

CHEMISTRY

Section I

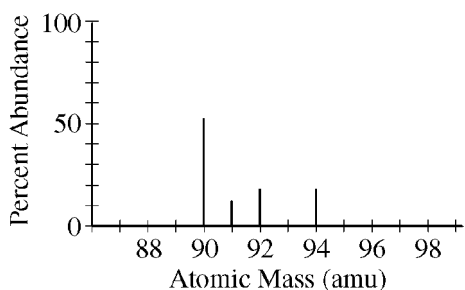
50 Questions

Time—90 minutes

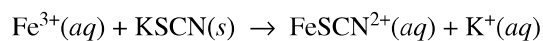
CALCULATORS ARE NOT ALLOWED FOR SECTION I.

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

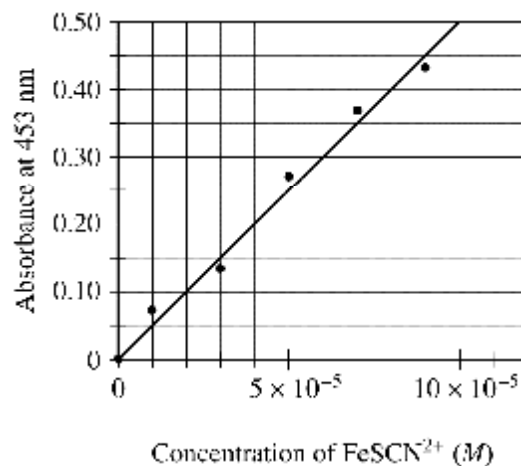
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.



- The mass spectrum of an average sample of a pure element is shown in the figure above. Which of the following is the identity of the element?
(A) Y
(B) Zr
(C) Nb
(D) Th
- The ideal gas law best describes the properties of which of the following gases at 0°C and 1 atm?
(A) PH_3
(B) HBr
(C) SO_2
(D) N_2
- At 298 K and 1 atm, Br_2 is a liquid with a high vapor pressure, and Cl_2 is a gas. Those observations provide evidence that under the given conditions, the
(A) forces among Br_2 molecules are stronger than those among Cl_2 molecules
(B) forces among Cl molecules are stronger than the Cl–Cl bond
(C) Br–Br bond is stronger than the Cl–Cl bond
(D) Cl–Cl bond is stronger than the Br–Br bond
- Which of the following has the bonds arranged in order of decreasing polarity?
(A) $\text{H–F} > \text{N–F} > \text{F–F}$
(B) $\text{H–I} > \text{H–Br} > \text{H–F}$
(C) $\text{O–N} > \text{O–S} > \text{O–Te}$
(D) $\text{Sb–I} > \text{Sb–Te} > \text{Sb–Cl}$

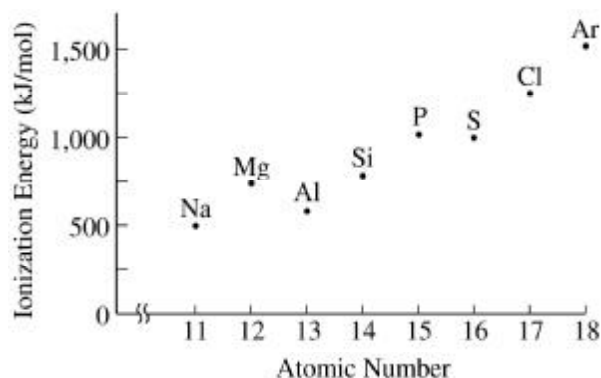


5. To determine the moles of $\text{Fe}^{3+}(aq)$ in a 100. mL sample of an unknown solution, excess $\text{KSCN}(s)$ is added to convert all the $\text{Fe}^{3+}(aq)$ into the dark red species $\text{FeSCN}^{2+}(aq)$, as represented by the equation above. The absorbance of $\text{FeSCN}^{2+}(aq)$ at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

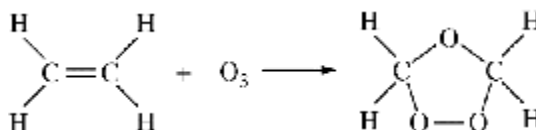


If the absorbance of the mixture is 0.20 at 453 nm, how many moles of $\text{Fe}^{3+}(aq)$ were present in the 100. mL sample? (Assume that any volume change due to adding the $\text{KSCN}(s)$ is negligible.)

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

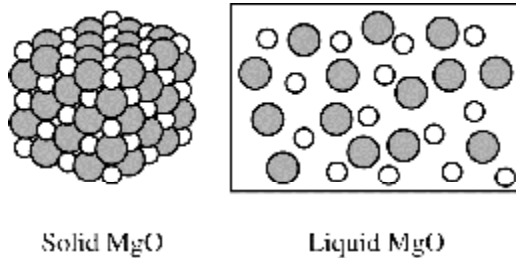


6. The first ionization energy of an element is the energy required to remove an electron from a gaseous atom of the element (i.e., $X(g) \rightarrow X^+(g) + e^-$). The values of the first ionization energies for the third-row elements are shown in the graph above. On the basis of the information given,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

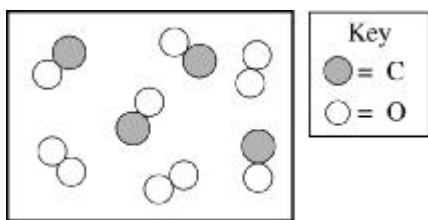


7. In the reaction represented above, what is the hybridization of the C atoms before and after the reaction occurs?

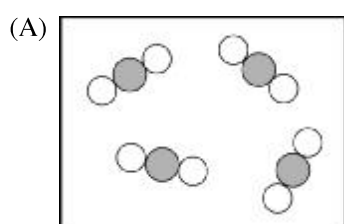
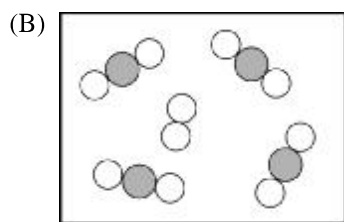
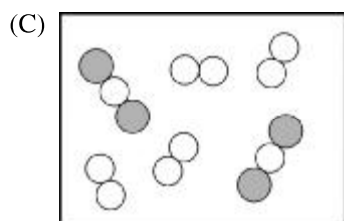
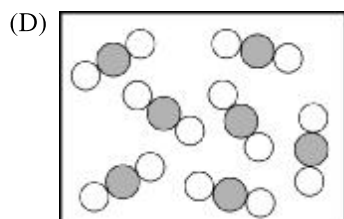
	Before	After
(A)	sp	sp^2
(B)	sp	sp^3
(C)	sp^2	sp
(D)	sp^2	sp^3



8. Based on the diagram above, which of the following best helps to explain why $\text{MgO}(s)$ is not able to conduct electricity, but $\text{MgO}(l)$ is a good conductor of electricity?
- (A) $\text{MgO}(s)$ does not contain free electrons, but $\text{MgO}(l)$ contains free electrons that can flow.
 - (B) $\text{MgO}(s)$ contains no water, but $\text{MgO}(l)$ contains water that can conduct electricity.
 - (C) $\text{MgO}(s)$ consists of separate Mg^{2+} ions and O^{2-} ions, but $\text{MgO}(l)$ contains MgO molecules that can conduct electricity.
 - (D) $\text{MgO}(s)$ consists of separate Mg^{2+} ions and O^{2-} ions held in a fixed lattice, but in $\text{MgO}(l)$ the ions are free to move and conduct electricity.



9. A mixture of CO(g) and $\text{O}_2\text{(g)}$ is placed in a container, as shown above. A reaction occurs, forming $\text{CO}_2\text{(g)}$. Which of the following best represents the contents of the box after the reaction has proceeded as completely as possible?



Questions 10-13 refer to the following information.



Each student in a class placed a 2.00 g sample of a mixture of Cu and Al in a beaker and placed the beaker in a fume hood. The students slowly poured 15.0 mL of 15.8 M $\text{HNO}_3(aq)$ into their beakers. The reaction between the copper in the mixture and the $\text{HNO}_3(aq)$ is represented by the equation above. The students observed that a brown gas was released from the beakers and that the solutions turned blue, indicating the formation of $\text{Cu}^{2+}(aq)$. The solutions were then diluted with distilled water to known volumes.

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

- (A) It is a Brønsted-Lowry acid-base reaction, because the solution is neutral at the end.
- (B) It is a Brønsted-Lowry acid-base reaction, because $\text{HNO}_3(aq)$ is a strong acid.
- (C) It is a redox reaction, because $\text{Cu}(s)$ is oxidized and $\text{H}^+(aq)$ is reduced.
- (D) It is a redox reaction, because $\text{Cu}(s)$ is oxidized and the nitrogen atom in $\text{NO}_3^-(aq)$ is reduced.

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

11. To determine the number of moles of Cu in the sample of the mixture, the students measured the absorbance of known concentrations of $\text{Cu}(\text{NO}_3)_2(aq)$ using a spectrophotometer. A cuvette filled with some of the solution produced from the sample of the mixture was also tested. The data recorded by one student are shown in the table above. On the basis of the data provided, which of the following is a possible error that the student made?

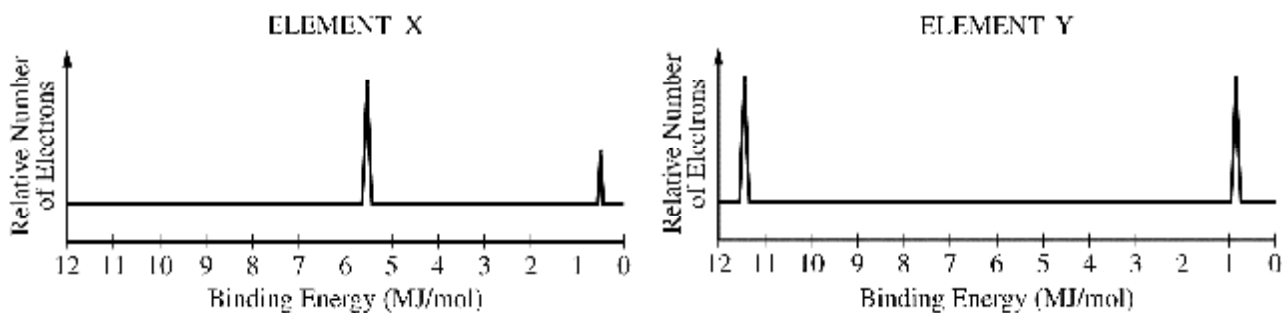
- (A) The $\text{Cu}(\text{NO}_3)_2(aq)$ from the sample of the mixture was not diluted properly.
- (B) The spectrophotometer was calibrated with tap water instead of distilled water.
- (C) The student labeled the cuvettes incorrectly, reversing the labels on two of the solutions of known concentration.
- (D) The spectrophotometer was originally set to an inappropriate wavelength, causing the absorbance to vary unpredictably.

