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. A quantity of 10,000 J of thermal energy is transferred to four different substances. In which of the following experiments could the greatest mass of the given substance undergo the indicated change?

   (A) Melting ice at 0 °C to form liquid water at 0 °C (ΔH_{fus} =330 J/g)

   (B) Boiling liquid acetone at 56 °C to form acetone vapor at 56 °C (ΔH_{vap} =540 J/g)

   (C) Increasing the temperature of liquid glycerin from 20 °C to 120 °C (Specific heat = 2.4 J/(g·°C))

   (D) Increasing the temperature of solid copper from 0 °C to 200 °C (Specific heat = 0.40 J/(g·°C))

2. Which of the following questions about the components in a mixture could be investigated with a paper chromatography experiment?

   (A) Do the components have different densities?

   (B) Do the components have different molecular masses?

   (C) Do the components have different molecular polarities?

   (D) Do the components have different average molecular speeds?

Bond	Approximate Bond Enthalpy (kJ/mol)
C−H	410
C−F	490
H−F	570
F−F	160

3. Based on the bond enthalpies given in the table above, which of the following is the best estimate of ΔH° for the reaction represented below?

$$CH_4 + F_2 \rightarrow CH_3F + HF$$

   (A) -650 kJ/mol$_{rxn}$

   (B) -490 kJ/mol$_{rxn}$

   (C) $+490$ kJ/mol$_{rxn}$

   (D) $+650$ kJ/mol$_{rxn}$

Acid	K_a
$HF(aq)$	4×10^{-4}
$HC_2H_3O_2(aq)$	2×10^{-5}
$HClO(aq)$	3×10^{-8}
$HCN(aq)$	5×10^{-10}

4. Based on the K_a values listed in the table above, equal volumes of which of the following pairs of solutions when mixed together will result in a buffer solution with a pH between 7 and 8?

   (A) 0.10 M $HC_2H_3O_2(aq)$ and 0.10 M $HF(aq)$
   (B) 0.10 M $HC_2H_3O_2(aq)$ and 0.10 M $NaC_2H_3O_2(aq)$
   (C) 0.10 M $HC_2H_3O_2(aq)$ and 0.10 M $HCN(aq)$
   (D) 0.10 M $HClO(aq)$ and 0.10 M $NaClO(aq)$

$$H_2O(g) + CO(g) \rightleftharpoons CO_2(g) + H_2(g)$$
$$K_p = 136 \text{ at } 500 \text{ K}$$

5. A vessel initially contains $H_2O(g)$ at a partial pressure of 0.30 atm, $CO(g)$ at a partial pressure of 0.10 atm, $CO_2(g)$ at a partial pressure of 1.5 atm, and $H_2(g)$ at a partial pressure of 10 atm at 500K. Which of the following occurs as the system approaches equilibrium at 500K?

   (A) The partial pressures of $H_2O(g)$ and $CO(g)$ increase because $Q > K_p$.
   (B) The partial pressures of $H_2O(g)$ and $CO(g)$ increase because $Q < K_p$.
   (C) The partial pressures of $CO_2(g)$ and $H_2(g)$ increase because $Q > K_p$.
   (D) The partial pressures of $CO_2(g)$ and $H_2(g)$ increase because $Q < K_p$.

Data for H_2O	
Specific heat capacity of liquid phase	4.2 J/(g·°C)
Heat of fusion	330 J/g

6. A sample of ice at 0 °C is added to 100 g of water at 33 °C. The mixture is stirred gently until the temperature of the water is 0 °C. All the remaining ice is quickly removed. Based on the information in the table above, the mass of ice that melted is closest to

   (A) 0.13 g
   (B) 0.42 g
   (C) 1.3 g
   (D) 42 g

$$AgNO_3(aq) + NaBr(aq) \rightarrow AgBr(s) + NaNO_3(aq)$$

7. A 10.0mL sample of 1.0 M $AgNO_3(aq)$ and a 10.0mL sample of 1.0 M $NaBr(aq)$, both originally at 25°C, are combined in a constant-pressure calorimeter where the reaction represented above occurs. If the final temperature of the mixture is 35°C, what is the value of ΔH for the reaction? (Assume that the heat absorbed by the calorimeter is negligible, that the total mass of the mixture is 20.0 g, and that the specific heat capacity of the mixture is 4.2 J/(g·°C).)

   (A) $-84,000$ J/mol$_{rxn}$
   (B) -84 J/mol$_{rxn}$
   (C) $+84$ J/mol$_{rxn}$
   (D) $+84,000$ J/mol$_{rxn}$

Step 1: $O_3(g) + Cl(g) \rightarrow O_2(g) + ClO(g)$
Step 2: $ClO(g) + O(g) \rightarrow O_2(g) + Cl(g)$

8. A proposed mechanism for the destruction of $O_3(g)$ in the upper atmosphere is represented above. Which of the following is the catalyst in the proposed mechanism?

   (A) $O(g)$
   (B) $Cl(g)$
   (C) $ClO(g)$
   (D) $O_2(g)$

$$NO(g) + CO_2(g) \rightleftharpoons NO_2(g) + CO(g)$$

9. Which of the following changes will increase the amount of $NO_2(g)$ in the equilibrium system represented by the equation above?

   (A) Removing $CO(g)$ from the system
   (B) Removing $CO_2(g)$ from the system
   (C) Increasing the volume of the reaction vessel
   (D) Decreasing the volume of the reaction vessel

Questions 10-14

The following balanced equation represents the decomposition of hydrogen peroxide, H_2O_2.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

A student carries out an experiment in which a sample of $H_2O_2(aq)$ decomposes in the presence of $MnO_2(s)$. The student measures the volume of $O_2(g)$ produced by the reaction at regular intervals while the temperature is held constant. The student's data are given in the following table.

Time (s)	Volume of $O_2(g)$ Collected (mL)
0	0
60	42
120	64
180	76
240	82
300	86
360	88
420	89

10. The student claims that the reaction is an oxidation-reduction reaction. Which of the following statements correctly describes a change in oxidation number as the decomposition reaction proceeds?

    (A) The oxidation number of hydrogen changes from $+2$ to $+1$.

    (B) The oxidation number of hydrogen changes from $+1$ to $+2$.

    (C) The oxidation number of oxygen changes from -2 to -1.

    (D) The oxidation number of oxygen changes from -1 to 0.

11. If 6.0×10^{-3} mol of H_2O_2 was consumed in the experiment, how many total moles of products were produced?

    (A) 6.0×10^{-3} mol

    (B) 9.0×10^{-3} mol

    (C) 12×10^{-3} mol

    (D) 18×10^{-3} mol

12. Based on the student's data, which of the following statements correctly describes how the rate of O_2 production changes during the experiment?

    (A) The rate is constant at first and then increases over time.

    (B) The rate decreases throughout the experiment.

    (C) The rate increases throughout the experiment.

    (D) The rate is constant throughout the experiment.

13. The student observes that under the same conditions, the reaction occurs at a much slower rate when $MnO_2(s)$ is not used. Which of the following statements best explains this observation?

    (A) $MnO_2(s)$ changes the reaction from endothermic to exothermic.

    (B) $MnO_2(s)$ shifts the equilibrium position of the reaction from reactant favored to product favored.

    (C) $MnO_2(s)$ releases heat in order to start the reaction.

    (D) $MnO_2(s)$ provides a reaction pathway with a lower activation energy.

