

CHEMISTRY

SECTION I

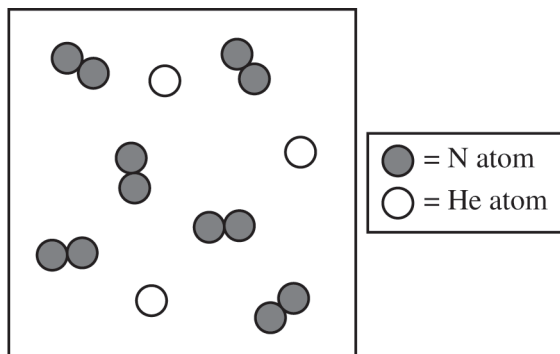
Time—1 hour and 30 minutes

60 Questions

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

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

1. The ratio of gases in a mixture of $\text{N}_2(g)$ and $\text{He}(g)$ is represented by the following particle diagram.



What is the mole fraction of N_2 in this sample of gas?

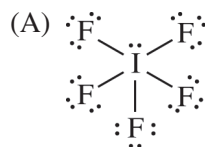
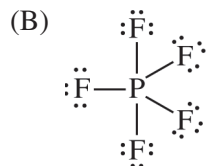
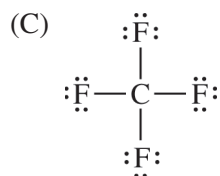
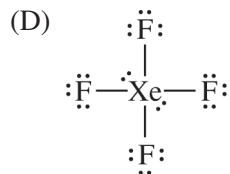
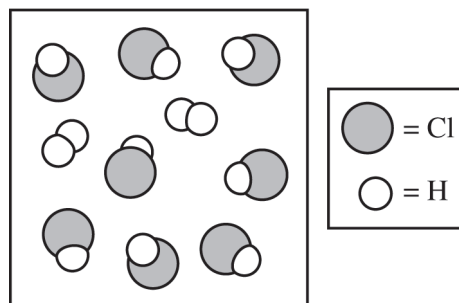
- (A) 0.33
- (B) 0.50
- (C) 0.67
- (D) 0.80

Trial	Completion Time (seconds)
1	37
2	59

2. A student performed an experiment to study the rate of reaction between solid magnesium, $\text{Mg}(s)$, and aqueous hydrochloric acid, $\text{HCl}(aq)$. The student conducted two trials under different experimental conditions, using 0.10 mol of $\text{Mg}(s)$ and 1.00 mol of $\text{HCl}(aq)$ in each trial. Which of the following changes in conditions could account for the difference in the time for the reaction to go to completion in trial 1 and trial 2?
- (A) The mixture of reactants was stirred in trial 2, but not in trial 1.
 - (B) The temperature of the hydrochloric acid was higher in trial 2.
 - (C) The concentration of the hydrochloric acid was greater in trial 2.
 - (D) The solid magnesium was a fine powder in trial 1 but a single chunk in trial 2.

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3. Which of the following represents a molecule with a trigonal bipyramidal geometry?



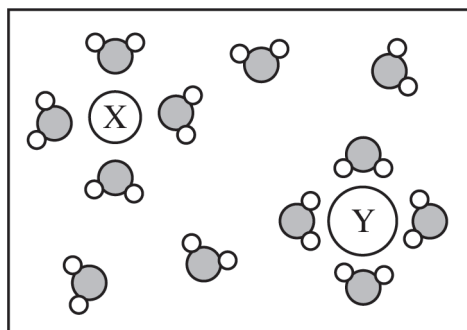
4. The diagram represents a mixture that results when samples of $\text{Cl}_2(g)$ and $\text{H}_2(g)$ are combined and react, producing $\text{HCl}(g)$. Which of the following identifies the limiting reactant and provides the best justification?

- (A) H_2 , because there is unreacted H_2 present.
- (B) H_2 , because it has a smaller molar mass than Cl_2 .
- (C) Cl_2 , because there is no unreacted Cl_2 present.
- (D) Cl_2 , because it has a larger molar mass than H_2 .

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5. A rigid container holds 0.50 mol of $\text{Ar}(g)$ and 0.75 mol of $\text{O}_2(g)$. How will the total pressure of the gases in the container and the partial pressure of $\text{O}_2(g)$ be affected by the addition of 0.25 mol of $\text{He}(g)$ at constant temperature?
- (A) Both the total pressure and the partial pressure of $\text{O}_2(g)$ will remain constant.
(B) Both the total pressure and the partial pressure of $\text{O}_2(g)$ will increase.
(C) The total pressure will increase, and the partial pressure of $\text{O}_2(g)$ will decrease.
(D) The total pressure will increase, and the partial pressure of $\text{O}_2(g)$ will remain constant.
6. The ideal gas law best describes the properties of which of the following gases at 0°C and 1 atm ?
- (A) O_2
(B) CF_4
(C) SO_2
(D) SF_6
7. Gallium, Ga, reacts with chlorine gas to produce gallium(III) chloride. When the equation for the reaction is balanced with lowest whole-number coefficients, the coefficient for gallium is
- (A) 1
(B) 2
(C) 3
(D) 4

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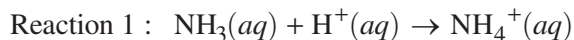
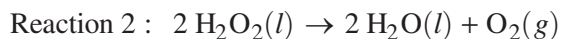


8. The diagram shown represents water molecules () as they interact with two ions, X and Y, in solution. Which of the following best identifies ions X and Y ?

	X	Y
A	Ba^{2+}	Cl^{-}
B	Cl^{-}	S^{2-}
C	S^{2-}	Na^{+}
D	Ba^{2+}	Na^{+}

- (A) A
(B) B
(C) C
(D) D

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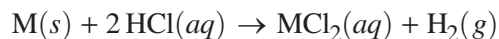


9. Which of the following statements about the reactions represented above is true?

- (A) Reaction 1 cannot be a redox reaction because total charge is conserved.
- (B) Reaction 1 is a redox reaction because the nitrogen atom transfers electrons to the H^+ ion.
- (C) Reaction 2 cannot be a redox reaction because both the reactant and the products have neutral charge.
- (D) Reaction 2 is a redox reaction because there is a transfer of electrons between the oxygen atoms.

10. Which of the following compounds has the strongest Coulombic attractions between its ions in the solid state?

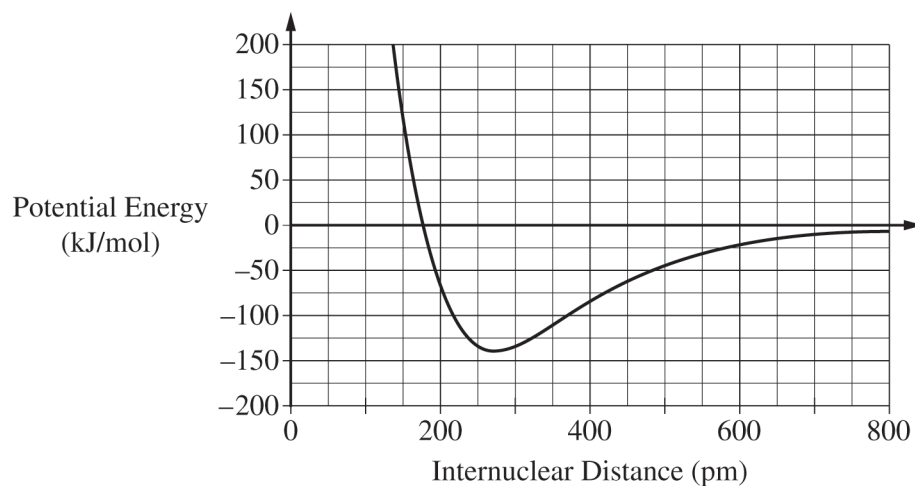
- (A) MgO
- (B) CaO
- (C) MgCl_2
- (D) CaCl_2



11. A student weighs a sample of a group 2 metal, M, and adds it to excess $\text{HCl}(aq)$ to react as represented in the equation. The student measures the volume of $\text{H}_2(g)$ produced by collecting the gas over water at 1.00 atm and 298 K, and uses the volume to calculate the moles of $\text{H}_2(g)$. Which of the following questions is most likely to be answered as a result of the experiment?

- (A) What is the value of ΔH_{rxn}° ?
- (B) What is the density of metal M ?
- (C) What is the molar mass of metal M ?
- (D) What is the value of the specific heat of metal M ?

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12. The graph shows the potential energy of two atoms as a function of internuclear distance. What is the approximate bond energy?
- (A) 140 kJ/mol
(B) 170 kJ/mol
(C) 200 kJ/mol
(D) 270 kJ/mol

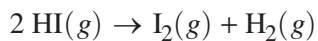
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Half-Reaction	E°
$\text{Ni}^{2+} + 2 e^- \rightarrow \text{Ni}$	-0.28 V
$\text{Fe}^{2+} + 2 e^- \rightarrow \text{Fe}$	-0.44 V
$\text{Cr}^{3+} + 3 e^- \rightarrow \text{Cr}$	-0.74 V

13. Based on the reduction potentials in the table, which of the following reactions is thermodynamically favorable?

- (A) $3 \text{ Ni}(s) + 2 \text{ Cr}^{3+}(aq) \rightarrow 3 \text{ Ni}^{2+}(aq) + 2 \text{ Cr}(s)$
- (B) $3 \text{ Fe}(s) + 2 \text{ Cr}^{3+}(aq) \rightarrow 3 \text{ Fe}^{2+}(aq) + 2 \text{ Cr}(s)$
- (C) $3 \text{ Ni}^{2+}(aq) + 2 \text{ Cr}(s) \rightarrow 3 \text{ Ni}(s) + 2 \text{ Cr}^{3+}(aq)$
- (D) $3 \text{ Fe}^{2+}(aq) + 2 \text{ Ni}(s) \rightarrow 3 \text{ Fe}(s) + 2 \text{ Ni}^{2+}(aq)$

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14. The decomposition of $\text{HI}(g)$ into $\text{I}_2(g)$ and $\text{H}_2(g)$ is represented by the equation. The reaction is second order with respect to $\text{HI}(g)$. Assuming all other conditions are held constant, which initial concentration of $\text{HI}(g)$ will result in an initial rate of formation of $\text{H}_2(g)$ that is 16 times higher than that in trial 1, as shown in the table?

Trial	Initial $[\text{HI}]$	Rate of Formation of $\text{H}_2(g)$
1	0.20 M	x
2	?	$16x$

- (A) 0.40 M
(B) 0.80 M
(C) 1.6 M
(D) 3.2 M

15. A pure sample of which of the following compounds has the highest boiling point?

- (A) LiCl
(B) Cl_2
(C) PCl_3
(D) CCl_4

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Questions 16 - 18 refer to the following information.



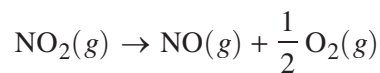
When a 0.64 g sample of $\text{CaC}_2(s)$ (molar mass 64 g/mol) is added to 100. mL of water at 25°C in a calorimeter, all of the $\text{CaC}_2(s)$ reacts with water as represented by the equation.

16. Which of the following is true of the reaction system when 0.64 g of $\text{CaC}_2(s)$ reacts?
- (A) 1.3 kJ of energy is absorbed.
 - (B) 1.3 kJ of energy is released.
 - (C) 82 kJ of energy is absorbed.
 - (D) 82 kJ of energy is released.
17. Which of the following statements about the thermodynamic favorability of the reaction at 25°C is correct?
- (A) The high activation energy results in the reaction being thermodynamically unfavorable.
 - (B) Only the ΔH° of the reaction contributes to the reaction being thermodynamically favorable.
 - (C) Only the ΔS° of the reaction contributes to the reaction being thermodynamically favorable.
 - (D) Both the ΔH° and the ΔS° of the reaction contribute to the reaction being thermodynamically favorable.
18. At the completion of the reaction, the pH of the product mixture is measured to be above 7. Which of the following can be concluded from this result?
- (A) $\text{Ca}(\text{OH})_2(s)$ is slightly soluble in water.
 - (B) $\text{C}_2\text{H}_2(g)$ is a proton donor.
 - (C) $\text{H}_2\text{O}(l)$ is the limiting reactant.
 - (D) The final temperature of the mixture is below 25°C.

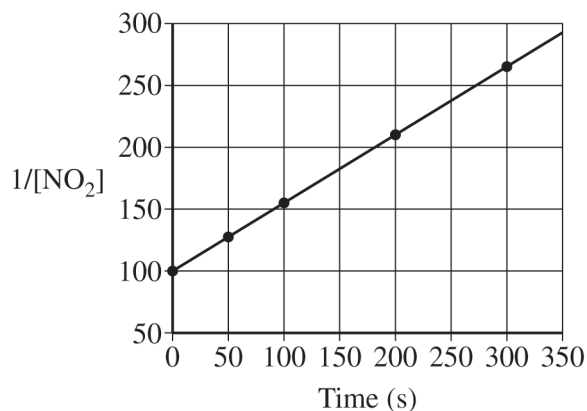
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19. Which of the following lists chemical species in order from largest to smallest radius?

- (A) $\text{S}^{2-} > \text{O} > \text{F}$
- (B) $\text{O} > \text{O}^{2-} > \text{Ne}$
- (C) $\text{K}^+ > \text{Ar} > \text{Cl}$
- (D) $\text{Na} > \text{Mg}^{2+} > \text{Mg}$



20. The following graph shows data from an experiment in which $\text{NO}_2(g)$ decomposes as represented by the equation.



The graph could be used to support which of the following statements?

- (A) The half-life of the reaction is constant.
- (B) The magnitude of the rate constant, k , is approximately 10.
- (C) The unit of the rate constant, k , is s^{-1} .
- (D) The rate law for the reaction is

$$\text{rate} = k[\text{NO}_2]^2.$$

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21. The system represented by the equation shown is at equilibrium in a rigid container. Which of the following would decrease the amount of the reactant $\text{CO}(g)$ in the container?

- (A) Increasing the temperature
- (B) Decreasing the temperature
- (C) Adding $\text{CH}_3\text{OH}(g)$ to the container
- (D) Removing $\text{H}_2(g)$ from the container

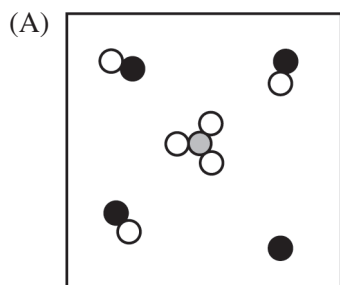
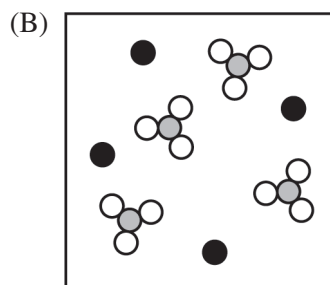
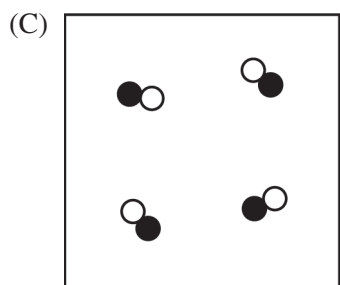
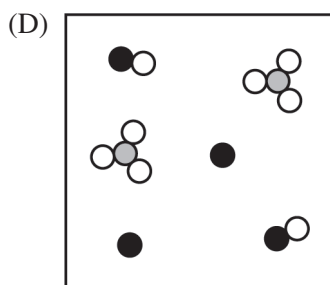
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Questions 22 through 25 refer to the following.

The table contains information about four samples of different monoprotic acids with the general formula HA.

Sample	Volume (mL)	Concentration (M)	pH at 25°C
1	10.0	0.10	1.0
2	5.0	0.10	2.3
3	10.0	0.10	4.7
4	20.0	0.10	2.3

22. Which particle drawing best represents a portion of sample 1 ? (Note that water molecules are omitted.)



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23. Which sample of acid would require the largest number of moles of NaOH to neutralize it completely?

- (A) Sample 1
- (B) Sample 2
- (C) Sample 3
- (D) Sample 4

24. Which sample of acid has the smallest value of K_a ?

- (A) Sample 1
- (B) Sample 2
- (C) Sample 3
- (D) Sample 4

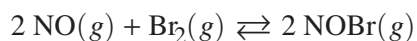
25. Which statement correctly explains why the pH value of sample 3 is the greatest?

- (A) It has the smallest value of $[\text{H}_3\text{O}^+]$.
- (B) It has the smallest value of $[\text{OH}^-]$.
- (C) It has the weakest conjugate base.
- (D) It is the strongest acid.

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26. Of the substances listed above, which has the highest boiling point, and why?
- (A) O_2 , because its molecules have a double bond between the oxygen atoms.
- (B) H_2O , because hydrogen bonds form between its molecules.
- (C) C_3H_8 , because multiple hydrogen bonds can form between its molecules.
- (D) CF_4 , because its molecules have the largest dipole moment, since C–F bonds are highly polar.



27. Which of the following is the expression for the equilibrium constant, K_c , for the reaction represented by the balanced chemical equation shown?

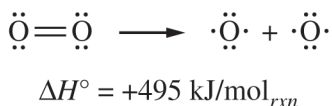
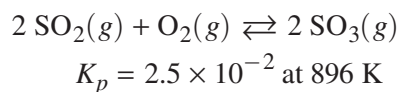
(A) $K_c = \frac{[\text{NO}][\text{Br}_2]}{[\text{NOBr}]}$

(B) $K_c = \frac{[\text{NOBr}]}{[\text{NO}][\text{Br}_2]}$

(C) $K_c = \frac{[\text{NO}]^2[\text{Br}_2]}{[\text{NOBr}]^2}$

(D) $K_c = \frac{[\text{NOBr}]^2}{[\text{NO}]^2[\text{Br}_2]}$

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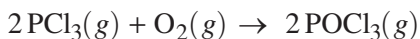
28. Which of the following best explains why the enthalpy change of the reaction represented above is positive?
- (A) The reaction is endothermic because breaking the O=O bond requires energy.
- (B) The reaction is endothermic because breaking the O=O bond releases energy.
- (C) The reaction is exothermic because breaking the O=O bond requires energy.
- (D) The reaction is exothermic because breaking the O=O bond releases energy.

Mass of metal	15 g
Initial temperature of metal	80.0°C
Mass of water	50. g
Initial temperature of water	18.0°C
Final temperature of water	20.0°C
Specific heat capacity of water	4.18 J / (g · °C)

29. A calorimetry experiment is conducted to determine the specific heat capacity of a metal. Based on the results shown in the table, what is the specific heat capacity of the metal?
- (A) 0.042 J / (g · °C)
- (B) 0.35 J / (g · °C)
- (C) 0.46 J / (g · °C)
- (D) 1.39 J / (g · °C)

30. Samples of $\text{SO}_2(g)$, $\text{O}_2(g)$, and $\text{SO}_3(g)$ are placed in a previously evacuated reaction vessel. In the vessel, initially P_{SO_2} is 4.0 atm, P_{O_2} is 10. atm, and P_{SO_3} is 2.0 atm. If the temperature is held constant, which of the following predicts what will happen to P_{O_2} when the reaction represented above occurs and best explains why?
- (A) P_{O_2} will increase, because $K_p < 1$.
- (B) P_{O_2} will decrease, because the total number of moles of reactants is less than the number of moles of product, and the reaction will proceed to form more product.
- (C) P_{O_2} will decrease, because the initial P_{SO_3} is lowest, and the reaction will proceed in the forward direction.
- (D) P_{O_2} will not change, because the system is already at equilibrium.