12. The students determined that the reaction produced 0.010 mol of $\text{Cu}(\text{NO}_3)_2$. Based on the measurement, what was the percent of Cu by mass in the original 2.00 g sample of the mixture?
- (A) 16%
(B) 32%
(C) 64%
(D) 96%
13. In one student's experiment the reaction proceeded at a much slower rate than it did in the other students' experiments. Which of the following could explain the slower reaction rate?
- (A) In the student's sample the metal pieces were much smaller than those in the other students' samples.
(B) The student heated the reaction mixture as the $\text{HNO}_3(aq)$ was added.
(C) The student used a 1.5 *M* solution of $\text{HNO}_3(aq)$ instead of a 15.8 *M* solution of $\text{HNO}_3(aq)$.
(D) The student used a 3.00 g sample of the mixture instead of the 2.00 g sample that was used by the other students.

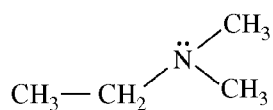
14. A student is given a sample of a pure, white crystalline substance. Which of the following would be most useful in providing data to determine if the substance is an ionic compound?
- (A) Examining the crystals of the substance under a microscope
 - (B) Determining the density of the substance
 - (C) Testing the electrical conductivity of the crystals
 - (D) Testing the electrical conductivity of an aqueous solution of the substance
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Ne, HF, C₂H₆, CH₄

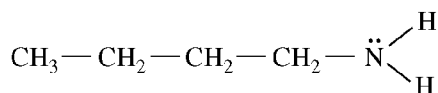
15. Which of the substances listed above has the highest boiling point, and why?
- (A) Ne, because its atoms have the largest radius
 - (B) HF, because its molecules form hydrogen bonds
 - (C) CH₄, because each molecule can form multiple hydrogen bonds
 - (D) CH₄, because its molecules have the greatest London dispersion forces
16. A sample of a solid labeled as NaCl may be impure. A student analyzes the sample and determines that it contains 75 percent chlorine by mass. Pure NaCl(s) contains 61 percent chlorine by mass. Which of the following statements is consistent with the data?
- (A) The sample contains only NaCl(s).
 - (B) The sample contains NaCl(s) and NaI(s).
 - (C) The sample contains NaCl(s) and KCl(s).
 - (D) The sample contains NaCl(s) and LiCl(s).
17. If a pure sample of an oxide of sulfur contains 40. percent sulfur and 60. percent oxygen by mass, then the empirical formula of the oxide is
- (A) SO₃
 - (B) SO₄
 - (C) S₂O₆
 - (D) S₂O₈
18. When 4.0 L of He(g), 6.0 L of N₂(g), and 10. L of Ar(g), all at 0°C and 1.0 atm, are pumped into an evacuated 8.0 L rigid container, the final pressure in the container at 0°C is
- (A) 0.5 atm
 - (B) 1.0 atm
 - (C) 2.5 atm
 - (D) 4.0 atm



19. The complete photoelectron spectra of neutral atoms of two unknown elements, X and Y, are shown above. Which of the following can be inferred from the data?
- (A) Element X has a greater electronegativity than element Y does.
 - (B) Element X has a greater ionization energy than element Y does.
 - (C) Element Y has a greater nuclear charge than element X does.
 - (D) The isotopes of element Y are approximately equal in abundance, but those of element X are not.



Compound 1



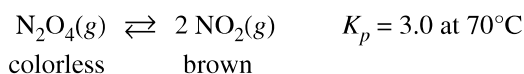
Compound 2

20. Based on the structures shown above, which of the following statements identifies the compound with the higher boiling point and provides the best explanation for the higher boiling point?
- (A) Compound 1, because it has stronger dipole-dipole forces than compound 2
 - (B) Compound 1, because it forms hydrogen bonds, whereas compound 2 does not
 - (C) Compound 2, because it is less polarizable and has weaker London dispersion forces than compound 1
 - (D) Compound 2, because it forms hydrogen bonds, whereas compound 1 does not

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

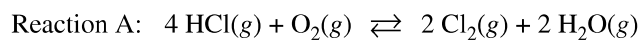
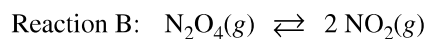
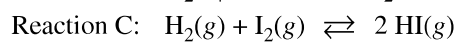
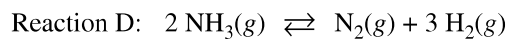
(A) CH₄
(B) CCl₄
(C) NH₃
(D) PH₃

Questions 22-25 refer to the following information.



A mixture of NO₂(g) and N₂O₄(g) is placed in a glass tube and allowed to reach equilibrium at 70°C, as represented above.

22. If $P_{\text{N}_2\text{O}_4}$ is 1.33 atm when the system is at equilibrium at 70°C, what is P_{NO_2} ?
- (A) 0.44 atm
(B) 2.0 atm
(C) 2.3 atm
(D) 4.0 atm
23. Which of the following statements best helps to explain why the contents of the tube containing the equilibrium mixture turned a lighter color when the tube was placed into an ice bath?
- (A) The forward reaction is exothermic.
(B) The forward reaction is endothermic.
(C) The ice bath lowered the activation energy.
(D) The ice bath raised the activation energy.
24. Which of the following best predicts how the partial pressures of the reacting species will be affected if a small amount of Ar(g) is added to the equilibrium mixture at constant volume?
- (A) P_{NO_2} will decrease and $P_{\text{N}_2\text{O}_4}$ will increase.
(B) P_{NO_2} will increase and $P_{\text{N}_2\text{O}_4}$ will decrease.
(C) Both P_{NO_2} and $P_{\text{N}_2\text{O}_4}$ will decrease.
(D) No change will take place.
25. Which of the following statements about ΔH° for the reaction is correct?
- (A) $\Delta H^\circ < 0$ because energy is released when the N–N bond breaks.
(B) $\Delta H^\circ < 0$ because energy is required to break the N–N bond.
(C) $\Delta H^\circ > 0$ because energy is released when the N–N bond breaks.
(D) $\Delta H^\circ > 0$ because energy is required to break the N–N bond.

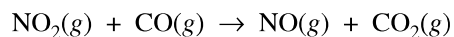


26. The reactions represented above are carried out in sealed, rigid containers and allowed to reach equilibrium. If the volume of each container is reduced from 1.0 L to 0.5 L at constant temperature, for which of the reactions will the amount of product(s) be increased?

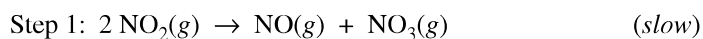
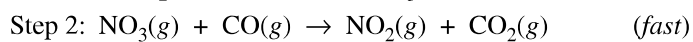
- (A) Reaction A
- (B) Reaction B
- (C) Reaction C
- (D) Reaction D

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

27. The table above provides some information about two types of steel, both of which are alloys of iron and carbon. Which of the following best helps to explain why high-carbon steel is more rigid than low-carbon steel?
- (A) Elemental carbon is harder than elemental iron.
 (B) The additional carbon atoms within the alloy make the high-carbon steel less dense.
 (C) The additional carbon atoms within the alloy increase the thermal conductivity of the high-carbon steel.
 (D) The additional carbon atoms within the alloy make it more difficult for the iron atoms to slide past one another.

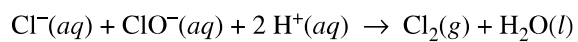


28. The reaction between $\text{NO}_2(g)$ and $\text{CO}(g)$ is represented above. The elementary steps of a proposed reaction mechanism are represented below.



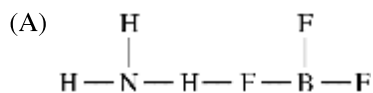
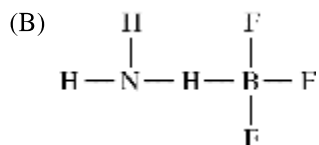
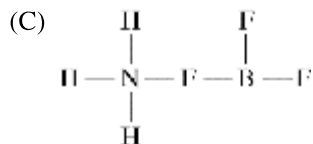
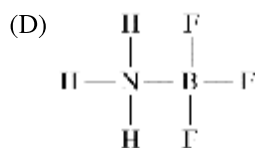
Which of the following is the rate law for the overall reaction that is consistent with the proposed mechanism?

- (A) $\text{Rate} = k [\text{NO}_2][\text{CO}]$
- (B) $\text{Rate} = k [\text{NO}_2]^2$
- (C) $\text{Rate} = k [\text{NO}_3][\text{CO}]$
- (D) $\text{Rate} = k [\text{NO}_2][\text{NO}_3][\text{CO}]$



29. What effect will increasing $[\text{H}^+]$ at constant temperature have on the reaction represented above?
- (A) The activation energy of the reaction will increase.
 - (B) The activation energy of the reaction will decrease.
 - (C) The frequency of collisions between H^+ (aq) ions and $\text{ClO}^-(aq)$ ions will increase.
 - (D) The value of the rate constant will increase.

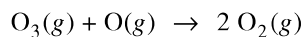
30. NH_3 reacts with BF_3 to form a single species.
Which of the following structural diagrams is the most likely representation of the product of the reaction?