14. A second experiment is done under identical conditions using a higher concentration of $H_2O_2(aq)$ in the presence of the same mass of $MnO_2(s)$. The volume of gas collected during the first 60 seconds will most likely be

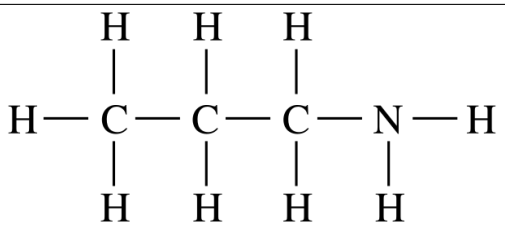
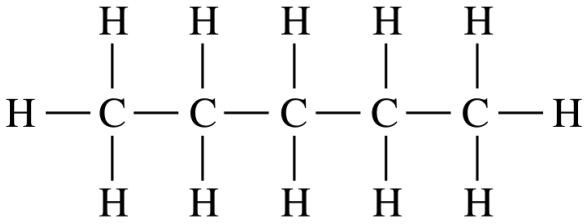
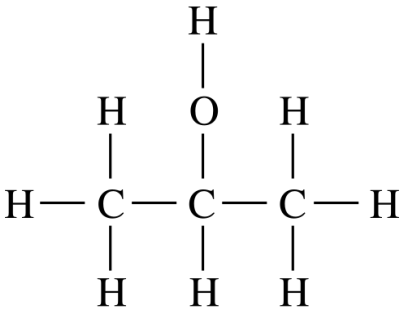
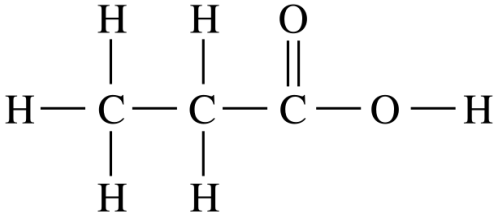
    (A) less than 42 mL

    (B) equal to 42 mL

    (C) greater than 42 mL

    (D) impossible to predict without knowing the actual concentration of H_2O_2 used in the two experiments

Questions 15-17

Substance	**Structural Formula**	**Molar Mass** (g/mol)
Propylamine		59
Pentane		72
2-propanol		60
Propanoic acid		74

A student was given samples of four different unknown liquids. The unknown liquids are propylamine, pentane, 2-propanol, and propanoic acid. The structures and molar masses of the compounds are shown in the table above. On the basis of this information, the student designed some experiments to identify the samples.

15. Of the following, which identifies the aqueous solution of the compound that will have the highest pH and explains why?

    (A) Propylamine, because the lone pair of electrons on N can accept an H^+ from the solution

    (B) Pentane, because it can produce the largest number of H^+ ions per molecule

    (C) 2-propanol, because it can completely dissociate into $C_3H_7^+$ and OH^-

    (D) Propanoic acid, because it dissociates into H^+ and $C_3H_5O_2^-$

16. Which of the following statements correctly identifies which compound, pentane or propanoic acid, has the higher boiling point and provides a valid justification?

    (A) Pentane, because it has greater London dispersion forces than propanoic acid does

    (B) Pentane, because it can form more hydrogen bonds per molecule than propanoic acid can

    (C) Propanoic acid, because double bonds are harder to break than single bonds

    (D) Propanoic acid, because it forms hydrogen bonds, whereas pentane does not

17. The student mixed samples of each of the four compounds with water. Only one of the four did not dissolve in water. Based on the structures of the molecules and the strengths and types of their intermolecular forces, the compound that did not dissolve is most likely

    (A) propylamine

    (B) pentane

    (C) 2-propanol

    (D) propanoic acid

	Ionization Energies (kJ/mol)
First	590
Second	1150
Third	4910
Fourth	6490

18. Based on the ionization energies of element X given in the table above, which of the following is most likely the formula of the compound formed between element X and SO_4^{2-}?

    (A) XSO_4

    (B) X_2SO_4

    (C) $X_2(SO_4)_3$

    (D) $X(SO_4)_2$

19. Based on the positions of elements in the periodic table, which of the following groups contains compounds that are most likely to have similar chemical properties?

    (A) KCl, KBr, and KI

    (B) $AsCl_3$, SCl_2, and ClF

    (C) CF_4, PF_3, and SeF_2

    (D) NH_3, H_2O, and HF

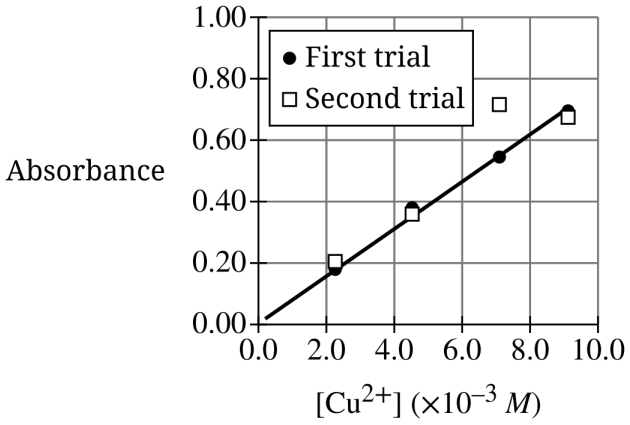
20. Which of the following correctly identifies a Brønsted-Lowry conjugate acid-base pair in a solution prepared by mixing together $HNO_2(aq)$ and $NH_3(aq)$?

    (A) The acid is $HNO_2(aq)$, and the conjugate base is $NH_3(aq)$.

    (B) The acid is $HNO_2(aq)$, and the conjugate base is $NO_2^-(aq)$.

    (C) The acid is $NH_4^+(aq)$, and the conjugate base is $NO_2^-(aq)$.

    (D) The acid is $NH_3(aq)$, and the conjugate base is $NH_4^+(aq)$.



21. A student prepared four solutions of known $[Cu^{2+}]$ and measured the absorbance of each solution using the same cuvette. The graph shows the data for two absorbance measurements done for each solution. Which of the following identifies the most likely error that affected the absorbance recorded for the solution with $[Cu^{2+}] \approx 7 \times 10^{-3} M$ in the second trial?

    (A) The cuvette was rinsed with water between measurements.

    (B) A fingerprint was left on the side of the cuvette facing the detector.

    (C) The absorbance was measured at a wavelength where Cu^{2+} has a lower molar absorptivity.

    (D) The cuvette was not filled with the same volume of solution.

Acid	Concentration of Acid (M)	Volume of Sample (mL)	Volume of Standardized NaOH(aq) Added to Reach Equivalence Point (mL)
$HClO_4(aq)$	0.100	25.0	24.0
$HClO(aq)$	0.200	25.0	?

22. Samples of two different acids are titrated using the same standardized solution of NaOH(aq). According to the data in the table above, how many milliliters of the standardized NaOH(aq) are required to reach the equivalence point when the 25.0mL sample of 0.200 M HClO(aq) is titrated?

(A) 12.0 mL

(B) 24.0 mL

(C) 48.0 mL

(D) It cannot be determined without knowing the values of K_a for $HClO_4(aq)$ and $HClO(aq)$.

Questions 23-24

$$2\mathrm{K}(s) + 2\mathrm{H_2O}(l) \rightarrow 2\mathrm{KOH}(aq) + \mathrm{H_2}(g) \qquad \Delta H^\circ = -393 \text{ kJ/mol}_{rxn}$$

When 3.9g of K(s) is added to 200 mL of water at 25 °C in a calorimeter, all the K(s) reacts with the water as represented by the equation above.