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31. At 398 K the reaction shown has a ΔH° of $-543 \text{ kJ/mol}_{rxn}$ and a ΔS° of $-178 \text{ J/(K} \cdot \text{mol}_{rxn})$. The reaction is run at both 398 K and 798 K. Which of the following correctly identifies the thermodynamic favorability for the reaction at the two temperatures? (Assume that ΔH° and ΔS° do not change with temperature.)

	At 398 K	At 798 K
A	Unfavorable	Favorable
B	Unfavorable	Unfavorable
C	Favorable	Favorable
D	Favorable	Unfavorable

- (A) A
(B) B
(C) C
(D) D

-
32. A student determines the concentration of an $\text{NaBr}(aq)$ solution by adding $\text{AgNO}_3(aq)$ until no more $\text{AgBr}(s)$ precipitate is formed. The precipitate is filtered out of the solution and then dried and weighed. The student uses the mass of the precipitate to determine the concentration of the $\text{NaBr}(aq)$ solution. Which of the following could result in the student calculating a concentration of $\text{NaBr}(aq)$ that is higher than the actual concentration?

- (A) The $\text{AgBr}(s)$ was not completely dried before being weighed.
(B) Some of the $\text{AgBr}(s)$ fell off the filter paper onto the balance while being weighed.
(C) An insufficient amount of $\text{AgNO}_3(aq)$ was added, so some $\text{NaBr}(aq)$ was left in solution.
(D) The filter paper had a hole in it, and some of the $\text{AgBr}(s)$ precipitate washed through the filter paper.

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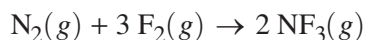
33. A scientist performed two trials in a study of the decomposition reaction of compound $\text{C}_2\text{H}_5\text{Cl}$, represented by the equation shown. Based on the data table below, which of the following outcomes will provide the best evidence that the decomposition reaction is first order?

	$[\text{C}_2\text{H}_5\text{Cl}]_0$	Initial Rate	Half-Life
Trial 1	1.0 M	R_1	t_1
Trial 2	2.0 M	R_2	t_2

- (A) $R_2 = R_1$, $t_2 = t_1$
(B) $R_2 = R_1$, $t_2 \neq t_1$
(C) $R_2 \neq R_1$, $t_2 = t_1$
(D) $R_2 \neq R_1$, $t_2 \neq t_1$

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34. $\text{N}_2(g)$ reacts with $\text{F}_2(g)$ in a sealed, rigid container to produce $\text{NF}_3(g)$ according to the following balanced equation.



The $\text{N}_2(g)$ had an initial partial pressure of 1.00 atm, and the $\text{F}_2(g)$ had an initial partial pressure of 1.80 atm. Assuming that the reaction goes to completion and the temperature remains constant, what is the maximum partial pressure of $\text{NF}_3(g)$ that could be produced?

- (A) 0.50 atm
- (B) 1.20 atm
- (C) 2.00 atm
- (D) 2.80 atm



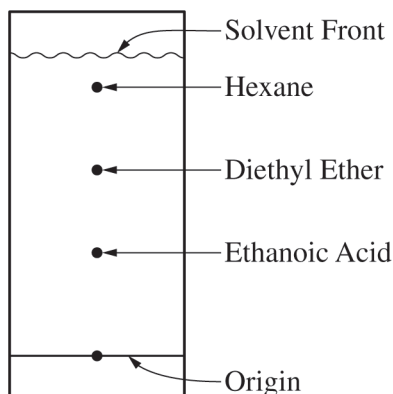
Structure 1

Structure 2

35. Both structure 1 and structure 2 shown are needed to describe the N_2O molecule. Which of the following indicates the better resonance structure and best explains why? (Formal charges are provided in circles on the diagrams.)
- (A) Structure 1, because it has two double bonds and is therefore more symmetrical.
 - (B) Structure 1, because the negative formal charge is on the more electronegative element.
 - (C) Structure 2, because the triple bond between the two nitrogen atoms is stronger than the double bond.
 - (D) Structure 2, because the negative formal charge is on the more electronegative element.

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Diethyl Ether	Ethanoic Acid	Hexane
$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \ddot{\text{O}} & - & \text{C} & - & \text{C} & - & \text{H} \\ & & & & & & & & & \\ & \text{H} & & \text{H} & & & & \text{H} & & \text{H} \end{array} $	$ \begin{array}{ccccccc} & \text{H} & & \text{:O:} & & & & \\ & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \ddot{\text{O}} & - & \text{H} \\ & & & & & & & \\ & \text{H} & & & & & & \end{array} $	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{H} \\ & & & & & & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \end{array} $



36. A mixture of diethyl ether, ethanoic acid, and hexane is separated using a thin-layer chromatography experiment. The Lewis diagrams of the compounds in the mixture and the results of the experiment are shown. A student determines the identity of the compound in each spot shown. Based on this information, which of the following conclusions can be drawn about the polarity of the stationary phase and mobile phase used in this experiment?

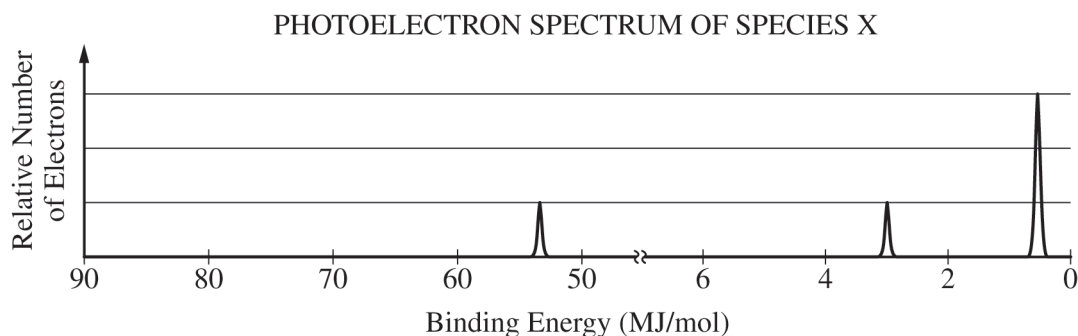
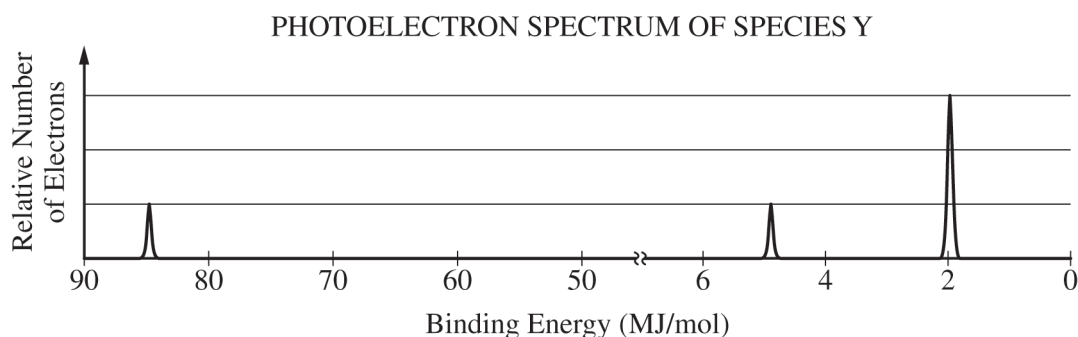
	Stationary Phase	Mobile Phase
A	Nonpolar	Polar
B	Nonpolar	Nonpolar
C	Polar	Polar
D	Polar	Nonpolar

- (A) A
(B) B
(C) C
(D) D

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37. CHF_3 has a normal boiling point of -82.1°C , and CHCl_3 has a normal boiling point of 61.2°C . Which of the following best helps to explain why CHCl_3 has a higher boiling point?
- (A) CHCl_3 has dipole-dipole forces, but CHF_3 does not.
 - (B) CHCl_3 experiences hydrogen bonding, but CHF_3 does not.
 - (C) CHCl_3 has stronger London dispersion forces than CHF_3 does.
 - (D) CHCl_3 has stronger covalent bonds than CHF_3 does.

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38. The complete photoelectron spectra for two species, X and Y, are represented above. One of the species is a neutral atom and the other species is a negatively charged ion. Both species have the same electron configuration. Which of the following can be inferred from the spectra?
- (A) X has a larger nuclear charge than Y has; therefore, X is neutral and Y is negatively charged.
 - (B) X has a larger nuclear charge than Y has; therefore, Y is neutral and X is negatively charged.
 - (C) X has a smaller nuclear charge than Y has; therefore, X is neutral and Y is negatively charged.
 - (D) X has a smaller nuclear charge than Y has; therefore, Y is neutral and X is negatively charged.

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Container	A	B	C	D
Pressure	2.0 atm	1.0 atm	1.5 atm	3.0 atm
Temperature	200 K	300 K	300 K	200 K
Volume	1.0 L	2.0 L	1.0 L	0.50 L

39. Four containers each hold a sample of $\text{O}_2(g)$. Based on the information in the table, which container has the largest number of $\text{O}_2(g)$ molecules?

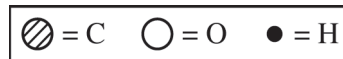
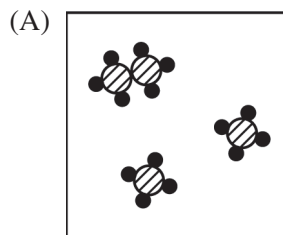
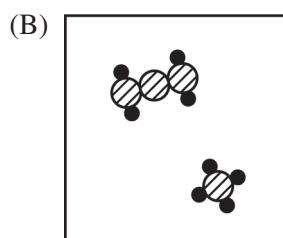
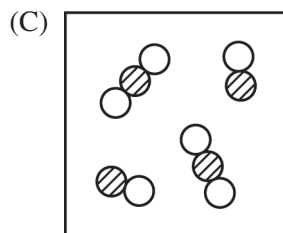
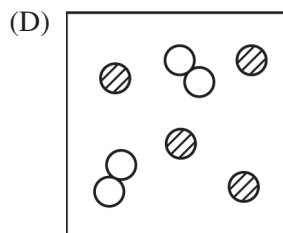
- (A) A
- (B) B
- (C) C
- (D) D

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Compound	Lattice Enthalpy (kJ/mol)
LiF	1030
LiCl	834
MgCl ₂	2510
SrCl ₂	2127

40. Lattice enthalpy can be defined as the ΔH° associated with the separation of a solid crystal into gaseous ions. Which of the following statements about lattice enthalpy is consistent with the information in the table above?
- (A) It increases with the increasing radii of the ions in the compound.
- (B) It increases with the decreasing radii of the ions in the compound.
- (C) It increases with the decreasing charge of the ions.
- (D) It increases with the decreasing electronegativity of the atoms.

41. Which of the following samples contains the greatest percentage of carbon by mass?

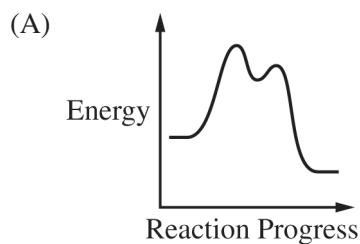
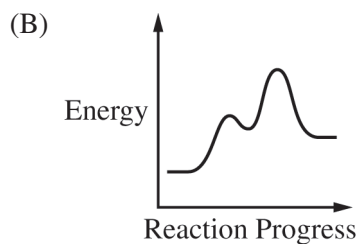
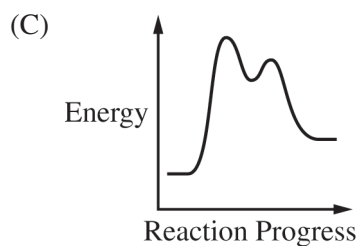
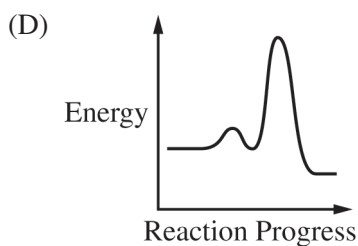


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42. The reaction $\text{NO}_2 + \text{CO} \rightarrow \text{NO} + \text{CO}_2$ is exothermic. A proposed mechanism for this reaction is shown.

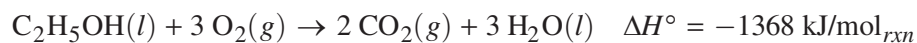


Which of the following energy profiles is most consistent with the exothermic nature of the reaction and the proposed mechanism?



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43. Which of the following processes results in a decrease in entropy of a system?
- (A) A pot of water is boiled.
 - (B) Water is frozen into ice cubes.
 - (C) Carbon dioxide gas is released from a pressurized container into the atmosphere.
 - (D) A container of pressurized carbon dioxide is heated to a higher temperature.
-

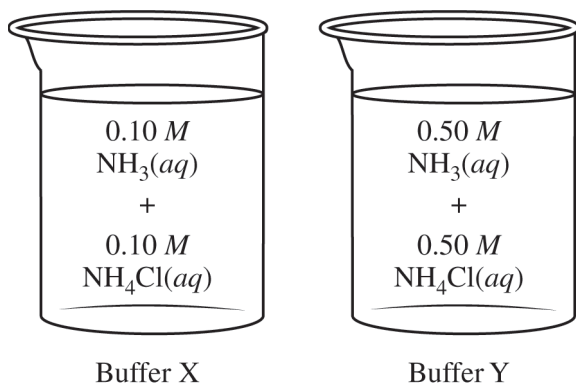


44. Based on the reaction and data table shown, what is the value of ΔH_f° of $\text{C}_2\text{H}_5\text{OH}(l)$?

Substance	ΔH_f° (kJ / mol)
$\text{CO}_2(g)$	-394
$\text{H}_2\text{O}(l)$	-286
$\text{O}_2(g)$	0

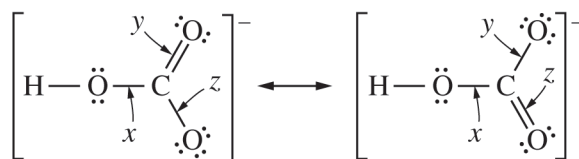
- (A) -688 kJ / mol
- (B) -278 kJ / mol
- (C) 278 kJ / mol
- (D) 688 kJ / mol

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45. Two buffers are represented in the diagram. How do the pH and buffer capacity of buffer X compare to those of buffer Y ?

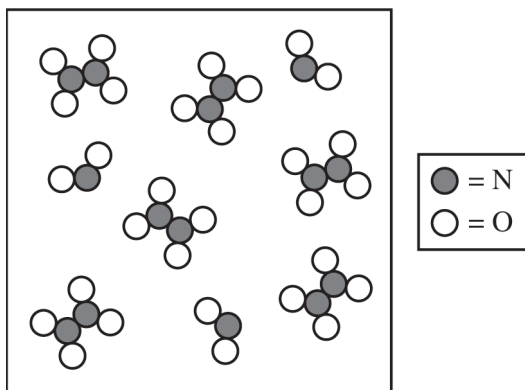
- (A) Buffer X has the same pH as buffer Y and a smaller buffer capacity than buffer Y.
- (B) Buffer X has the same pH as buffer Y and the same buffer capacity as buffer Y.
- (C) Buffer X has a lower pH than buffer Y and a smaller buffer capacity than buffer Y.
- (D) Buffer X has a higher pH than buffer Y and a larger buffer capacity than buffer Y.



46. The two primary resonance structures for HCO_3^- are shown. What are the relative lengths of the carbon-to-oxygen bonds in this ion?

- (A) Bonds y and z are equal in length and longer than bond x .
- (B) Bonds y and z are equal in length and shorter than bond x .
- (C) Bonds x and z are equal in length and longer than bond y .
- (D) All three bonds are equal in length.

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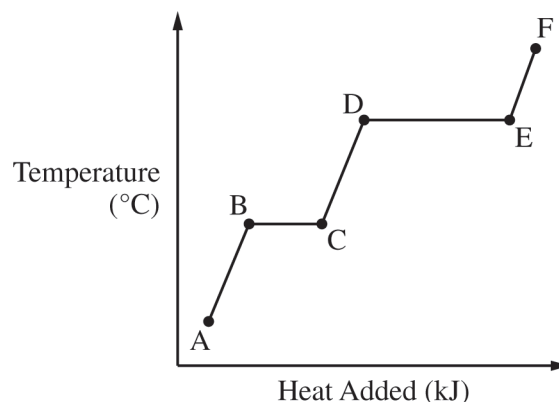
47. The particle diagram shown represents a mixture of NO_2 and N_2O_4 at equilibrium according to the reaction $2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$. Which of the following is the value of K_p for the reaction? (Assume that each particle represents a partial pressure of 1.0 atm for that substance.)

(A) 0.50
(B) 0.67
(C) 1.5
(D) 2.0

48. Which of the following compounds would be most effective in decreasing the pH when added to a sample of water that has a pH of 10.3?

(A) KCl
(B) NaNO_3
(C) NH_4NO_3
(D) $\text{NaC}_2\text{H}_3\text{O}_2$

49. A pure substance begins as a solid at point A and is heated at a constant rate. Which of the following best describes the process occurring from point B to point C on the heating curve shown?



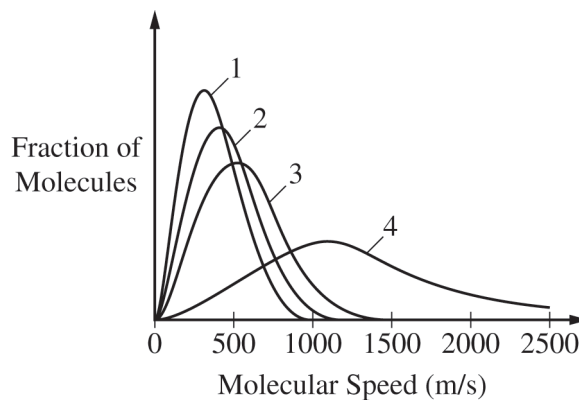
- (A) The average kinetic energy of the particles in the system is increasing as the substance melts.
(B) The average kinetic energy of the particles in the system is increasing as the substance boils.
(C) The potential energy of the particles in the system is increasing as the substance melts.
(D) The potential energy of the particles in the system is increasing as the substance boils.

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Substance	Cl ₂	I ₂
Boiling point (K)	239	457

50. The boiling points of two diatomic elements are listed in the table shown. Which statement best explains the observed difference in the boiling points?