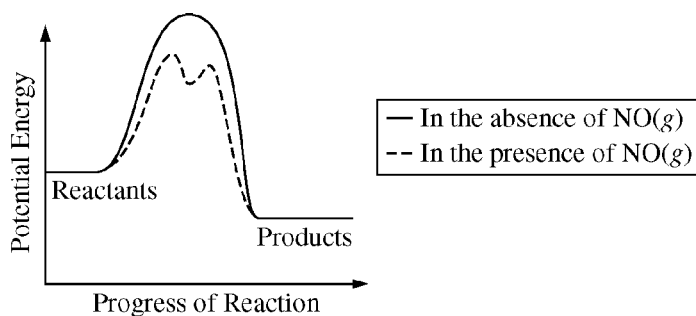
Half-Reaction	E° (V)
$\text{Mg}^{2+}(\text{aq}) + 2 e^- \rightarrow \text{Mg}(\text{s})$	-2.37
$\text{Cr}^{3+}(\text{aq}) + 3 e^- \rightarrow \text{Cr}(\text{s})$	-0.74

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

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

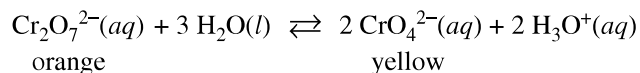


32. The decomposition of $\text{O}_3(g)$ in the upper atmosphere is represented by the equation above. The potential energy diagram for the decomposition of $\text{O}_3(g)$ in the presence and absence of $\text{NO}(g)$ is given below.

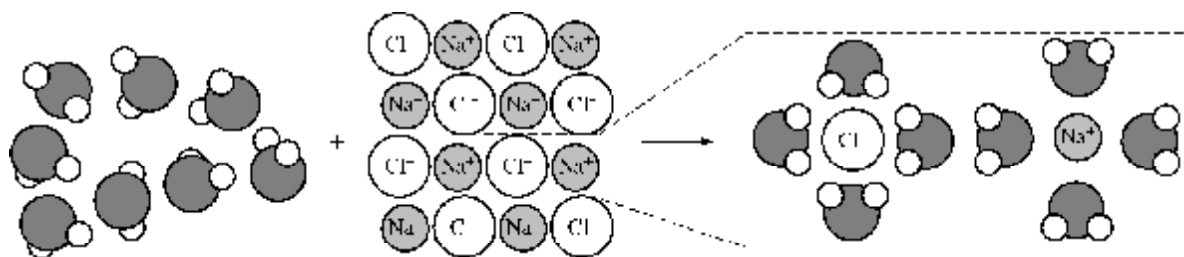


Which of the following mechanisms for the catalyzed reaction is consistent with the equation and diagram above?

- (A) $2 \text{O}_3(g) + 2 \text{NO}(g) \rightarrow 4 \text{O}_2(g) + \text{N}_2(g)$ *slow*
- (B) $\text{O}_3(g) + \text{NO}(g) \rightarrow \text{NO}_2(g) + \text{O}_2(g)$ *slow*
 $\text{NO}_2(g) + \text{O}(g) \rightarrow \text{NO}(g) + \text{O}_2(g)$ *fast*
- (C) $\text{NO}_2(g) + \text{O}_3(g) \rightarrow \text{NO}(g) + 2 \text{O}_2(g)$ *slow*
 $\text{NO}(g) + \text{O}(g) \rightarrow \text{NO}_2(g)$ *fast*
- (D) $\text{NO}_2(g) + \text{O}(g) \rightarrow \text{NO}_3(g)$ *slow*
 $\text{NO}_3(g) + \text{O}_3(g) \rightarrow \text{NO}_2(g) + 2 \text{O}_2(g)$ *fast*

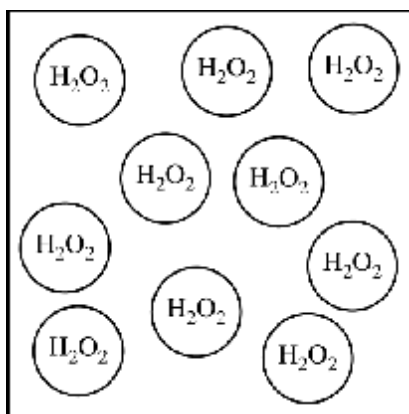


33. The equilibrium system represented by the equation above initially contains equal concentrations of $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ and $\text{CrO}_4^{2-}(\text{aq})$. Which of the following statements correctly predicts the result of adding a sample of $6.0 \text{ M NaOH}(\text{aq})$ to the system, and provides an explanation?
- (A) The mixture will become more orange because $\text{OH}^-(\text{aq})$ will oxidize the Cr in $\text{CrO}_4^{2-}(\text{aq})$.
 - (B) The mixture will become more yellow because $\text{OH}^-(\text{aq})$ will reduce the Cr in $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$.
 - (C) The mixture will become more yellow because $\text{OH}^-(\text{aq})$ will shift the equilibrium toward products.
 - (D) The color of the mixture will not change because $\text{OH}^-(\text{aq})$ does not appear in the equilibrium expression.

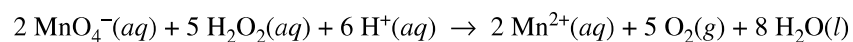


34. The process of dissolution of $\text{NaCl}(s)$ in $\text{H}_2\text{O}(l)$ is represented in the diagram above. Which of the following summarizes the signs of ΔH° and ΔS° for each part of the dissolution process?

	Breaking solvent-solvent interactions		Breaking solute-solute interactions		Forming solute-solvent interactions	
	ΔH°	ΔS°	ΔH°	ΔS°	ΔH°	ΔS°
(A)	+	+	+	+	–	–
(B)	+	+	+	+	–	+
(C)	–	–	–	–	+	+
(D)	–	+	–	+	+	–



35. A particle view of a sample of $\text{H}_2\text{O}_2(\text{aq})$ is shown above. The $\text{H}_2\text{O}_2(\text{aq})$ is titrated with $\text{KMnO}_4(\text{aq})$, as represented by the equation below.



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

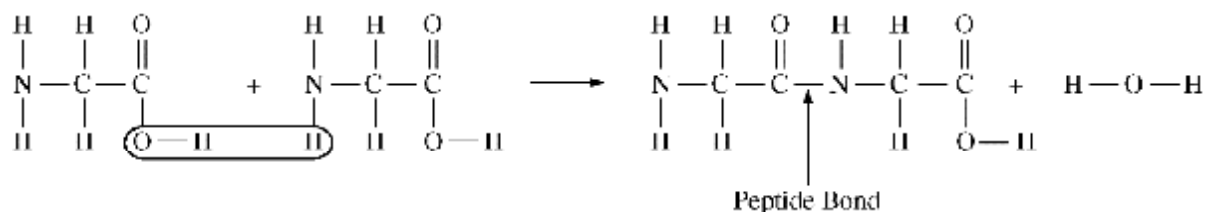
(A)

(B)

(C)

(D)

Questions 36-38 refer to the following information.



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

ΔG_{298}°	ΔH_{298}°	ΔS_{298}°
+15 kJ/mol _{rxn}	+12 kJ/mol _{rxn}	-10 J/(K·mol _{rxn})

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

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

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

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

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

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

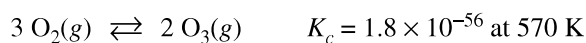
(A) $K_{eq} = 0$
 (B) $0 < K_{eq} < 1$
 (C) $K_{eq} = 1$
 (D) $K_{eq} > 1$

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

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

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

40. When 5.0 g of $\text{NH}_4\text{ClO}_4(s)$ is added to 100. mL of water in a calorimeter, the temperature of the solution formed decreases by 3.0°C . If 5.0 g of $\text{NH}_4\text{ClO}_4(s)$ is added to 1000. mL of water in a calorimeter initially at 25.0°C , the final temperature of the solution will be approximately
- (A) 22.0°C
 - (B) 24.7°C
 - (C) 25.3°C
 - (D) 28.0°C
-

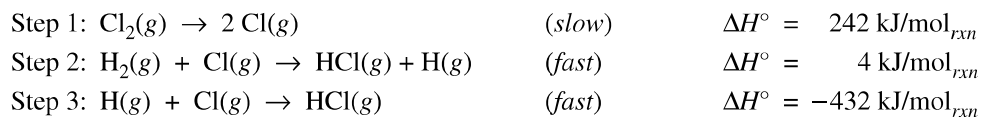


41. For the system represented above, $[\text{O}_2]$ and $[\text{O}_3]$ initially are 0.150 mol/L and 2.5 mol/L respectively. Which of the following best predicts what will occur as the system approaches equilibrium at 570 K?
- (A) The amount of $\text{O}_3(g)$ will increase, because $Q < K_c$.
 - (B) The amount of $\text{O}_3(g)$ will decrease, because $Q < K_c$.
 - (C) The amount of $\text{O}_3(g)$ will increase, because $Q > K_c$.
 - (D) The amount of $\text{O}_3(g)$ will decrease, because $Q > K_c$.

Questions 42-43 refer to the following.



HCl(g) can be synthesized from H₂(g) and Cl₂(g) as represented above. A student studying the kinetics of the reaction proposes the following mechanism.



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

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

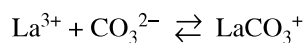
43. What is the value of the enthalpy change per mole of HCl(g) produced?