23. Which of the following is true when the 3.9 g of K(s) has completely reacted?

    (A) 10 kJ of energy is absorbed by the reaction.

    (B) 20 kJ of energy is absorbed by the reaction.

    (C) 10 kJ of energy is released by the reaction.

    (D) 20 kJ of energy is released by the reaction.

24. Which of the following is true about the pH of the water after the reaction is complete?

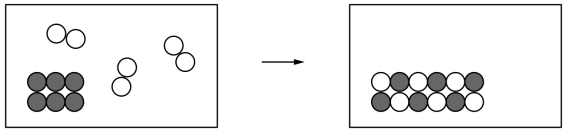
    (A) pH< 7

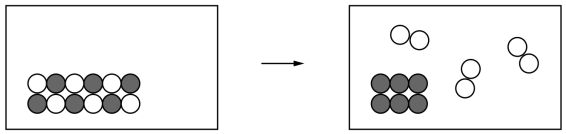
    (B) pH$= 7$

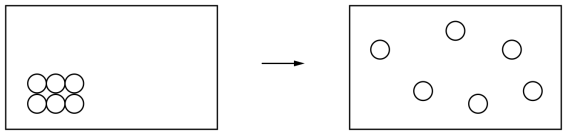
    (C) pH> 7

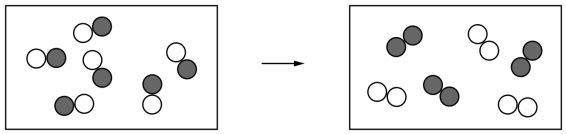
    (D) The pH of the water cannot be determined without additional information.

25. Which of the following pairs of diagrams represents the change with the greatest positive value of ΔS°?

(A) 

(B) 

(C) 

(D) 

26. A 10.0 g sample of $Pb(NO_3)_2(s)$ is dissolved in distilled water and an excess of 1.0 *M* $HCl(aq)$ is added. The $PbCl_2(s)$ formed is filtered and placed in an oven to dry. The final mass of the precipitate is significantly greater than predicted. Which of the following could account for the discrepancy?

(A) The sample of $Pb(NO_3)_2(s)$ was wet.

(B) The K_{sp} of $PbCl_2(s)$ is extremely small.

(C) The precipitate was not dried to a constant mass.

(D) A 3.0 *M* $HCl(aq)$ solution was used instead of a 1.0 *M* $HCl(aq)$ solution.

$$2N_2O(g) \rightarrow 2N_2(g) + O_2(g)$$

27. The rate law for the reaction represented above is experimentally determined to be rate$= k[N_2O]$. Which of the following best explains why increasing the initial concentration of $N_2O(g)$ at a constant temperature increases the reaction rate?

(A) Molecular collisions become more frequent.

(B) There is a higher probability of effective molecular collisions.

(C) The rate constant for the reaction increases.

(D) The reaction mechanism changes to one that has a lower activation energy.

28. A sample of an ideal gas in a sealed container occupies a volume of 50.0 L at 200 K. The temperature of the gas is changed to 400 K, and the pressure doubles. Which of the following must occur and why?

(A) Volume must decrease because the pressure is higher.

(B) Volume must increase because the temperature is higher.

(C) Volume must remain the same because the pressure and temperature change proportionately.

(D) Volume cannot be predicted without knowing the number of moles of gas in the sample.

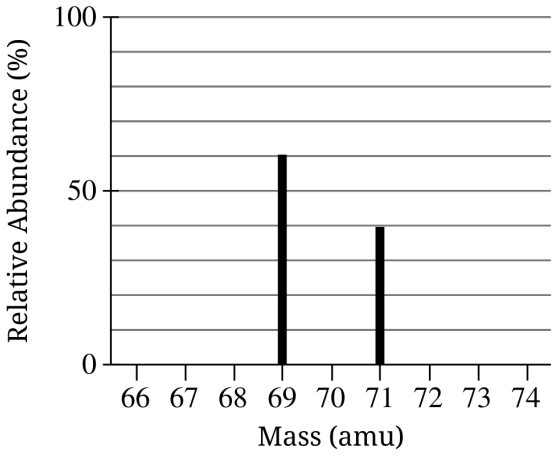
29. A student mixes 100 mL of 0.25 *M* $HCl(aq)$ with 200 mL of 0.50 *M* $HClO_4(aq)$ and then dilutes the mixture with distilled water to a total volume of 500 mL. The $[H_3O^+]$ in the final solution is closest to

(A) 0.0025 *M*

(B) 0.12 *M*

(C) 0.25 *M*

(D) 0.75 *M*



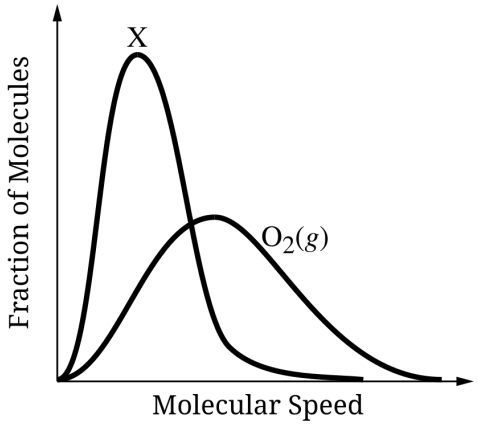
30. The mass spectrum of an element is represented above. Which of the following is most likely the identity of the element?

(A) Ga

(B) Ge

(C) Tm

(D) Lu



31. Based on the Maxwell-Boltzmann distributions at 300 K shown above, which of the following gases could be represented by curve X?

(A) $Br_2(g)$

(B) $CH_4(g)$

(C) $He(g)$

(D) $N_2(g)$

32. The value of K_{sp} for the salt PbF_2 is 3.2×10^{-8}. The $[Pb^{2+}]$ in a saturated solution of PbF_2 is approximately

(A) $2 \times 10^{-4}\ M$

(B) $4 \times 10^{-4}\ M$

(C) $2 \times 10^{-3}\ M$

(D) $4 \times 10^{-3}\ M$

$$PCl_3, Cl_2, CaCl_2$$

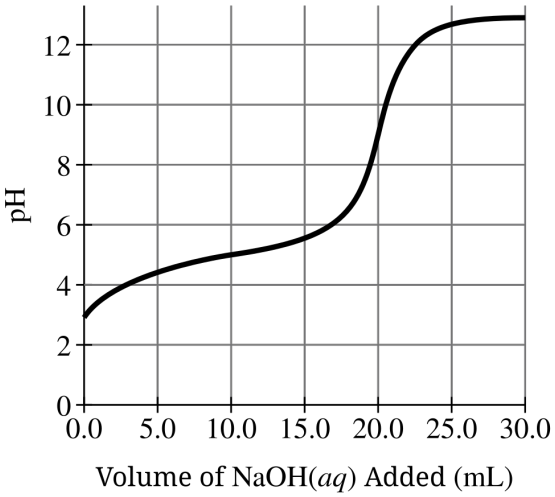
33. Which of the following correctly ranks the substances listed above in order of increasing ionic character in their bonding?