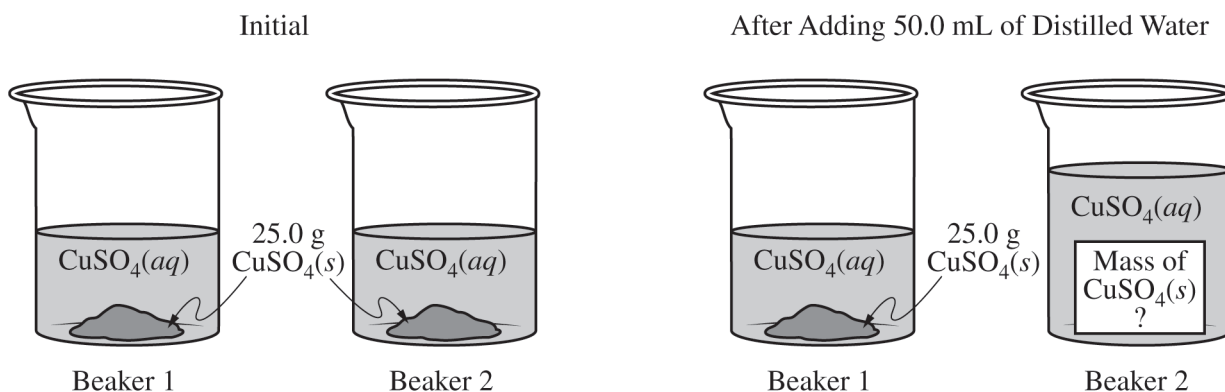
- (A) Iodine has the larger electron cloud, so molecules of I₂ are more polarizable.
- (B) Iodine has the lower electronegativity, so molecules of I₂ are more polar.
- (C) Chlorine has the smaller atomic radius, so molecules of Cl₂ contain weaker bonds.
- (D) Chlorine has the higher electronegativity, so molecules of Cl₂ are more polar.



51. The curves in the figure above represent the distribution of the molecular speeds for the gases H₂, O₂, N₂, and CH₄ at the same temperature. Which curve corresponds to the distribution for CH₄ ?

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

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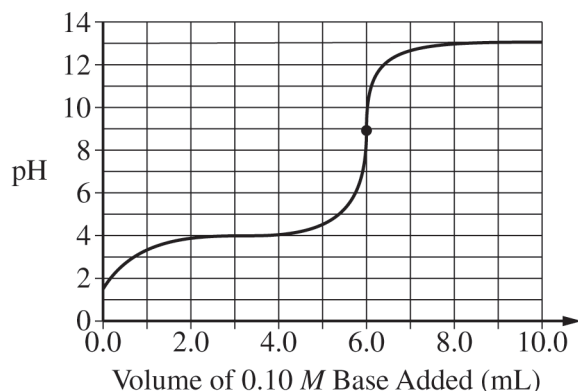


52. Beaker 1 and beaker 2 each contain 100.0 mL of saturated $\text{CuSO}_4(aq)$ and 25.0 g of undissolved $\text{CuSO}_4(s)$. A 50.0 mL sample of distilled water is added to beaker 2, the contents are stirred for several minutes, and $\text{CuSO}_4(s)$ is observed at the bottom of the beaker. After stirring, which of the following is true about the contents of the beakers? (Assume temperature remains constant.)
- (A) The concentration of $\text{CuSO}_4(aq)$ in beaker 2 is less than in beaker 1.
 - (B) The concentration of $\text{CuSO}_4(aq)$ in beaker 2 is greater than in beaker 1.
 - (C) The mass of undissolved $\text{CuSO}_4(s)$ in beaker 2 is less than in beaker 1.
 - (D) The mass of undissolved $\text{CuSO}_4(s)$ in beaker 2 is greater than in beaker 1.

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Questions 53 through 55 refer to the following.

The curve shows the results of an acid-base titration.



53. Which of the following is closest to the pK_a of the acid for which the titration curve is shown?

- (A) 2
- (B) 4
- (C) 8
- (D) 13

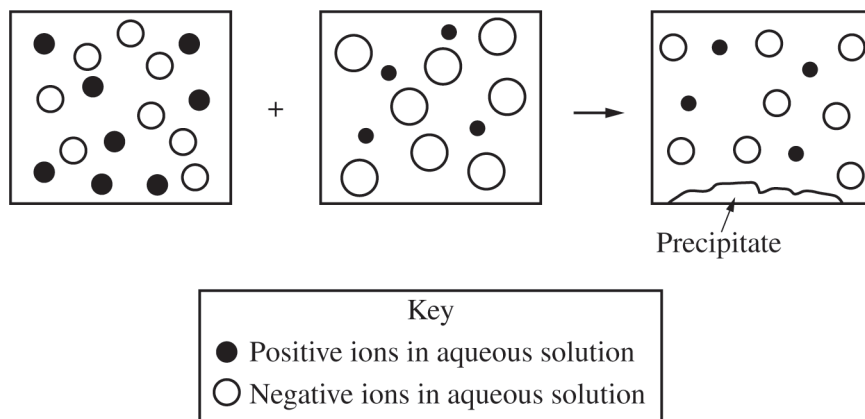
54. In addition to the information provided in the titration curve, what other value is needed to determine the concentration of the acid used in the titration?

- (A) The molar mass of the acid
- (B) The density of the acid
- (C) The volume of the acid
- (D) The initial temperature of the acid

55. Which of the following molecular equations could represent the reaction used to generate the titration curve?

- (A) $\text{H}_3\text{PO}_4(aq) + 3\text{LiOH}(aq) \rightarrow 3\text{H}_2\text{O}(l) + \text{Li}_3\text{PO}_4(aq)$
- (B) $\text{HCl}(aq) + \text{KOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{KCl}(aq)$
- (C) $\text{HF}(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NaF}(aq)$
- (D) $\text{HNO}_3(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4\text{NO}_3(aq)$

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56. Which of the following chemical changes is best represented by the particle diagram shown? (Water molecules are omitted for clarity.)

- (A) $2 \text{AgNO}_3(aq) + \text{MgI}_2(aq) \rightarrow 2 \text{AgI}(s) + \text{Mg}(\text{NO}_3)_2(aq)$
- (B) $\text{AgNO}_3(aq) + \text{KCl}(aq) \rightarrow \text{AgCl}(s) + \text{KNO}_3(aq)$
- (C) $2 \text{HCl}(aq) + \text{Ba}(\text{OH})_2(aq) \rightarrow \text{BaCl}_2(s) + 2 \text{H}_2\text{O}(l)$
- (D) $\text{MnSO}_4(aq) + \text{K}_2\text{S}(aq) \rightarrow \text{MnS}(aq) + \text{K}_2\text{SO}_4(aq)$

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57. A reversible reaction at standard conditions has a negative enthalpy change ($\Delta H^\circ < 0$) and a positive entropy change ($\Delta S^\circ > 0$). Which of the following must be true for the equilibrium constant, K , and the standard cell potential, E° , for the forward reaction?

	K	E°
A	Greater than 1	Positive
B	Greater than 1	Negative
C	Less than 1	Positive
D	Less than 1	Negative

- (A) A
(B) B
(C) C
(D) D

58. A 15.0 g sample of $\text{H}_2\text{O}(l)$ initially at 20.0°C absorbs 4.60 kJ of heat. The final temperature of the $\text{H}_2\text{O}(l)$ is closest to which of the following? (Assume the specific heat capacity of $\text{H}_2\text{O}(l)$ is constant at $4.18 \text{ J}/(\text{g}\cdot^\circ\text{C})$.)

- (A) 20.1°C
(B) 36.5°C
(C) 73.4°C
(D) 93.4°C

59. Which of the following elements has the largest first ionization energy?

- (A) Be
(B) Li
(C) Na
(D) Mg

Mass of Isotope	Percent Abundance
185 amu	37%
187 amu	63%

60. A certain element has two naturally occurring isotopes, as shown in the table. The element's average atomic mass is closest to which of the following?

- (A) 185.0 amu
(B) 185.6 amu
(C) 186.3 amu
(D) 187.0 amu

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CHEMISTRY

SECTION II

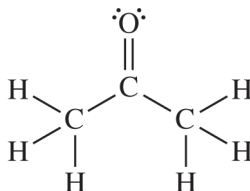
Time—1 hour and 45 minutes

7 Questions

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

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

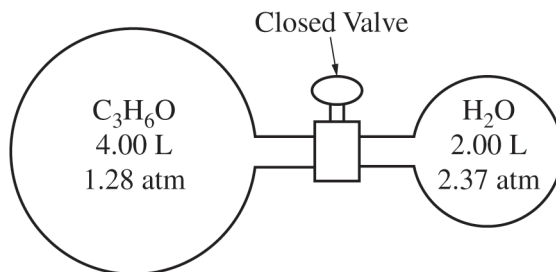
1. Answer the following questions about acetone, $\text{C}_3\text{H}_6\text{O}$, which is represented in the following Lewis diagram.



- (a) The bonding in an acetone molecule can be modeled using sigma and pi bonds. Based on the Lewis diagram, identify the number of sigma bonds and the number of pi bonds.

Sigma bonds: _____

Pi bonds: _____



- (b) While held at a constant temperature of 800. K, a sample of $\text{C}_3\text{H}_6\text{O}(g)$ and a sample of $\text{H}_2\text{O}(g)$ are in containers separated by a closed valve, as shown in the diagram.

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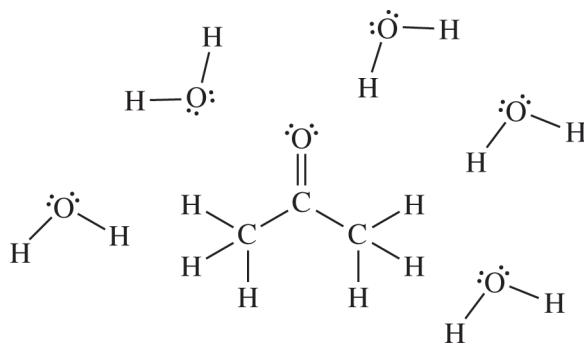
(i) Assuming ideal behavior, constant temperature, and initial volumes of 4.00 L and 2.00 L for the gases shown, what is the partial pressure, in atm, of the $\text{C}_3\text{H}_6\text{O}(g)$ after the valve is opened and the gases have mixed?

(ii) After the gases mix, the system is cooled to 400. K. What is the ratio of the acetone partial

pressures, $\frac{P_{400\text{K}}}{P_{800\text{K}}}$, at the two temperatures? $\frac{P_{400\text{K}}}{P_{800\text{K}}} = \underline{\hspace{2cm}}$

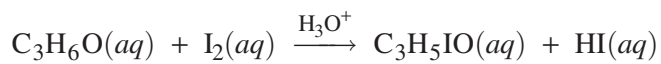
(c) After the gases are cooled to 400. K, the measured pressure of the system is significantly lower than the predicted value, partially because of strong interactions between molecules of $\text{C}_3\text{H}_6\text{O}$ and molecules of H_2O .

(i) Draw a single dashed line (---) on the following diagram to indicate the location of the strongest interaction between a molecule of $\text{C}_3\text{H}_6\text{O}$ and a molecule of H_2O .



(ii) Using principles of kinetic molecular theory, explain why the attraction between molecules of $\text{C}_3\text{H}_6\text{O}$ and H_2O results in a pressure that is lower than the predicted value.

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Acetone, $\text{C}_3\text{H}_6\text{O}$, reacts with I_2 in acidic solution, as represented by the preceding equation. A student conducts several trials at constant temperature using different concentrations of the reactants. The results of the student's experiment are provided in the following table.

Trial	$[\text{C}_3\text{H}_6\text{O}] (M)$	$[\text{I}_2] (M)$	$[\text{H}_3\text{O}^+] (M)$	Initial Rate (M/s)
1	1.33	0.00100	0.162	8.11×10^{-6}
2	1.33	0.00100	0.323	16.6×10^{-6}
3	0.667	0.00100	0.323	8.25×10^{-6}

(d) Explain how the data in the table support that the reaction is first order with respect to $\text{C}_3\text{H}_6\text{O}$.

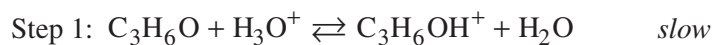
(e) The reaction is found to be zero order with respect to I_2 . Use the data to determine the overall rate law for the reaction.

(f) Using the data from trial 3, calculate the value of the rate constant, k , in $M^{-1} s^{-1}$.

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(g) When the reaction occurs at a higher temperature, the value of the rate constant, k , increases. Based on collision theory, explain why the value of k increases with temperature.

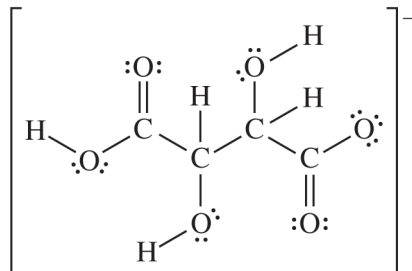
(h) The following mechanism was proposed for the reaction. Explain how this mechanism is consistent with the reaction being zero order with respect to I_2 .



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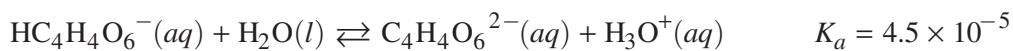
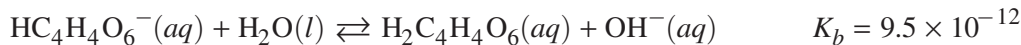
2. Answer the following questions about potassium hydrogen tartrate, $\text{KHC}_4\text{H}_4\text{O}_6$.

When $\text{KHC}_4\text{H}_4\text{O}_6$ dissolves in water, it dissociates into K^+ and $\text{HC}_4\text{H}_4\text{O}_6^-$ ions. The Lewis diagram of $\text{HC}_4\text{H}_4\text{O}_6^-$ is shown.



(a) In the diagram, circle the atom that detaches when $\text{HC}_4\text{H}_4\text{O}_6^-$ acts as a proton donor.

The $\text{HC}_4\text{H}_4\text{O}_6^-$ ion can act as a proton donor and a proton acceptor. The ionization reactions of $\text{HC}_4\text{H}_4\text{O}_6^-(aq)$ in water and their corresponding K values are provided.



(b) Calculate the $\text{p}K_a$ of $\text{HC}_4\text{H}_4\text{O}_6^-(aq)$.

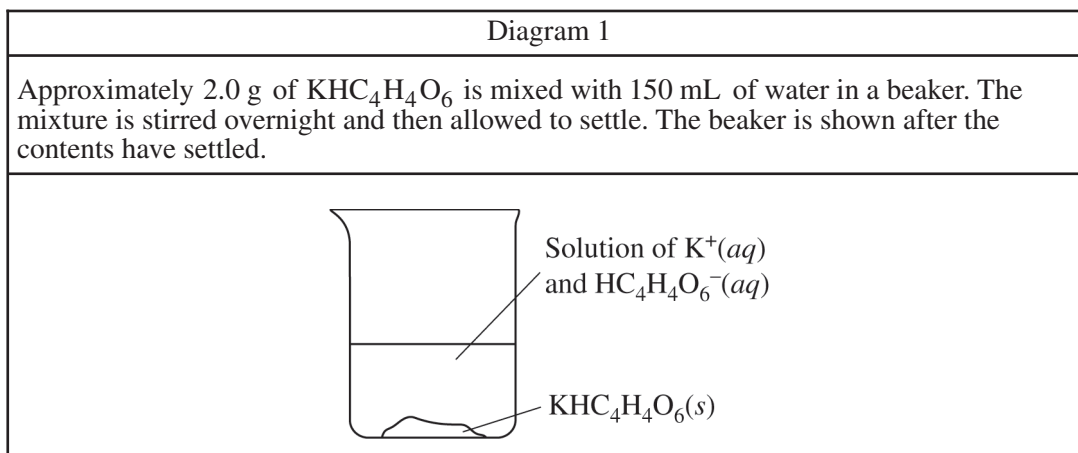
(c) When $\text{HC}_4\text{H}_4\text{O}_6^-$ is dissolved in water, $[\text{C}_4\text{H}_4\text{O}_6^{2-}]$ is greater than $[\text{H}_2\text{C}_4\text{H}_4\text{O}_6]$. Explain this observation based on the information provided.

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Unlike many potassium salts, $\text{KHC}_4\text{H}_4\text{O}_6$ is only slightly soluble in water. It dissociates according to the following equation. The K_{sp} expression is given.



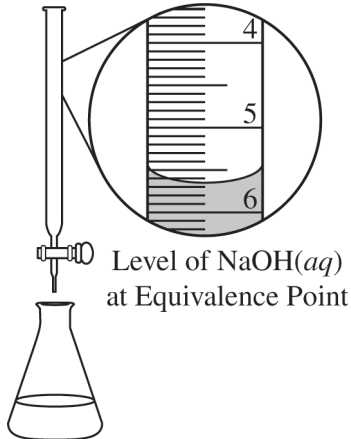
In order to determine the K_{sp} of this salt, a student prepares a saturated solution as shown in diagram 1.



(d) What observation can the student make to confirm that the solution in the beaker is saturated?

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- (e) The student continues the experiment by filtering the saturated solution and then titrating it with $\text{NaOH}(aq)$. These steps are shown in diagrams 2 and 3.

Diagram 2	Diagram 3
The mixture is filtered to separate the solid from the solution.	A 25.00 mL sample of the solution is transferred to an Erlenmeyer flask and titrated with 0.1376 M $\text{NaOH}(aq)$.
	

The magnified view in diagram 3 shows part of the buret at the equivalence point of the titration. The remaining data are shown in the following table.

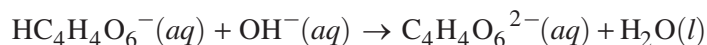
Volume of $\text{KHC}_4\text{H}_4\text{O}_6$ solution in the flask	25.00 mL
Initial buret reading of $\text{NaOH}(aq)$	0.00 mL
Final buret reading of $\text{NaOH}(aq)$	?
Concentration of $\text{NaOH}(aq)$ in the buret	0.1376 M

- (i) Based on the magnified view in diagram 3, what should the student record as the final volume reading of $\text{NaOH}(aq)$ in the buret?

_____ mL

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- (ii) Using the data from the titration, calculate the value of $[\text{HC}_4\text{H}_4\text{O}_6^-]$ in the $\text{KHC}_4\text{H}_4\text{O}_6$ solution. The equation shown represents the reaction that occurs during the titration.



- (iii) Using the data from the experiment, calculate the value of K_{sp} for $\text{KHC}_4\text{H}_4\text{O}_6$, given that

$$K_{sp} = [\text{K}^+][\text{HC}_4\text{H}_4\text{O}_6^-].$$

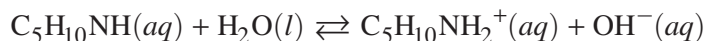
- (f) A second student performs the same experiment, but some $\text{KHC}_4\text{H}_4\text{O}_6(s)$ passes around the filter paper and remains in the 25.00 mL sample that is titrated. As a result, the second student requires a greater volume of $\text{NaOH}(aq)$ to reach the equivalence point of the titration.

- (i) Assuming no other errors occurred, explain why the presence of the $\text{KHC}_4\text{H}_4\text{O}_6(s)$ increases the volume of $\text{NaOH}(aq)$ needed to reach the equivalence point.

- (ii) Would the second student's calculated value of K_{sp} be larger, smaller, or the same as the first student's calculated value of K_{sp} obtained in part (e)(iii) ? Justify your answer.

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3. Piperidine, $\text{C}_5\text{H}_{10}\text{NH}$, is a weak organic base. The reaction of $\text{C}_5\text{H}_{10}\text{NH}(aq)$ with $\text{H}_2\text{O}(l)$ is represented by the following equation.



- (a) Identify one Brønsted-Lowry conjugate acid-base pair in the reaction of piperidine with water. Be sure to label which species is the acid and which is the base.

- (b) Write the expression for the equilibrium constant, K_b , for piperidine, $\text{C}_5\text{H}_{10}\text{NH}$.

- (c) A 20.0 mL sample of 0.750 M $\text{C}_5\text{H}_{10}\text{NH}(aq)$ is prepared at 25°C.

