation is $C_2H_2 + 5/2\ O_2 \rightarrow 2\ CO_2 + H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 1.
(B)	This option is incorrect. The balanced chemical equation is $C_2H_6 + 7/2\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 3.
(C)	**This option is correct. The balanced chemical equation is $C_4H_8 + 6\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 1 to 1, in agreement with the observed equimolar ratio.**
(D)	This option is incorrect. The balanced chemical equation is $C_6H_6 + 15/2\ O_2 \rightarrow 6\ CO_2 + 3\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 1.

Question 2

Essential Knowledge	2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.

(A)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.
(B)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.
(C)	**This option is correct. Since the transition from liquid to vapor breaks the intermolecular interactions, a high vapor pressure indicates weak interactions between molecules. Based on the data, this substance has the highest vapor pressure and thus the weakest intermolecular interactions.**
(D)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.

Question 3

Essential Knowledge		2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practices		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		2.14 The student is able to apply Coulomb's Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds.
(A)	**This option is correct. The interaction of ions with water is a Coulombic (specifically ion-dipole) interaction. Since all three ions have the same charge (+2), the strength of the interaction is related to distance, with shorter distances leading to the stronger interactions. The smaller ions therefore have stronger columbic attraction to water, as stated in this option.**	
(B)	This option is incorrect. The trend in electronegativity across these ions has no bearing on the interaction between these ions and water. The electronegativity is useful for determining the ionic character and polarity of a bond, which is not of relevance to the interaction of these cations with water.	
(C)	This option is incorrect. While Ba^{2+} is the largest ion and so the most polarizable, the interaction with water is dominated by ion-dipole interactions, and polarizability of the ion is not a relevant factor for such interactions.	
(D)	This option is incorrect. The trend in electronegativity is not of relevance here, as discussed in option B.	

Question 4

Essential Knowledge		1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice		6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model.
(A)	**This option is correct. Na has a single valence electron and a low first ionization energy and so can readily lose an electron and reduce other species.**	
(B)	This option is incorrect. H^+ has no electrons to transfer to, and thereby reduce, another chemical species. (If the notation H^+ is interpreted as $H_3O^+(aq)$, this option is still incorrect since the hydronium ion is a much weaker reducing agent than Na.)	
(C)	This option is incorrect. K^+ has the electronic configuration of Ar, giving it a much higher ionization energy than K. (Equivalently, the second ionization energy of K is much larger in magnitude than the first ionization energy.) The high ionization energy of K^+ makes it a poor choice for reducing other chemical species.	
(D)	This option is incorrect. Cl^- has the electronic configuration of Ar, giving it a high ionization energy and making it a poor choice for reducing other chemical species.	

Practice Exam

Question 5

Essential Knowledge	2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles.

(A)	This option is incorrect. This interaction is a covalent bond within a water molecule, not a hydrogen bond between water molecules.
(B)	This option is incorrect. This interaction is between oxygens on different water molecules, as opposed to a hydrogen bond.
(C)	This option is incorrect. This interaction is between hydrogens on different water molecules, as opposed to a hydrogen bond.
(D)	**This option is correct. This interaction correctly identifies a hydrogen bond as being between the hydrogen of one water molecule and the oxygen of an adjacent water molecule.**

Question 6

Essential Knowledge	4.A.1 The rate of a reaction is influenced by the concentration or pressure of reactants, the phase of the reactants and products, and environmental factors such as temperature and solvent.
Science Practice	4.2 The student can design a plan for collecting data to answer a particular scientific question.
Learning Objective	4.1 The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction.

(A)	This option is incorrect. The rate of the reaction depends on the concentration of the ethanoic acid and the surface area of the solid $CaCO_3$. Decreasing the volume of ethanoic acid solution will not alter either of these factors and so has no effect on the rate of gas production.
(B)	This option is incorrect. Decreasing the concentration of ethanoic acid solution will decrease the rate of the reaction and thus decrease the rate of gas production.
(C)	This option is incorrect. Decreasing the temperature will decrease the rate of the reaction and thus decrease the rate of gas production.
(D)	**This option is correct. Decreasing the particle size by grinding the $CaCO_3$ into a fine powder will increase the surface area of the $CaCO_3$ and increase the rate of the reaction and the rate of gas production.**

Question 7

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.4 The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, K, use the tendency of Q to approach K to predict and justify the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached.

(A)	This option is incorrect. As discussed in option B, $Q < K$ and the reaction will proceed in the forward direction, decreasing the amount of H_2 and I_2.
(B)	**This option is correct. Since the container is rigid and has a volume of 1.0 L, the original concentrations of the species are $[H_2] = [I_2] = [HI] = 2.0\ M$. The reaction quotient is therefore $Q = [HI]^2/([H_2][I_2]) = 1$. Since K is 50, $Q < K$ and the reaction proceeds in the forward direction, producing more HI, as stated in this option.**
(C)	This option is incorrect. As the reaction progresses in either direction, the number of moles of gas remains the same. (The reaction has two gas phase particles as both reactants and products.) The pressure will therefore not change as the reaction progresses.
(D)	This option is incorrect. The direction of the net reaction is determined by the relationship between Q and K, not the number of reactant and product molecules in the chemical equation. The system is not at equilibrium because $Q = 1$, which is not equal to 50, the given value of K.

Question 8

Essential Knowledge	5.A.1 Temperature is a measure of the average kinetic energy of atoms and molecules.
Science Practices	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	5.2 The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution.

(A)	This option is incorrect. A decrease in temperature results in a decrease in the average speed of the molecules, as opposed to the increase shown here.
(B)	This option is incorrect. This is the distribution expected for a smaller number of particles at the same temperature as the original sample.
(C)	This option is incorrect. A decrease in temperature results in a decrease in the speed of the molecules, as opposed to the increase shown here.
(D)	**This option is correct. A decrease in temperature results in a decrease in the average speed of the molecules, as shown here.**

Practice Exam

Question 9

Essential Knowledge		5.B.3 Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.
Science Practice		2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective		5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work.
(A)	This option is incorrect. The amount of energy lost by the metal equals the amount of energy gained by the water.	
(B)	**This option is correct. The amount of energy lost by the metal is equal to the amount of energy gained by the water.**	
(C)	This option is incorrect. The observation that the change in temperature of the metal is larger than that of water indicates that the metal has a smaller heat capacity than water.	
(D)	This option is incorrect. Energy is transferred from the metal to the water, with the total energy being conserved.	

Question 10

Essential Knowledge		1.D.2 An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.
Science Practice		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective		1.14 The student is able to use data from mass spectrometry to identify the elements and the masses of individual atoms of a specific element.
(A)	This option is incorrect. The data are reported as mass number in amu, for which the charge on the ion is not relevant. (If the horizontal axis is interpreted as mass/charge, this option remains incorrect since the data provides evidence for an isotopic distribution of similarly charged species.)	
(B)	This option is incorrect. The abundance in a particular sample does not necessarily reflect the abundance in the universe.	
(C)	**This option is correct. The mass spectrum indicates the presence of multiple isotopes in the sample, providing evidence for Te. Furthermore, the graph shows no peak at 127, the mass number of the only stable isotope of I. This shows that there is no I in the sample, and the sample must be pure Te.**	
(D)	This option is incorrect. The data provides evidence for an isotopic distribution, which is unrelated to the ionization energies of the elements.	

Question 11

Essential Knowledge	3.B.2 In a neutralization reaction, protons are transferred from an acid to a base.
Science Practice	6.1 The student can justify claims with evidence.
Learning Objective	3.7 The student is able to identify compounds as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, using proton-transfer reactions to justify the identification.

(A)	This option is incorrect. $H_2C_2O_4$ and $C_2O_4^{2-}$ is not a conjugate acid-base pair since conversion of $H_2C_2O_4$ to $C_2O_4^{2-}$ involves the loss of two hydrogen ions.
(B)	**This option is correct. Since $HC_2O_4^-$ loses one hydrogen ion to form $C_2O_4^{2-}$, these species are a conjugate acid-base pair.**
(C)	This option is incorrect. H_2O and $HC_2O_4^-$ are not related by loss or gain of a single hydrogen ion.
(D)	This option is incorrect. OH^- and H_3O^+ are not related by loss or gain of a single hydrogen ion.

Question 12

Essential Knowledge	5.E.2 Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H^\circ < 0$) under consideration and an increase in the entropy of those components ($\Delta S^\circ > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G^\circ < 0$).
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both ΔH° and ΔS°, and calculation or estimation of ΔG° when needed.

(A)	This option is incorrect. $\Delta G = \Delta H - T\Delta S$. At low temperature, ΔG is dominated by ΔH, and since $\Delta H < 0$, the reaction is favored. At high temperatures, ΔG is dominated by $-T\Delta S$, and since $\Delta S < 0$, the reaction is not favored.
(B)	**This option is correct. $\Delta G = \Delta H - T\Delta S$. At low temperature, ΔG is dominated by ΔH, and since $\Delta H > 0$, the reaction is not favored. At high temperatures, ΔG is dominated by $-T\Delta S$, and since $\Delta S > 0$, the reaction is favored.**
(C)	This option is incorrect. This reaction is favored at all temperatures, because it is driven by both enthalpy and entropy.
(D)	This option is incorrect. This reaction is not favored at any temperature, because it is not driven by either enthalpy or entropy.