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

44. The compound CCl_4 is nonflammable and was once commonly used in fire extinguishers. On the basis of the periodic properties, which of the following compounds can most likely be used as a fire-resistant chemical?
- (A) BCl_3
 - (B) CH_4
 - (C) CBr_4
 - (D) PbCl_2

Reaction	K_{eq}
$\text{La}^{3+} + \text{OH}^- + \text{HCO}_3^- \rightleftharpoons \text{LaCO}_3^+ + \text{H}_2\text{O}$	K_1
$\text{HCO}_3^- \rightleftharpoons \text{H}^+ + \text{CO}_3^{2-}$	K_a
$\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$	K_w

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

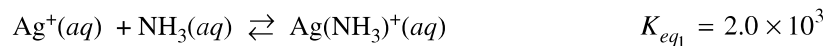


- (A) $K = (K_1)(K_a)(K_w)$
- (B) $K = \frac{(K_1)(K_a)}{K_w}$
- (C) $K = \frac{K_1}{(K_a)(K_w)}$
- (D) $K = \frac{(K_1)(K_w)}{K_a}$



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

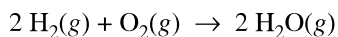
<u>Acid Strength</u>	<u>Base Strength</u>
(A) $\text{HClO}_2 < \text{HCOOH}$	$\text{ClO}_2^- < \text{HCOO}^-$
(B) $\text{HClO}_2 < \text{HCOOH}$	$\text{ClO}_2^- > \text{HCOO}^-$
(C) $\text{HClO}_2 > \text{HCOOH}$	$\text{ClO}_2^- > \text{HCOO}^-$
(D) $\text{HClO}_2 > \text{HCOOH}$	$\text{ClO}_2^- < \text{HCOO}^-$



47. Equal volumes of 0.1 M $\text{AgNO}_3(aq)$ and 2.0 M $\text{NH}_3(aq)$ are mixed and the reactions represented above occur. Which Ag species will have the highest concentration in the equilibrium system shown below, and why?



- (A) $\text{Ag}^+(aq)$, because $K_{eq3} = 4$
 (B) $\text{Ag}^+(aq)$, because $K_{eq1} < K_{eq2}$
 (C) $\text{Ag}(\text{NH}_3)_2^+(aq)$, because $K_{eq3} = 1.6 \times 10^7$
 (D) $\text{Ag}(\text{NH}_3)_2^+(aq)$, because $K_{eq1} < K_{eq2}$

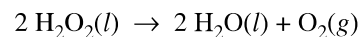


48. When $\text{H}_2(\text{g})$ and $\text{O}_2(\text{g})$ are mixed together in a rigid reaction vessel at 25°C , no reaction occurs. When the mixture is sparked, however, the gases react vigorously according to the equation above, releasing heat. Which of the following statements correctly explains why the spark is needed for the reaction to occur when the gases are originally at 25°C ?

(A) The reaction is not thermodynamically favorable at 25°C .
 (B) ΔH° for the reaction has a large positive value at 25°C .
 (C) ΔS° for the reaction has a large negative value at 25°C .
 (D) The reaction has a large activation energy at 25°C .

49. A student prepares a solution by combining 100 mL of $0.30 \text{ M HNO}_2(\text{aq})$ and 100 mL of $0.30 \text{ M KNO}_2(\text{aq})$. Which of the following equations represents the reaction that best helps to explain why adding a few drops of $1.0 \text{ M HCl}(\text{aq})$ does not significantly change the pH of the solution?

(A) $\text{K}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{KCl}(\text{s})$
 (B) $\text{HNO}_2(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{NO}_2^-(\text{aq})$
 (C) $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
 (D) $\text{H}^+(\text{aq}) + \text{NO}_2^-(\text{aq}) \rightarrow \text{HNO}_2(\text{aq})$



50. The exothermic process represented above is best classified as a

(A) physical change because a new phase appears in the products
 (B) physical change because $\text{O}_2(\text{g})$ that was dissolved comes out of solution
 (C) chemical change because entropy increases as the process proceeds
 (D) chemical change because covalent bonds are broken and new covalent bonds are formed

CHEMISTRY

Section II

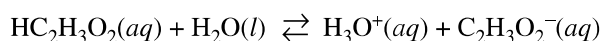
7 Questions

Time—1 hour and 45 minutes

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

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

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



1. The dissociation of ethanoic acid, $\text{HC}_2\text{H}_3\text{O}_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using two different experimental procedures.
 - (a) The student is first asked to prepare 100.0 mL of 0.115 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using a 2.000 M standard solution.
 - (i) Calculate the volume, in mL, of 2.000 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ the student needs to prepare 100.0 mL of 0.115 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$.
 - (ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

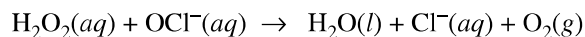
• 100 mL beaker	• Eye dropper
• 100 mL graduated cylinder	• 500 mL wash bottle filled with distilled water
• 100 mL volumetric flask	• 2.000 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ in a 50 mL buret
 - (b) Using a pH probe, the student determines that the pH of 0.115 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ is 2.92.
 - (i) Using the pH value, calculate the value of K_a for $\text{HC}_2\text{H}_3\text{O}_2(aq)$.
 - (ii) Calculate the percent dissociation of ethanoic acid in 0.115 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$.

In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 M $\text{HC}_2\text{H}_3\text{O}_2(aq)$ with an $\text{NaOH}(aq)$ solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

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-9-



2. A student investigates the reaction between $\text{H}_2\text{O}_2(aq)$ and $\text{NaOCl}(aq)$, which is represented by the net-ionic equation shown above.

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

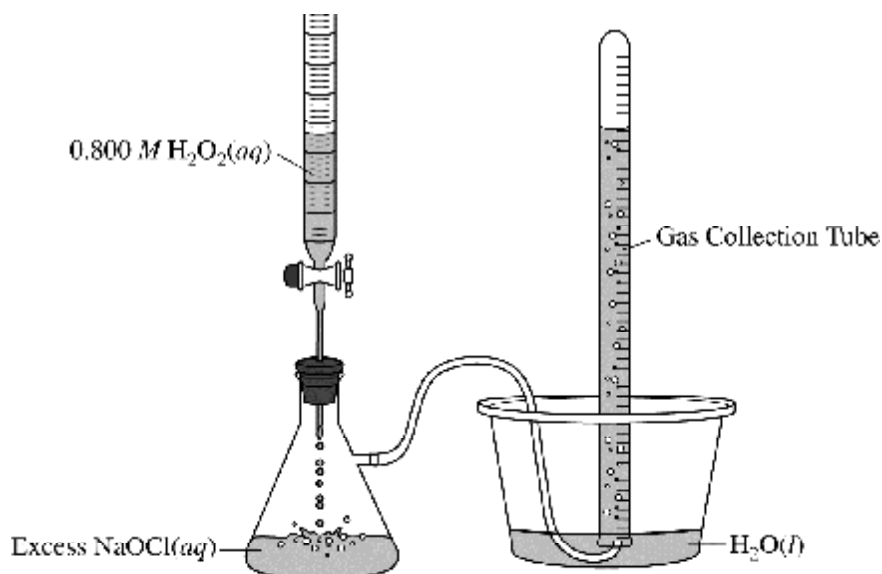
To better understand the reaction, the student looks up thermodynamic data for the reaction. For the reaction represented above, the value of ΔG_{298}° is $-197 \text{ kJ/mol}_{rxn}$ and the value of ΔS_{298}° is $144 \text{ J/(K}\cdot\text{mol}_{rxn})$.

(b) Calculate the value of ΔH_{298}° for the reaction in kJ/mol_{rxn} .

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

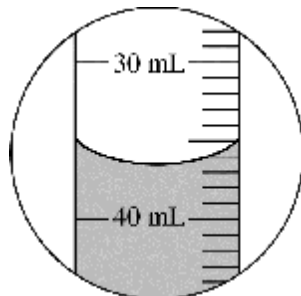
(d) Calculate the value of the equilibrium constant, K , for the reaction at 298 K.

The student decides to produce 40.0 mL of $\text{O}_2(g)$ at a pressure of 0.988 atm and a temperature of 298 K using the reaction represented above. The student uses the equipment shown below. The student sets up a 250 mL Erlenmeyer flask fitted with a one-hole stopper. The flask is connected to a 50 mL gas-collection tube that initially is completely filled with water.



- (e) Calculate the volume of $0.800 \text{ M H}_2\text{O}_2(aq)$ that the student should add to excess $\text{NaOCl}(aq)$ to produce 40.0 mL of $\text{O}_2(g)$ at 0.988 atm and 298 K.

- (f) The student added the amount of $\text{H}_2\text{O}_2(aq)$ calculated in part (e) to excess $\text{NaOCl}(aq)$. However, instead of producing 40.0 mL of $\text{O}_2(g)$, the volume indicated in the diagram below was produced.



- (i) Based on the diagram above, what volume of gas was produced?
- (ii) Assuming that all the gas in the tube is $\text{O}_2(\text{g})$, calculate the percent yield of $\text{O}_2(\text{g})$.
- (iii) Is the assumption that all the gas in the tube is $\text{O}_2(\text{g})$ correct? Explain.
- (g) To account for the percent yield being less than 100 percent, the student claims that the reaction reached equilibrium before the expected amount of $\text{O}_2(\text{g})$ was produced. Considering your answer to part (d) above, do you agree or disagree with the student's claim? Justify your answer.

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-12-

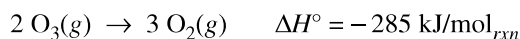
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3. Answer the following questions about ozone.

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

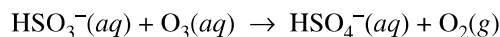
- (b) Based on the diagram you drew in part (a), what is the shape of the ozone molecule?

Ozone decomposes according to the reaction represented below.

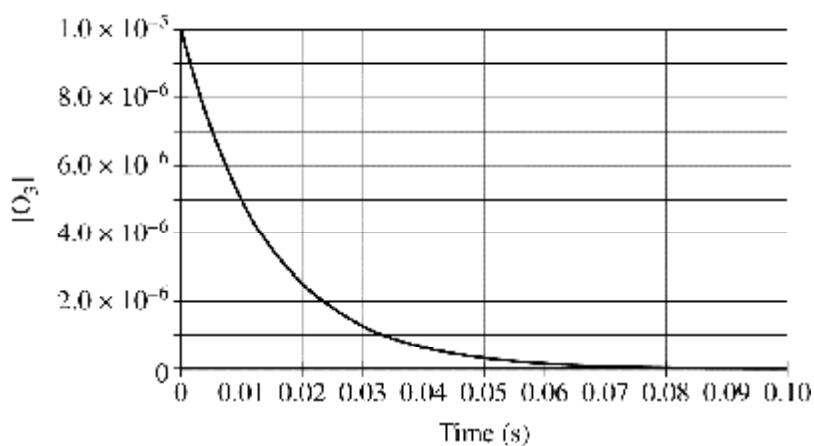


- (c) The bond enthalpy of the oxygen-oxygen bond in O_2 is 498 kJ/mol. Based on the enthalpy of the reaction represented above, what is the average bond enthalpy, in kJ/mol, of an oxygen-oxygen bond in O_3 ?