- (i) The equilibrium concentration of $\text{OH}^-(aq)$ in the solution is $3.09 \times 10^{-2} M$. Calculate the pH of the 0.750 M $\text{C}_5\text{H}_{10}\text{NH}(aq)$ solution at 25°C.

- (ii) What is the percent ionization of piperidine in the 0.750 M solution?

GO ON TO THE NEXT PAGE.

(d) When a small volume of strong acid is added to the $0.750\text{ M C}_5\text{H}_{10}\text{NH}(aq)$ solution, the number of moles of $\text{C}_5\text{H}_{10}\text{NH}_2^+$ increases.

(i) Write the balanced net ionic equation for the reaction that occurs between major species in solution when the strong acid is added.

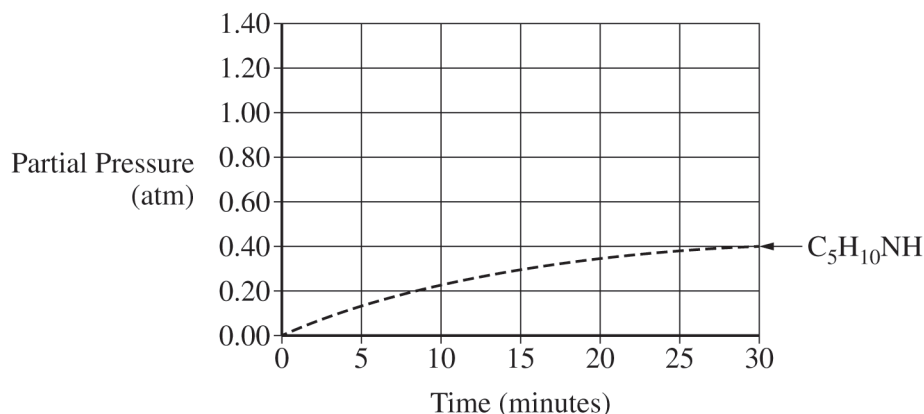
(ii) Using Q and K , explain why the moles of $\text{C}_5\text{H}_{10}\text{NH}_2^+$ increase when a small amount of strong acid is added to the solution.

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A scientist prepares piperidine, $\text{C}_5\text{H}_{10}\text{NH}$, by reacting $\text{C}_5\text{H}_5\text{N}$ and H_2 in a nickel-coated container at 400. K according to the following reaction equation.



The scientist fills a previously evacuated, sealed, rigid container with 1.40 atm of $\text{C}_5\text{H}_5\text{N}$ and 1.40 atm of H_2 and records the partial pressure of $\text{C}_5\text{H}_{10}\text{NH}(g)$ as the reaction progresses. The data are shown in the following graph.



(e) On the graph, sketch a single curve that represents the partial pressure of $\text{H}_2(g)$ as the reaction proceeds from 0 minutes to 30 minutes. Your curve should reflect

- (i) the rate of change of $\text{H}_2(g)$ compared to that of $\text{C}_5\text{H}_{10}\text{NH}(g)$ and
- (ii) the initial partial pressure of $\text{H}_2(g)$ and the partial pressure of $\text{H}_2(g)$ at 30 minutes.

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(f) In this reaction, 4 mol of gaseous reactants produce 1 mol of gaseous product. Based on this fact, a student claims that the entropy change of the forward reaction, ΔS_{rxn}° , is negative.

(i) Use particulate-level reasoning to explain why the student's claim is correct.

(ii) Given the signs of ΔG_{rxn}° and ΔS_{rxn}° at 400. K, is the sign of ΔH_{rxn}° positive or negative? Justify your answer.

GO ON TO THE NEXT PAGE.

4. A student conducts a calorimetry experiment using $\text{CaBr}_2(s)$ (molar mass 199.88 g / mol) to determine the enthalpy of solution. The student prepares the solution by dissolving $\text{CaBr}_2(s)$ in water. The following data table includes the information from the experiment.



Mass of water	46.00 g
Mass of CaBr_2	7.11 g
Initial temperature	23.5°C
Final temperature	44.0°C

- (a) Other than preventing the solution from splashing out, explain why it is important to keep the lid on the calorimeter during the experiment.
- (b) Based on the data in the table, what is the sign of the enthalpy of solution, $\Delta H_{\text{solution}}^\circ$? Justify your answer.

GO ON TO THE NEXT PAGE.

(c) Using the data from the experiment, calculate the magnitude of thermal energy, q , in joules, transferred in the dissolution of CaBr_2 . Assume that the mixture in the calorimeter has a specific heat capacity of $3.61 \text{ J/(g}\cdot^\circ\text{C)}$.

(d) Using the data from the experiment, calculate the magnitude of $\Delta H_{\text{solution}}^\circ$ of CaBr_2 in kJ/mol .

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5. Answer the following questions about magnesium nitrate and sodium carbonate.

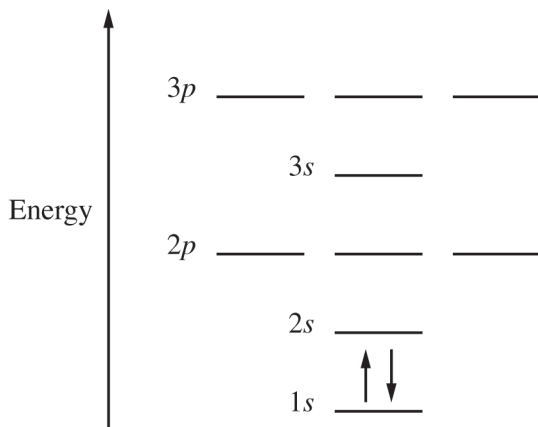
When a student combines equal volumes of $0.1\ M$ aqueous solutions of magnesium nitrate, $\text{Mg}(\text{NO}_3)_2$, and sodium carbonate, Na_2CO_3 , a white solid forms.

(a) Write the balanced net ionic equation for the reaction.

(b) A student filters the mixture from part (a) to remove the solid from the solution. Describe an experimental technique that the student can use to demonstrate that ions remain in the filtered solution.

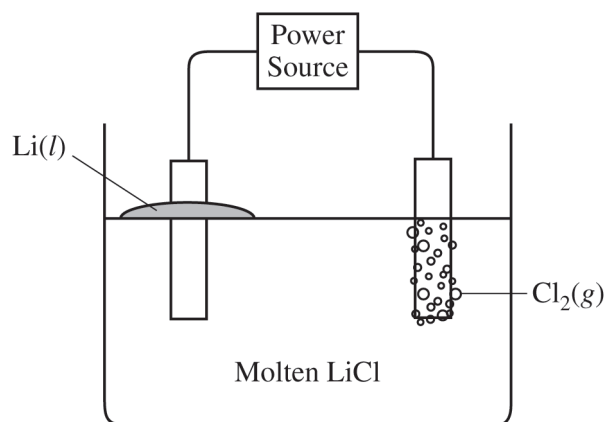
(c) The $\text{Na}_2\text{CO}_3(aq)$ used in the reaction has a 2:1 ratio of cations to anions. Identify a metallic element, M, other than sodium that results in a compound that has a formula of M_2CO_3 .

(d) An incomplete orbital energy diagram for the magnesium cation in the ground state is shown. Using arrows to represent electrons, complete the diagram with the correct number of electrons in the cation. The arrows for the $1s$ sublevel are already shown.



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6. Molten lithium chloride, $\text{LiCl}(l)$, is electrolyzed using an external power supply and inert electrodes, as represented in the following diagram. Liquid lithium metal and chlorine gas are produced.



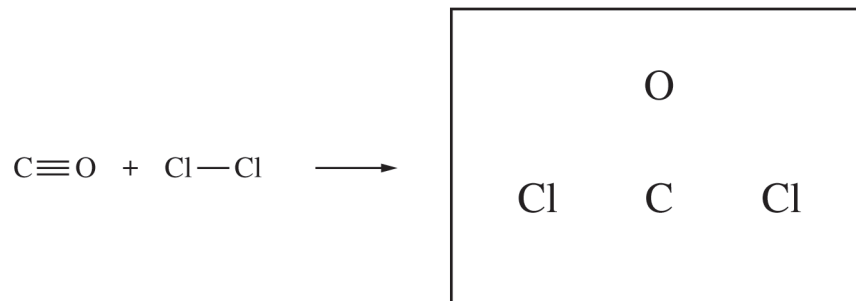
The reduction potentials for the half-reactions associated with this process are shown in the following table.

Half-Reaction	E (V)
$\text{Cl}_2 + 2 e^- \rightarrow 2 \text{Cl}^-$	-1.36
$\text{Li}^+ + e^- \rightarrow \text{Li}$	-2.10

- (a) On the diagram, draw an arrow to show the direction of electron flow in the wire.
- (b) Use the half-reactions in the table to write the balanced net ionic equation for the reaction that occurs in the electrolytic cell.
- (c) Calculate the average current, in C/s, that must flow through the cell to produce 0.18 g of lithium metal in 3200. seconds.

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7. Phosgene gas (COCl_2) can be synthesized in the reaction represented by the following equation.



- (a) Complete the Lewis diagram for phosgene in which the formal charge on each atom is zero. Include all bonding and nonbonding valence electrons.
- (b) A student claims that the hybridization of the carbon atom is the same in CO and COCl_2 . Do you agree or disagree with the student's claim? Justify your answer in terms of the hybridization of the C atom in each structure.
- (c) When CO and Cl_2 are combined, no reaction is observed to occur. The reaction is initiated by exposing the reactants to ultraviolet light that has a frequency of $8.67 \times 10^{14} \text{ s}^{-1}$. Calculate the energy of 1.00 mol of photons at this frequency. Include units with your answer.

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APPENDIX - ANSWERS

AP CHEMISTRY 2024

Multiple-choice key transcribed from the matching supplied source.

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

Notes on the AP Chemistry Practice Exam

Multiple-Choice Section

Course Framework Alignment and Rationales

Question 1

Skill	Learning Objective	Topic
5.F	3.4.A	Ideal Gas Law
(A)	Incorrect. This response calculates the mole fraction of He instead of the mole fraction of N ₂ , resulting in $\chi = \frac{\text{number of He particles}}{\text{total number of particles}} = \frac{3}{9} = 0.33.$	
(B)	Incorrect. This response incorrectly determines the mole fraction using the fact that N ₂ is one of the two types of particles present, $\chi = \frac{1}{2} = 0.50$, or by dividing the number of He particles by the number of N ₂ particles, rather than using the number of N ₂ particles and the total number of particles.	
(C)	Correct. The mole fraction of N ₂ is determined by first counting the number of N ₂ particles (6) and the number of He particles (3). The mole fraction of N ₂ is then calculated as $\chi_{\text{N}_2} = \frac{\text{number of N}_2 \text{ particles}}{\text{total number of particles}} = \frac{6}{(6+3)} = 0.67.$	
(D)	Incorrect. This response incorrectly determines the mole fraction of N ₂ by using the number of atoms rather than the number of gas particles, resulting in $\chi = \frac{\text{number of N atoms}}{\text{total number of atoms}} = \frac{12}{15} = 0.80.$	

Question 2

Skill	Learning Objective	Topic
2.F	5.1.A	Reaction Rates
(A)	Incorrect. The response incorrectly states that stirring the reaction mixture would increase the time for the reaction to go to completion, whereas it would probably decrease the time by speeding up the reaction.	
(B)	Incorrect. The response incorrectly states that raising the temperature for trial 2 would increase the time for the reaction to go to completion, whereas it would probably decrease the time by speeding up the reaction.	
(C)	Incorrect. The response incorrectly states that increasing the concentration of a reactant would increase the time for the reaction to go to completion, whereas it would probably decrease the time by speeding up the reaction.	
(D)	Correct. The reaction rate between a solid and an aqueous solution frequently depends on the surface area of solid exposed to the solution. If the solid magnesium is in the form of a fine powder, it will have a greater surface area exposed to the solution than if it is a single chunk of magnesium. When a solid reactant has a greater surface area, more frequent collisions between reactant molecules can occur in each unit of time. Hence, the rate of reaction will be greater for powdered magnesium, and the time for the reaction to go to completion will be less.	

Question 3

Skill	Learning Objective	Topic
1.A	2.7.A	VSEPR and Hybridization
(A)	Incorrect. A correct Lewis diagram for IF_5 is drawn with five bonding pairs and one nonbonding pair of electrons around the central I atom. The resulting geometry is square pyramidal; it is not trigonal bipyramidal.	
(B)	Correct. The Lewis diagram for a molecule having trigonal bipyramidal geometry must have five bonding pairs and no nonbonding pairs of electrons around the central atom. This response has the required arrangement of bonding and nonbonding pairs around the central P atom.	
(C)	Incorrect. A correct Lewis diagram for CF_4 is drawn with four bonding pairs and no nonbonding pairs of electrons around the central C atom. The resulting geometry is tetrahedral; it is not trigonal bipyramidal.	
(D)	Incorrect. A correct Lewis diagram for XeF_4 is drawn with four bonding pairs and two nonbonding pairs of electrons around the central Xe atom. The resulting geometry is square planar; it is not trigonal bipyramidal.	

Question 4

Skill	Learning Objective	Topic
6.C	4.5.A	Stoichiometry
(A)	Incorrect. The unreacted H_2 in the diagram shows that there is excess H_2 , so H_2 is not the limiting reactant.	
(B)	Incorrect. The diagram represents the number of molecules of each species; molar mass is not involved in the determination of the limiting reactant from the number of molecules of each type.	
(C)	Correct. The limiting reactant is the reactant that runs out first and that is not present in the final mixture. There are no Cl_2 molecules in the diagram shown, so Cl_2 must be the limiting reactant.	
(D)	Incorrect. The diagram represents the number of molecules of each species; molar mass is not involved in the determination of the limiting reactant from the number of molecules of each type.	

Question 5

Skill	Learning Objective	Topic
2.B	3.4.A	Ideal Gas Law
(A)	Incorrect. The ideal gas equation is $PV = nRT$. If the number of moles of gas in the container increases at constant volume and temperature, the total pressure must increase; it will not remain constant. The number of moles of $O_2(g)$ remains constant, so the partial pressure of $O_2(g)$ remains constant.	
(B)	Incorrect. The total pressure will increase because the number of moles of gas in the container increases at constant volume and temperature. However, the number of moles of $O_2(g)$ remains constant, so the partial pressure of $O_2(g)$ remains constant; the partial pressure does not increase.	
(C)	Incorrect. The total pressure will increase because the number of moles of gas in the container increases at constant volume and temperature. However, the number of moles of $O_2(g)$ remains constant, so the partial pressure of $O_2(g)$ remains constant; the partial pressure does not decrease.	
(D)	Correct. The ideal gas equation is $PV = nRT$. If the number of moles of gas in the container increases at constant volume and temperature, the total pressure must increase. However, the addition of an inert gas ($He(g)$ in this case) will not change the partial pressure of the species initially present, $Ar(g)$ and $O_2(g)$, although it will decrease the mole fraction of each.	

Question 6

Skill	Learning Objective	Topic
4.B	3.6.A	Deviation from Ideal Gas Law
(A)	Correct. Gases that have the weakest intermolecular forces behave most like ideal gases. Of the choices given, O ₂ is the smallest in size and has the weakest intermolecular forces. It is nonpolar, so its only intermolecular forces are London dispersion forces.	
(B)	Incorrect. Gases that have the weakest intermolecular forces behave most like ideal gases. CF ₄ only has London dispersion forces, but CF ₄ has a larger, more polarizable electron cloud than O ₂ does, so CF ₄ has greater London dispersion forces than O ₂ does. Therefore, CF ₄ behaves less ideally than O ₂ does.	
(C)	Incorrect. Gases that have the weakest intermolecular forces behave most like ideal gases. SO ₂ has London dispersion forces and dipole-dipole forces between its molecules. The total intermolecular forces are greater for SO ₂ than for O ₂ , so SO ₂ behaves less ideally than O ₂ does.	
(D)	Incorrect. Gases that have the weakest intermolecular forces behave most like ideal gases. SF ₆ has only London dispersion forces, but SF ₆ has a larger, more polarizable electron cloud than O ₂ does, so SF ₆ has greater London dispersion forces than O ₂ does. Therefore, SF ₆ behaves less ideally than O ₂ does.	

Question 7

Skill	Learning Objective	Topic
5.E	4.2.A	Net Ionic Equations
(A)	Incorrect. This is the coefficient for gallium if Cl is given as a reactant instead of Cl ₂ , resulting in the equation $\text{Ga} + 3 \text{Cl} \rightarrow \text{GaCl}_3.$	
(B)	Correct. The balanced chemical equation for the reaction of gallium with chlorine gas is $2 \text{Ga} + 3 \text{Cl}_2 \rightarrow 2 \text{GaCl}_3$. Therefore, the coefficient for gallium is 2.	
(C)	Incorrect. This is the coefficient for chlorine gas in the balanced chemical equation and also the charge of gallium in GaCl ₃ .	
(D)	Incorrect. This could be the coefficient for gallium if the lowest whole-number coefficients are not used; for example, $4 \text{Ga} + 6 \text{Cl}_2 \rightarrow 4 \text{GaCl}_3.$	

Question 8

Skill	Learning Objective	Topic
1.A	3.8.A	Representations of Solutions
(A)	Correct. The negative side of each water molecule (the O side) is oriented toward the X ion and away from the Y ion. Therefore, the X ion has a positive charge and the Y ion has a negative charge.	
(B)	Incorrect. The negative side of each water molecule (the O side) is oriented toward the X ion and away from the Y ion. Therefore, the X ion has a positive charge and the Y ion has a negative charge. Both ions in this response have a negative charge.	
(C)	Incorrect. The negative side of each water molecule (the O side) is oriented toward the X ion and away from the Y ion. Therefore, the X ion has a positive charge and the Y ion has a negative charge. Both ions in this response have an incorrect charge.	
(D)	Incorrect. The negative side of each water molecule (the O side) is oriented toward the X ion and away from the Y ion. Therefore, the X ion has a positive charge and the Y ion has a negative charge. Both ions in this response have a positive charge.	

Question 9

Skill	Learning Objective	Topic
4.C	4.7.A	Types of Chemical Reactions
(A)	Incorrect. Reaction 1 is not a redox reaction, but the reasoning is incorrect. Charge conservation is necessary for all balanced chemical equations and does not indicate that a reaction is not a redox reaction.	
(B)	Incorrect. Reaction 1 is not a redox reaction. The oxidation number of nitrogen is -3 in NH_3 and NH_4^+ , and the oxidation number of hydrogen is $+1$ in NH_3 , H^+ , and NH_4^+ .	
(C)	Incorrect. Reaction 2 is a redox reaction. Species involved in redox reactions can have neutral charges.	
(D)	Correct. In reaction 2, the oxidation number of oxygen is -1 in H_2O_2 , -2 in H_2O , and 0 in O_2 . Therefore, there is a transfer of electrons between oxygen atoms as the reaction occurs, and the reaction is a redox reaction.	