Question 13

Essential Knowledge	1.E.1 Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
Science Practice	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Learning Objective	1.17 The student is able to express the law of conservation of mass quantitatively and qualitatively using symbolic representations and particulate drawings.

(A)	This option is incorrect. Both hydrogen and oxygen are diatomic molecules, unlike the monatomic gases depicted for the reactants. In addition, the number of atoms is not conserved.
(B)	This option is incorrect. Both hydrogen and oxygen are diatomic molecules, unlike the monatomic gases depicted for the reactants.
(C)	**This option is correct. The reactants are shown as diatomic molecules and the number of atoms is conserved (6 oxygen and 12 hydrogen atoms on both the reactant and product side).**
(D)	This option is incorrect. The number of atoms is not conserved (12 oxygen atoms on the reactant side but only 6 oxygen atoms on the product side).

Question 14

Essential Knowledge	6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.19 The student can relate the predominant form of a chemical species involving a labile proton (i.e., protonated/deprotonated form of a weak acid) to the pH of a solution and the pK_a associated with the labile proton.

(A)	**This option is correct. Point *R* is in the buffer region, where HA and A^- have the highest concentration of the four species listed as options. At the half-equivalence point, HA and A^- have equal concentrations and pH = pK_a. Point *R* is before the half-equivalence point, with a pH < pK_a, and so HA will have a higher concentration than A^-.**
(B)	This option is incorrect. As discussed for option A, since *R* is before the half-equivalence point, the concentration of A^- will be less than that of HA.
(C)	This option is incorrect. Since the pH at point *R* is about 3.5, the concentration of H_3O^+ is between 10^{-3} and 10^{-4}. Since the equivalence point is at 40 mL, the concentration of both HA and A^- are of the same order of magnitude as the titrant (0.1 *M* NaOH) and so are much larger than H_3O^+.
(D)	This option is incorrect. Since the pH is acidic, OH^- is present with very small concentration.

Question 15

Big Idea		3 Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Science Practice		7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective		3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views.
(A)	This option is incorrect. Point *U* is substantially beyond the equivalence point and so OH^- is present in the solution with substantial concentration.	
(B)	**This option is correct. Na^+, OH^-, and A^- ions are all present in large concentration. The ratio of species is also correct, since at point *U*, the concentrations of Na^+, A^-, and OH^- should be approximately 3:2:1.**	
(C)	This option is incorrect. Since point *U* is substantially beyond the equivalence point, HA will be present in very small concentration. This is inconsistent with the two HA molecules shown in this option.	
(D)	This option is incorrect. Since point *U* is substantially beyond the equivalence point, HA will be present in very small concentration. This is inconsistent with the four HA molecules shown in this option.	

Question 16

Essential Knowledge		6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice		5.1 The student can analyze data to identify patterns or relationships.
Learning Objective		6.13 The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pK_a for a weak acid, or the pK_b for a weak base.
(A)	This option is incorrect. At the half-equivalence point, [HA] = [A^-]. Point *R* is before the half-equivalence point, and [HA] > [A^-].	
(B)	This option is incorrect. Point *S* is the half-equivalence point, at which [HA] = [A^-].	
(C)	**This option is correct. At the half-equivalence point, [HA] = [A^-]. Since point *T* is after the half-equivalence point but within the buffer region, [HA] and [A^-] will both be present with large concentration with [A^-] > [HA].**	
(D)	This option is incorrect. Point *U* is well past the equivalence point, with a pH greater than 12. The concentration of HA will therefore be very small, and much less than half that of A^-.	

Practice Exam

Question 17

Essential Knowledge	1.E.2 Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
Science Practice	5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	1.20 The student can design and/or interpret data from an experiment that uses titration to determine the concentration of an analyte in a solution.

(A)	This option is incorrect. The experimental error will be in a direction that increases the estimated concentration of the acid, as discussed in option B.
(B)	**This option is correct. The relation $M_1V_1 = M_2V_2$ at the equivalence point (40.0 mL) gives a concentration of 0.0800 *M*. If the endpoint of the titration is measured past the actual endpoint, then the moles of base added to reach the endpoint is overestimated and this will lead to an overestimation of the number of moles of acid, and so a calculated concentration that is somewhat larger than the actual concentration.**
(C)	This option is incorrect. An acid concentration of 0.125 *M* would place the equivalence point at 60.0 mL instead of the observed 40.0 mL.
(D)	This option is incorrect. An acid concentration of 0.125 *M* would place the equivalence point at 60.0 mL instead of the observed 40.0 mL.

Question 18

Essential Knowledge	5.A.1 Temperature is a measure of the average kinetic energy of atoms and molecules.
Science Practices	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	5.2 The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution.

(A)	This option is incorrect. See option D.
(B)	This option is incorrect. See option D.
(C)	This option is incorrect. See option D.
(D)	**This option is correct. The average kinetic energy is a function only of temperature, and each vessel has the same temperature.**

Question 19

Essential Knowledge		2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practice		2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective		2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases.
(A)	This option is incorrect. See the explanation for option B.	
(B)	**This option is correct. Since all three containers are at the same temperature, the number of particles per unit volume is directly proportional to the pressure. The density is the mass per unit volume, so the density is proportional to the product of the pressure and the molar mass. This product is greatest for container B.**	
(C)	This option is incorrect. See the explanation for option B.	
(D)	This option is incorrect. See the explanation for option B.	

Question 20

Essential Knowledge		2.B.1 London dispersion forces are attractive forces present between all atoms and molecules. London dispersion forces are often the strongest net intermolecular force between large molecules.
Science Practice		6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		2.11 The student is able to explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces.
(A)	This option is incorrect. See the explanation for option C.	
(B)	This option is incorrect. See the explanation for option C.	
(C)	**This option is correct. Condensation will occur at the lowest pressure for the gas with the strongest intermolecular interactions. Since all of these gases are nonpolar, the interactions are dominated by London dispersion forces, which are largest for the most polarizable species. Since butane is the largest species, it is the most polarizable.**	
(D)	This option is incorrect. See the explanation for option C.	

Practice Exam

Question 21

Essential Knowledge	1.A.2 Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.1 The student can justify claims with evidence.
Learning Objective	1.3 The student is able to select and apply mathematical relationships to mass data in order to justify a claim regarding the identity and/or estimated purity of a substance.

(A)	**This option is correct. An impurity that contains no carbon will decrease the mass percent of carbon relative to the pure substance. The mass percent of carbon in the sample is lower than that of pure glucose. So this option is consistent with the observation.**
(B)	This option is incorrect. Ribose has the same empirical formula as glucose (CH_2O) and so has the same mass percent of carbon as glucose. A ribose impurity would therefore have no effect on the measured mass percent of carbon and so cannot account for the low mass percent of carbon in the sample.
(C)	This option is incorrect. Since fructose is an isomer of glucose, it has the same mass percent of carbon as glucose. A fructose impurity would therefore have no effect on the measured mass percent of carbon and so cannot account for the low mass percent of carbon in the sample.
(D)	This option is incorrect. Sucrose has a higher mass percent of carbon than glucose. This can be seen by comparing the number of atoms in two glucose molecules, which is equivalent to $C_{12}H_{24}O_{12}$, to that in one sucrose molecule, $C_{12}H_{22}O_{11}$. Since sucrose has more carbon, relative to hydrogen and oxygen, a sucrose impurity would raise the mass percent of carbon in the sample. This is opposite to the experimentally observed effect.

Question 22

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.16 The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base) and calculate the pH and concentration of all species in the solution and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations.

(A)	This option is incorrect. A weak base solution will have a basic pH. The pH range of 2-3 corresponds to an acidic solution.
(B)	This option is incorrect. A weak base solution will have a basic pH. The pH range of 5-6 corresponds to an acidic solution.
(C)	This option is incorrect. See option D for an estimation of the pH.
(D)	**This option is correct. The equilibrium expression for a weak base, B, is $K_b = \frac{[HB^+][OH^-]}{[B]}$. Here [B] = 0.01 M, K_b= 4 × 10^{-4} and $[HB^+] = [OH^-]$. Therefore $[OH^-] = \sqrt{K_b \times 0.01}$. This corresponds to $\sqrt{4 \times 10^{-6}}$ or 2 × 10^{-3}. The pOH is therefore somewhat less than 3, making the pH somewhat larger than 11. The pH therefore lies within the range of this option, pH = 11-12.**

Question 23

Essential Knowledge	2.C.4 The localized electron bonding model describes and predicts molecular geometry using Lewis diagrams and the VSEPR model.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity.

(A)	This option is incorrect. Although the molecular formulas are similar, the geometries are not similar and the differences in geometry lead to substantial differences in polarity.
(B)	This option is incorrect. Although C and S do have similar electronegativities, this implies only that the bond dipoles are similar in the two molecules. The differences in geometry cause the bond dipoles to cancel in CO_2 but not SO_2, leading to substantially different net dipoles for the molecules and substantial differences in polarity.
(C)	This option is incorrect. The lone pair on the sulfur is an important difference between these molecules. However, the most important effect of this lone pair is its influence on the molecular geometry, which causes SO_2 to be a bent molecule.
(D)	**This option is correct. Both the C-O and S-O bonds are polar, due to the different electronegativities of the bonded atoms. However, the CO_2 molecule is linear and so the bond dipoles cancel and the molecule has no net dipole. In SO_2, the molecule is bent and so the bond dipoles do not cancel and a net dipole is present. The polarity of the two substances differs because of the differences in geometry, which is a direct consequence of the number of electron domains around the central atom (2 in CO_2 and 3 in SO_2), as stated in this option.**

Practice Exam

Question 24

Enduring Understanding	4.C Many reactions proceed via a series of elementary reactions.
Science Practice	6.5 The student can evaluate alternative scientific explanations.
Learning Objective	4.7 The student is able to evaluate alternative explanations, as expressed by reaction mechanisms, to determine which are consistent with data regarding the overall rate of a reaction, and data that can be used to infer the presence of a reaction intermediate.