Ozone can oxidize $\text{HSO}_3^-(aq)$, as represented by the equation below.



A solution is prepared in which the initial concentration of $\text{HSO}_3^-(aq)$ ($6.4 \times 10^{-4} M$) is much larger than that of $\text{O}_3(aq)$ ($1.0 \times 10^{-5} M$). The concentration of $\text{O}_3(aq)$ is monitored as the reaction proceeds, and the data are plotted in the graph below.



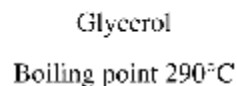
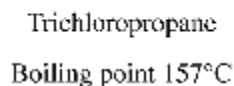
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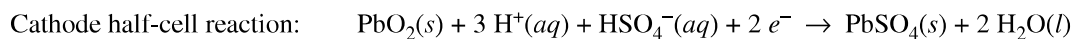
[illegible]

-17-



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

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

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

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

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

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

(i) Calculate the molar solubility of $\text{AgCl}(s)$ in seawater.

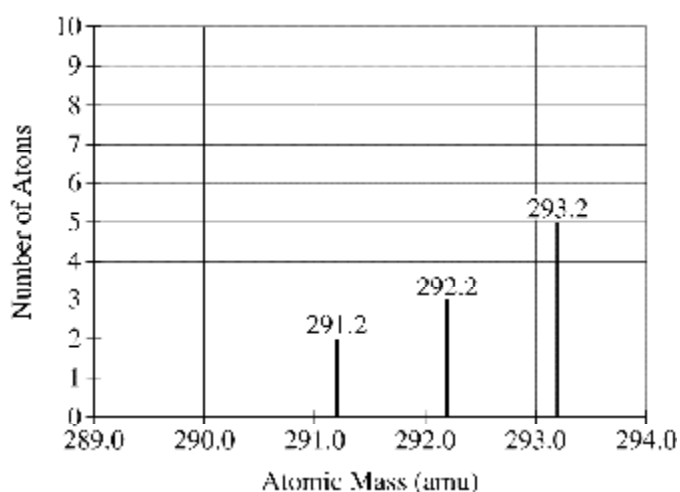
(ii) Explain why $\text{AgCl}(s)$ is less soluble in seawater than in distilled water.

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-23-

7. A new element with atomic number 116 was discovered in 2000. In 2012 it was named livermorium, Lv. Although Lv is radioactive and short-lived, its chemical properties and reactivity should follow periodic trends.
- (a) Write the electron configuration for the valence electrons of Lv in the ground state.
- (b) According to periodic properties, what would be the most likely formula for the product obtained when Lv reacts with $\text{H}_2(\text{g})$?
- (c) The first ionization energy of polonium, Po, is 812 kJ/mol. Is the first ionization energy of Lv expected to be greater than, less than, or equal to that of Po? Justify your answer in terms of Coulomb's law.
- (d) Shown below is a hypothetical mass spectrum for a sample of Lv containing 10 atoms.



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

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DO NOT DETACH FROM BOOK.

1	2	13	14	15	16	17	18
1 H 1.008	2 He 4.00	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3 Li 6.94	4 Be 9.01	11 Na 22.99	12 Mg 24.30	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc 97.91	44 Ru 101.1
55 Cs 132.91	56 Ba 137.33	57 *La 138.91	58 Hf 178.49	59 Ta 180.95	60 W 183.84	61 Re 186.21	62 Os 190.2
87 Fr (223)	88 Ra (226)	89 †Ac (227)	90 Rf (261)	91 Db (262)	92 Sg (266)	93 Bh (269)	94 Hs (271)
101 La (138.91)	102 Ce (140.12)	103 Pr (140.91)	104 Nd (144.24)	105 Pm (145)	106 Sm (150.4)	107 Eu (151.97)	108 Gd (157.25)
117 Lu (174.97)	118 Yb (173.05)	119 Tm (168.93)	120 Er (167.26)	121 Ho (164.93)	122 Dy (162.50)	123 Tb (158.93)	124 Pr (140.91)
133 Fr (223)	134 Ra (226)	135 Ac (227)	136 Rf (261)	137 Db (262)	138 Sg (266)	139 Bh (269)	140 Hs (271)
151 La (138.91)	152 Ce (140.12)	153 Pr (140.91)	154 Nd (144.24)	155 Pm (145)	156 Sm (150.4)	157 Eu (151.97)	158 Gd (157.25)
173 Lu (174.97)	174 Yb (173.05)	175 Tm (168.93)	176 Er (167.26)	177 Ho (164.93)	178 Dy (162.50)	179 Tb (158.93)	180 Pr (140.91)
197 Lu (174.97)	198 Yb (173.05)	199 Tm (168.93)	200 Er (167.26)	201 Ho (164.93)	202 Dy (162.50)	203 Tb (158.93)	204 Pr (140.91)
217 Lu (174.97)	218 Yb (173.05)	219 Tm (168.93)	220 Er (167.26)	221 Ho (164.93)	222 Dy (162.50)	223 Tb (158.93)	224 Pr (140.91)
239 Fr (223)	240 Ra (226)	241 Ac (227)	242 Rf (261)	243 Db (262)	244 Sg (266)	245 Bh (269)	246 Hs (271)
257 Lu (174.97)	258 Yb (173.05)	259 Tm (168.93)	260 Er (167.26)	261 Ho (164.93)	262 Dy (162.50)	263 Tb (158.93)	264 Pr (140.91)
289 Lu (174.97)	290 Yb (173.05)	291 Tm (168.93)	292 Er (167.26)	293 Ho (164.93)	294 Dy (162.50)	295 Tb (158.93)	296 Pr (140.91)
313 Lu (174.97)	314 Yb (173.05)	315 Tm (168.93)	316 Er (167.26)	317 Ho (164.93)	318 Dy (162.50)	319 Tb (158.93)	320 Pr (140.91)
337 Lu (174.97)	338 Yb (173.05)	339 Tm (168.93)	340 Er (167.26)	341 Ho (164.93)	342 Dy (162.50)	343 Tb (158.93)	344 Pr (140.91)
353 Lu (174.97)	354 Yb (173.05)	355 Tm (168.93)	356 Er (167.26)	357 Ho (164.93)	358 Dy (162.50)	359 Tb (158.93)	360 Pr (140.91)
377 Lu (174.97)	378 Yb (173.05)	379 Tm (168.93)	380 Er (167.26)	381 Ho (164.93)	382 Dy (162.50)	383 Tb (158.93)	384 Pr (140.91)
397 Lu (174.97)	398 Yb (173.05)	399 Tm (168.93)	400 Er (167.26)	401 Ho (164.93)	402 Dy (162.50)	403 Tb (158.93)	404 Pr (140.91)
417 Lu (174.97)	418 Yb (173.05)	419 Tm (168.93)	420 Er (167.26)	421 Ho (164.93)	422 Dy (162.50)	423 Tb (158.93)	424 Pr (140.91)
433 Lu (174.97)	434 Yb (173.05)	435 Tm (168.93)	436 Er (167.26)	437 Ho (164.93)	438 Dy (162.50)	439 Tb (158.93)	440 Pr (140.91)
453 Lu (174.97)	454 Yb (173.05)	455 Tm (168.93)	456 Er (167.26)	457 Ho (164.93)	458 Dy (162.50)	459 Tb (158.93)	460 Pr (140.91)
477 Lu (174.97)	478 Yb (173.05)	479 Tm (168.93)	480 Er (167.26)	481 Ho (164.93)	482 Dy (162.50)	483 Tb (158.93)	484 Pr (140.91)
497 Lu (174.97)	498 Yb (173.05)	499 Tm (168.93)	500 Er (167.26)	501 Ho (164.93)	502 Dy (162.50)	503 Tb (158.93)	504 Pr (140.91)
517 Lu (174.97)	518 Yb (173.05)	519 Tm (168.93)	520 Er (167.26)	521 Ho (164.93)	522 Dy (162.50)	523 Tb (158.93)	524 Pr (140.91)
537 Lu (174.97)	538 Yb (173.05)	539 Tm (168.93)	540 Er (167.26)	541 Ho (164.93)	542 Dy (162.50)	543 Tb (158.93)	544 Pr (140.91)
557 Lu (174.97)	558 Yb (173.05)	559 Tm (168.93)	560 Er (167.26)	561 Ho (164.93)	562 Dy (162.50)	563 Tb (158.93)	564 Pr (140.91)
577 Lu (174.97)	578 Yb (173.05)	579 Tm (168.93)	580 Er (167.26)	581 Ho (164.93)	582 Dy (162.50)	583 Tb (158.93)	584 Pr (140.91)
597 Lu (174.97)	598 Yb (173.05)	599 Tm (168.93)	600 Er (167.26)	601 Ho (164.93)	602 Dy (162.50)	603 Tb (158.93)	604 Pr (140.91)
617 Lu (174.97)	618 Yb (173.05)	619 Tm (168.93)	620 Er (167.26)	621 Ho (164.93)	622 Dy (162.50)	623 Tb (158.93)	624 Pr (140.91)
637 Lu (174.97)	638 Yb (173.05)	639 Tm (168.93)	640 Er (167.26)	641 Ho (164.93)	642 Dy (162.50)	643 Tb (158.93)	644 Pr (140.91)
657 Lu (174.97)	658 Yb (173.05)	659 Tm (168.93)	660 Er (167.26)	661 Ho (164.93)	662 Dy (162.50)	663 Tb (158.93)	664 Pr (140.91)
677 Lu (174.97)	678 Yb (173.05)	679 Tm (168.93)	680 Er (167.26)	681 Ho (164.93)	682 Dy (162.50)	683 Tb (158.93)	684 Pr (140.91)
697 Lu (174.97)	698 Yb (173.05)	699 Tm (168.93)	700 Er (167.26)	701 Ho (164.93)	702 Dy (162.50)	703 Tb (158.93)	704 Pr (140.91)
717 Lu (174.97)	718 Yb (173.05)	719 Tm (168.93)	720 Er (167.26)	721 Ho (164.93)	722 Dy (162.50)	723 Tb (158.93)	724 Pr (140.91)
737 Lu (174.97)	738 Yb (173.05)	739 Tm (168.93)	740 Er (167.26)	741 Ho (164.93)	742 Dy (162.50)	743 Tb (158.93)	744 Pr (140.91)
757 Lu (174.97)	758 Yb (173.05)	759 Tm (168.93)	760 Er (167.26)	761 Ho (164.93)	762 Dy (162.50)	763 Tb (158.93)	764 Pr (140.91)
777 Lu (174.97)	778 Yb (173.05)	779 Tm (168.93)	780 Er (167.26)	781 Ho (164.93)	782 Dy (162.50)	783 Tb (158.93)	784 Pr (140.91)
797 Lu (174.97)	798 Yb (173.05)	799 Tm (168.93)	800 Er (167.26)	801 Ho (164.93)	802 Dy (162.50)	803 Tb (158.93)	804 Pr (140.91)
817 Lu (174.97)	818 Yb (173.05)	819 Tm (168.93)	820 Er (167.26)	821 Ho (164.93)	822 Dy (162.50)	823 Tb (158.93)	824 Pr (140.91)
837 Lu (174.97)	838 Yb (173.05)	839 Tm (168.93)	840 Er (167.26)	841 Ho (164.93)	842 Dy (162.50)	843 Tb (158.93)	844 Pr (140.91)
857 Lu (174.97)	858 Yb (173.05)	859 Tm (168.93)	860 Er (167.26)	861 Ho (164.93)	862 Dy (162.50)	863 Tb (158.93)	864 Pr (140.91)
877 Lu (174.97)	878 Yb (173.05)	879 Tm (168.93)	880 Er (167.26)	881 Ho (164.93)	882 Dy (162.50)	883 Tb (158.93)	884 Pr (140.91)
897 Lu (174.97)	898 Yb (173.05)	899 Tm (168.93)	900 Er (167.26)	901 Ho (164.93)	902 Dy (162.50)	903 Tb (158.93)	904 Pr (140.91)
917 Lu (174.97)	918 Yb (173.05)	919 Tm (168.93)	920 Er (167.26)	921 Ho (164.93)	922 Dy (162.50)	923 Tb (158.93)	924 Pr (140.91)
937 Lu (174.97)	938 Yb (173.05)	939 Tm (168.93)	940 Er (167.26)	941 Ho (164.93)	942 Dy (162.50)	943 Tb (158.93)	944 Pr (140.91)
957 Lu (174.97)	958 Yb (173.05)	959 Tm (168.93)	960 Er (167.26)	961 Ho (164.93)	962 Dy (162.50)	963 Tb (158.93)	964 Pr (140.91)
977 Lu (174.97)	978 Yb (173.05)	979 Tm (168.93)	980 Er (167.26)	981 Ho (164.93)	982 Dy (162.50)	983 Tb (158.93)	984 Pr (140.91)
997 Lu (174.97)	998 Yb (173.05)	999 Tm (168.93)	1000 Er (167.26)	1001 Ho (164.93)	1002 Dy (162.50)	1003 Tb (158.93)	1004 Pr (140.91)
1017 Lu (174.97)	1018 Yb (173.05)	1019 Tm (168.93)	1020 Er (167.26)	1021 Ho (164.93)	1022 Dy (162.50)	1023 Tb (158.93)	1024 Pr (140.91)
1037 Lu (174.97)	1038 Yb (173.05)	1039 Tm (168.93)	1040 Er (167.26)	1041 Ho (164.93)	1042 Dy (162.50)	1043 Tb (158.93)	1044 Pr (140.91)
1057 Lu (174.97)	1058 Yb (173.05)	1059 Tm (168.93)	1060 Er (167.26)	1061 Ho (164.93)	1062 Dy (162.50)	1063 Tb (158.93)	1064 Pr (140.91)
1077 Lu (174.97)	1078 Yb (173.05)	1079 Tm (168.93)	1080 Er (167.26)	1081 Ho (164.93)	1082 Dy (162.50)	1083 Tb (158.93)	1084 Pr (140.91)
1097 Lu (174.97)	1098 Yb (173.05)	1099 Tm (168.93)	1100 Er (167.26)	1101 Ho (164.93)	1102 Dy (162.50)	1103 Tb (158.93)	1104 Pr (140.91)
1117 Lu (174.97)	1118 Yb (173.05)	1119 Tm (168.93)	1120 Er (167.26)	1121 Ho (164.93)	1122 Dy (162.50)	1123 Tb (158.93)	1124 Pr (140.91)
1137 Lu (174.97)	1138 Yb (173.05)	1139 Tm (168.93)	1140 Er (167.26)	1141 Ho (164.93)	1142 Dy (162.50)	1143 Tb (158.93)	1144 Pr (140.91)
1157 Lu (174.97)	1158 Yb (173.05)	1159 Tm (168.93)	1160 Er (167.26)	1161 Ho (164.93)	1162 Dy (162.50)	1163 Tb (158.93)	1164 Pr (140.91)
1177 Lu (174.97)	1178 Yb (173.05)	1179 Tm (168.93)	1180 Er (167.26)	1181 Ho (164.93)	1182 Dy (162.50)	1183 Tb (158.93)	1184 Pr