Question 10

Skill	Learning Objective	Topic
6.A	2.2.A	Intramolecular Force and Potential Energy
(A)	<p>Correct. The Coulombic force is directly proportional to $\frac{q_1 q_2}{r^2}$, where q_1 and q_2 are the charges of the ions and r is the distance between the ions. Ionic compounds that contain the smallest ions and ions with the greatest charges therefore have the strongest Coulombic attractions between ions. The charge on the cation is +2 in all responses. MgO and CaO have a -2 charge on the anion, whereas MgCl₂ and CaCl₂ have a -1 charge on the anion. The Mg²⁺ ion has one less occupied electron shell and thus is smaller than the Ca²⁺ ion, so MgO has the strongest Coulombic attractions among the choices given.</p>	
(B)	<p>Incorrect. The Coulombic force is directly proportional to $\frac{q_1 q_2}{r^2}$, where q_1 and q_2 are the charges of the ions and r is the distance between the ions. Ionic compounds that contain the smallest ions and ions with the greatest charges therefore have the strongest Coulombic attractions between ions. The charge on the cation is +2 in all responses. MgO and CaO have a -2 charge on the anion, whereas MgCl₂ and CaCl₂ have a -1 charge on the anion. The Mg²⁺ ion has one less occupied electron shell and thus is smaller than the Ca²⁺ ion, so MgO has the strongest Coulombic attractions among the choices given.</p>	
(C)	<p>Incorrect. The Coulombic force is directly proportional to $\frac{q_1 q_2}{r^2}$, where q_1 and q_2 are the charges of the ions and r is the distance between the ions. Ionic compounds that contain the smallest ions and ions with the greatest charges therefore have the strongest Coulombic attractions between ions. The charge on the cation is +2 in all responses. MgO and CaO have a -2 charge on the anion, whereas MgCl₂ and CaCl₂ have a -1 charge on the anion. The Mg²⁺ ion has one less occupied electron shell and thus is smaller than the Ca²⁺ ion, so MgO has the strongest Coulombic attractions among the choices given.</p>	
(D)	<p>Incorrect. The Coulombic force is directly proportional to $\frac{q_1 q_2}{r^2}$, where q_1 and q_2 are the charges of the ions and r is the distance between the ions. Ionic compounds that contain the smallest ions and ions with the greatest charges therefore have the strongest Coulombic attractions between ions. The charge on the cation is +2 in all responses. MgO and CaO have a -2 charge on the anion, whereas MgCl₂ and CaCl₂ have a -1 charge on the anion. The Mg²⁺ ion has one less occupied electron shell and thus is smaller than the Ca²⁺ ion, so MgO has the strongest Coulombic attractions among the choices given.</p>	

Question 11

Skill	Learning Objective	Topic
2.A	4.5.A	Stoichiometry
(A)	Incorrect. The value of ΔH_{rxn}° cannot be determined from the experiment; that calculation requires the amount of heat produced, q , which cannot be determined from the data collected in the procedure.	
(B)	Incorrect. The density of the metal cannot be determined from the experiment; the measurement of the volume of the metal is not included in the procedure.	
(C)	Correct. The number of moles of $H_2(g)$ and the balanced chemical equation can be used to determine the number of moles of metal M. The molar mass of M can then be calculated using the equation $\text{molar mass of metal M} = \frac{\text{grams of metal M}}{\text{number of moles of metal M}}.$	
(D)	Incorrect. The value of the specific heat of the metal cannot be determined from the experiment; that calculation requires the initial and final temperatures of the metal and the amount of heat produced, q , which cannot be determined from the data collected in the procedure.	

Question 12

Skill	Learning Objective	Topic
5.D	2.2.A	Intramolecular Force and Potential Energy
(A)	Correct. The minimum in the potential energy curve is -140 kJ/mol . Bond energy is the energy required to break a bond and has the corresponding positive value, 140 kJ/mol .	
(B)	Incorrect. The curve shows a potential energy of 0 at 170 pm ; this does not correspond to the bond energy.	
(C)	Incorrect. The value of 200 kJ/mol is the maximum potential energy shown on the curve; it is not the bond energy.	
(D)	Incorrect. The bottom of the curve is at 270 pm ; 270 does not correspond to the bond energy, but it instead corresponds to the bond length.	

Question 13

Skill	Learning Objective	Topic
5.E	9.9.A	Cell Potential and Free Energy
(A)	Incorrect. For this reaction, $E_{cell}^{\circ} = -0.74 \text{ V} - (-0.28 \text{ V}) = -0.46 \text{ V}$. The voltage is negative, so the reaction is not thermodynamically favorable.	
(B)	Incorrect. For this reaction, $E_{cell}^{\circ} = -0.74 \text{ V} - (-0.44 \text{ V}) = -0.30 \text{ V}$. The voltage is negative, so the reaction is not thermodynamically favorable.	
(C)	Correct. Reactions with a positive E_{cell}° are thermodynamically favorable. For this reaction, $E_{cell}^{\circ} = -0.28 \text{ V} - (-0.74 \text{ V}) = +0.46 \text{ V}$, so the reaction is thermodynamically favorable.	
(D)	Incorrect. For this reaction, $E_{cell}^{\circ} = -0.44 \text{ V} - (-0.28 \text{ V}) = -0.16 \text{ V}$. The voltage is negative, so the reaction is not thermodynamically favorable.	

Question 14

Skill	Learning Objective	Topic
5.C	5.2.A	Introduction to Rate Law
(A)	Incorrect. The reaction is second order with respect to $\text{HI}(g)$, so when the rate increases by a factor of 16, the initial concentration of $\text{HI}(g)$ must have increased by a factor of 4. This option is an increase by a factor of 2.	
(B)	Correct. The reaction is second order with respect to $\text{HI}(g)$, so the rate is proportional to $[\text{HI}]^2$. $\frac{\text{Rate}_{\text{trial 2}}}{\text{Rate}_{\text{trial 1}}} = \frac{([\text{HI}]_{\text{trial 2}})^2}{([\text{HI}]_{\text{trial 1}})^2}$, so $\frac{16x}{x} = \frac{([\text{HI}]_{\text{trial 2}})^2}{(0.20M)^2}$ and $[\text{HI}]_{\text{trial 2}} = \sqrt{16(0.20M)^2} = 0.80 M$.	
(C)	Incorrect. The reaction is second order with respect to $\text{HI}(g)$, so when the rate increases by a factor of 16, the initial concentration of $\text{HI}(g)$ must have increased by a factor of 4. This option is an increase by a factor of 8.	
(D)	Incorrect. The reaction is second order with respect to $\text{HI}(g)$, so when the rate increases by a factor of 16, the initial concentration of $\text{HI}(g)$ must have increased by a factor of 4. This option is an increase by a factor of 16, which is what would occur if the reaction were first order with respect to $\text{HI}(g)$.	

Question 15

Skill	Learning Objective	Topic
1.B	3.2.A	Properties of Solids
(A)	Correct. Ionic compounds have higher boiling points than molecular substances with covalent bonds do. LiCl is the only ionic compound among the choices given; the other choices are molecular compounds that have covalent bonds and are held together by intermolecular forces that are weaker than the attractions between ions.	
(B)	Incorrect. Cl_2 is a molecular gas at room temperature. It has only London dispersion forces, and it has a relatively low boiling point.	
(C)	Incorrect. PCl_3 is a molecular compound with a relatively low boiling point.	
(D)	Incorrect. CCl_4 is a molecular compound with a relatively low boiling point.	

Question 16

Skill	Learning Objective	Topic
5.F	6.6.A	Introduction to Enthalpy of Reaction
(A)	<p>Incorrect. $0.64 \text{ g CaC}_2 \times \frac{1 \text{ mol CaC}_2}{64 \text{ g CaC}_2} \times \frac{-128 \text{ kJ}}{1 \text{ mol CaC}_2} = -1.3 \text{ kJ}$.</p> <p>While the magnitude of the energy transfer is calculated correctly, the negative sign indicates that the reaction is exothermic, so energy is released; it is not absorbed.</p>	
(B)	<p>Correct. $0.64 \text{ g CaC}_2 \times \frac{1 \text{ mol CaC}_2}{64 \text{ g CaC}_2} \times \frac{-128 \text{ kJ}}{1 \text{ mol CaC}_2} = -1.3 \text{ kJ}$. The reaction is exothermic, so 1.3 kJ of energy is released.</p>	
(C)	<p>Incorrect. This response is obtained by neglecting to convert from grams to moles and multiplying 0.64 g by -128 kJ/mol. Additionally, the reaction is exothermic, so energy is released; it is not absorbed.</p>	
(D)	<p>Incorrect. This response is obtained by neglecting to convert from grams to moles and multiplying 0.64 g by -128 kJ/mol.</p>	

Question 17

Skill	Learning Objective	Topic
5.B	9.3.A	Gibbs Free Energy and Thermodynamic Favorability
(A)	Incorrect. Activation energy relates to chemical kinetics, the rate of the reaction, rather than whether or not the reaction is thermodynamically favorable.	
(B)	Incorrect. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. A reaction is thermodynamically favorable when ΔG° is negative, so a negative ΔH° and a positive ΔS° contribute to thermodynamic favorability. This reaction has a negative ΔH° . None of the reactants is a gas, but one of the products is a gas, so ΔS° is positive. Therefore, both ΔH° and ΔS° contribute to the reaction being thermodynamically favorable, not just ΔH° .	
(C)	Incorrect. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. A reaction is thermodynamically favorable when ΔG° is negative, so a negative ΔH° and a positive ΔS° contribute to thermodynamic favorability. This reaction has a negative ΔH° . None of the reactants is a gas, but one of the products is a gas, so ΔS° is positive. Therefore, both ΔH° and ΔS° contribute to the reaction being thermodynamically favorable, not just ΔS° .	
(D)	Correct. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. A reaction is thermodynamically favorable when ΔG° is negative, so a negative ΔH° and a positive ΔS° contribute to thermodynamic favorability. This reaction has a negative ΔH° . None of the reactants is a gas, but one of the products is a gas, so ΔS° is positive. Therefore, both ΔH° and ΔS° contribute to the reaction being thermodynamically favorable.	

Question 18

Skill	Learning Objective	Topic
4.A	8.2.A	pH and pOH of Strong Acids and Bases
(A)	<p>Correct. $\text{Ca}(\text{OH})_2(s)$ is one of the products of the reaction.</p> <p>The resulting solution is slightly basic, so $\text{OH}^-(aq)$ ions must have formed. The presence of $\text{OH}^-(aq)$ ions indicates that $\text{Ca}(\text{OH})_2(s)$ is slightly soluble and that the reaction $\text{Ca}(\text{OH})_2(s) \rightleftharpoons \text{Ca}^{2+}(aq) + 2 \text{OH}^-(aq)$ occurs to a small extent.</p>	
(B)	<p>Incorrect. $\text{C}_2\text{H}_2(g)$ is not a proton donor and would not increase the pH of the product mixture. If $\text{C}_2\text{H}_2(g)$ were a proton donor, it would decrease the pH rather than increase it.</p>	
(C)	<p>Incorrect. $\text{H}_2\text{O}(l)$ is not the limiting reactant (100. mL of $\text{H}_2\text{O}(l)$ is approximately 5.6 mol).</p>	
(D)	<p>Incorrect. The reaction is exothermic, so the temperature would not decrease.</p>	

Question 19

Skill	Learning Objective	Topic
1.A	1.7.A	Periodic Trends
(A)	<p>Correct. S^{2-} has a larger radius than O and F because the outermost electrons in S^{2-} are in a higher principal energy level than those in O and F. F has a smaller radius than O does, because the outermost electrons are in the same principal energy level, but F has a greater nuclear charge, causing a greater Coulombic attraction between the nucleus and the outermost electrons in F.</p>	
(B)	<p>Incorrect. O^{2-} has a larger radius than O does, not a smaller radius. O^{2-} has more electrons and the same number of protons as O.</p>	
(C)	<p>Incorrect. Cl has a larger radius than Ar does, not a smaller radius. The outermost electrons in Cl and Ar are in the same principal energy level, but Ar contains more protons, so the Coulombic attractions are greater in Ar.</p>	
(D)	<p>Incorrect. Mg and Mg^{2+} have the same number of protons, but Mg^{2+} has fewer electrons than Mg does and the outermost electrons in Mg^{2+} are in a lower principal energy level than the outermost electrons in Mg. Therefore, Mg^{2+} has a smaller radius than Mg does, not a larger radius.</p>	

Question 20

Skill	Learning Objective	Topic
6.B	5.3.A	Concentration Changes Over Time
(A)	Incorrect. The plot of $1 / [\text{NO}_2]$ versus time is linear, indicating that the reaction is second order with respect to $[\text{NO}_2]$. The half-life for second-order reactions is not constant.	
(B)	Incorrect. The integrated rate law for a second order process is $\frac{1}{[\text{A}]_t} - \frac{1}{[\text{A}]_0} = kt$, so $k = \frac{(290\text{M}^{-1} - 100\text{M}^{-1})}{350\text{ s}} \approx 0.5\text{ M}^{-1}\text{ s}^{-1}$.	
(C)	Incorrect. The plot of $1 / [\text{NO}_2]$ versus time is linear, indicating that the reaction is second order with respect to $[\text{NO}_2]$. The units of the rate constant are therefore $\text{M}^{-1}\text{ s}^{-1}$. This can be determined by dimensional analysis of the rate law: $k = \frac{\text{rate}}{[\text{NO}_2]^2}$, with units $\frac{\text{M s}^{-1}}{\text{M M}} = \text{M}^{-1}\text{ s}^{-1}$.	
(D)	Correct. The plot of $1 / [\text{NO}_2]$ versus time is linear, indicating that the reaction is second order with respect to $[\text{NO}_2]$. The rate law is therefore $\text{rate} = k[\text{NO}_2]^2$.	

Question 21

Skill	Learning Objective	Topic
2.B	7.9.A	Introduction to Le Châtelier's Principle
(A)	Incorrect. Increasing the temperature for an exothermic reaction will cause the position of equilibrium to shift toward reactants, increasing the amount of $\text{CO}(g)$ rather than decreasing it.	
(B)	Correct. In order for the amount of reactant $\text{CO}(g)$ to decrease, the position of equilibrium should shift toward the product. According to Le Châtelier's principle, a decrease in temperature causes a shift toward products for an exothermic reaction (indicated by the fact that ΔH° is negative).	
(C)	Incorrect. Adding $\text{CH}_3\text{OH}(g)$, which is the product, will cause the position of equilibrium to shift toward reactants, increasing the amount of $\text{CO}(g)$ rather than decreasing it.	
(D)	Incorrect. Removing $\text{H}_2(g)$ will cause the position of equilibrium to shift toward reactants, increasing the amount of $\text{CO}(g)$ rather than decreasing it.	

Question 22

Skill	Learning Objective	Topic
4.C	8.3.A	Weak Acid and Base Equilibria
(A)	Incorrect. The pH of a 0.10 M solution of a strong acid is 1.0, so sample 1 must be a strong acid. The particle drawing shows one dissociated HA molecule and three undissociated molecules. The acid does not dissociate completely in water, so it is a weak acid with a pH greater than 1.0.	
(B)	Correct. The pH of a 0.10 M solution of a strong acid is 1.0, so sample 1 must be a strong acid. Strong acids dissociate completely in water to form A^- and H_3O^+ ; no HA is present.	
(C)	Incorrect. The pH of a 0.10 M solution of a strong acid is 1.0, so sample 1 must be a strong acid. The particle drawing shows four undissociated HA molecules, with no H_3O^+ produced; the pH of the solution illustrated is 7.0, not 1.0.	
(D)	Incorrect. The pH of a 0.10 M solution of a strong acid is 1.0, so sample 1 must be a strong acid. The particle drawing shows two undissociated HA molecules and two dissociated molecules. The acid does not dissociate completely in water, so it is a weak acid with a pH greater than 1.0.	

Question 23

Skill		Learning Objective	Topic
2.B		8.4.A	Acid-Base Reactions and Buffers
(A)	Incorrect. All four samples have the same concentration, and sample 4 has the largest volume, so sample 4 must contain the largest number of moles of acid.		
(B)	Incorrect. All four samples have the same concentration, and sample 4 has the largest volume, so sample 4 must contain the largest number of moles of acid.		
(C)	Incorrect. All four samples have the same concentration, and sample 4 has the largest volume, so sample 4 must contain the largest number of moles of acid.		
(D)	Correct. All four samples have the same concentration, and sample 4 has the largest volume, so sample 4 must contain the largest number of moles of acid. The largest number of moles of acid would require the largest number of moles of NaOH for complete neutralization.		

Question 24

Skill	Learning Objective	Topic
5.B	8.3.A	Weak Acid and Base Equilibria
(A)	Incorrect. A pH of 1.0 for an acid with a concentration of 0.10 <i>M</i> indicates that the acid is a strong acid. Strong acids have large K_a values. $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$, so for a given concentration of acid, $[\text{HA}]$, the acid with the smallest K_a has the smallest $[\text{H}_3\text{O}^+]$ and is the weakest acid.	
(B)	Incorrect. $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$, so for a given concentration of acid, $[\text{HA}]$, the acid with the smallest K_a has the smallest $[\text{H}_3\text{O}^+]$ and is the weakest acid. Sample 2 does not have the highest pH of the choices given, so it does not have the smallest K_a value.	
(C)	Correct. $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$, so for a given concentration of acid, $[\text{HA}]$, the acid with the smallest K_a has the smallest $[\text{H}_3\text{O}^+]$ and is the weakest acid. A smaller value of $[\text{H}_3\text{O}^+]$ corresponds to a higher pH. The four acids shown in the table have the same concentration, so the one with the highest pH has the smallest K_a . Therefore, sample 3 has the smallest K_a value.	
(D)	Incorrect. $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$, so for a given concentration of acid, $[\text{HA}]$, the acid with the smallest K_a has the smallest $[\text{H}_3\text{O}^+]$ and is the weakest acid. Sample 4 does not have the highest pH of the choices given, so it does not have the smallest K_a value.	

Question 25

Skill	Learning Objective	Topic
4.C	8.3.A	Weak Acid and Base Equilibria
(A)	Correct. Given that $\text{pH} = -\log[\text{H}_3\text{O}^+]$, the smallest value of $[\text{H}_3\text{O}^+]$ corresponds to the greatest pH due to the negative sign in the expression. The solution with the greatest pH is the least acidic and has the lowest concentration of H_3O^+ .	
(B)	Incorrect. The smallest value of $[\text{OH}^-]$ corresponds to the most acidic solution with the greatest pOH and the lowest pH rather than the greatest pH.	
(C)	Incorrect. The weakest conjugate base corresponds to the strongest acid, which would have the lowest pH rather than the greatest pH.	
(D)	Incorrect. The strongest acid would have the highest $[\text{H}_3\text{O}^+]$ and the lowest pH rather than the greatest pH.	

Question 26

Skill	Learning Objective	Topic
4.C	3.1.A	Intermolecular and Interparticle Forces
(A)	Incorrect. O_2 does have a double bond, but covalent bonds are not broken when a molecular substance boils, so covalent bonding cannot be used to explain relative boiling points. The boiling point of a molecular substance depends on the strength of the intermolecular forces in the substance.	
(B)	Correct. The substance with the highest boiling is the substance with the strongest intermolecular forces. Hydrogen bonding is the strongest intermolecular force for small molecules, and H_2O is the only substance listed that exhibits hydrogen bonding; therefore, H_2O has the highest boiling point.	
(C)	Incorrect. The boiling point of a molecular substance depends on the strength of the intermolecular forces in the substance. Hydrogen bonding is a strong intermolecular force, but C_3H_8 cannot form hydrogen bonds. The molecule does not contain a nitrogen, oxygen, or fluorine atom to form a hydrogen bond.	
(D)	Incorrect. While the C – F bonds are highly polar, the CF_4 molecule is symmetrical and has a tetrahedral shape, so the bond dipoles cancel out, and the molecule has no net dipole moment. Therefore, it has only London dispersion forces and a relatively low boiling point.	