(A)	This option is incorrect. A unimolecular reaction is one involving a single reactant molecule. The first step of this mechanism corresponds to a collision between two NO molecules, making it a bimolecular reaction.
(B)	This option is incorrect. The fast and reversible character of the first step in the mechanism will establish an equilibrium. Increasing the concentration of NO will shift this equilibrium to the product side, increasing the concentration of the N_2O_2 intermediate. This increase in N_2O_2 will lead to an increase in the rate of the second step of the mechanism and so increase the overall rate of the reaction.
(C)	This option is incorrect. The rate constant for this reaction depends on temperature. In particular, the slow character of the second step in the reaction mechanism implies a substantial activation energy.
(D)	**This option is correct. The fast and reversible character of the first step in the mechanism will establish an equilibrium in which the concentration of the intermediate N_2O_2 is directly proportional to $[NO_2]^2$. The overall rate of the reaction is given by the second step, for which the rate is proportional to the product $[N_2O_2][O_2]$. Since $[N_2O_2]$ is directly proportional to $[NO_2]^2$ from step 1, substitution yields an overall reaction rate law of rate = $k\,[NO_2]^2[O_2]$, as stated in this option.**

Question 25

Essential Knowledge	2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.

(A)	This option is incorrect. Both Br_2 and I_2 form molecular solids.
(B)	This option is incorrect. The boiling point is established by the strength of the intermolecular forces. The covalent bonds remain intact on boiling and so their strength does not influence the boiling points.
(C)	**This option is correct. Since both Br_2 and I_2 are nonpolar, London dispersion forces establish the boiling points. The larger electron cloud in I_2 gives it a greater polarizability and therefore stronger London dispersion forces. The higher boiling point of I_2 is therefore due to the greater polarizability of I_2, as stated in this option.**
(D)	This option is incorrect. The bond polarity is related to the difference in electronegativity of the bonded atoms. Here, the bonds are between identical elements and so the bonds are nonpolar.

Question 26

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.3 The student can refine representations and models of natural or man-made phenomena and systems in the domain. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	2.5 The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample.

(A)	This option is incorrect. The correct pressure is 4.5 atm, as described below for option B.
(B)	**This option is correct. Since the volume of the three original containers are equal, the pressures are proportional to the number of atoms in the containers, which are in the ratio of 2:1:6. The pressure in the first container is given as 2 atm, therefore the pressures in the three containers are 2 atm, 1 atm, and 6 atm, respectively. If these were combined into a single container with a volume equal to that of the original vessels (1 liter), the total pressure would be the sum of these partial pressures, corresponding to 9 atm. The final container has a volume of 2 liters, which lowers the pressure by a factor of 2, to 4.5 atm.**
(C)	This option is incorrect. This option would be correct if the gases were combined in a 1-liter container, as opposed to the 2-liter container stated in the problem.
(D)	This option is incorrect. This option is obtained if one mistakenly assumes that doubling the size of the final container from 1 to 2 liters doubles the pressure as opposed to cutting it in half.

Practice Exam

Question 27

Essential Knowledge	5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practices	2.3 The student can estimate numerically quantities that describe natural phenomena. 7.1 The student can connect phenomena and models across spatial and temporal scales. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.

(A)	This option is incorrect. Steps 1 and 2 break favorable intermolecular interactions and so are both endothermic.
(B)	This option is incorrect. The final step establishes favorable intermolecular interactions between solute and solvent and so is exothermic.
(C)	This option is incorrect. This option corresponds to the opposite of the correct response, as explained in option D below.
(D)	**This option is correct. In steps 1 and 2, favorable intermolecular interactions are broken and this increases the enthalpy, corresponding to an endothermic process. In step 3, favorable intermolecular interactions are established, which decreases the enthalpy, corresponding to an exothermic process. (The sign of the enthalpy change for the overall process is established by the difference in magnitude between these enthalpy changes, and so the overall process can be either endothermic or exothermic.)**

Question 28

Big Idea	3 Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Science Practices	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views.

(A)	This option is incorrect. The solution corresponds to AgCl solid with $NaNO_3$ in solution. Since excess NaCl was added, the drawing should show Na^+ and Cl^- in solution.
(B)	This option is incorrect. There should be Na^+ and NO_3^- ions in solution. In addition, since K_{sp} is small, the concentration of Ag^+ should be very low, and far below that of Na^+ and NO_3^-.
(C)	**This option is correct. The addition of excess NaCl will cause there to be additional Na^+ and Cl^- ions in the solution, along with NO_3^- ions remaining from the original $AgNO_3$ solution. Due to the low K_{sp}, almost all of the Ag^+ ions have precipitated from solution.**
(D)	This option is incorrect. Since K_{sp} is very small, the concentration of Ag^+ should be very low, and far below that of Na^+ and NO_3^-. In this drawing, Ag^+ has a concentration equal to that of Na^+ and NO_3^-.

Question 29

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors.

(A)	This option is incorrect. The principal effect on the pressure is a change in the number of particles in the vessel, not the strength of their interactions.
(B)	This option is incorrect. The principal effect on the pressure is a change in the number of particles in the vessel, not the strength of their interactions. In addition, an increase in intermolecular attractions would serve to decrease the pressure, unlike the observed increase in pressure.
(C)	**This option is correct. The number of particles in the vessel increases as the system reaches equilibrium. This increases the frequency of collisions with the walls and thus increases the pressure, as stated in this option.**
(D)	This option is incorrect. The speed of the particles influences pressure only via the temperature, and since the reaction is carried out at constant temperature, the only relevant variable regarding pressure is the number of particles in the container.

Practice Exam

Question 30

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	6.3 The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions.
(A)	This option is incorrect. Since the concentration of reactant species decreases as the reaction progresses, the rate of the forward reaction decreases.
(B)	This option is incorrect. Since the concentration of reactant species decreases as the reaction progresses, the rate of the forward reaction changes.
(C)	**This option is correct. As the reaction reaches equilibrium, the rate of the forward reaction decreases and the rate of the reverse reaction increases. Equilibrium is reached when the forward and reverse rates are equal. The statement in this option, that the forward rate decreases to a constant value, is therefore correct.**
(D)	This option is incorrect. The rate of the forward reaction decreases as the reaction progresses; however, equilibrium is established when the forward and reverse reaction rates are equal. The rate of the forward reaction therefore reaches a steady nonzero value, not zero as stated in this option.

Question 31

Essential Knowledge	3.A.2 Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note so that it does not seem to be simply an exercise done only by chemists.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results.
(A)	This option is incorrect. If the system is allowed to reach equilibrium, the pressure is 1.40 atm, as indicated in the stimulus to the question. This question specifically asks for the reaction going to completion.
(B)	**This option is correct. It demonstrates recognition of the stoichiometry of the provided reaction and application of mole ratios (1 mole of reactant decomposing to produce 2 moles of product) to determine the total pressure of the system, should it go to completion.**
(C)	This option is incorrect. This answer can be achieved by doubling the equilibrium pressure, which demonstrates confusion on what the equilibrium pressure represents in relation to the stoichiometry of the reaction.
(D)	This option is incorrect. This answer can be achieved by forgetting that the partial pressure of the reactant is equal to zero if the reaction goes to completion.

Question 32

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K.

(A)	This option is incorrect. K_p is not greater than 1 based on the equilibrium pressure of the system provided in the stimulus.
(B)	**This option is correct. It demonstrates the ability to use an ICE chart or a K_p expression to determine the amount of change needed to reach equilibrium conditions: the pressure of the reactant drops by 0.40 atm and the products increase by 0.40 atm each, giving a total pressure of 1.40 atm.** $K_p = \frac{(0.40\text{ atm})^2}{(0.60\text{ atm})} < 1$
(C)	This option is incorrect. Each of the partial pressures of the products at equilibrium would have to be exactly equal to the square root of the equilibrium pressure of the reactant to achieve a K of 1.
(D)	This option is incorrect. Enough information is provided in the problem to calculate a value of K_p and compare its magnitude to 1.

Question 33

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	6.3 The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions.

(A)	This option is incorrect. The rate of the reverse reaction would increase, but the rate would not be zero at equilibrium.
(B)	**This option is correct. It demonstrates recognition that the rate of the reverse reaction would rapidly increase upon the injection of more Cl_2 because a greater concentration of reactant (Cl_2 in this case) means an increase in the reaction rate. It also demonstrates understanding that as more Cl_2 is consumed and the system returns to equal forward and reverse reaction rates (i.e., equilibrium), the reverse rate will decrease and reach a new non-zero value that is higher than the original value.**
(C)	This option is incorrect. While increasing the concentration of Cl_2 will increase the reaction rate initially, it would not be possible for the reverse rate to be less than it was in the initial equilibrium, given the greater concentration of Cl_2.
(D)	This option is incorrect. Increasing the concentration of Cl_2 would increase the reaction rate, but it would not do so slowly if the time for injection and mixing is negligible, as the question states; as Cl_2 is consumed by the reverse reaction, the rate should drop some, not only increase.