AP[®] CHEMISTRY EQUATIONS AND CONSTANTS

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

L, mL = liter(s), milliliter(s)
g = gram(s)
nm = nanometer(s)
atm = atmosphere(s)

mm Hg = millimeters of mercury
J, kJ = joule(s), kilojoule(s)
V = volt(s)
mol = mole(s)

<p>ATOMIC STRUCTURE</p> $E = h\nu$ $c = \lambda\nu$	$E = \text{energy}$ $\nu = \text{frequency}$ $\lambda = \text{wavelength}$ <p>Planck's constant, $h = 6.626 \times 10^{-34} \text{ J s}$ Speed of light, $c = 2.998 \times 10^8 \text{ m s}^{-1}$ Avogadro's number = $6.022 \times 10^{23} \text{ mol}^{-1}$ Electron charge, $e = -1.602 \times 10^{-19} \text{ coulomb}$</p>
<p>EQUILIBRIUM</p> $K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}, \text{ where } a \text{ A} + b \text{ B} \rightleftharpoons c \text{ C} + d \text{ D}$ $K_p = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b}$ $K_a = \frac{[H^+][A^-]}{[HA]}$ $K_b = \frac{[OH^-][HB^+]}{[B]}$ $K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\text{C}$ $= K_a \times K_b$ $\text{pH} = -\log [H^+], \text{ pOH} = -\log [OH^-]$ $14 = \text{pH} + \text{pOH}$ $\text{pH} = \text{p}K_a + \log \frac{[A^-]}{[HA]}$ $\text{p}K_a = -\log K_a, \text{ p}K_b = -\log K_b$	<p><u>Equilibrium Constants</u></p> K_c (molar concentrations) K_p (gas pressures) K_a (weak acid) K_b (weak base) K_w (water)
<p>KINETICS</p> $\ln[A]_t - \ln[A]_0 = -kt$ $\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$ $t_{1/2} = \frac{0.693}{k}$	$k = \text{rate constant}$ $t = \text{time}$ $t_{1/2} = \text{half-life}$

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

$$P_{\text{total}} = P_A + P_B + P_C + \dots$$

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

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

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

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

Molarity, M = moles of solute per liter of solution

$$A = abc$$

P = pressure

V = volume

T = temperature

n = number of moles

m = mass

M = molar mass

D = density

KE = kinetic energy

v = velocity

A = absorbance

a = molar absorptivity

b = path length

c = concentration

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

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

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

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

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

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

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

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K$$

$$= -nFE^\circ$$

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

q = heat

m = mass

c = specific heat capacity

T = temperature

S° = standard entropy

H° = standard enthalpy

G° = standard Gibbs free energy

n = number of moles

E° = standard reduction potential

I = current (amperes)

q = charge (coulombs)

t = time (seconds)

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

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

APPENDIX - ANSWERS

AP CHEMISTRY 2017

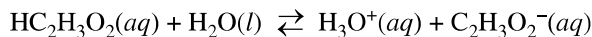
Multiple-choice key transcribed from the matching supplied source.

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

This supplied modified practice paper contains 50 MCQs and 7 FRQs.

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Question 1



The dissociation of ethanoic acid, $\text{HC}_2\text{H}_3\text{O}_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using two different experimental procedures.

(a) The student is first asked to prepare 100.0 mL of 0.115 *M* $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using a 2.000 *M* standard solution.

- (i) Calculate the volume, in mL, of 2.000 *M* $\text{HC}_2\text{H}_3\text{O}_2(aq)$ the student needs to prepare 100.0 mL of 0.115 *M* $\text{HC}_2\text{H}_3\text{O}_2(aq)$.

$M_i V_i = M_f V_f$ $V_i = \frac{(0.115 \text{ M})(100.0 \text{ mL})}{2.000 \text{ M}} = 5.75 \text{ mL}$	<p>1 point is earned for the correct volume.</p>
---	--

- (ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 *M* $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

- | | |
|-----------------------------|---|
| • 100 mL beaker | • Eye dropper |
| • 100 mL graduated cylinder | • 500 mL wash bottle filled with distilled water |
| • 100 mL volumetric flask | • 2.000 <i>M</i> $\text{HC}_2\text{H}_3\text{O}_2(aq)$ in a 50 mL buret |

<p>Use the buret to deliver 5.75 mL of 2.000 <i>M</i> $\text{HC}_2\text{H}_3\text{O}_2$ to the 100 mL volumetric flask. Then add distilled water from the wash bottle to the flask (adding the last few drops with an eyedropper) until the volume of liquid in the flask is at the calibration mark.</p>	<p>1 point is earned for dispensing from the buret.</p> <p>1 point is earned for diluting the solution to the calibration mark of the volumetric flask.</p>
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Question 1 (continued)

(b) Using a pH probe, the student determines that the pH of 0.115 *M* HC₂H₃O₂(*aq*) is 2.92.