Question 27

Skill	Learning Objective	Topic
5.B	7.3.A	Reaction Quotient and Equilibrium Constant
(A)	Incorrect. $K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$, where $a A + b B \rightleftharpoons c C + d D$. This response has the expression inverted, and it neglects the coefficients of the species in the balanced chemical equation.	
(B)	Incorrect. $K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$, where $a A + b B \rightleftharpoons c C + d D$. This response neglects the coefficients of the species in the balanced chemical equation.	
(C)	Incorrect. $K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$, where $a A + b B \rightleftharpoons c C + d D$. This response has the expression inverted.	
(D)	Correct. $K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$, where $a A + b B \rightleftharpoons c C + d D$. Therefore, the correct expression is $K_c = \frac{[\text{NOBr}]^2}{[\text{NO}]^2 [\text{Br}_2]}$.	

Question 28

Skill	Learning Objective	Topic
4.C	6.7.A	Bond Enthalpies
(A)	Correct. It requires energy to break a bond and separate two atoms, so the reaction is endothermic with a positive ΔH° .	
(B)	Incorrect. The value of ΔH° is positive, so it is correct that the reaction is endothermic. However, breaking a bond requires the absorption of energy; it does not release energy.	
(C)	Incorrect. The value of ΔH° is positive, so the reaction is endothermic rather than exothermic.	
(D)	Incorrect. The value of ΔH° is positive, so the reaction is endothermic rather than exothermic. Also, breaking a bond requires the absorption of energy; it does not release energy.	

Question 29

Skill	Learning Objective	Topic
5.F	6.4.A	Heat Capacity and Calorimetry
(A)	Incorrect. The calculation incorrectly reverses the masses of the metal and water. The equations for this incorrect response are $q = mc\Delta T = (15 \text{ g})(4.18 \text{ J / (g}\cdot\text{C)})(20.0^\circ\text{C} - 18.0^\circ\text{C}) = 125 \text{ J}$ and $-q = mc\Delta T = -125 \text{ J} = (50. \text{ g})(c)(20.0^\circ\text{C} - 80.0^\circ\text{C})$, resulting in $c = 0.042 \text{ J / (g}\cdot\text{C)}$.	
(B)	Incorrect. The calculation of q for the metal incorrectly uses the initial temperature of the metal rather than the temperature change. The equation for this incorrect response is $q = mc\Delta T = 418 \text{ J} = (15 \text{ g})(c)(80.0^\circ\text{C})$, resulting in $c = 0.35 \text{ J / (g}\cdot\text{C)}$.	
(C)	Correct. In this experiment, $q_{\text{H}_2\text{O}} = -q_{\text{metal}}$ and $q = mc\Delta T$. For the water, $q = mc\Delta T = (50. \text{ g})(4.18 \text{ J / (g}\cdot\text{C)})(20.0^\circ\text{C} - 18.0^\circ\text{C}) = 418 \text{ J}$. For the metal, $-q = mc\Delta T = -418 \text{ J} = (15 \text{ g})(c)(20.0^\circ\text{C} - 80.0^\circ\text{C})$ and $c = 0.46 \text{ J / (g}\cdot\text{C)}$.	
(D)	Incorrect. The calculation of q for the metal incorrectly uses the final temperature of the water rather than the temperature change. The equation for this incorrect response is $q = mc\Delta T = 418 \text{ J} = (15 \text{ g})(c)(20.0^\circ\text{C})$, resulting in $c = 1.39 \text{ J / (g}\cdot\text{C)}$.	

Question 30

Skill	Learning Objective	Topic
5.F	7.7.A	Calculating Equilibrium Concentrations
(A)	Incorrect. It is true that K_p is less than 1, but this option does not compare Q with K_p , so the change in P_{O_2} cannot be predicted.	
(B)	Incorrect. The comparison of simply the number of moles of reactants and product cannot be used to predict which way a reaction system shifts to reach equilibrium; a comparison of Q and K_p is needed to make the prediction.	
(C)	Incorrect. A reaction system does not necessarily shift in the direction to increase the amount of the species with the lowest concentration. A comparison of Q and K_p is needed to make the prediction.	
(D)	<p>Correct. $Q = \frac{(P_{SO_3})^2}{(P_{SO_2})^2 (P_{O_2})} = \frac{(2.0)^2}{(4.0)^2 (10.)} = 0.025 = K_p$, so the system is at equilibrium and P_{O_2} will not change.</p>	

Question 31

Skill	Learning Objective	Topic
5.C	9.3.A	Gibbs Free Energy and Thermodynamic Favorability
(A)	<p>Incorrect. Reactions with a $\Delta G < 0$ are thermodynamically favorable.</p> $\Delta G_{398K}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 398(-0.178) = -472 \text{ kJ/mol}_{rxn}.$ <p>The reaction is favorable rather than unfavorable at 398 K .</p>	
(B)	<p>Incorrect. Reactions with a $\Delta G < 0$ are thermodynamically favorable.</p> $\Delta G_{398K}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 398(-0.178) = -472 \text{ kJ/mol}_{rxn}.$ $\Delta G_{798}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 798(-0.178) = -400 \text{ kJ/mol}_{rxn}.$ <p>The reaction is favorable at both temperatures rather than unfavorable at both temperatures. If the value of ΔS° is not converted from J / (K·mol) to kJ / (K·mol) prior to computing ΔG°, then an incorrect positive value of ΔG° would be calculated, which would lead to the incorrect conclusion that the reaction is unfavorable at both temperatures.</p>	
(C)	<p>Correct. Reactions with a $\Delta G < 0$ are thermodynamically favorable.</p> $\Delta G_{398K}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 398(-0.178) = -472 \text{ kJ/mol}_{rxn}.$ <p>The reaction is favorable at 398 K .</p> $\Delta G_{798K}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 798(-0.178) = -400 \text{ kJ/mol}_{rxn}.$ <p>The reaction is favorable at 798 K . The reaction is favorable at both temperatures.</p>	
(D)	<p>Incorrect. Reactions with a $\Delta G < 0$ are thermodynamically favorable.</p> $\Delta G_{798}^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} = -543 - 798(-0.178) = -400 \text{ kJ/mol}_{rxn}.$ <p>The reaction is favorable rather than unfavorable at 798 K .</p>	

Question 32

Skill	Learning Objective	Topic
2.E	1.1.A	Moles and Molar Mass
(A)	<p>Correct. If the $\text{AgBr}(s)$ was not completely dried, the measured mass of $\text{AgBr}(s)$ would include some mass of the residual water. As a result, the calculated concentration of $\text{NaBr}(aq)$ would be higher than the actual concentration, because the student would assume that all of the measured mass was $\text{AgBr}(aq)$ and conclude that the moles of the bromide ion and concentration of $\text{NaBr}(aq)$ were greater than they actually were.</p>	
(B)	<p>Incorrect. If some of the $\text{AgBr}(s)$ was lost during weighing, the calculated concentration of $\text{NaBr}(aq)$ would be lower than the actual concentration, because the student would assume that the number of moles of the bromide ion was smaller than it actually was.</p>	
(C)	<p>Incorrect. If an insufficient amount of $\text{AgNO}_3(aq)$ was added, the bromide ions left in solution would not be accounted for in the $\text{AgBr}(s)$ precipitate. As a result, the calculated concentration of $\text{NaBr}(aq)$ would be lower than the actual concentration.</p>	
(D)	<p>Incorrect. If the filter paper had a hole in it, some of the $\text{AgBr}(s)$ would have been lost during filtration. As a result, the calculated concentration of $\text{NaBr}(aq)$ would be lower than the actual concentration.</p>	

Question 33

Skill	Learning Objective	Topic
6.B	5.3.A	Concentration Changes Over Time
(A)	Incorrect. First-order reactions have constant half-lives $\left(t_{1/2} = \frac{\ln 2}{k_1}\right)$, so $t_2 = t_1$. However, in that same amount of time $R_2 > R_1$, because this first order reaction would have a rate law of rate = $k[\text{C}_2\text{H}_5\text{Cl}]$, and the second trial would proceed at double the rate because it has double the concentration of $\text{C}_2\text{H}_5\text{Cl}$.	
(B)	Incorrect. First-order reactions have constant half-lives $\left(t_{1/2} = \frac{\ln 2}{k_1}\right)$, so $t_2 = t_1$. This response would be correct if the reaction were zero order.	
(C)	Correct. First-order reactions have constant half-lives $\left(t_{1/2} = \frac{\ln 2}{k_1}\right)$, so $t_2 = t_1$. Additionally, $R_2 > R_1$, because this first order reaction would have a rate law of rate = $k[\text{C}_2\text{H}_5\text{Cl}]$, and the second trial would proceed at double the rate because it has double the concentration of $\text{C}_2\text{H}_5\text{Cl}$.	
(D)	Incorrect. First-order reactions have constant half-lives $\left(t_{1/2} = \frac{\ln 2}{k_1}\right)$, so $t_2 = t_1$. This response would be correct if the reaction were second order.	

Question 34

Skill	Learning Objective	Topic
5.F	4.5.A	Stoichiometry
(A)	Incorrect. V and T are constant, so the numbers of moles are proportional to the partial pressures. The value 0.50 atm would be the inverse of the theoretical yield if N_2 were the limiting reactant. $\left(0.50 = \frac{1}{2.00}\right)$	
(B)	Correct. V and T are constant, so the numbers of moles are proportional to the partial pressures. The limiting reactant is the one that produces the least amount of product: $1.00 \text{ atm } N_2 \left(\frac{2 \text{ mol } NF_3}{1 \text{ mol } N_2} \right) = 2.00 \text{ atm } NF_3$ $1.80 \text{ atm } F_2 \left(\frac{2 \text{ mol } NF_3}{3 \text{ mol } F_2} \right) = 1.20 \text{ atm } NF_3$ The theoretical yield is 1.20 atm NF_3 , because F_2 is the limiting reactant.	
(C)	Incorrect. V and T are constant, so the numbers of moles are proportional to the partial pressures. The value 2.00 atm would be the theoretical yield if N_2 were the limiting reactant.	
(D)	Incorrect. This value is the sum of the two starting pressures. $(2.80 \text{ atm} = 1.00 \text{ atm} + 1.80 \text{ atm})$	

Question 35

Skill	Learning Objective	Topic
6.C	2.6.A	Resonance and Formal Charge
(A)	Incorrect. The formal charges of the atoms are used to determine the better resonance structure. Symmetry is unrelated.	
(B)	Incorrect. The electronegativity of O is greater than that of N. The more electronegative element should have the negative formal charge, but N has a negative formal charge in structure 1.	
(C)	Incorrect. The formal charges of the atoms are used to determine the better resonance structure. The relative strengths of the bonds are unrelated.	
(D)	Correct. Elements that have a higher electronegativity tend to have formal charges that are more negative. The electronegativity of O is greater than that of N, and O has a formal charge of -1 in structure 2.	

Question 36

Skill	Learning Objective	Topic
6.F	3.9.A	Separation of Solutions and Mixtures
(A)	Incorrect. In thin-layer chromatography, molecules with greater affinity for the stationary phase move the slowest during development of the chromatogram, and those with greater affinity for the mobile phase move the fastest. The nonpolar hexane moves the fastest in this experiment and the polar ethanoic acid moves the slowest, so the stationary phase is polar and the mobile phase is nonpolar.	
(B)	Incorrect. Typically, the phases must be significantly different in polarity for thin-layer chromatography to work well.	
(C)	Incorrect. Typically, the phases must be significantly different in polarity for thin-layer chromatography to work well.	
(D)	Correct. In thin-layer chromatography, molecules with greater affinity for the stationary phase move the slowest during development of the chromatogram, and those with greater affinity for the mobile phase move the fastest. The nonpolar hexane moves the fastest in this experiment and the polar ethanoic acid moves the slowest, so the stationary phase is polar and the mobile phase is nonpolar.	

Question 37

Skill	Learning Objective	Topic
6.E	3.1.A	Intermolecular and Interparticle Forces
(A)	Incorrect. Both molecules are polar and experience dipole-dipole forces.	
(B)	Incorrect. Neither molecule experiences hydrogen bonding forces. The molecules do not contain hydrogen atoms bonded to fluorine, oxygen, or nitrogen atoms.	
(C)	Correct. CHCl_3 has more electrons than CHF_3 has (58 compared to 34). Therefore, CHCl_3 has a larger, more polarizable electron cloud, resulting in stronger London dispersion forces and a higher boiling point.	
(D)	Incorrect. Covalent bonds are not broken during phase changes.	

Question 38

Skill		Learning Objective	Topic
4.A		1.6.A	Photoelectron Spectroscopy
(A)	Incorrect. The electrons in species X have smaller binding energies than the electrons in species Y do. Therefore, X must have a smaller nuclear charge, not a larger one.		
(B)	Incorrect. The electrons in species X have smaller binding energies than the electrons in species Y do. Therefore, X must have a smaller nuclear charge, not a larger one.		
(C)	Incorrect. The electrons in species X have smaller binding energies than the electrons in species Y do. If the two species are isoelectronic, then X must be negatively charged because it has a smaller nuclear charge.		
(D)	Correct. The electrons in species X have smaller binding energies than the electrons in species Y do. If the two species are isoelectronic, then X must be negatively charged because it has a smaller nuclear charge.		

Question 39

Skill	Learning Objective	Topic
5.F	3.4.A	Ideal Gas Law
(A)	<p>Correct. The number of moles for an ideal gas is $n = \frac{PV}{RT}$.</p> $n_A = \frac{(2.0)(1.0)}{200R} = \frac{0.010}{R} = 0.12 \text{ mol.}$ <p>The largest value is n_A.</p> <p>Therefore, container A has the greatest number of $O_2(g)$ molecules:</p> $N_{O_2, \text{container A}} = 0.12 \times 6.022 \times 10^{23} = 7.2 \times 10^{22} \text{ molecules.}$	
(B)	<p>Incorrect. $n_B = \frac{(1.0)(2.0)}{300R} = \frac{0.0067}{R} = 0.082 \text{ mol.}$ The value $n_B < n_A$. Therefore, container B does not have the greatest number of $O_2(g)$ molecules.</p> $N_{O_2, \text{container B}} = 0.082 \times 6.022 \times 10^{23} = 4.9 \times 10^{22} \text{ molecules.}$	
(C)	<p>Incorrect. $n_C = \frac{(1.5)(1.0)}{300R} = \frac{0.0050}{R} = 0.061 \text{ mol.}$ The value $n_C < n_A$. Therefore, container C does not have the greatest number of $O_2(g)$ molecules.</p> $N_{O_2, \text{container C}} = 0.061 \times 6.022 \times 10^{23} = 3.7 \times 10^{22} \text{ molecules.}$	
(D)	<p>Incorrect. $n_D = \frac{(3.0)(0.50)}{200R} = \frac{0.0075}{R} = 0.091 \text{ mol.}$ The value $n_D < n_A$. Therefore, container D does not have the greatest number of $O_2(g)$ molecules.</p> $N_{O_2, \text{container D}} = 0.091 \times 6.022 \times 10^{23} = 5.5 \times 10^{22} \text{ molecules.}$	

Question 40

Skill	Learning Objective	Topic
4.C	2.2.A	Intramolecular Force and Potential Energy
(A)	Incorrect. Cl^- has a greater number of occupied electron shells and is a larger ion than F^- is, but LiCl has a smaller lattice enthalpy than LiF does. Similarly, Sr^{2+} is a larger ion than Mg^{2+} is, but SrCl_2 has a smaller lattice enthalpy than MgCl_2 does. Therefore, this statement is inconsistent with the data in the table.	
(B)	Correct. F^- has fewer occupied electron shells and is a smaller ion than Cl^- is, and LiF has a larger lattice enthalpy than LiCl does. Similarly, Mg^{2+} is a smaller ion than Sr^{2+} is, and MgCl_2 has a larger lattice enthalpy than SrCl_2 does. Therefore, this statement is consistent with the data in the table.	
(C)	Incorrect. Li^+ has a smaller charge than Mg^{2+} has, but MgCl_2 has a larger lattice enthalpy than LiCl does. Therefore, this statement is inconsistent with the data in the table.	
(D)	Incorrect. Cl^- has a smaller electronegativity than F^- has, but LiF has a larger lattice enthalpy than LiCl does. Therefore, this statement is inconsistent with the data in the table.	

Question 41

Skill	Learning Objective	Topic
5.F	1.4.A	Composition of Mixtures
(A)	Incorrect. $\%C_{\text{Sample A}} = \frac{m_C}{m_C + m_H} = \frac{4 \times 12}{(4 \times 12) + (14 \times 1.0)} \times 100\% = 77\%.$ $\%C_{\text{Sample A}} < \%C_{\text{Sample B}}, \text{ so sample A does not contain the greatest percentage of carbon by mass.}$	
(B)	Correct. Sample B has the greatest percentage of carbon by mass. $\%C_{\text{Sample B}} = \frac{m_C}{m_C + m_H} = \frac{4 \times 12}{(4 \times 12) + (8 \times 1.0)} \times 100\% = 86\%.$	
(C)	Incorrect. $\%C_{\text{Sample C}} = \frac{m_C}{m_C + m_O} = \frac{4 \times 12}{(4 \times 12) + (6 \times 16)} \times 100\% = 33\%.$ $\%C_{\text{Sample C}} < \%C_{\text{Sample B}}, \text{ so sample C does not contain the greatest percentage of carbon by mass.}$	
(D)	Incorrect. $\%C_{\text{Sample D}} = \frac{m_C}{m_C + m_O} = \frac{4 \times 12}{(4 \times 12) + (4 \times 16)} \times 100\% = 43\%.$ $\%C_{\text{Sample D}} < \%C_{\text{Sample B}}, \text{ so sample D does not contain the greatest percentage of carbon by mass.}$	

Question 42

Skill	Learning Objective	Topic
4.B	5.10.A	Multistep Reaction Energy Profile
(A)	Correct. The mechanism has a slow first step and a fast second step, so the first step has a high activation energy and the second step has a low activation energy; this energy profile is consistent with the kinetics of the reaction. The overall reaction is exothermic; this energy profile shows that the energy at the end of the reaction is less than the energy at the beginning of the reaction, which is characteristic of an exothermic reaction.	
(B)	Incorrect. The mechanism has a slow first step and a fast second step, so the first step has a high activation energy and the second step has a low activation energy; this energy profile is not consistent with the kinetics of the reaction. The overall reaction is exothermic; this energy profile shows that the energy at the end of the reaction is greater than the energy at the beginning of the reaction, which is characteristic of an endothermic reaction, not an exothermic reaction.	
(C)	Incorrect. The overall reaction is exothermic; this energy profile shows that the energy at the end of the reaction is greater than the energy at the beginning of the reaction, which is characteristic of an endothermic reaction, not an exothermic reaction.	
(D)	Incorrect. The mechanism has a slow first step and a fast second step, so the first step has a high activation energy and the second step has a low activation energy; this energy profile is not consistent with the kinetics of the reaction.	