Practice Exam

Question 34

Essential Knowledge	5.B.3 Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work.
(A)	This option is incorrect. Reversing the exothermic process described in the stimulus reverses the direction of energy flow. Also, the stoichiometry of the reaction indicates that the energy value in the equation is for a half mole of Cl_2, not a full mole of Cl_2.
(B)	This option is incorrect. Reversing the exothermic process described in the stimulus reverses the direction of energy flow.
(C)	**This option is correct. It demonstrates understanding of the magnitude of the energy change based on the stoichiometry of the reaction and the correct direction of the energy transfer based on reversing the reaction.**
(D)	This option is incorrect. It correctly predicts the direction of the energy flow, but it does not correctly reflect the stoichiometry of the reaction.

Question 35

Essential Knowledge	3.A.2 Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note so that it does not seem to be simply an exercise done only by chemists.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	3.4 The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion.
(A)	This option is incorrect. Equal masses of K and Cl_2 do not have a 1:1/2 mole ratio, as required by the balanced chemical equation provided in the stimulus.
(B)	This option is incorrect. Since the molar mass of K is more than half that of Cl_2, there are fewer than twice the moles of K than Cl_2, so K cannot be the limiting reactant.
(C)	**This option is correct. It demonstrates correct calculation or recognition of the limiting reactant in the setup, based on moles of each reactant and the stoichiometry of the reaction and that the product of the reaction will also be present at the reaction conclusion.**
(D)	This option is incorrect. The reaction proceeds until one or both of the reactants have been completely consumed, so both reactants cannot remain in the reaction vessel upon reaction completion.

Question 36

Essential Knowledge	5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.

(A)	This option is incorrect. The formation of an ionic bond releases energy, but adding an electron to a gaseous halogen atom also releases energy.
(B)	**This option is correct. It demonstrates understanding of the exothermic processes listed in the stimulus that are a result of bond formation and Coulombic attractions: the electron affinity of Cl(*g*) and the ionic-bond formation between K^+(*g*) and Cl^-(*g*), both of which can be estimated to have a negative enthalpy value.**
(C)	This option is incorrect. Bond breaking always requires energy; it is not an exothermic process.
(D)	This option is incorrect. Both ionization of a K atom and breaking a Cl-Cl bond require the addition of energy and so are endothermic processes.

Question 37

Essential Knowledge	5.E.2 Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H° < 0$) under consideration and an increase in the entropy of those components ($\Delta S° > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G° < 0$).
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both $\Delta H°$ and $\Delta S°$, and calculation or estimation of $\Delta G°$ when needed.

(A)	**This option is correct. It predicts correctly that the sign of the free energy change would be negative (thermodynamically favorable since it goes to completion) and driven by an enthalpy change, since the overall reaction listed in the stimulus is exothermic. The reaction is not driven by an entropy change because the entropy of the system decreases as reactants convert to products.**
(B)	This option is incorrect. The reaction is observed to go to completion (so is favorable), and the entropy of the system decreases; the entropy change does not drive the reaction.
(C)	This option is incorrect. The reaction is thermodynamically favorable, but the entropy change is not a factor driving the reaction toward the products.
(D)	This option is incorrect. The reaction is favorable and driven only by the enthalpy change.

Question 38

Essential Knowledge	5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.

(A)	This option is incorrect. Two atoms (or two moles of atoms) of chlorine are each gaining one electron (or one mole of electrons), requiring a coefficient of 2 in front of the *y* term.
(B)	This option is incorrect. It does not account for two atoms of chlorine gaining electrons.
(C)	**This option is correct. It correctly tracks the ionization of diatomic chlorine, which requires both the endothermic breaking of the Cl-Cl covalent bond and the exothermic electron affinity of the separated chlorine atoms (of which there are two, yielding the coefficient on the *y* term). The negative sign is not required for the *y* term because the addition of an electron to a chlorine atom is exothermic, already implying a negative sign by convention.**
(D)	This option is incorrect. The question asks specifically about ionizing one mole of diatomic chlorine molecules, not one-half of a mole.

Question 39

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors.

(A)	**This option is correct. It demonstrates understanding that gases with similar molar masses (HCl = 36 g/mol and CH_3NH_2 = 31 g/mol) at the same temperature will travel with similar average speeds, resulting in a solid being formed at roughly equal distances from each cotton ball.**
(B)	This option is incorrect. The molar mass of NH_3 is less than half of the molar mass of HCl, meaning NH_3 molecules will travel with greater average speed, and the solid will form closer to the cotton ball on the left.
(C)	This option is incorrect. The molar mass of HBr is more than double that of CH_3NH_3, which would result in a solid closer to the cotton ball on the left.
(D)	This option is incorrect. The molar mass of HBr is almost five times as large as that of NH_3, which would result in the least centered solid of any of the choices, residing far on the left side of the tube.

Question 40

Essential Knowledge	1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice	3.1 The student can pose scientific questions.
Learning Objective	1.11 The student can analyze data, based on periodicity and the properties of binary compounds, to identify patterns and generate hypotheses related to the molecular design of compounds for which data are not supplied.

(A)	**This option is correct. It recognizes that phosphorus atoms contain one additional valence electron over the silicon atoms that make up the bulk of the material, and that these additional mobile charges will increase the conductivity of the silicon material.**
(B)	This option is incorrect. While phosphorus does have additional protons, the particles in the nucleus are bound and are not able to move throughout the material like electrons can.
(C)	This option is incorrect. While germanium atoms do have more electrons than silicon atoms, the number of valence electrons is the same as in silicon, and it will not improve the conductivity of the material anywhere nearly as effectively as adding an impurity with a different valence electron count.
(D)	This option is incorrect. Germanium atoms have an additional electron shell, and they are therefore larger than silicon atoms, not smaller.

Practice Exam

Question 41

Essential Knowledge	1.D.3 The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms and molecules, and to measure their concentration.
Science Practice	4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
Learning Objective	1.15 The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules.

(A)	This option is incorrect. Infrared light, not UV and visible, is matched to the vibrational states of chemical bonds in molecules.
(B)	This option is incorrect. While electromagnetic radiation can be used to remove an electron from atoms and molecules, the energy of visible and UV light is insufficient to overcome both the bond energy and ionization energy.
(C)	**This option is correct. It correctly justifies the observations about the molecules by recognizing that visible light and ultraviolet light can promote electrons to higher energy levels in atoms and molecules. Ultraviolet light is more energetic than visible light, so there must be some lower energy electronic transitions available in I_2 molecules that are not present in N_2 molecules; visible light would be a useful tool for differentiating I_2 from N_2 (which is exhibited by iodine vapor having a deep purple color and nitrogen gas being colorless).**
(D)	This option is incorrect. Molecular mass is unrelated to UV and visible light spectroscopy; molecular mass would only be relevant if conducting a mass spectrometry experiment.

Question 42

Essential Knowledge	2.D.2 Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
Science Practice	7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	2.25 The student is able to compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning.

(A)	This option is incorrect. The number of available oxidation states for these metals is not related to the hardness of the alloy.
(B)	This option is incorrect. The melting points of the component metals are unrelated to the hardness of the alloy.
(C)	**This option is correct. It reflects the data provided that the radii of Cu atoms is smaller than Ag atoms, which would prevent movement of Ag atoms in the alloy by creating points where Ag atoms could not slip past other atoms, making the overall alloy less deformable (i.e., less malleable).**
(D)	This option is incorrect. London dispersion forces are not a significant factor in the nature of the metallic bond, and weaker interparticle forces would likely increase, not decrease, malleability.

Question 43

Essential Knowledge		1.B.1 The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's Law is qualitatively useful for understanding the structure of the atom.
Science Practice		6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective		1.5 The student is able to explain the distribution of electrons in an atom or ion based upon data.
(A)	This option is incorrect. The presence or lack of electron-electron repulsions in the 2*p* sublevel would have no detectable effect on the amount of energy needed to remove a 1*s* electron from an atom.	
(B)	This option is incorrect. The increased electron-electron repulsions in the oxygen atoms would have no detectable effect on the attraction of the 1*s* electrons to the nucleus of either atom, as both atoms have the same number of electrons (and hence the same degree of electron-electron repulsion) in the 1*s* sublevel.	
(C)	This option is incorrect. Electron shielding involves inner electrons reducing the effective pull from the nucleus on outer electrons. Electrons in the 2*p* sublevel would have negligible, if any, shielding effect on the 1*s* electrons.	
(D)	**This option is correct. It correctly explains the differences in the provided PES spectra for the energies required to remove electrons from the 1*s* sublevel, based on the increased Coulombic attraction to the nucleus due to a greater number of protons in the nucleus of the oxygen atom than in the nucleus of the nitrogen atom.**	

Question 44

Essential Knowledge		2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice		6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective		2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.
(A)	This option is incorrect. Covalent bonds within molecules do not break when boiling occurs; boiling only involves molecules having enough energy to overcome interparticle attractions.	
(B)	This option is incorrect. While the C-F bond is more polar than the C-H bond, the boiling point data indicate that the London dispersion forces between nonane molecules must be greater than the combined dipole-dipole attractions and London dispersion forces between molecules of 2,3,4-trifluoropentane.	
(C)	**This option is correct. It correctly explains the higher boiling point of nonane due to the increased size and surface area of the electron cloud (yielding greater polarizability), which leads to more significant London dispersion forces between nonane molecules than between molecules of 2,3,4-trifluoropentane.**	
(D)	This option is incorrect. Greater separation between molecules would have only slight effects on boiling point, and, if anything, the greater spacing between carbon chains in nonane would be consistent with a lower boiling point, not higher.	