(i) Using the pH value, calculate the value of K_a for HC₂H₃O₂(*aq*).

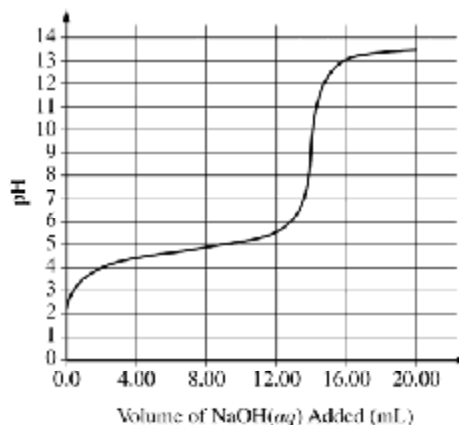
$\text{pH} = 2.92 \Rightarrow [\text{H}_3\text{O}^+] = 10^{-2.92} = 0.0012 \text{ M}$ $K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_2\text{H}_3\text{O}_2^-]}{[\text{HC}_2\text{H}_3\text{O}_2]}$ <p>Since $[\text{H}_3\text{O}^+] = [\text{C}_2\text{H}_3\text{O}_2^-]$, then</p> $K_a = \frac{(0.0012)(0.0012)}{(0.115 - 0.0012)} = \frac{(0.0012)^2}{(0.114)} = 1.3 \times 10^{-5}$	<p>1 point is earned for correct conversion of pH to $[\text{H}_3\text{O}^+]$.</p> <p>1 point is earned for a value of K_a consistent with the student's value of $[\text{H}_3\text{O}^+]$.</p>
--	--

(ii) Calculate the percent dissociation of ethanoic acid in 0.115 *M* HC₂H₃O₂(*aq*).

$\text{Percent dissociation} = \frac{[\text{C}_2\text{H}_3\text{O}_2^-]}{[\text{HC}_2\text{H}_3\text{O}_2]_0} = \frac{0.0012}{0.115} \times 100 = 1.0\%$	<p>1 point is earned for the correct percent dissociation.</p>
--	--

In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 *M* HC₂H₃O₂(*aq*) with an NaOH(*aq*) solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

Volume of NaOH(<i>aq</i>) Added (mL)	pH
0.00	2.23
2.00	3.99
4.00	4.37
6.00	4.63
8.00	4.90
10.00	5.17
12.00	5.55
14.00	9.35
16.00	13.04
18.00	13.31
20.00	13.46



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Question 1 (continued)

- (c) Write the balanced net ionic equation for the reaction that occurs when $\text{HC}_2\text{H}_3\text{O}_2(aq)$ and $\text{NaOH}(aq)$ are combined.

$\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{OH}^-(aq) \rightarrow \text{C}_2\text{H}_3\text{O}_2^-(aq) + \text{H}_2\text{O}(l)$	1 point is earned for the correct equation.
--	---

- (d) Calculate the molar concentration of the $\text{NaOH}(aq)$ solution.

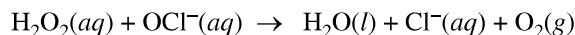
<p>From the pH curve, the equivalence point occurs at 14.0 mL.</p> $10.0 \text{ mL} \times \frac{2.000 \text{ mol HC}_2\text{H}_3\text{O}_2}{1000 \text{ mL}} = 0.0200 \text{ mol HC}_2\text{H}_3\text{O}_2(aq)$ $0.0200 \text{ mol HC}_2\text{H}_3\text{O}_2(aq) \times \frac{1 \text{ mol NaOH}}{1 \text{ mol HC}_2\text{H}_3\text{O}_2} = 0.0200 \text{ mol NaOH}$ $\frac{0.0200 \text{ mol NaOH}}{0.0140 \text{ L solution}} = 1.43 \text{ M NaOH}(aq)$	<p>1 point is earned for determining the moles of acid.</p> <p>1 point is earned for determining the molar concentration of the base.</p>
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- (e) Explain how the student can estimate the value of K_a for $\text{HC}_2\text{H}_3\text{O}_2(aq)$ using the titration curve.

<p>At the half-equivalence point (~7.0 mL) the pH of the solution is equal to the $\text{p}K_a$ of the acid. The antilog of the negative pH is equal to the value of K_a.</p>	<p>1 point is earned for a correct explanation (numerical explanation not required).</p>
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Question 2



A student investigates the reaction between $\text{H}_2\text{O}_2(aq)$ and $\text{NaOCl}(aq)$, which is represented by the net-ionic equation shown above.

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

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

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

(b) Calculate the value of ΔH_{298}° for the reaction in kJ/mol_{rxn} .

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

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

The temperature increases because the reaction is exothermic ($\Delta H^\circ < 0$).	1 point is earned for indicating an increase in temperature with a valid justification.
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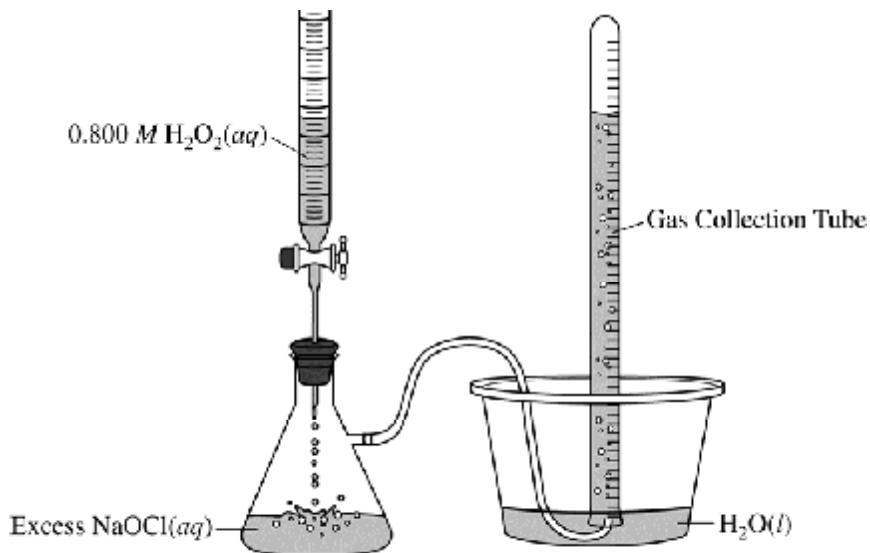
(d) Calculate the value of the equilibrium constant, K , for the reaction at 298 K.

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

The student decides to produce 40.0 mL of $\text{O}_2(g)$ at a pressure of 0.988 atm and a temperature of 298 K using the reaction represented above. The student uses the equipment shown below. The student sets up a 250 mL Erlenmeyer flask fitted with a one-hole stopper. The flask is connected to a 50 mL gas-collection tube that initially is completely filled with water.

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Question 2 (continued)



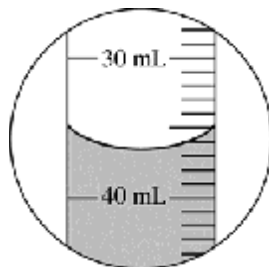
- (e) Calculate the volume of 0.800 M $\text{H}_2\text{O}_2(\text{aq})$ that the student should add to excess $\text{NaOCl}(\text{aq})$ to produce 40.0 mL of $\text{O}_2(\text{g})$ at 0.988 atm and 298 K.

$PV = nRT$ $n = \frac{PV}{RT} = \frac{(0.988 \text{ atm})(0.0400 \text{ L})}{(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(298 \text{ K})} = 0.00162 \text{ mol O}_2$ $0.00162 \text{ mol O}_2 \times \frac{1 \text{ mol H}_2\text{O}_2}{1 \text{ mol O}_2} = 0.00162 \text{ mol H}_2\text{O}_2 \text{ needed}$ $0.00162 \text{ mol H}_2\text{O}_2 \times \frac{\text{L}}{0.800 \text{ mol H}_2\text{O}_2} = 0.00202 \text{ L}$	<p>1 point is earned for calculating the number of moles of O_2 needed.</p> <p>1 point is earned for calculating the volume of H_2O_2 solution that should be added.</p>
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Question 2 (continued)

- (f) The student added the amount of $\text{H}_2\text{O}_2(aq)$ calculated in part (e) to excess $\text{NaOCl}(aq)$. However, instead of producing 40.0 mL of $\text{O}_2(g)$, the volume indicated in the diagram below was produced.



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

36.5 mL (values within ± 0.4 of 36.5 are acceptable)	1 point is earned for the correct reading of the meniscus level to three significant figures.
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- (ii) Assuming that all the gas in the tube is $\text{O}_2(g)$, calculate the percent yield of $\text{O}_2(g)$.

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

- (iii) Is the assumption that all the gas in the tube is $\text{O}_2(g)$ correct? Explain.

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

- (g) To account for the percent yield being less than 100 percent, the student claims that the reaction reached equilibrium before the expected amount of $\text{O}_2(g)$ was produced. Considering your answer to part (d) above, do you agree or disagree with the student's claim? Justify your answer.

Disagree. The very large value of K implies that the reaction goes essentially to completion, so essentially all of the H_2O_2 reacts to form O_2 .	1 point is earned for an appropriate conclusion and valid justification based on the value of K in part (d).
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Question 3

Answer the following questions about ozone.

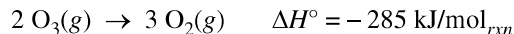
- (a) The O₃ molecule has a central oxygen atom bonded to two outer oxygen atoms that are not bonded to one another. In the box below, draw the Lewis electron-dot diagram of the O₃ molecule. Include all valid resonance structures.

	<p>1 point is earned for a diagram that includes all 18 valence electrons and obeys the octet rule.</p> <p>1 point is earned for showing correct application of resonance.</p>
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- (b) Based on the diagram you drew in part (a), what is the shape of the ozone molecule?