(A) Cl_2, PCl_3, $CaCl_2$

(B) Cl_2, $CaCl_2$, PCl_3

(C) $CaCl_2$, PCl_3, Cl_2

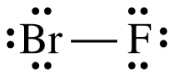
(D) $CaCl_2$, Cl_2, PCl_3

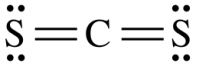


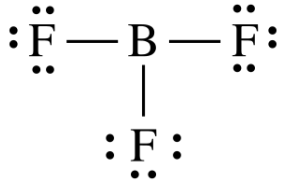
34. A 0.10 *M* solution of a weak acid is titrated with 0.10 *M* NaOH(aq). Based on the titration curve above, which of the following could be the identity of the weak acid?

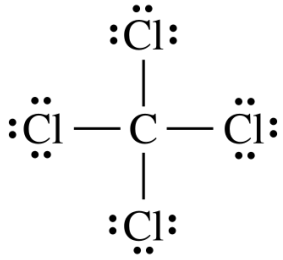
(A) HCN with a K_a value of 5×10^{-10}
(B) HOCl with a K_a value of 3×10^{-8}
(C) CH_3CH_2COOH with a K_a value of 1×10^{-5}
(D) $ClCH_2COOH$ with a K_a value of 1×10^{-3}

35. Which of the following molecules has the largest dipole moment?

(A) 

(B) 

(C) 

(D) 

Step 1: $4FeS_2(s) + 11O_2(g) \rightarrow 2Fe_2O_3(s) + 8SO_2(g)$
Step 2: $Fe_2O_3(s) + 3CO(g) \rightarrow 3CO_2(g) + 2Fe(s)$

36. Extraction of Fe(s) from pyrite, FeS_2, is a two-step process, as represented above. The maximum amount of Fe(s) that could be extracted from 120 grams of FeS_2 (molar mass 120 g/mol) is approximately

(A) 28 grams
(B) 56 grams
(C) 84 grams
(D) 112 grams

37. A solid is tested in a laboratory to determine its properties. Which of the following provides the best evidence to support the hypothesis that the solid is a metal as opposed to a nonmetal?

(A) It reacts with oxygen.

(B) It is lustrous and malleable.

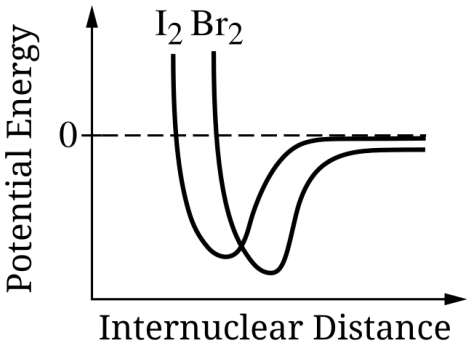
(C) It has a high melting point (1700°C).

(D) It has the same density as aluminum (2.7g/mL).

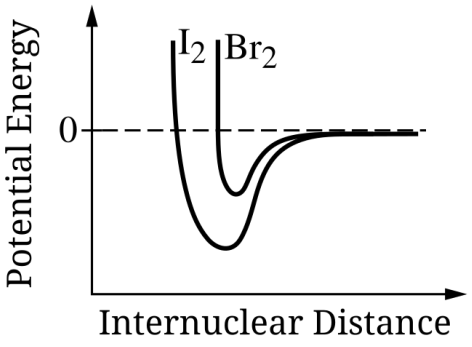
Molecule	Bond Dissociation Energy (kJ/mol)
Br_2	193
I_2	151

38. The table above shows the bond dissociation energies for Br_2 and I_2 at 298K. Which of the following correctly shows the potential energy as a function of internuclear distance for two bromine atoms and two iodine atoms?

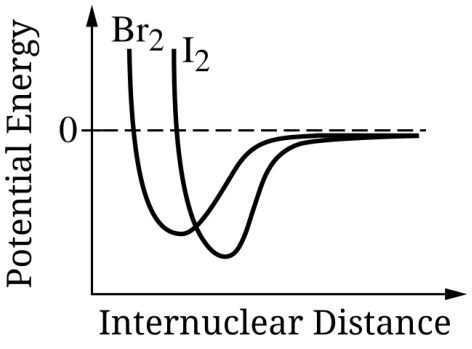
(A)



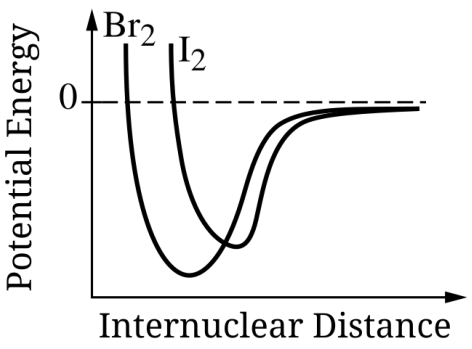
(B)



(C)



(D)



39. Which element, Ne or Xe, has the lower boiling point, and why?

(A) Ne, because it has a smaller, less polarizable electron cloud than Xe

(B) Ne, because its atoms have a faster average speed at a given temperature than Xe atoms

(C) Xe, because it has a larger, more polarizable electron cloud than Ne

(D) Xe, because its atoms have a slower average speed at a given temperature than Ne atoms

P (atm)	$V_{\text{experimental}}$(L)	V_{ideal} (L)
0.200	122.2	122.2
2.000	12.17	12.22
8.000	2.925	3.055

40. The pressure of a sample of $NH_3(g)$ was changed by adjusting the volume of the container. The experimental volumes that were needed to achieve the desired pressures were different from the volumes predicted by the ideal gas law as shown in the table above. Which of the following best explains the difference between the experimental volumes and the volumes predicted by the ideal gas law?

(A) The attraction between the molecules becomes significant at high pressure.

(B) The repulsion between the molecules becomes significant at high pressure.

(C) The average speed of the molecules decreases as the pressure increases.

(D) The average speed of the molecules increases as the pressure increases.

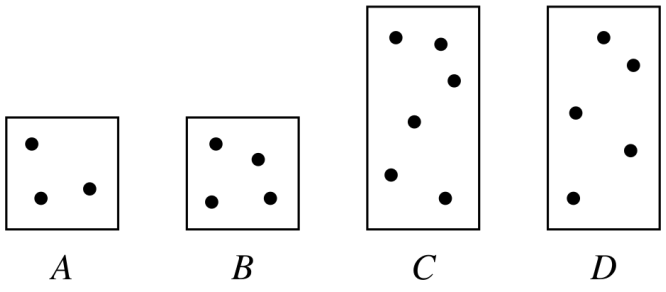
41. A 100.0 g sample of which of the following compounds contains the most molecules?

(A) CO_2

(B) SO_2

(C) H_2O

(D) N_2O



42. The diagrams above represent aqueous solutions of compound X at various molarities. Each dot represents one mole of the solute, and the volume of solution in the large boxes is twice the volume in the small boxes. Which solution has the highest molarity?

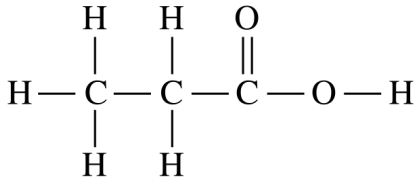
(A) *A*

(B) *B*

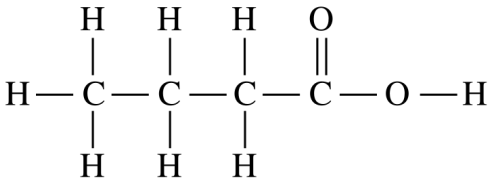
(C) *C*

(D) *D*

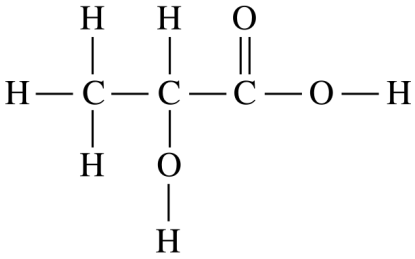
43. A student determines that an unknown compound contains 49 percent C by mass. Which of the following could be the compound?