Practice Exam

Question 45

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws.
(A)	This option is incorrect. Molar coefficients do not affect cell potential, so dividing by 3 does not yield the correct cell potential, even though reversing reaction Y and combining it with X yields a net reaction for Z that has molar coefficients 3 times greater than those in the equation given for Z.
(B)	**This option is correct. It predicts the standard cell potential for cell Z by reversing the net reaction for galvanic cell Y and adding it to the net reaction for cell X. Molar coefficients do not affect cell potential, so no further mathematical manipulations are necessary. (This is one method among several of reaching the correct answer.)**
(C)	This option is incorrect. Multiplying the cell potential by 3 does not yield the correct cell potential for Z, since molar coefficients do not affect cell potential.
(D)	This option is incorrect. The reaction in cell Y must be reversed, reversing the sign on the cell potential. Adding the net reaction from X and Y together does not yield the reaction given for Z without this reversal.

Question 46

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	3.13 The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions.
(A)	This option is incorrect. Fe^{2+} ions are reduced only in cell Y, not cell Z.
(B)	This option is incorrect. Fe atoms are oxidized only in cell Z, not cell Y.
(C)	**This option is correct. It correctly tracks the oxidation numbers of the iron, based on the net reactions for each galvanic cell: Fe^{2+} ions are reduced to iron metal in galvanic cell Y, and Fe atoms are oxidized to Fe^{2+} ions in galvanic cell Z.**
(D)	This option is incorrect. Oxidation involves the loss of electrons, which does not happen to the Fe^{2+} ions in galvanic cell Y. Reduction involves the gain of electrons, which does not happen to the Fe atoms in the galvanic cell Z.

Question 47

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws.

(A)	This option is incorrect. Since Fe^{2+} ions are a reactant in cell Y and a product in cell Z, increasing the concentration of Fe^{2+} ions cannot increase the voltage in both cells.
(B)	This option is incorrect. Since Fe^{2+} ions are a reactant in cell Y and a product in cell Z, increasing the concentration of Fe^{2+} ions cannot decrease the voltage in both cells.
(C)	**This option is correct. It correctly predicts that increasing the Fe^{2+} ion concentration will increase the voltage for cell Y, where Fe^{2+} ions are reactants. Increasing the Fe^{2+} ion concentration will decrease the voltage for cell Z, where Fe^{2+} ions are products.**
(D)	This option is incorrect. It states the exact opposite of what would occur (see option C).

Question 48

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.16 The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), and calculate the pH and concentration of all species in the solution and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations.

(A)	**This option is correct. It correctly identifies that Acid 1 is a weak acid, and that it must have the lowest acid-dissociation constant since it has the highest pH (closest to neutral) at each of the provided concentrations.**
(B)	This option is incorrect. The pH values provided for this acid reflect the behavior of a strong acid using the relationship $pH = -\log[H_3O^+]$.
(C)	This option is incorrect. While the data on Acid 3 is consistent with a weak acid, the pH is lower than Acid 1 at all concentrations, indicating a greater degree of ionization than Acid 1.
(D)	This option is incorrect. While the data on Acid 4 is consistent with a weak acid, the pH is fairly close to Acid 2, indicating that it has a larger K_a value than Acid 1.

Practice Exam

Question 49

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	6.12 The student can reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration.
(A)	This option is incorrect. The pH values provided for various concentrations of Acid 1 are not reflective of a strong acid.
(B)	**This option is correct. It is based on recognition that HCl is a strong acid and reasoning that in every case the concentration of Acid 2 is equal to the H_3O^+ ion concentration, indicating 100 percent dissociation.**
(C)	This option is incorrect. The pH values provided for various concentrations of Acid 3 are not reflective of a strong acid.
(D)	This option is incorrect. The pH values provided for various concentrations of Acid 4 are not reflective of a strong acid.

Question 50

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.17 The student can, given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine which species will react strongly with one another (i.e., with $K > 1$), and what species will be present in large concentrations at equilibrium.
(A)	This option is incorrect. The pH value provided for the 1.0 *M* solution of Acid 1 indicates that the $[OH^-]$ is many orders of magnitude less than any of the other substances in solution.
(B)	This option is incorrect. The pH value provided for the 1.0 *M* solution of Acid 1 indicates that the $[H_3O^+]$ is more than one order of magnitude less than 1.0 *M*.
(C)	**This option is correct. It correctly determines that Acid 1 is a weak acid, which has a small degree of ionization. In the 1.0 *M* solution, the protonated form of the acid will have the highest concentration.**
(D)	This option is incorrect. The conjugate base for the acid would have an equal concentration to the $[H_3O^+]$, which is more than one order of magnitude less than 1.0 *M*.

Question 51

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	6.12 The student can reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration.

(A)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(B)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(C)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(D)	**This option is correct. Since the concentrations of the acids are identical, the same volume of base is required to reach the equivalence point.**

Question 52

Essential Knowledge	6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.20 The student can identify a solution as being a buffer solution and explain the buffer mechanism in terms of the reactions that would occur on addition of acid or base.

(A)	This option is incorrect. The pH does not change much because the solution is a buffer.
(B)	This option is incorrect. The pH does not change much because the solution is a buffer.
(C)	**This option is correct. Acid 1 is a weak acid because the starting pH is higher than expected for complete dissociation. The added base converts half of the weak acid to its conjugate base, creating a buffer solution. If concentrated acid is added to the buffer solution, the acid reacts with the conjugate base, thereby keeping the pH roughly constant.**
(D)	This option is incorrect. The dominant species in solution are the weak acid and its conjugate base. There is very little OH^- ion in the buffer solution.

Practice Exam

Question 53

Essential Knowledge	4.D.2 Important classes in catalysis include acid-base catalysis, surface catalysis, and enzyme catalysis.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	4.9 The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present.

(A)	**This option is correct. Cl(*g*) is a catalyst for the reaction. The presence of Cl(*g*) decreases the activation energy and increases the rate.**
(B)	This option is incorrect. Cl(*g*) does not decrease the rate as it promotes the decomposition of ozone.
(C)	This option is incorrect. The equilibrium constant does not change with addition of a reactant, nor does the equilibrium constant have to do with overall reaction rate.
(D)	This option is incorrect. The equilibrium constant does not change with addition of a reactant, nor does the equilibrium constant have to do with overall reaction rate.

Question 54

Big Idea	2 Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	2.1 Students can predict properties of substances based on their chemical formulas and provide explanations of their properties based on particle views.

(A)	**This option is correct. The Cl^- ion is larger than the F^- ion so the attractive interactions in NaCl are weaker than in NaF.**
(B)	This option is incorrect. The bonding is weaker in NaCl and it is ionic, not covalent.
(C)	This option is incorrect. The ions are spaced farther apart in NaCl compared with MgO, but this makes the bonding weaker and the boiling point for NaCl lower.
(D)	This option is incorrect. The boiling point for NaCl is lower. Moreover, more energy is required to transfer two electrons from Mg to O than to transfer one electron from Na to Cl.

Question 55

Essential Knowledge	6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	6.18 The student can design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity.

(A)	This option is incorrect. This solution would not be a buffer solution.
(B)	This option is incorrect. The pK_a of $HC_3H_5O_2$ is not close to 7.5.
(C)	**This option is correct. The pK_a of HClO is close to 7.5.**
(D)	This option is incorrect. The pK_a of C_6H_5OH is not close to 7.5.

Question 56

Essential Knowledge	2.A.3 Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	2.9 The student is able to create or interpret representations that link the concept of molarity with particle views of solutions.

(A)	This option is incorrect. The solution in Z is the most dilute. The number of ions per volume is the smallest, contradicting that the concentrations of $Mg(NO_3)_2$ is 4.0 *M*.
(B)	This option is incorrect. The metal ion concentrations are not equal in all three solutions.
(C)	This option is incorrect. The relationship of concentrations in X and Y are correct, but the concentration of Mg^{2+} is not equal in Y and Z. The number of ions is equal, but the volume is twice as large in Z.
(D)	**This option is correct. The concentration of Mg^{2+} in Y is half the concentration of Ag^{+} in X. The concentration of Mg^{2+} in Z is half of what it is in Y because the volume doubled.**

Question 57

Essential Knowledge	4.A.2 The rate law shows how the rate depends on reactant concentrations.
Science Practice	5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	4.2 The student is able to analyze concentration versus time data to determine the rate law for a zeroth-, first-, or second-order reaction.

(A)	This option is incorrect. A plot of [A] versus *t* is not a straight line.
(B)	**This option is correct. A plot of ln[A] versus *t* is a straight line.**
(C)	This option is incorrect. A plot of 1/[A] versus *t* is not a straight line.
(D)	This option is incorrect. The linearity of the plot of ln[A] versus *t* suggests the reaction order is 1, not 3.