Question 43

Skill		Learning Objective	Topic
1.A		9.1.A	Introduction to Entropy
(A)	Incorrect. When water molecules change from the liquid state to the gas state, they become more dispersed and their entropy increases.		
(B)	Correct. When water molecules change from the liquid state to the solid state, they are less free to move and their entropy decreases.		
(C)	Incorrect. When carbon dioxide molecules are released from a pressurized container, the gas molecules are able to move within a larger space; they are more dispersed and their entropy increases.		
(D)	Incorrect. When the temperature increases, the distribution of kinetic energy among the molecules broadens; energy is more dispersed and the entropy increases.		

Question 44

Skill	Learning Objective	Topic
5.F	6.8.A	Enthalpy of Formation
(A)	<p>Incorrect. This answer is obtained if the stoichiometric coefficients are not used and the incorrect equation</p> $\Delta H^{\circ} = [\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) + \Delta H_f^{\circ}(\text{O}_2)] + [\Delta H_f^{\circ}(\text{CO}_2) + \Delta H_f^{\circ}(\text{H}_2\text{O})]$ <p>is used, resulting in</p> $\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) = [(-1368) + (0)] - [(-394) + (-286)] = -688 \text{ kJ/mol}.$	
(B)	<p>Correct. The enthalpy of a reaction is equal to the sum of the enthalpies of formation of products minus reactants.</p> $\Delta H^{\circ} = [2 \Delta H_f^{\circ}(\text{CO}_2) + 3 \Delta H_f^{\circ}(\text{H}_2\text{O})] - [\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) + 3 \Delta H_f^{\circ}(\text{O}_2)].$ <p>Solving for the enthalpy of formation of $\text{C}_2\text{H}_5\text{OH}(l)$ gives</p> $\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) = [2(-394) + 3(-286)] - [(-1368) + 3(0)] = -278 \text{ kJ/mol}.$	
(C)	<p>Incorrect. This answer is obtained if the incorrect equation</p> $\Delta H^{\circ} = [\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) + 3 \Delta H_f^{\circ}(\text{O}_2)] + [2 \Delta H_f^{\circ}(\text{CO}_2) + 3 \Delta H_f^{\circ}(\text{H}_2\text{O})]$ <p>is used, resulting in</p> $\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) = [(-1368) + 3(0)] - [2(-394) + 3(-286)] = 278 \text{ kJ/mol}.$	
(D)	<p>Incorrect. This answer is obtained if the stoichiometric coefficients are not used in the calculation, resulting in</p> $\Delta H^{\circ} = [\Delta H_f^{\circ}(\text{CO}_2) + \Delta H_f^{\circ}(\text{H}_2\text{O})] - [\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) + \Delta H_f^{\circ}(\text{O}_2)]$ <p>and</p> $\Delta H_f^{\circ}(\text{C}_2\text{H}_5\text{OH}) = [(-394) + (-286)] - [(-1368) + (0)] = 688 \text{ kJ/mol}.$	

Question 45

Skill	Learning Objective	Topic
4.A	8.10.A	Buffer Capacity
(A)	<p>Correct. According to the Henderson-Hasselbalch equation,</p> $\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$ <p>If the ratio of the concentration of the base to that of the conjugate acid is the same in two buffers of the same acid, the pH values will be the same. If those concentrations increase in the same proportion, the buffer capacity increases, because the higher concentrations allow the buffer to react with more added acid or base. In the two buffers shown, the ratio of the concentrations are the same, so the buffers have the same pH. Buffer X has lower concentrations of the base and conjugate acid, so it has a smaller buffer capacity than buffer Y does.</p>	
(B)	<p>Incorrect. It is true that the two buffers have the same pH, but they do not have the same buffer capacity. The pH values will be the same if the ratio $\frac{[\text{A}^-]}{[\text{HA}]}$ is the same, but the buffer capacities will differ if the concentration of the acid and the concentration of the base are different in the two buffers.</p>	
(C)	<p>Incorrect. It is true that buffer X has a smaller buffer capacity than buffer Y does. However, the ratio $\frac{[\text{A}^-]}{[\text{HA}]}$ is the same for the two buffers, so the buffers have the same pH.</p>	
(D)	<p>Incorrect. The ratio $\frac{[\text{A}^-]}{[\text{HA}]}$ is the same for both buffers, so they have the same pH. The concentrations of base and conjugate acid are lower in buffer X, so buffer X has a smaller buffer capacity than Y does.</p>	

Question 46

Skill	Learning Objective	Topic
1.A	2.6.A	Resonance and Formal Charge
(A)	Incorrect. In the two resonance structures, electrons partially (and equally) occupy the two equivalent carbon-to-oxygen bonds labeled y and z , giving them a bond order of 1.5 (halfway between a single and double bond). As a result, the two bonds are expected to be equal in length. The single carbon-to-oxygen bond labeled x has a bond order of 1, so bonds y and z are shorter than bond x is.	
(B)	Correct. The structure of the HCO_3^- ion is a resonance hybrid of the two forms shown in the diagram. The electrons partially (and equally) occupy the two equivalent carbon-to-oxygen bonds labeled y and z , giving them a bond order of 1.5 (halfway between a single and double bond). As a result, the two bonds are expected to be equal in length and shorter than the single carbon-to-oxygen bond labeled x .	
(C)	Incorrect. Bonds y and z participate in the sharing of electrons by resonance, so they are equal in length and have a bond order of 1.5. Bond x has a bond order of 1, so it is longer than bonds y and z are. Therefore, bonds x and z are not equal in length and bond z is not longer than bond y .	
(D)	Incorrect. Bonds y and z participate in the sharing of electrons by resonance, so they are equal in length and have a bond order of 1.5. Bond x has a bond order of 1, so it is longer than bonds y and z are.	

Question 47

Skill	Learning Objective	Topic
5.F	7.4.A	Calculating the Equilibrium Constant
(A)	Incorrect. This value is obtained if the K_p expression is inverted and if P_{NO_2} is not squared, which results in the incorrect expression, $K_p = \frac{P_{\text{NO}_2}}{P_{\text{N}_2\text{O}_4}} = \frac{3}{6} = 0.50.$	
(B)	Correct. There are six N_2O_4 particles and three NO_2 particles in the diagram, and each particle represents 1.0 atm of gas. Therefore, the value of the equilibrium constant is given by $K_p = \frac{P_{\text{N}_2\text{O}_4}}{(P_{\text{NO}_2})^2} = \frac{6}{3^2} = 0.67.$	
(C)	Incorrect. This value is obtained if the K_p expression is inverted, which results in the incorrect expression, $K_p = \frac{(P_{\text{NO}_2})^2}{P_{\text{N}_2\text{O}_4}} = \frac{3^2}{6} = 1.5.$	
(D)	Incorrect. This value is obtained if P_{NO_2} is not squared, which results in the incorrect expression, $K_p = \frac{P_{\text{N}_2\text{O}_4}}{P_{\text{NO}_2}} = \frac{6}{3} = 2.0.$	

Question 48

Skill	Learning Objective	Topic
4.A	8.3.A	Weak Acid and Base Equilibria
(A)	Incorrect. KCl is a neutral salt that would not affect the pH of the solution. Neither $K^+(aq)$ ions nor $Cl^-(aq)$ ions would react with hydroxide ions to decrease the pH.	
(B)	Incorrect. $NaNO_3$ is a neutral salt that would not affect the pH of the solution. Neither $Na^+(aq)$ ions nor $NO_3^-(aq)$ ions would react with hydroxide ions to decrease the pH.	
(C)	Correct. Ammonium nitrate is an acidic salt that would be effective at decreasing the pH of the solution. $NH_4^+(aq)$ is the conjugate acid of the weak base $NH_3(aq)$. $NH_4^+(aq)$ can react according to the equation $NH_4^+(aq) + OH^-(aq) \rightarrow NH_3(aq) + H_2O(l)$ (or $NH_4^+(aq) + H_2O(l) \rightarrow NH_3(aq) + H_3O^+(aq)$), which would reduce the concentration of hydroxide ions in solution and decrease its pH.	
(D)	Incorrect. $NaC_2H_3O_2$ is a basic salt that would be effective at increasing, not decreasing, the pH of the solution. $C_2H_3O_2^-$ can react according to the equation $C_2H_3O_2^-(aq) + H_3O^+(aq) \rightarrow HC_2H_3O_2(aq) + H_2O(l)$ (or $C_2H_3O_2^-(aq) + H_2O(l) \rightarrow HC_2H_3O_2(aq) + OH^-(aq)$), which would increase its pH.	

Question 49

Skill	Learning Objective	Topic
4.C	6.5.A	Energy of Phase Changes
(A)	Incorrect. The temperature remains constant as the system goes from point B to point C. The average kinetic energy of the particles of the system, which is proportional to temperature, also remains constant. As the substance melts, the energy goes into increasing the average potential energy of the particles.	
(B)	Incorrect. The temperature remains constant as the system goes from point B to point C. The average kinetic energy of the particles of the system, which is proportional to temperature, also remains constant. The phase change occurring in this region is melting, not boiling.	
(C)	Correct. When the temperature of the system reaches the melting point of the substance, the particles of the system begin to transition from the solid state to the liquid state. During melting, the added energy goes into increasing the potential energy of the particles, while their average kinetic energy and the temperature of the system remain constant.	
(D)	Incorrect. The phase change occurring in this region is melting, not boiling.	

Question 50

Skill	Learning Objective	Topic
4.C	3.1.A	Intermolecular and Interparticle Forces
(A)	Correct. Iodine molecules, I_2 , with a total of 106 electrons, have a much larger and more polarizable electron cloud than do chlorine molecules, Cl_2 , with a total of 34 electrons. Therefore, I_2 has greater London dispersion forces among its molecules, giving it a higher boiling point than chlorine.	
(B)	Incorrect. Neither I_2 molecules nor Cl_2 molecules have a permanent dipole moment, so they are nonpolar.	
(C)	Incorrect. Intramolecular covalent bonding has no direct effect on boiling points of molecular substances.	
(D)	Incorrect. Neither I_2 molecules nor Cl_2 molecules have a permanent dipole moment, so they are nonpolar.	

Question 51

Skill	Learning Objective	Topic
5.D	3.5.A	Kinetic Molecular Theory
(A)	Incorrect. According to kinetic molecular theory, the peak of the curve for CH_4 will be at the second highest speed of the curves given, because the mass of CH_4 is the second smallest of the molecules given. Curve 1 is the curve for the most massive molecule, which is O_2 .	
(B)	Incorrect. According to kinetic molecular theory, the peak of the curve for CH_4 will be at the second highest speed of the curves given, because the mass of CH_4 is the second smallest of the molecules given. Curve 2 is the curve for the second most massive molecule, which is N_2 .	
(C)	Correct. Gas molecules at the same temperature have the same average kinetic energy, $KE = \frac{1}{2}mv^2$. In a speed distribution plot for a given temperature, molecules with smaller masses have greater average speeds. The molar masses of the set of molecules in the plot are 2 g/mol for H_2 , 32 g/mol for O_2 , 28 g/mol for N_2 , and 16 g/mol for CH_4 . CH_4 has the second smallest mass molecule represented in the graph, so the peak of its curve will be at the second highest speed, curve 3.	
(D)	Incorrect. According to kinetic molecular theory, the peak of the curve for CH_4 will be at the second highest speed of the curves given, because the mass of CH_4 is the second smallest of the molecules given. Curve 4 is the curve for the least massive molecule, which is H_2 .	

Question 52

Skill	Learning Objective	Topic
2.B	7.11.A	Introduction to Solubility Equilibria
(A)	Incorrect. Water is added to the saturated solution in beaker 2 and the contents are stirred, so some of the $\text{CuSO}_4(s)$ at the bottom of the beaker dissolves and the solution becomes saturated again. The $\text{CuSO}_4(s)$ at the bottom of the beaker indicates that no more $\text{CuSO}_4(s)$ can dissolve. The solutions in both beakers are saturated, so the concentration of $\text{CuSO}_4(aq)$ is the same in both beakers at constant temperature.	
(B)	Incorrect. Water is added to the saturated solution in beaker 2 and the contents are stirred, so some of the $\text{CuSO}_4(s)$ at the bottom of the beaker dissolves and the solution becomes saturated again. The $\text{CuSO}_4(s)$ at the bottom of the beaker indicates that no more $\text{CuSO}_4(s)$ can dissolve. The solutions in both beakers are saturated, so the concentration of $\text{CuSO}_4(aq)$ is the same in both beakers at constant temperature.	
(C)	Correct. Distilled water was added to beaker 2 and the contents were stirred, so some of the $\text{CuSO}_4(s)$ at the bottom of the beaker must have dissolved in that process. Therefore, the mass of undissolved $\text{CuSO}_4(s)$ in beaker 2 must be less than in beaker 1.	
(D)	Incorrect. Some of the $\text{CuSO}_4(s)$ in beaker 2 must have dissolved after the addition of distilled water. Therefore, the mass of $\text{CuSO}_4(s)$ in beaker 2 cannot be greater than in beaker 1.	

Question 53

Skill	Learning Objective	Topic
5.D	8.5.A	Acid-Base Titrations
(A)	Incorrect. The pH is approximately 2 at the start of the titration. This cannot be the pK_a because it is not at the half-equivalence point of the titration.	
(B)	Correct. According to the Henderson-Hasselbalch equation, $pH = pK_a + \log \frac{[A^-]}{[HA]}$ At the half-equivalence point in a titration, $pH = pK_a$ because at that point, $[A^-] = [HA]$ and the log term is equal to zero. The half-equivalence point in the titration curve in the graph is at a volume of 3.0 mL of added titrant. At this volume $pH = pK_a = 4$.	
(C)	Incorrect. The pH is close to 8 at the equivalence point of the titration. This cannot be the pK_a because it is not at the half-equivalence point of the titration.	
(D)	Incorrect. The pH is 13 after the equivalence point of the titration. This cannot be the pK_a because it is not at the half-equivalence point of the titration.	

Question 54

Skill	Learning Objective	Topic
5.A	8.5.A	Acid-Base Titrations
(A)	Incorrect. For the titration of a monoprotic acid, the moles of acid are equal to the moles of base, which can be calculated using the volume and molarity of the base. To determine the molarity of the acid, the calculated moles of acid must be divided by the volume of acid used. Thus, molar mass of the acid is not needed to determine the concentration of the acid in this problem.	
(B)	Incorrect. For the titration of a monoprotic acid, the moles of acid are equal to the moles of base, which can be calculated using the volume and molarity of the base. To determine the molarity of the acid, the calculated moles of acid must be divided by the volume of acid used. The density of the acid is not needed to determine the concentration of the acid in this problem.	
(C)	Correct. At the equivalence point in the titration of a monoprotic acid with a base, the number of moles of acid originally present is equal to the number of moles of base needed to reach the equivalence point. Therefore, $n_{acid} = M_{acid}V_{acid} = M_{base}V_{base} = n_{base}$. In the titration that generated the curve in the graph, M_{base} is known and V_{base} can be determined from the graph. In order to calculate M_{acid} , the volume of acid, V_{acid} , is needed.	
(D)	Incorrect. For the titration of a monoprotic acid, the moles of acid are equal to the moles of base, which can be calculated using the volume and molarity of the base. To determine the molarity of the acid, the calculated moles of acid must be divided by the volume of acid used. Therefore, the initial temperature of the acid is not needed.	

Question 55

Skill	Learning Objective	Topic
5.E	8.5.A	Acid-Base Titrations
(A)	Incorrect. The titration of the triprotic acid $\text{H}_3\text{PO}_4(aq)$ would show three equivalence points in its titration curve.	
(B)	Incorrect. The titration of $\text{HCl}(aq)$ would show the titration profile of a titration of a strong acid with a strong base. The half-equivalence point would occur at a much lower pH value.	
(C)	Correct. The curve shown in the diagram results from the titration of a weak acid with a strong base, and HF is a weak acid. The half-equivalence point is at $\text{pH} = 4 = \text{p}K_a$ and the equivalence point is at $\text{pH} = 9$, so the acid must be weak. $\text{HCl}(aq)$ and $\text{HNO}_3(aq)$ are strong acids. The curve is that of a monoprotic acid, not a polyprotic acid, so the acid is not $\text{H}_3\text{PO}_4(aq)$.	
(D)	Incorrect. The titration of $\text{HNO}_3(aq)$ with $\text{NH}_3(aq)$ would have a different profile. The pH would remain very low at the beginning of the titration, and the equivalence point would occur at an acidic pH.	

Question 56

Skill	Learning Objective	Topic
4.A	4.3.A	Representations of Reactions
(A)	Correct. The reactant in the first box of the particle diagram shows a dissolved ionic compound with a 1 : 1 ratio of cations to anions, and the reactant in the second box of the particle diagram shows a dissolved ionic compound with a 1 : 2 ratio of cations to anions. This is consistent with the equations in options (A) and (C). The product box shows that all of the cations in the first box precipitate with all of the anions in the second box in a ratio of 1 : 1. The spectator ions are the eight anions in the first box and the four cations in the second box, and the ratio of cations to anions is 1 : 2. The stoichiometry of the precipitate and the spectator ions is consistent with the chemical equation.	
(B)	Incorrect. Both reactants in the chemical equation have a 1 : 1 ratio of cations to anions. This is inconsistent with the diagram.	
(C)	Incorrect. The particle diagram shows that there are spectator ions remaining in solution. This is inconsistent with the chemical equation.	
(D)	Incorrect. The chemical equation shows aqueous ionic reactants forming aqueous reactants forming aqueous ionic products. No net reaction is shown, as no precipitate is formed, which is inconsistent with the diagram.	

Question 57

Skill	Learning Objective	Topic
5.B	9.9.A	Cell Potential and Free Energy
(A)	Correct. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$, so when $\Delta H^\circ < 0$ and $\Delta S^\circ > 0$, $\Delta G^\circ < 0$ and the reaction is thermodynamically favorable. $\Delta G^\circ = -RT \ln K$, so if $\Delta G^\circ < 0$, then $K > 1$. $\Delta G^\circ = -nFE^\circ$, so if $\Delta G^\circ < 0$, then $E^\circ > 0$. When a reaction is thermodynamically favorable, K is greater than 1, and E° is positive.	
(B)	Incorrect. $\Delta G^\circ < 0$, so the standard cell potential, E° , cannot be negative.	
(C)	Incorrect. $\Delta G^\circ < 0$, so the equilibrium constant, K , cannot be less than 1.	
(D)	Incorrect. $\Delta G^\circ < 0$, so K cannot be less than 1 and E° cannot be negative.	

Question 58

Skill	Learning Objective	Topic
5.F	6.4.A	Heat Capacity and Calorimetry
(A)	Incorrect. This is the value that is obtained if 4.60 kJ isn't converted to J before calculating ΔT .	
(B)	Incorrect. This value is obtained if the equation $q = mc\Delta T$ is rearranged incorrectly and if 4.60 J is used in the calculation instead of converting 4.60 kJ to 4600 J, resulting in the incorrect calculated value of ΔT . The incorrect equation is $\Delta T = \frac{qm}{c} = \frac{(4.60\text{J})(15.0\text{g})}{(4.18\text{J}/(\text{g}\cdot^\circ\text{C}))} = 16.5^\circ\text{C}$. This incorrect ΔT results in a final temperature of $(20.0^\circ\text{C} + 16.5^\circ\text{C}) = 36.5^\circ\text{C}$.	
(C)	Incorrect. This is the change in temperature rather than the final temperature.	
(D)	Correct. Given that $q = mc\Delta T$, $\Delta T = \frac{q}{mc} = \frac{4600\text{ J}}{(15.0\text{g})(4.18\text{J}/(\text{g}\cdot^\circ\text{C}))} = 73.4^\circ\text{C}$. The initial temperature is 20.0°C , so the final temperature is $(20.0^\circ\text{C} + 73.4^\circ\text{C}) = 93.4^\circ\text{C}$.	