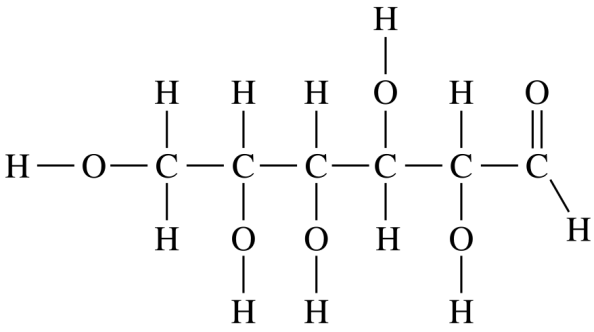
(A) Propanoic acid (74 g/mol)



(B) Butanoic acid (88 g/mol)



(C) Lactic acid (90 g/mol)



(D) Glucose (180 g/mol)

44. At 298 K and 1 atm, Br_2 is a liquid and I_2 is a crystalline solid. Which of the following statements best explains the different physical states of Br_2 and I_2 at 298 K and 1 atm?

(A) The London dispersion forces among I_2 molecules are stronger than those among Br_2 molecules.

(B) The London dispersion forces among Br_2 molecules are stronger than those among I_2 molecules.

(C) The Br−Br bond is stronger than the I−I bond.

(D) The I−I bond is stronger than the Br−Br bond.

Compound	K_{sp}
$Fe(OH)_2$	4.9×10^{-17}
$Cu(OH)_2$	1.6×10^{-19}
$Co(OH)_2$	1.1×10^{-15}

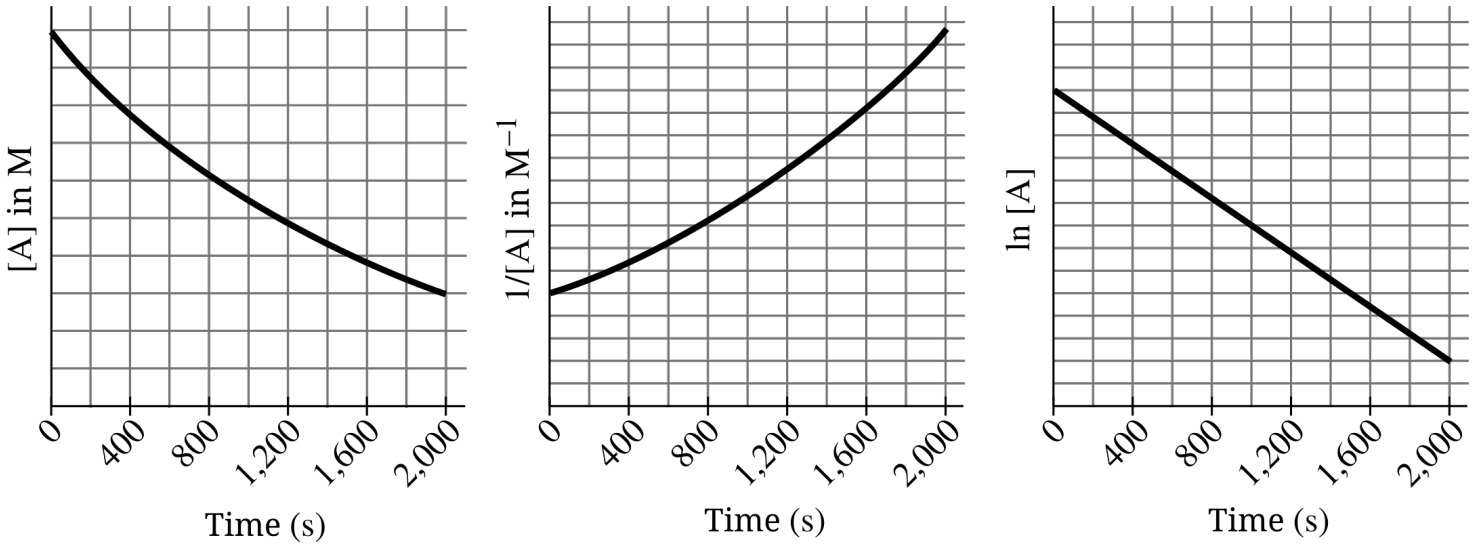
45. Which of the following ranks the compounds listed in the table above in order of increasing solubility?

(A) $Fe(OH)_2 < Cu(OH)_2 < Co(OH)_2$

(B) $Fe(OH)_2 < Co(OH)_2 < Cu(OH)_2$

(C) $Co(OH)_2 < Fe(OH)_2 < Cu(OH)_2$

(D) $Cu(OH)_2 < Fe(OH)_2 < Co(OH)_2$



46. A student recorded the rate of decomposition of compound A as a function of time at 45 °C. The experimental data are shown above. What is the rate law for the decomposition of A at this temperature?

(A) Rate $= k$

(B) Rate $= k[\mathrm{A}]$

(C) Rate $= k[\mathrm{A}]^2$

(D) The rate law cannot be determined without additional experimentation.

$$2\mathrm{NO_2} \rightarrow \mathrm{NO_3} + \mathrm{NO} \text{ (slow)}$$
$$\mathrm{NO_3} \rightarrow \mathrm{NO} + \mathrm{O_2} \text{ (fast)}$$

47. A proposed two-step mechanism for the reaction $2\mathrm{NO_2} \rightarrow 2\mathrm{NO} + \mathrm{O_2}$ is represented. Which of the following rate laws is consistent with the mechanism?

(A) rate=$k[\mathrm{NO_3}]$

(B) rate=$k[\mathrm{NO_2}]^2$

(C) rate=$k[\mathrm{NO_2}]^2[\mathrm{NO_3}]$

(D) rate$= k\dfrac{[\mathrm{NO}]^2[\mathrm{O_2}]}{[\mathrm{NO_2}]^2}$

$$2\mathrm{Mg}(s) + \mathrm{CO_2}(g) \rightarrow 2\mathrm{MgO}(s) + \mathrm{C}(s) \qquad \Delta H_{\mathrm{rxn}} < 0;\ \Delta H_{\mathrm{rxn}} < 0 \text{ at } 298\mathrm{K}$$

48. Which of the following is true about the reaction represented above?

(A) At 298 K, it is driven by enthalpy only.

(B) At 298 K, it is driven by entropy only.

(C) At 298 K, it is driven by both enthalpy and entropy.

(D) It is thermodynamically favorable at all temperatures.

Reduction Half-Reaction	E° (V)
$Ag^+ + e^- \rightarrow Ag$	0.80
$Sn^{2+} + 2e^- \rightarrow Sn$	-0.14
$Fe^{2+} + 2e^- \rightarrow Fe$	-0.44
$Zn^{2+} + 2e^- \rightarrow Zn$	-0.76

49. The standard reduction potentials of some half-reactions are given in the table above. Of the following equations, which represents the reaction that would be the basis of a cell with the most positive E°_{cell}?