Question 58

Essential Knowledge	1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model.

(A)	This option is incorrect. The ionization energy of potassium is smaller than that of calcium.
(B)	**This option is correct. Potassium is larger than calcium because it has a smaller effective nuclear charge. Because potassium is larger, less energy is required to remove an electron from it than is required to remove an electron from calcium.**
(C)	This option is incorrect. The relative radii and ionization energies of potassium and calcium are both incorrect.
(D)	This option is incorrect. The atomic radius of potassium is larger than that of calcium.

Question 59

Essential Knowledge	2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles.

(A)	This option is incorrect. The accommodation of bond angles does not account for differences in bond lengths.
(B)	**This option is correct. There is a shorter covalent bond between H and F within the molecules and longer hydrogen bond between the H in one molecule and the F in a second molecule.**
(C)	This option is incorrect. Different isotopes do not cause significant differences in bond lengths.
(D)	This option is incorrect. Repulsions between nonbonding pairs of electrons do not account for differences in bond lengths.

Question 60

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K.

(A)	This option is incorrect. See option B.
(B)	**This option is correct. Each molecule of $COCl_2$ that decomposes creates two moles of gas. When the number of moles of $COCl_2$ decreases such that the pressure is 0.8 atm, there is 0.2 mol of each of the product gas. The equilibrium constant $K = (0.2)(0.2)/(0.8) = 0.050$.**
(C)	This option is incorrect. See option B.
(D)	This option is incorrect. See option B. This assumes that K_p is equal to the original pressure in the flask.

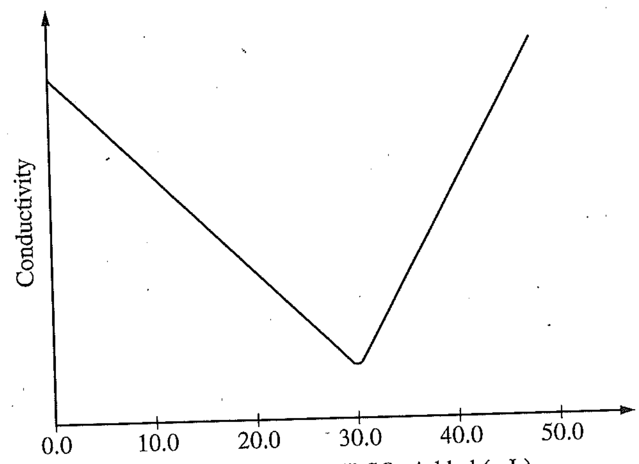
Practice Exam

Answers to Multiple-Choice Questions

1 – C	18 – D	35 – C	52 – C
2 – C	19 – B	36 – B	53 – A
3 – A	20 – C	37 – A	54 – A
4 – A	21 – A	38 – C	55 – C
5 – D	22 – D	39 – A	56 – D
6 – D	23 – D	40 – A	57 – B
7 – B	24 – D	41 – C	58 – B
8 – D	25 – C	42 – C	59 – B
9 – B	26 – B	43 – D	60 – B
10 – C	27 – D	44 – C	
11 – B	28 – C	45 – B	
12 – B	29 – C	46 – C	
13 – C	30 – C	47 – C	
14 – A	31 – B	48 – A	
15 – B	32 – B	49 – B	
16 – C	33 – B	50 – C	
17 – B	34 – C	51 – D	

Scoring Guidelines for Free-Response Question 1

Question 1
(10 Points)



A student performs an experiment in which the conductivity of a solution of $Ba(OH)_2$ is monitored as the solution is titrated with 0.10 M H_2SO_4. The original volume of the $Ba(OH)_2$ solution is 25.0 mL. A precipitate of $BaSO_4$ ($K_{sp} = 1.0 \times 10^{-10}$) formed during the titration. The data collected from the experiment are plotted in the graph above.

(a) As the first 30.0 mL of 0.10 M H_2SO_4 are added to the $Ba(OH)_2$ solution, two types of chemical reactions occur simultaneously. On the lines provided below, write the balanced net-ionic equations for (i) the neutralization reaction and (ii) the precipitation reaction.

(i) Equation for neutralization reaction: ______________________________

(ii) Equation for precipitation reaction: ______________________________

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	1 point is earned for <u>each</u> correct product. 1 point is earned for the correct reactants with atoms <u>and</u> charges balanced in <u>both</u> reactions.

(b) The conductivity of the $Ba(OH)_2$ solution decreases as the volume of added 0.10 M H_2SO_4 changes from 0.0 mL to 30.0 mL.

(i) Identify the chemical species that enable the solution to conduct electricity as the first 30.0 mL of 0.10 M H_2SO_4 are added.

$Ba^{2+}(aq)$ and/or $OH^-(aq)$	1 point is earned for either ion.

(ii) On the basis of the equations you wrote in part (a), explain why the conductivity decreases.

As the titration approaches the equivalence point, $Ba^{2+}(aq)$ ions are removed from solution by the precipitation reaction, <u>and</u> $OH^-(aq)$ ions are removed from solution by the neutralization reaction.	1 point is earned for each correct explanation. <u>Note</u>: response must refer to <u>both</u> reactions for full credit.

(c) Using the information in the graph, calculate the molarity of the original $Ba(OH)_2$ solution.

moles $Ba(OH)_2$ = moles H_2SO_4 (at equivalence point) moles $H_2SO_4 = \frac{0.10 \text{ mol}}{1.0 \text{ L}} \times 0.030 \text{ L} = 0.0030 \text{ mol}$ $[Ba(OH)_2] = \frac{\text{mol } Ba(OH)_2}{\text{volume of original solution}} =$ $\frac{0.0030 \text{ mol}}{0.025 \text{ L}} = 0.12\ M$	1 point is earned for the correct determination of the number of moles of titrant added at the equivalence point (can be implicit). 1 point is earned for the correct calculation of the original concentration of $Ba(OH)_2(aq)$.

(d) Calculate the concentration of $Ba^{2+}(aq)$ in the solution at the equivalence point (after exactly 30.0 mL of 0.10 M H_2SO_4 are added).

$K_{sp} = [Ba^{2+}] \times [SO_4^{2-}] = 1.0 \times 10^{-10}$ $[Ba^{2+}] = [SO_4^{2-}]$ $[Ba^{2+}] = \sqrt{1.0 \times 10^{-10}} = 1.0 \times 10^{-5}\ M$	1 point is earned for the correct calculation based on K_{sp}.

(e) The concentration of $Ba^{2+}(aq)$ in the solution decreases as the volume of added 0.10 M H_2SO_4 increases from 30.0 mL to 31.0 mL. Explain.

Because of the common ion effect, adding sulfate ions to an equilibrium reaction involving sulfate ions will cause the reaction to consume the added ions as a new equilibrium is established. Consequently, more $BaSO_4(s)$ is formed, causing the $Ba^{2+}(aq)$ concentration to decrease.	1 point is earned for a correct explanation, which must use an equilibrium argument (for example, citing the common ion effect or Le Chatelier's principle) rather than a stoichiometric argument.

Question 2
(10 Points)

A student is given the task of determining the enthalpy of reaction for the reaction between $HCl(aq)$ and $NaOH(aq)$. The following materials are available.

1.00 *M* $HCl(aq)$	1.00 *M* $NaOH(aq)$	distilled water
2.00 *M* $HCl(aq)$	2.00 *M* $NaOH(aq)$	goggles
insulated cups with covers	gloves	lab coat
thermometer (± 0.1°C)	stirring rod	

The student may select from the glassware listed in the table below.

Glassware Items	Precision
250 mL Erlenmeyer flasks	± 25 mL
100 mL beakers	± 10 mL
100 mL graduated cylinders	± 0.1 mL

(a) The student selects two 100 mL beakers, uses them to measure 50 mL each of 1.00 *M* $HCl(aq)$ solution and 1.00 *M* $NaOH(aq)$ solution, and measures an initial temperature of 24.5°C for each solution. Then the student pours the two solutions into an insulated cup, stirs the mixture, covers the cup, and records a maximum temperature of 29.9°C.

(i) Is the experimental design sufficient to determine the enthalpy of reaction to a precision of two significant figures? Justify your answer.

No. The use of the beakers to measure 50 mL ±10 mL of solutions limits the precision of the volume measurements and of the calculations to ±20% or 1 significant figure.	1 point is earned for the correct answer with the correct explanation.

(ii) List two specific changes to the experiment that will allow the student to determine the enthalpy of reaction to a precision of three significant figures. Explain.

Use graduated cylinders to measure the volumes of acid and base allowing a volume precision of ±0.1 mL or 3 significant figures for a volume of 50.0 mL. AND Use the 2.00 *M* HCl and 2.00 *M* NaOH solutions (instead of 1.00 *M*) to get a larger ΔT, thereby improving the relative precision in ΔT to ±1%.	1 point is earned for the change of glassware to graduated cylinders with a proper explanation. 1 point is earned for using the 2.00 *M* solutions for improved relative precision in temperature. Note: doubling the volumes will not increase ΔT or significantly improve volume precision.

(b) A second student is given two solutions, 75.0 mL of 1.00 *M* HCl and 75.0 mL of 1.00 *M* NaOH, each at 25.0°C. The student pours the solutions into an insulated cup, stirs the mixture, covers the cup, and records the maximum temperature of the mixture.