The ozone molecule has a bent shape.	1 point is earned for the shape based on student's Lewis diagram.
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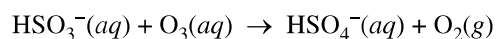
Ozone decomposes according to the reaction represented below.



- (c) The bond enthalpy of the oxygen-oxygen bond in O₂ is 498 kJ/mol. Based on the enthalpy of the reaction represented above, what is the average bond enthalpy, in kJ/mol, of an oxygen-oxygen bond in O₃?

$\Delta H^\circ = \sum (\text{bond enthalpies})_{\text{reactants}} - \sum (\text{bond enthalpies})_{\text{products}}$ <p>Four equivalent bonds are broken in two O₃ molecules. Three oxygen-oxygen bonds are formed in three O₂ molecules. Let x = the bond enthalpy in ozone, therefore $4x - 3(498 \text{ kJ/mol}) = -285 \text{ kJ/mol}_{\text{rxn}}$ $x = 302 \text{ kJ/mol}$</p>	<p>1 point is earned for the correct determination of the number of bonds broken in the reactants and the number of bonds formed in the products.</p> <p>1 point is earned for the calculation of the energy of the bonds in O₃ consistent with bond counting, the bond energy of O₂, and the $\Delta H^\circ_{\text{rxn}}$.</p>
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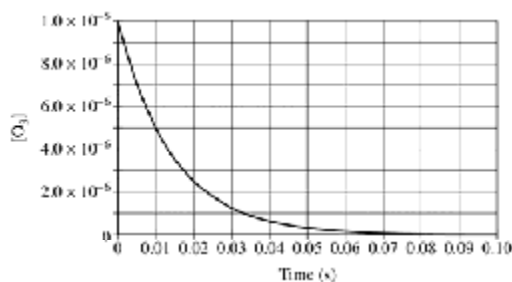
Ozone can oxidize HSO₃[−](aq), as represented by the equation below.



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Question 3 (continued)

A solution is prepared in which the initial concentration of $\text{HSO}_3^-(aq)$ ($6.4 \times 10^{-4} M$) is much larger than that of $\text{O}_3(aq)$ ($1.0 \times 10^{-5} M$). The concentration of $\text{O}_3(aq)$ is monitored as the reaction proceeds, and the data are plotted in the graph below.



(d) The data are consistent with the following rate law: $\text{rate} = k_1 [\text{O}_3]$.

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

Half-life = 0.010 s	1 point is earned for the correct answer.
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(ii) Determine the value of the rate constant, k_1 , for the rate law. Include units with your answer.

$t_{1/2} = \frac{0.693}{k_1} \Rightarrow k_1 = \frac{0.693}{t_{1/2}} = \frac{0.693}{0.010 \text{ s}} = 69 \text{ s}^{-1}$	1 point is earned for the correct value. 1 point is earned for the correct unit.
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(iii) Considering the relative concentrations of the reactants, briefly explain why the data in the graph are also consistent with the following rate law: $\text{rate} = k_2 [\text{O}_3] [\text{HSO}_3^-]$.

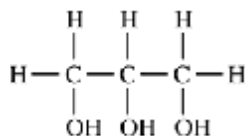
The data are consistent with $\text{rate} = k_2 [\text{O}_3] [\text{HSO}_3^-]$ because $[\text{HSO}_3^-]$ remains essentially constant during the experiment. ($[\text{HSO}_3^-]$ can be contained in the rate constant k_1 .)	1 point is earned for a correct explanation.
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(iv) Briefly describe an experiment that could provide evidence to support the rate law given in part (d)(iii).

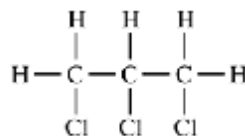
Repeat the experiment with a different initial concentration of HSO_3^- . (If the change in the rate of the reaction is directly proportional to the change in $[\text{HSO}_3^-]$, then the reaction is first order with respect to HSO_3^- .)	1 point is earned for describing a valid experiment.
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Question 4



Glycerol
Boiling point 290°C



Trichloropropane
Boiling point 157°C

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

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

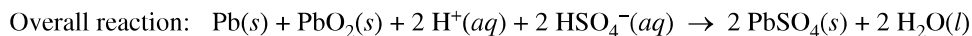
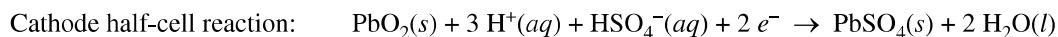
<p>Each substance has intermolecular London dispersion forces and dipole-dipole forces. Glycerol also has hydrogen bonding. The presence of hydrogen bonding in glycerol results in the total intermolecular forces in glycerol being stronger than the total intermolecular forces in trichloropropane.</p>	<p>1 point is earned for identifying the IMFs in <u>each</u> liquid.</p> <p>1 point is earned for a correct explanation.</p>
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- (b) Glycerol (molar mass 92.09 g/mol) has been suggested for use as an alternative fuel. The enthalpy of combustion, $\Delta H_{\text{comb}}^{\circ}$, of glycerol is -1654 kJ/mol . What mass of glycerol would need to be combusted to heat 500.0 g of water from 20.0°C to 100.0°C? (The specific heat capacity of water is $4.184 \text{ J/(g} \cdot ^{\circ}\text{C)}$. Assume that all the heat released by the combustion reaction is absorbed by the water.)

$q_{\text{H}_2\text{O}} = mc\Delta T = (500.0 \text{ g}) \times (4.184 \text{ J/(g} \cdot ^{\circ}\text{C)}) \times (100.0^{\circ}\text{C} - 20.0^{\circ}\text{C})$ $= 167,000 \text{ J} = 167 \text{ kJ}$ $-q_{\text{H}_2\text{O}} = q_{\text{comb}}$ $-167 \text{ kJ} \times \frac{1 \text{ mol glycerol}}{-1654 \text{ kJ}} \times \frac{92.09 \text{ g glycerol}}{1 \text{ mol glycerol}} = 9.30 \text{ g glycerol}$	<p>1 point is earned for a correct calculation of q.</p> <p>1 point is earned for the correct mass of glycerol.</p>
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Question 5



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

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

+6	1 point is earned for the correct answer.
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- (b) Write the equation for the half-reaction that occurs at the anode as the battery operates.

$\text{Pb}(s) + \text{HSO}_4^-(aq) \rightarrow \text{PbSO}_4(s) + \text{H}^+(aq) + 2 e^-$	1 point is earned for a correct equation.
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After the battery has operated for some time, it can be recharged by applying a current to reverse the overall reaction.

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

$100. \text{ g Pb} \times \frac{1 \text{ mol Pb}}{207.2 \text{ g}} = 0.483 \text{ mol Pb}$ $0.483 \text{ mol Pb} \times \frac{2 \text{ mol } e^-}{1 \text{ mol Pb}} = 0.966 \text{ mol } e^-$ $0.966 \text{ mol } e^- \times \frac{96,485 \text{ C}}{1 \text{ mol } e^-} = 93,200 \text{ C}$ $I = \frac{q}{t} \Rightarrow t = \frac{q}{I}$ $\frac{93,200 \text{ C}}{5.00 \text{ amp}} \times \frac{1 \text{ amp}}{1 \text{ C/s}} = 18,600 \text{ s}$	<p style="text-align: center;">1 point is earned for the correct number of moles of electrons (may be implicit).</p> <p style="text-align: center;">1 point is earned for the correct time based on the moles of electrons.</p>
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Question 6

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

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

$K_{sp} = [Ag^+][Cl^-]$ Let $x = [Ag^+] = [Cl^-]$ Then $1.8 \times 10^{-10} = (x)(x) \Rightarrow x = \sqrt{1.8 \times 10^{-10}}$ $x = [Ag^+] = 1.3 \times 10^{-5} M$	1 point is earned for the correct K_{sp} expression and indication that the two ions have equal concentrations. 1 point is earned for correct calculation of the value of $[Ag^+]$.
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(b) The concentration of $Cl^-(aq)$ in seawater is $0.54 M$.

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

$1.8 \times 10^{-10} = [Ag^+] \times (0.54) \Rightarrow [Ag^+] = 3.3 \times 10^{-10} M$	1 point is earned for the correct answer with supporting work.
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(ii) Explain why AgCl(s) is less soluble in seawater than in distilled water.

An increased $[Cl^-]$ will decrease the solubility of AgCl(s) since the K_{sp} is a product of the $[Ag^+]$ and $[Cl^-]$. (This is an example of the common ion effect.)	1 point is earned for a correct explanation.
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Question 7

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

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

$7s^2 7p^4$	1 point is earned for the correct configuration.
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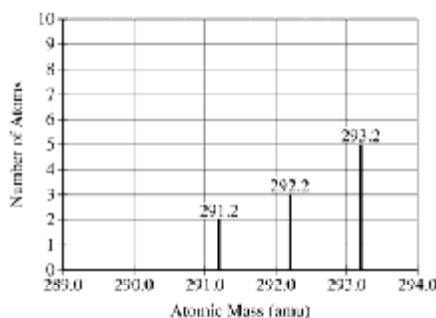
- (b) According to periodic properties, what would be the most likely formula for the product obtained when Lv reacts with $H_2(g)$?

LvH_2 (or H_2Lv)	1 point is earned for the correct formula.
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- (c) The first ionization energy of polonium, Po, is 812 kJ/mol. Is the first ionization energy of Lv expected to be greater than, less than, or equal to that of Po? Justify your answer in terms of Coulomb's law.

<p>Less than that of Po.</p> <p>The two atoms have comparable effective nuclear charges, but the valence electrons in Lv would be at a greater distance from the nucleus than those in Po. By Coulomb's law, the attractive force between the valence electrons and the nucleus decreases by the inverse square of the distance between them.</p>	<p>1 point is earned for a correct prediction <u>with</u> a valid justification.</p>
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- (d) Shown below is a hypothetical mass spectrum for a sample of Lv containing 10 atoms.



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

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