(A) $2Ag^+ + Sn \rightarrow 2Ag + Sn^{2+}$

(B) $Sn^{2+} + 2Ag \rightarrow Sn + 2Ag^+$

(C) $Fe^{2+} + Zn \rightarrow Fe + Zn^{2+}$

(D) $Zn^{2+} + Fe \rightarrow Zn + Fe^{2+}$

50. Which of the following correctly compares the atomic radius of F to that of O and provides the best explanation?

(A) The atomic radius of F is larger than that of O because F has more occupied subshells than O does.

(B) The atomic radius of F is larger than that of O because F has more protons in the nucleus than O does.

(C) The atomic radius of F is smaller than that of O because F has a greater effective nuclear charge than O does.

(D) The atomic radius of F is smaller than that of O because valence electrons in F experience more shielding than those in O.

Compound	$\Delta H_{\text{solution}}$ (kJ/mol)
$NaF(s)$	$+0.91$
$MgF_2(s)$	-18

51. Based on the information in the table above, the solubility of which compound, if any, will increase if the water temperature is increased?

(A) $NaF(s)$ only

(B) $MgF_2(s)$ only

(C) Both $NaF(s)$ and $MgF_2(s)$

(D) The solubility of neither $NaF(s)$ nor $MgF_2(s)$ will increase.

52. Which of the following identifies the four species that are present in an aqueous solution of the weak acid $H_2C_2O_4$, from the highest to the lowest concentration at equilibrium?

(A) $H_3O^+ > HC_2O_4^- > {C_2O_4}^{2-} > H_2C_2O_4$

(B) $H_3O^+ > {C_2O_4}^{2-} > HC_2O_4^- > H_2C_2O_4$

(C) $H_2C_2O_4 > HC_2O_4^- > {C_2O_4}^{2-} > H_3O^+$

(D) $H_2C_2O_4 > H_3O^+ > HC_2O_4^- > {C_2O_4}^{2-}$

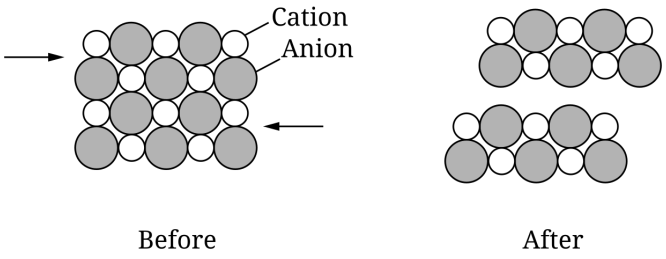
53. A student is given the task of making a calibration curve for $CoCl_2(aq)$ for use in a spectrophotometry experiment. The student pours a sample of $CoCl_2(aq)$ of known concentration into a cuvette with a 1.0 cm path length and tries to measure the absorbance at 500 nm, which is the wavelength of maximum absorbance. However, the absorbance is too high to give an accurate reading. Which of the following is the most appropriate next step for the student?

(A) Switching to using a cuvette with a 1.5cm path length

(B) Repeating the experiment after warming the solution to 40°C

(C) Diluting a measured volume of the solution to a new known volume using distilled water

(D) Pouring some solution out of the cuvette



54. When a stress is applied to an ionic crystal, the planes of the ions slide and separate due to the alignment of like charges, as shown in the diagram above. Which of the following characteristics of the crystal is represented by the observation?

(A) Luster

(B) Brittleness

(C) High melting point

(D) Solubility in water

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

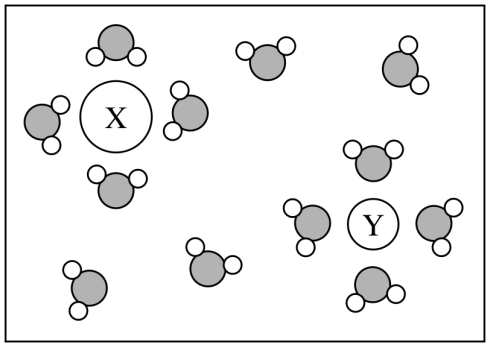
55. A 1.0 mol sample of $H_2(g)$ and a 1.0 mol sample of $I_2(g)$ are placed in a previously evacuated 1.0 L container and allowed to reach the equilibrium shown above. If the equilibrium concentration of $HI(g)$ is 0.40 M, which of the following is the value of the equilibrium constant?

(A) 0.16

(B) 0.25

(C) 0.44

(D) 1.0



56. The diagram above represents a solution of ions in water. Which of the following are the most likely identities of ions X and Y?

(A) Ion X is Na^+, and ion Y is K^+.

(B) Ion X is Na^+, and ion Y is F^-.

(C) Ion X is Cl^-, and ion Y is K^+.

(D) Ion X is Cl^-, and ion Y is F^-.

57. A student placed a piece of $Zn(s)$ in a beaker containing $CuSO_4(aq)$. After 45 minutes, the student observed a brown solid at the bottom of the beaker and that the solution had turned from blue to colorless. Which of the following balanced equations best represents only the species that react and the species that are produced in the reaction?

(A) $2Zn(s) + CuSO_4(aq) \rightarrow Zn_2SO_4(aq) + Cu(s)$

(B) $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

(C) $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

(D) $Zn(s) + Cu^{+}(aq) \rightarrow Zn^{+}(aq) + Cu(s)$

Items #58-#60 was not scored.

STOP
END OF SECTION I

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

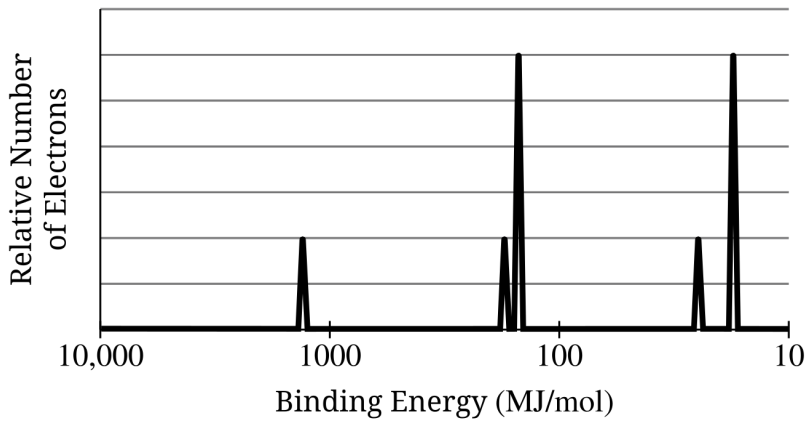
Note: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

Directions: 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. Bromine is the only nonmetal that exists as a liquid at room temperature and 1 atm.

   (a) Write the complete ground-state electron configuration of a bromine atom.

   (b) Following is a partial photoelectron spectrum (PES) showing only the core electrons in bromine.



   i. Circle the peak in the spectrum that corresponds to the 3*s* electrons of bromine.

   ii. Both bromine and krypton have 18 core electrons. Would the peaks for the core electrons in the PES of krypton be shifted to the right, shifted to the left, or remain unchanged as compared to those in the PES of bromine? Explain your reasoning.

Elemental bromine, $Br_2(l)$, is produced in the reaction represented by the following chemical equation.

$$Cl_2(g) + 2Br^-(aq) \rightarrow Br_2(l) + 2Cl^-(aq)$$

(c) A student claims that elemental chlorine, $Cl_2(g)$, is reduced in this reaction. Do you agree or disagree with the student's claim? Justify your answer in terms of oxidation numbers.

The overall reaction, related half-cell reactions, and standard reduction potentials are given in the following table.