Question 59

Skill	Learning Objective	Topic
1.A	1.7.A	Periodic Trends
(A)	<p>Correct. According to Coulomb's law, the strength of attraction between the nucleus of an atom and the valence electrons increases with the magnitude of the charges and decreases with the distance between them. The first ionization energy generally increases for main group elements going across a period from left to right because the effective nuclear charge increases as the number of protons in the nucleus increases and the number of electron shells remains constant. The first ionization energy decreases going down a group because the atomic radius increases. Be is to the right of Li , above Mg , and above and to the right of Na on the periodic table. Therefore, Be has the largest first ionization energy of the choices given.</p>	
(B)	<p>Incorrect. Li has the same number of electron shells and one less proton than Be , so Li has a smaller effective nuclear charge than Be does. Therefore, Li has a smaller first ionization energy than Be does.</p>	
(C)	<p>Incorrect. Na has more occupied electron shells, a smaller effective nuclear charge, and a larger atomic radius than Be does. So Na has a smaller first ionization energy than Be does because Na has a smaller effective nuclear charge and a larger atomic radius than Be does.</p>	
(D)	<p>Incorrect. Mg is below Be in the same group of the periodic table, so Mg has more occupied electron shells and a larger atomic radius than Be does. Therefore, Mg has a smaller first ionization energy than Be does.</p>	

Question 60

Skill	Learning Objective	Topic
5.F	1.2.A	Mass Spectra of Elements
(A)	Incorrect. The average atomic mass cannot be 185.0 amu , because a significant number of atoms have mass 187 amu , which would increase the weighted average.	
(B)	Incorrect. The isotope with a mass of 187 amu has a greater percent abundance than the isotope with a mass of 185 amu , so the average atomic mass is between 186 amu and 187 amu .	
(C)	Correct. The element's average atomic mass will be between 185 amu and 187 amu . The isotope with a mass of 187 amu has a greater percent abundance than the isotope with a mass of 185 amu , so the average atomic mass should be between 186 amu and 187 amu . The weighted average isotopic mass is $m_{average} = (0.37)(185 \text{ amu}) + (0.63)(187 \text{ amu}) = 186.3 \text{ amu} .$	
(D)	Incorrect. The average atomic mass cannot be 187.0 amu , because a significant number of atoms have mass 185 amu , which would decrease the weighted average.	

AP[®] CHEMISTRY

Practice Exam SCORING GUIDELINES

Question 1: Long Answer

10 points

(a) For the correct answer:

1 point

Sigma bonds: 9

Pi bonds: 1

(b)(i) For the correct calculated value:

1 point

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2} = \frac{(1.28 \text{ atm})(4.00 \text{ L})}{(6.00 \text{ L})} = 0.853 \text{ atm}$$

(ii) For the correct ratio:

1 point

Accept one of the following:

$$\bullet \frac{P_{400K}}{P_{800K}} = \frac{1}{2}$$

$$\bullet \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = \frac{P_1T_2}{T_1} = \frac{0.853 \text{ atm} \times 400 \text{ K}}{800 \text{ K}} = 0.427 \text{ atm}$$

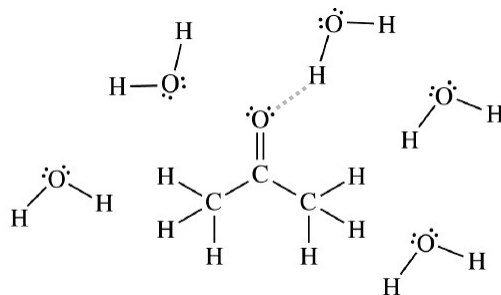
$$\frac{P_{400K}}{P_{800K}} = \frac{0.427 \text{ atm}}{0.853 \text{ atm}} = \frac{1}{2}$$

Total for part (b) 2 points

(c)(i) For the correct drawing:

1 point

A dashed line should appear between the O atom in acetone and one of the H atoms in a nearby water molecule. See example response below.



(ii) For a correct explanation:

1 point

Because C_3H_6O and H_2O are attracted to each other significantly through hydrogen bonding and dipole-dipole interactions, the molecules will strike the walls of the container less frequently and with less force, reducing the pressure.

Total for part (c) 2 points

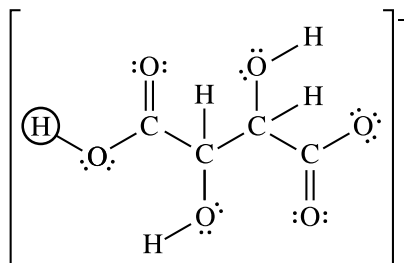
(d)	For a correct explanation: <i>Comparing trial 3 to 2, when $[\text{C}_3\text{H}_6\text{O}]$ was doubled and the other reactant concentrations were held constant, the initial rate doubled. Thus, the reaction is first order with respect to $\text{C}_3\text{H}_6\text{O}$.</i>	1 point
(e)	For the correct rate law, consistent with part (d) (explanation not required): $\text{rate} = k[\text{C}_3\text{H}_6\text{O}][\text{H}_3\text{O}^+]$ <i>(Comparing trial 1 to 2, when $[\text{H}_3\text{O}^+]$ was doubled and the other reactant concentrations were held constant, the initial rate doubled. Thus, the reaction is first order with respect to H_3O^+, leading to the rate law shown.)</i>	1 point
(f)	For the correct calculated value, consistent with part (e): $k = \frac{\text{rate}}{[\text{C}_3\text{H}_6\text{O}][\text{H}_3\text{O}^+]} = \frac{8.25 \times 10^{-6} \text{ M/s}}{(0.667 \text{ M})(0.323 \text{ M})} = 3.83 \times 10^{-5} \text{ M}^{-1} \text{ s}^{-1}$	1 point
(g)	For a correct explanation: <i>The value of k increases at a higher temperature because the particles collide with greater frequency, and a higher proportion of particle collisions have sufficient energy for the reaction to occur.</i>	1 point
(h)	For a correct explanation: Accept one of the following: <ul style="list-style-type: none"> <i>The first step is the slow step, and I_2 does not appear in the first step.</i> <i>I_2 appears in the fast step of the mechanism, so it would not appear in the overall rate law.</i> 	1 point
Total for question 1		10 points

Question 2: Long Answer
10 points

(a) For the correct answer:

1 point

Only the leftmost H atom should be circled.



(b) For the correct calculated value:

1 point

$$pK_a = -\log(K_a) = -\log(4.5 \times 10^{-5}) = 4.35$$

(c) For a valid explanation:

1 point

The K_a value is larger than the K_b value, so $\text{HC}_4\text{H}_4\text{O}_6^-$ ions are more likely to donate a proton and form $\text{C}_4\text{H}_4\text{O}_6^{2-}$ than they are to accept a proton and form $\text{H}_2\text{C}_4\text{H}_4\text{O}_6$.

(d) For the correct answer:

1 point

There is still solid at the bottom of the beaker.

(e) (i) For the correct answer (units are not required):

1 point

5.65 mL

(ii) For the correct calculated value of the number of moles, consistent with part (e)(i):

1 point

$$5.65 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.1376 \text{ mol}}{1 \text{ L}} = 7.77 \times 10^{-4} \text{ mol}$$

For the correct calculated value of $[\text{HC}_4\text{H}_4\text{O}_6^-]$:

1 point

$$7.77 \times 10^{-4} \text{ mol NaOH} \times \frac{1 \text{ mol HC}_4\text{H}_4\text{O}_6^-}{1 \text{ mol NaOH}} = 7.77 \times 10^{-4} \text{ mol HC}_4\text{H}_4\text{O}_6^-$$

$$\frac{7.77 \times 10^{-4} \text{ mol HC}_4\text{H}_4\text{O}_6^-}{0.02500 \text{ L}} = 3.11 \times 10^{-2} \text{ M} = 0.0311 \text{ M}$$

(iii) For the correct calculated value:

1 point

$$K_{sp} = (3.11 \times 10^{-2})^2 = 9.67 \times 10^{-4}$$

Total for part (e) 4 points

(f) (i)	For a correct explanation:	1 point
<i>Because there are more moles of $\text{KHC}_4\text{H}_4\text{O}_6$ present in the flask, more moles and a greater volume of NaOH(aq) will be needed to reach the equivalence point.</i>		
(ii)	For the correct answer and a valid justification:	1 point
<i>It would be larger. Because there are more moles of $\text{KHC}_4\text{H}_4\text{O}_6$ present in the second student's flask, greater values of $[\text{K}^+]$ and $[\text{HC}_4\text{H}_4\text{O}_6^-]$ will be calculated, which will increase the calculated value of K_{sp}.</i>		
		Total for part (f) 2 points
		Total for question 2 10 points

Question 3: Long Answer**10 points**

(a) For a correct answer: **1 point**

Accept one of the following:

- $\text{C}_5\text{H}_{10}\text{NH}$ is a base, and $\text{C}_5\text{H}_{10}\text{NH}_2^+$ is its conjugate acid.
- H_2O is an acid, and OH^- is its conjugate base.

(b) For the correct answer: **1 point**

$$K_b = \frac{[\text{C}_5\text{H}_{10}\text{NH}_2^+][\text{OH}^-]}{[\text{C}_5\text{H}_{10}\text{NH}]}$$

(c) (i) For the correct calculated value: **1 point**

Accept one of the following:

- $\text{pOH} = -\log[\text{OH}^-] = -\log(3.09 \times 10^{-2}) = 1.510$
 $\text{pH} = 14 - \text{pOH} = 14 - 1.510 = 12.490$
- $K_w = [\text{H}^+][\text{OH}^-] \Rightarrow [\text{H}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.00 \times 10^{-14}}{3.09 \times 10^{-2}} = 3.24 \times 10^{-13} M$
 $\text{pH} = -\log[\text{H}^+] = -\log(3.24 \times 10^{-13}) = 12.489$

(ii) For the correct calculated value: **1 point**

$$\% \text{ ionization} = \frac{(3.09 \times 10^{-2} M)}{0.750 M} \times 100\% = 4.12\%$$

Total for part (c) 2 points

(d)(i) For a correct equation: **1 point**

Accept one of the following:

- $\text{C}_5\text{H}_{10}\text{NH}(\text{aq}) + \text{H}^+(\text{aq}) \rightleftharpoons \text{C}_5\text{H}_{10}\text{NH}_2^+(\text{aq})$
- $\text{C}_5\text{H}_{10}\text{NH}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightleftharpoons \text{C}_5\text{H}_{10}\text{NH}_2^+(\text{aq}) + \text{H}_2\text{O}(\text{l})$

(ii) For a correct explanation: **1 point**

Accept one of the following:

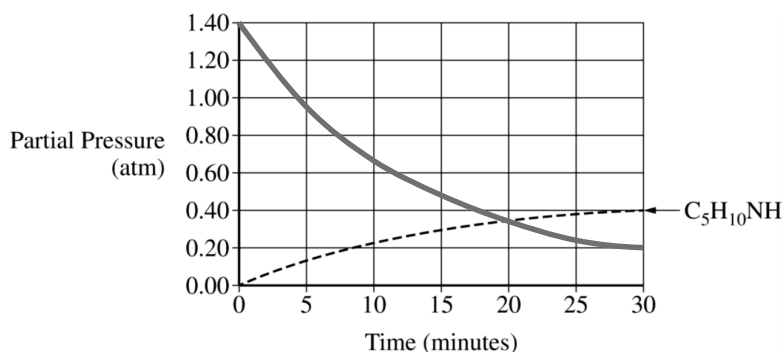
- *The moles of $\text{C}_5\text{H}_{10}\text{NH}_2^+$ increase because the addition of the strong acid increases $[\text{H}_3\text{O}^+]$, which results in $Q < K$, and the reaction proceeds to form more products as it re-establishes equilibrium.*
- *The moles of $\text{C}_5\text{H}_{10}\text{NH}_2^+$ increase because the addition of the strong acid decreases $[\text{OH}^-]$, which results in $Q_b < K_b$, and the reaction proceeds to form more products as it re-establishes equilibrium.*

Total for part (d) 2 points

(e)(i) For a graph that shows a concave curve with a negative slope. **1 point**

See sample response below.

(ii) For a curve that shows a partial pressure of 1.40 atm at 0 minutes and 0.20 atm at 30 minutes: **1 point**



Total for part (e) 2 points

(f) (i)	For the correct explanation:	1 point
<i>Having more particles of gas means the reactants have a greater number of microstates and are more dispersed than the products. The reaction proceeding to a less dispersed arrangement would result in a decrease in entropy.</i>		
(ii)	For the correct answer and a valid justification:	1 point
Accept one of the following:		
<ul style="list-style-type: none"> Negative. Given that $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ and that ΔS_{rxn}° is negative, the only way for ΔG_{rxn}° to be negative at 400. K is if the ΔH_{rxn}° is negative. Negative. Given that the reaction is thermodynamically favorable and that the entropy decreases, the reaction must be exothermic to be favorable. 		
Total for part (f)		2 points
Total for question 3		10 points

Question 4: Short Answer**4 points**

(a) For the correct answer: 1 point

If the lid is not present, some of the heat will be lost from the calorimeter.

(b) For the correct answer and a valid justification: 1 point

Negative. The temperature of the surrounding solution increases, indicating that there is a thermal energy transfer from the system to the surroundings as dissolution occurs.

(c) For the correct calculated value: 1 point

$$|q_{surr}| = |mc\Delta T| = \left| (53.11 \text{ g}) \left(3.61 \frac{\text{J}}{\text{g} \cdot ^\circ\text{C}} \right) (44.0^\circ\text{C} - 23.5^\circ\text{C}) \right| = 3930 \text{ J}$$

(d) For the correct calculated value, consistent with part (c): 1 point

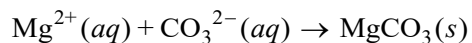
$$q_{\text{sys}} = -q_{\text{surr}} = -(3930 \text{ J}) = -3930 \text{ J}$$

$$|\Delta H_{\text{solution}}^\circ| = \left| \frac{-3930 \text{ J}}{7.11 \text{ g CaBr}_2} \times \frac{199.88 \text{ g}}{1 \text{ mol CaBr}_2} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \right| = 110. \text{ kJ/mol}$$

Total for question 4 4 points

Question 5: Short Answer**4 points**

(a) For the correct balanced net-ionic equation (state symbols not required): **1 point**



(b) For a correct experimental technique (justification not required): **1 point**

Accept one of the following:

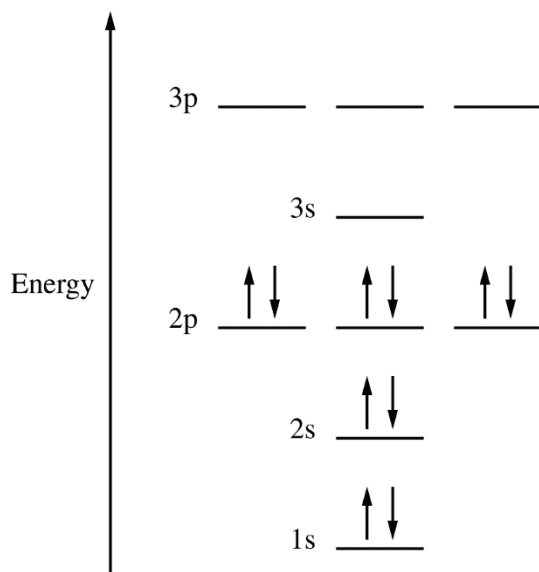
- *Test the conductivity of the solution (the solution would conduct electricity if ions are present).*
- *Evaporate the water from the filtrate to leave solid crystals.*

(c) For a correct answer: **1 point**

Accept one of the following:

- *Any Group 1 metal other than sodium: Li, K, Rb, Cs*
- *Another metal that can exist stably as a +1 ion*

(d) For the correct electron configuration: **1 point**



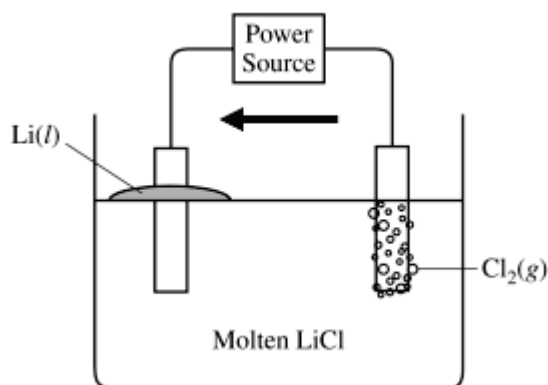
Total for question 5 4 points

Question 6: Short Answer**4 points**

(a) For the correct answer:

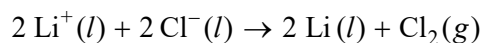
1 point

Electron flow should be indicated only in a counterclockwise direction in the external circuit, from the Cl_2 anode to the Li cathode.



(b) For the correct net ionic equation (state symbols not required):

1 point



(c) For the correct calculated number of moles (may be implicit):

1 point

$$0.18 \text{ g} \times \frac{1 \text{ mol Li}}{6.94 \text{ g Li}} \times \frac{1 \text{ mol } e^-}{1 \text{ mol Li}} = 0.026 \text{ mol } e^-$$

For the correct calculated value of current:

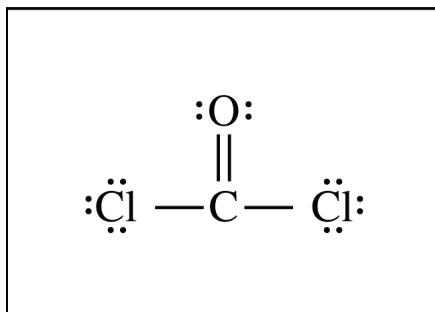
1 point

$$0.026 \text{ mol } e^- \times \frac{96,485 \text{ C}}{1 \text{ mol } e^-} \times \frac{1}{3200. \text{ s}} = 0.78 \text{ C/s}$$

Total for part (c) 2 points

Total for question 6 4 points

Question 7: Short Answer**4 points**

(a) For the correct answer:**1 point**

(b) For the correct answer and a valid justification, consistent with part (a):**1 point**

Disagree. The hybridization of the carbon atom is sp in CO and is sp^2 in COCl_2 .

(c) For the correct calculated energy of the photon (may be implicit):**1 point**

$$E = h\nu = (6.626 \times 10^{-34} \text{ J} \cdot \text{s})(8.67 \times 10^{14} \text{ s}^{-1}) = 5.74 \times 10^{-19} \text{ J/photon}$$

For the correct calculated energy per mole of photons:**1 point**

$$\frac{5.74 \times 10^{-19} \text{ J}}{1 \text{ photon}} \times \frac{6.022 \times 10^{23} \text{ photons}}{1 \text{ mol}} = 346,000 \text{ J/mol} = 346 \text{ kJ/mol}$$

Total for part (c) 2 points

Total for question 7 4 points