(i) The student calculates the amount of heat evolved in the experiment to be 4.1 kJ. Calculate the student's experimental value for the enthalpy of reaction, in kJ/mol_{rxn}.

$75.0 \text{ mL} \times \dfrac{1.00 \text{ mol HCl (or NaOH)}}{1000 \text{ mL}} = 0.0750 \text{ mol HCl (or NaOH)}$	1 point is earned for the correct calculation of moles of reactants.
$\Delta H = \dfrac{-4.1 \text{ kJ}}{0.0750 \text{ mol of reactants}} = -55 \text{ kJ/mol}_{rxn}$	1 point is earned for the correct substitution and answer.

(ii) The student assumes that the thermometer and the calorimeter do not absorb energy during the reaction. Does this assumption result in a calculated value of the enthalpy of reaction that is higher than, lower than, or the same as it would have been had the heat capacities of the thermometer and calorimeter been taken into account? Justify your answer.

The calculated value of the enthalpy of reaction will be lower (smaller or less negative) than it would have been had the thermometer and calorimeter been taken into account.	1 point is earned for the correct prediction.
The thermometer and calorimeter will absorb some of the heat of reaction. This lost heat is ignored in the original calculation of ΔH_{rxn}, making it smaller in magnitude (less negative). OR The actual heat capacity of the system is the sum of the heat capacities of the water, thermometer, and calorimeter. The assumed heat capacity of the system (water only) is less than the actual value, resulting in a lower (less negative) calculated value of ΔH_{rxn}.	1 point is earned for an acceptable justification.

(iii) One assumption in interpreting the results of the experiment is that the reaction between HCl(*aq*) and NaOH(*aq*) goes to completion. Justify the validity of this assumption in terms of the equilibrium constant for the reaction.

$H^+ + OH^- \rightarrow H_2O$, the reaction between HCl(*aq*) and NaOH(*aq*), is the reverse of $H_2O \rightarrow H^+ + OH^-$, the autoionization of water (for which $K = K_w = 1.0 \times 10^{-14}$). Thus the value of K for the neutralization reaction is the reciprocal of K_w, or 1.0×10^{14}, a very large number. Thus the neutralization reaction goes virtually to completion.	1 point is earned for the correct justification.

Practice Exam

(c) A third student calculates a value for the enthalpy of reaction that is significantly higher than the accepted value.

(i) Identify a specific error in procedure made by the student that will result in a calculated value for the enthalpy of reaction that is higher than the accepted value. (Vague statements like "human error" or "incorrect calculations" will not earn credit.)

The student read the thermometer incorrectly in such a way to result in a calculated value of ΔT that was too high (either read T_i too low or read T_f too high). OR The student mistakenly used 2.00 *M* acid and 2.00 *M* base, thinking they were both 1.00 *M*.	1 point is earned for an acceptable procedural error that results in a higher calculated value.

(ii) Explain how the error that you identified in part (c)(i) leads to a calculated value for the enthalpy of reaction that is higher than the accepted value.

The calculation of the molar enthalpy of reaction may be expressed as $\text{Molar } \Delta H_{rxn} = -\dfrac{\text{mass}_{soln} \times c \times \Delta T}{n_{rxn}}$. If there is a measurement error that results in a ΔT that is too high, the magnitude (i.e., the absolute value) of the calculated molar enthalpy of reaction will be too high.	1 point is earned for an explanation that is consistent with the stated procedural error.

Question 3
(10 Points)

$$SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g)$$

A 4.32 g sample of liquid SO_2Cl_2 is placed in a rigid, evacuated 1.50 L reaction vessel. As the container is heated to 400. K, the sample vaporizes completely and starts to decompose according to the equation above. The decomposition reaction is endothermic.

(a) If no decomposition occurred, what would be the pressure, in atm, of the $SO_2Cl_2(g)$ in the vessel at 400. K ?

Assuming no decomposition, $\text{moles}_{SO_2Cl_2} = \frac{m}{M} = \frac{4.32\text{ g}}{134.96\text{ g/mol}} = 0.0320\text{ mol}$ $P_{SO_2Cl_2} = \frac{nRT}{V} = \frac{(0.0320\text{ mol})(0.0821\text{ L·atm/mol·K})(400.\text{ K})}{1.50\text{ L}}$ $= 0.701$ atm	1 point is earned for the correct calculation of moles of SO_2Cl_2 (may be implicit). 1 point is earned for the correct calculation of the pressure.

(b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ in the container at 400. K.

Pressures at equilibrium at 400. K: $SO_2Cl_2(g) \rightarrow SO_2(g) + Cl_2(g)$ Total $0.701 - x$ x x $0.701 + x$ $P_{total} = 0.701 + x = 1.26$ atm $x = P_{SO_2} = P_{Cl_2} = 0.56$ atm $P_{SO_2Cl_2} = 0.701 - x = 0.14$ atm	1 point is earned for the correct setup. 1 point is earned for the correct calculation of pressures.

(c) For the decomposition reaction at 400. K,

(i) write the equilibrium-constant expression for K_p for the reaction, and

$K_p = \frac{P_{SO_2} \cdot P_{Cl_2}}{P_{SO_2Cl_2}}$	1 point is earned for the correct K_p expression. <u>Note</u>: the pressure subscripts must be specific (i.e., SO_2, Cl_2, and SO_2Cl_2 — NOT, e.g., A, B, C, and D).

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

$K_p = \frac{(0.56)(0.56)}{0.14} = 2.2$	1 point is earned for the correct calculation of K_p that is consistent with the K_p expression stated in part (c)(i) and with the partial pressures calculated in part (b).

(d) The temperature of the equilibrium mixture is increased to 425 K. Will the value of K_p increase, decrease, or remain the same? Justify your prediction.

At a higher temperature, K_p will increase. According to Le Chatelier's principle, raising the temperature of an endothermic reaction at equilibrium adds a thermal stress that increases the value of K_p and produces more products.	1 point is earned for the correct prediction. 1 point is earned for a proper justification in terms of Le Chatelier's principle.

(e) In another experiment, the original partial pressures of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ are 1.0 atm each at 400. K. Predict whether the amount of $SO_2Cl_2(g)$ in the container will increase, decrease, or remain the same. Justify your prediction.

The amount of SO_2Cl_2 in the container will decrease. Initially $Q_p = 1.0 < 2.2. = K_p$, thus the reaction will consume SO_2Cl_2 as it proceeds in the forward direction to reestablish equilibrium.	1 point is earned for the correct prediction. 1 point is earned for an acceptable justification. Note: the justification must consider the relative values of Q_p and K_p.

Practice Exam

Scoring Guidelines for Free-Response Question 4

Question 4
(4 Points)

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

It is proposed that the reaction represented above proceeds via the mechanism represented by the two elementary steps shown below.

Step I:	$NO_2 + F_2 \rightarrow NO_2F + F$	*(slow)*
Step II:	$NO_2 + F \rightleftarrows NO_2F$	*(fast reversible)*

(a) Step I of the proposed mechanism involves the collision between NO_2 and F_2 molecules. This step is slow even though such collisions occur very frequently in a mixture of $NO_2(g)$ and $F_2(g)$. Consider a specific collision between a molecule of NO_2 and a molecule of F_2.

(i) One factor that affects whether the collision will result in a reaction is the magnitude of the collision energy. Explain.

Successful molecular collisions must have sufficient energy in order to result in reaction. Only collisions with sufficient energy to overcome the activation energy barrier, E_a, will be able to reach the transition state and begin to break the F–F bond.	1 point is earned for a correct explanation that makes reference to the <u>activation energy</u> of the reaction.

(ii) Identify and explain one other factor that affects whether the collision will result in a reaction.

For a collision to be successful, the molecules must have the correct orientation.	1 point is earned for identifying the relative <u>orientation</u> of the colliding molecules.
Only collisions with the correct orientation will be able to begin to form an N–F bond and begin to break an F–F bond as the transition state is approached (that is, the molecules must contact each other at very specific locations on their surfaces for the transition state to be accessible).	1 point is earned for an explanation that makes reference to <u>specific parts</u> (atoms or bonds) of the reacting molecules.

(b) Consider the following potential rate laws for the reaction. Circle the rate law below that is consistent with the mechanism proposed above. Explain the reasoning behind your choice in terms of the details of the elementary steps of the mechanism.

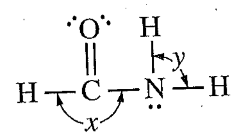
rate = $k[NO_2]^2[F_2]$ rate = $k[NO_2][F_2]$

The rate law that is consistent with the mechanism is the one on the right above (rate = $k[NO_2][F_2]$). Step I is the slower step and the rate-determining step in the mechanism. Since Step I is an elementary reaction, its rate law is given by the stoichiometry of the reacting molecules, $rate_{Step\ I} = k_1[NO_2][F_2]$.	1 point is earned for identifying the correct rate law with a proper explanation. The explanation must correlate the <u>overall rate law</u> with the <u>rate law derived</u> from the stoichiometry of the slow step in the mechanism. <u>Note</u>: a statement relating the <u>coefficients</u> of the reactants in Step I to the <u>exponents</u> in the rate law indicates a correct understanding.

Question 5
(4 Points)

Methanamide, CH_3NO, is a liquid at 25°C.