Reaction	E° (V)
$Cl_2(g) + 2Br^-(aq) \rightarrow Br_2(l) + 2Cl^-(aq)$	?
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	$+1.36$
$Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$	$+1.07$

(d) Calculate the standard cell potential for the overall reaction between chlorine gas and bromide ions.

(e) Calculate the value of the standard Gibbs free energy (in kJ/mol$_{rxn}$) for the reaction between chlorine gas and bromide ions.

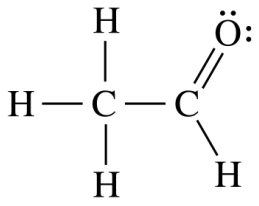
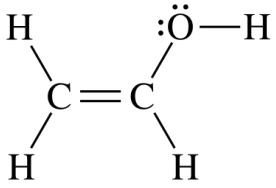
(f) At 298 K, is this reaction thermodynamically favorable? Justify your answer based on the standard change in Gibbs free energy you calculated in part (e).

(g) The standard enthalpy change of the reaction is $\Delta H^\circ_{\text{rxn}} = -91.2$ kJ/mol$_{rxn}$. Calculate the standard entropy change for the reaction at 298 K. Include units with your answer.

2. Answer the following questions about C_2H_4O.

(a) C_2H_4O (molar mass 44.06 g/mol) is a gas at room temperature and can be harmful at concentrations above $8.17 \times 10^{-6} M$. What is the maximum mass of this compound that can safely be present in a room with a volume of 3.00×10^5 L?

Two structures, X and Z, with the molecular formula C_2H_4O are shown in the table below.

Structure	Lewis Dot Diagram
X	
Z	

(b) Based on VSEPR theory, predict the H−C−H bond angle in structure X.

(c) A student incorrectly claims that X and Z are resonance structures of each other. Explain why the student's claim is incorrect.

X and Z are both gases at room temperature and 1 atm, and they react according to the following equation.

$$X \rightleftharpoons Z$$

(d) Write the expression for the equilibrium constant, K_p, in terms of the partial pressures of X and Z.

(e) For the reaction represented above, the value of the equilibrium constant, K_p, is 3.3×10^{-8} at 25 °C. Which would have a greater partial pressure at equilibrium: the reactant, X, or the product, Z? Circle one of the options and justify your choice.
Option 1: The partial pressure of reactant X is greater.
Option 2: The partial pressure of reactant Z is greater.

(f) An empty vessel is filled with compound X and sealed shut. The initial pressure of compound X is 0.55 atm. Calculate the partial pressure of compound Z in the vessel after equilibrium is established at constant temperature.

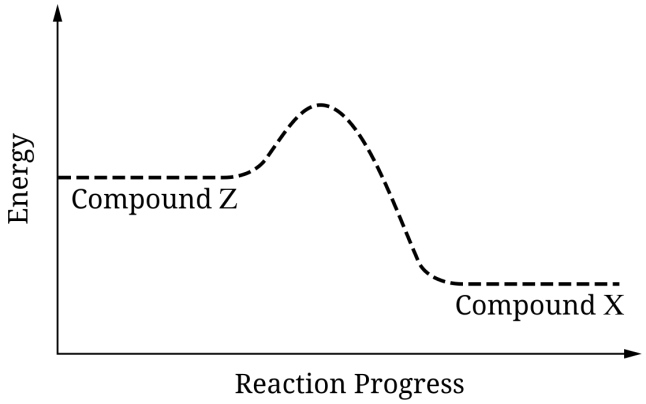
(g) The sample is compressed to half of the original volume, without any change in temperature. Does the value of K_p increase, decrease, or remain the same? Justify your choice.

(h) In the reverse reaction, the conversion of compound Z to compound X is catalyzed in the presence of trace amounts of water. The catalyzed reaction is proposed to occur via the following two-step mechanism.

Step 1: $Z + H_2O \rightarrow Y$ (slow)

Step 2: $Y \rightarrow X + H_2O$ (fast)

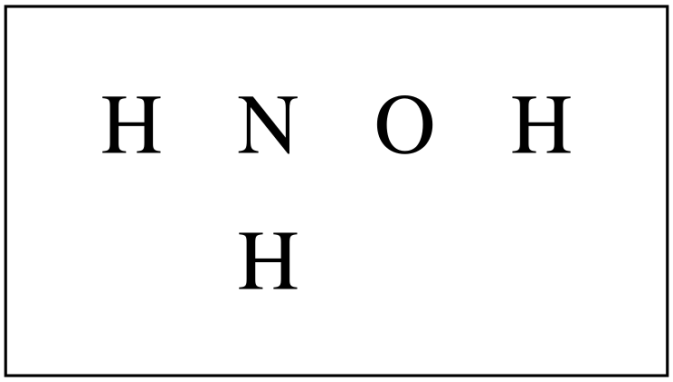
i. Identify the intermediate in the mechanism, if any.



ii. A reaction profile of the uncatalyzed reaction is shown above. On the same axes, sketch a reaction profile consistent with the proposed mechanism for the catalyzed reaction.

3. Answer the following questions about hydroxylamine, NH_2OH.

   (a) Complete the Lewis electron-dot diagram of the NH_2OH molecule in the box below, including all bonding and nonbonding valence electrons.



   (b) Hydroxylamine, $NH_2OH(aq)$, is a weak base. Write the balanced net ionic equation for the reaction that occurs when $NH_2OH(aq)$ and $HCl(aq)$ are combined.

A student is preparing to titrate a $NH_2OH(aq)$ solution with $HCl(aq)$. To prepare for the titration, the student places the NH_2OH solution into an Erlenmeyer flask.

(c) The titration procedure instructs the student to prepare 100.00 mL of a 0.1000*M* HCl solution. The stock solution available is 0.5604*M* HCl. Calculate the volume, in liters, of stock solution required for the dilution.

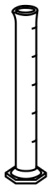
(d) Using the following choices, identify the glassware that should be used to deliver the $HCl(aq)$ with the greatest precision. Circle your choice and provide a brief justification.



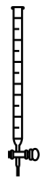
Beaker,
50 mL ± 5 mL



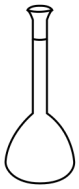
Erlenmeyer Flask,
50 mL ± 5 mL



Graduated Cylinder,
50 mL ± 0.5 mL



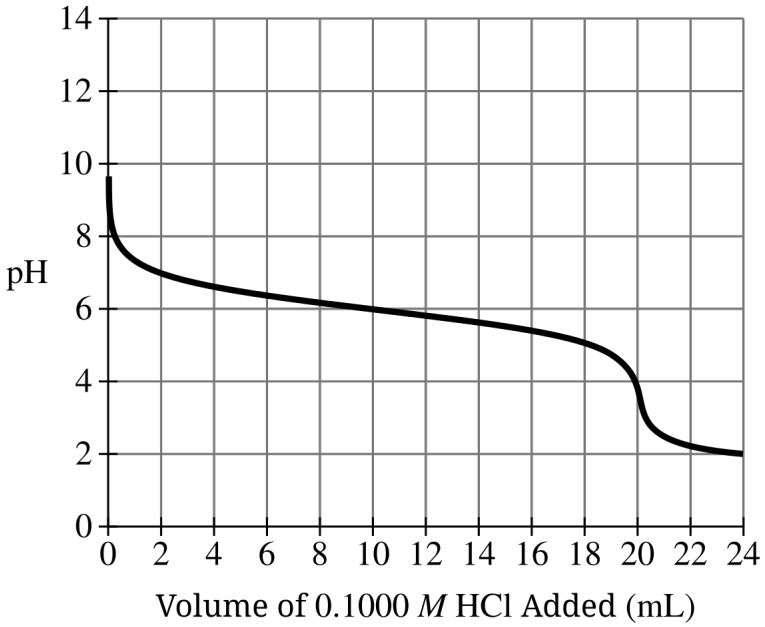
Buret,
50 mL ± 0.05 mL



Volumetric Flask,
50 mL ± 0.05 mL

(e) The student titrates a 25.00 mL sample of a NH_2OH solution with 0.1000M HCl. The student monitors the pH during the experiment and creates the following titration curve. Selected data are given in the table.