(a) The complete Lewis electron-dot diagram for methanamide is shown below.



(i) In the molecule, angle x is not 180°. Estimate the observed angle. Justify your answer.

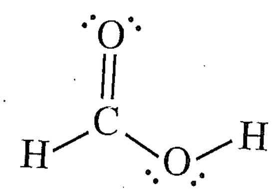
Angle x is approximately 120°. Three electron domains around the carbon atom will maximally separate the electrons and minimize the energy when the bond angles are 120°.	1 point is earned for the correct angle with justification. <u>Note</u>: accept 120° ± 10° for the angle (i.e., $110° \le x \le 130°$.) Also accept steric number (SN) = 3 or trigonal planar geometry for the justification in part (i) only.)

(ii) In the molecule, angle y is not 90°. Explain why in terms of electron domains (VSEPR model).

Angle y is approximately 109.5°. Four electron domains around the nitrogen atom will maximally separate the electrons and minimize the energy when the bond angles are 109.5°. OR Angle y is approximately 120°. Considering possible resonance structures involving a double bond between the C and N atoms, there are three electron domains around the nitrogen atom. In this case, minimization of energy leads to bond angles of approximately 120°.	1 point is earned for the correct justification for an angle different than 90°. <u>Note</u>: the justification need not give a specific bond angle, but it must mention the repulsion of 4 electron domains (or 3 electron domains, if resonance structures are mentioned).

Practice Exam

(b) Consider a molecule with the formula CH_2O_2. The structure of this molecule has a geometry around the carbon atom similar to the geometry around carbon in methanamide. In the box provided below, draw the complete Lewis electron-dot diagram for the molecule.



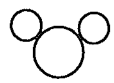
2 points are earned for a correct Lewis electron-dot diagram for formic acid.

Notes: 1 point is earned for the correct skeletal structure for formic acid with the C=O double bond (i.e., containing all five bonding pairs) but missing one or more lone pairs.

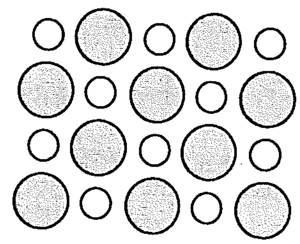
Also, 1 point is earned for a Lewis electron-dot diagram representing

(i) the correct molecular formula (CH_2O_2)
(ii) with three electron domains and at least three bonded pairs of electrons around the carbon atom, with no more than three bonded pairs of electrons around any oxygen atom, and
(iii) the proper distribution of all 18 electrons in accordance with the octet rule.

Question 6
(4 Points)



H_2O molecule

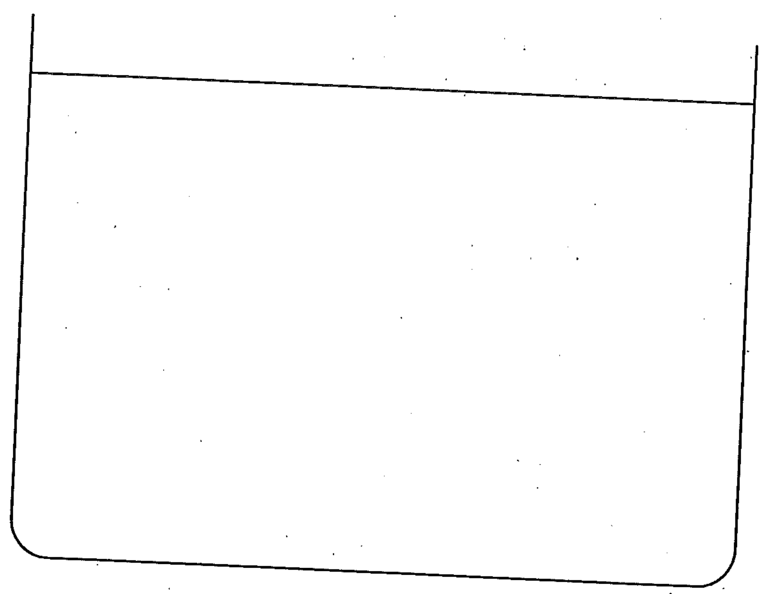


LiCl crystal

The structures of a water molecule and a crystal of LiCl(*s*) are represented above. A student prepares a 1.0 *M* solution by dissolving 4.2 g of LiCl(*s*) in enough water to make 100 mL of solution.

(a) In the space provided below, show the interactions of the components of LiCl(*aq*) by making a drawing that represents the different particles present in the solution. Base the particles in your drawing on the particles shown in the representations above. Include only one formula unit of LiCl and no more than ten molecules of water. Your drawing must include the following details.

- identity of ions (symbol and charge)
- the arrangement and proper orientation of the particles in the solution



LiCl (*aq*)

The sketch should clearly show: 1. a clear representation of at least one Li^+ ion and one Cl^- ion separated from each other, labeled, and charged; 2. each ion surrounded by at least two H_2O molecules; and 3. H_2O molecules with the proper orientation around each ion (i.e., the oxygen end of the water molecules closer to the lithium ion and the hydrogen end of the water molecules closer to the chloride ion).	1 point is earned for a correctly drawn and labeled particulate representation of the ions. (Representation must indicate that the smaller ion is Li^+. Representations that include more than one formula unit of LiCl (dissolved or undissolved) are acceptable as long as at least one of the formula units is separated into its ions and the ions are correctly labeled with their respective identities and charges.) 1 point is earned for a correctly drawn particulate representation of water molecules of hydration surrounding the ions. 1 point is earned for correctly representing the orientation of the water molecules of hydration with the proper polarity.

(b) The student passes a direct current through the solution and observes that chlorine gas is produced at the anode. Identify the chemical species produced at the cathode and justify your answer using the information given in the table below.

Half-reaction	Standard Reduction Potential at 25°C (V)
$Li^+(aq) + e^- \rightarrow Li(s)$	– 3.05
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$	– 0.83

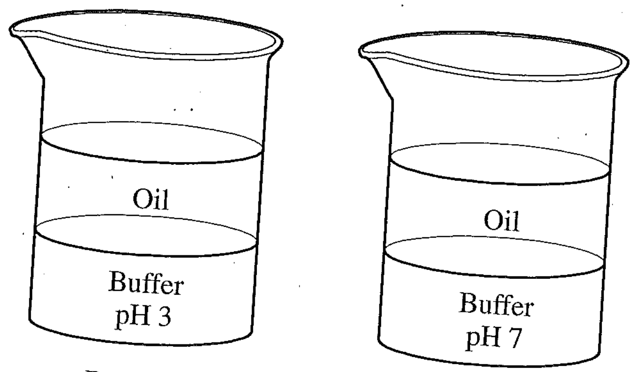
$H_2(g)$ and $OH^-(aq)$ The hydrogen atoms in H_2O are reduced to H_2 at the cathode because this reaction has a higher (more favorable or less negative) standard reduction potential than the reduction of lithium ions to $Li(s)$.	1 point is earned for correctly identifying either of the chemical species produced at the cathode with the proper justification. <u>Note</u>: the justification must clearly indicate that "higher" means "less negative." A "lower magnitude" negative value also earns the point.

Practice Exam

Question 7
(4 Points)

$$\underset{yellow}{HIn(aq)} + H_2O(l) \rightleftarrows \underset{blue}{In^-(aq)} + H_3O^+(aq)$$

The indicator HIn is a weak acid with a pK_a value of 5.0. It reacts with water as represented in the equation above. Consider the two beakers below. Each beaker has a layer of colorless oil (a nonpolar solvent) on top of a layer of aqueous buffer solution. In beaker X the pH of the buffer solution is 3, and in beaker Y the pH of the buffer solution is 7. A small amount of HIn is placed in both beakers. The mixtures are stirred well, and the oil and water layers are allowed to separate.



Beaker X Beaker Y

(a) What is the predominant form of HIn in the aqueous buffer in beaker Y, the acid form or the conjugate base form? Explain your reasoning.

The conjugate base form, $In^-(aq)$, is the predominant form of the indicator in the aqueous pH 7 buffer in beaker Y. This is because the pH is greater than the pK_a of HIn, causing the equilibrium to form a significant amount of products, $In^-(aq)$ and $H_3O^+(aq)$.	1 point is earned for correctly identifying $In^-(aq)$ as the predominant form in the aqueous layer of beaker Y because the solution is not acidic (may be implicit). 1 point is earned for stating that pH > pK_a and that this causes the equilibrium to favor the products.

(b) In beaker X the oil layer is yellow, whereas in beaker Y the oil layer is colorless. Explain these observations in terms of both acid-base equilibria and interparticle forces.

At pH 3 the acid form $HIn(aq)$ predominates in the aqueous layer of beaker X because pH < pK_a. Since $HIn(aq)$ is a neutral molecule, some of it can dissolve in the oil layer of beaker X because of London dispersion interactions with the oil, causing the oil layer to be yellow.	1 point is earned for explaining the yellow color in the oil layer of beaker X in terms of acid-base equilibrium and interparticle forces between HIn molecules and oil molecules.
Since $In^-(aq)$ is charged, it will preferentially dissolve in the aqueous layer of beaker Y because of ion-dipole interactions with the water, leaving the oil layer colorless.	1 point is earned for explaining the colorless oil layer of beaker Y in terms of interparticle forces between In^- ions and water molecules.