Volume of HCl Added (mL)	pH
0.00	9.67
2.00	7.00
6.00	6.40
8.00	6.21
10.00	6.03
12.00	5.85
14.00	5.66
18.00	5.08
20.00	3.44
24.00	2.01



i. Based on the data from the titration experiment, estimate the value of pK_b for NH_2OH.

ii. Calculate the molar concentration of the 25.00 mL sample of $NH_2OH(aq)$.

iii. In a second trial, using a different 25.00 mL sample of NH_2OH solution, the volume of HCl used to reach the equivalence point is greater than in the first trial. The student incorrectly claims that the 0.5604 M stock solution of HCl was used in the second trial instead of the diluted solution. Explain why the student's claim is incorrect.

$$3NH_2OH(aq) \rightarrow N2(g) + NH_3(aq) + 3H_2O(l) \qquad \Delta H_{rxn} = -688 \text{ kJ/mol}_{rxn}$$

At elevated temperatures, $NH_2OH(aq)$ undergoes decomposition according to the equation shown above.

(f) If 8.00 g of NH_2OH decomposes according to the equation above, how much heat, in kJ, is produced?

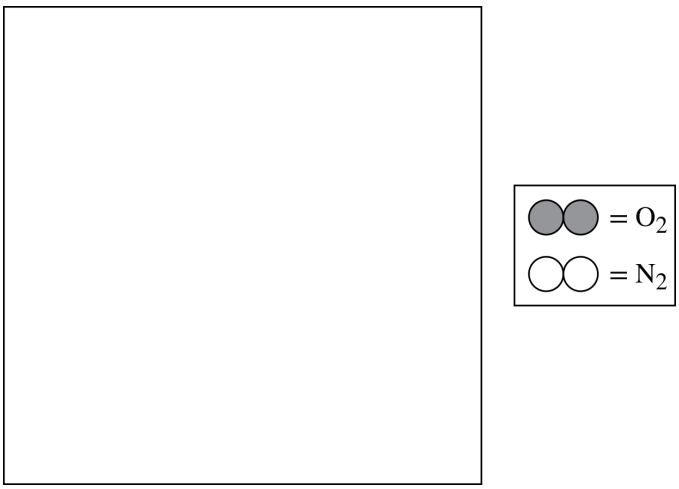
4. Dry air is comprised of N_2, O_2, and traces of other gases.

A student obtains a 2.00L container filled with a sample of dry air at a total pressure of 1.30 atm and a temperature of 295K.

(a) Calculate the total number of moles of gas in the container.

(b) The student cools the gaseous mixture until either N_2 or O_2 condenses. Which gas will condense first? Justify your answer in terms of the types and relative strengths of the intermolecular forces in N_2 and O_2.

(c) Using the legend given, draw at least three molecules of each type of gas in the sealed container represented below when one of the substances has condensed, but the other substance is still a gas.

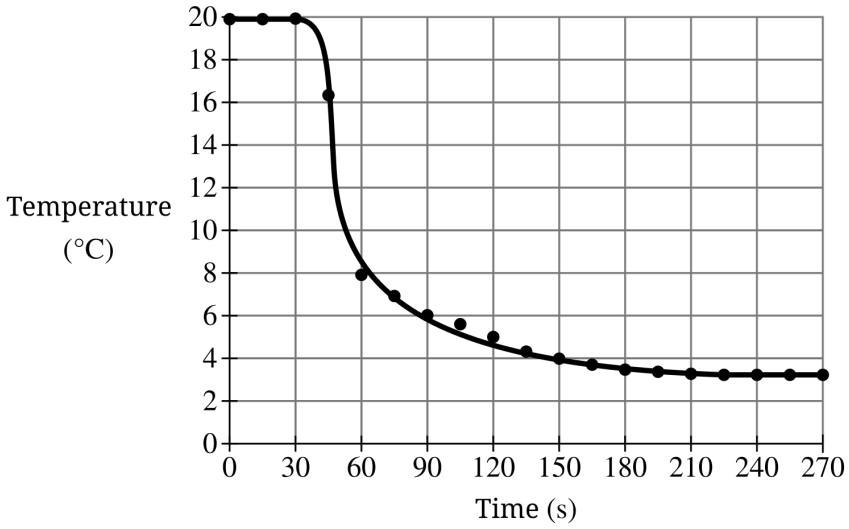


(d) In this sample, 78% of the molecules are N_2 and 21% of the molecules are O_2. Calculate the total number of grams of the substance that condenses first.

$$NaHCO_3(s) + H_3C_6H_5O_7(aq) \rightarrow NaH_2C_6H_5O_7(aq) + H_2O(l) + CO_2(g)$$

5. A student conducts a calorimetry experiment in which solid baking soda, $NaHCO_3$, reacts with excess aqueous citric acid, $H_3C_6H_5O_7$, as represented by the equation above. The student places 36.40 g of the $H_3C_6H_5O_7$ solution into a calorimeter and measures the temperature. After 30 seconds, 8.00 g of $NaHCO_3$ is added. The data are recorded in the following table and graph.

Mass of $H_3C_6H_5O_7(aq)$	36.40 g
Mass of $NaHCO_3(s)$	8.00 g
Total mass of reaction mixture	44.40 g
Initial temperature	19.9 °C
Final temperature	3.2 °C



(a) Calculate the magnitude of q, in joules, for this mixture using the data in the table. Assume that the reaction mixture in the calorimeter has a specific heat capacity of 4.22 J/(g·°C).

(b) Based on the collisions that occur between particles, explain why the graph shows temperature changing less rapidly as time progresses in the experiment.

(c) Make a claim about the flow of heat between the reaction system and the surroundings during this experiment. The claim should be consistent with the data in the graph.

(d) The student conducts a second experiment using 36.40 g of $H_3C_6H_5O_7(aq)$ at an initial temperature of 19.9 °C. However, the student adds only 4.00 g of $NaHCO_3(s)$. Would the temperature change in the second experiment be greater than, less than, or equal to the temperature change in the first experiment? Justify your answer.

6. A student is interested in studying the $Cu^{2+}(aq)$ ion, which is important in the environment.

$$Cu(NO_3)_2(aq) + K_3PO_4(aq) \rightarrow$$

(a) First, the student carries out a precipitation reaction. A solution of copper(II) nitrate is mixed with a solution of potassium phosphate, as represented above, and a blue precipitate forms. Write the balanced net ionic equation for the process.

(b) In a separate experiment the student decides to precipitate the $Cu^{2+}(aq)$ as $Cu(OH)_2(s)$. To make sure that $Cu(OH)_2(s)$ will precipitate, the student looks up the K_{sp} value for $Cu(OH)_2(s)$, as shown below.

$$Cu(OH)_2(s)Cu^{2+}(aq) + 2OH^-(aq) \qquad K_{sp} = 2.2 \times 10^{-20}$$

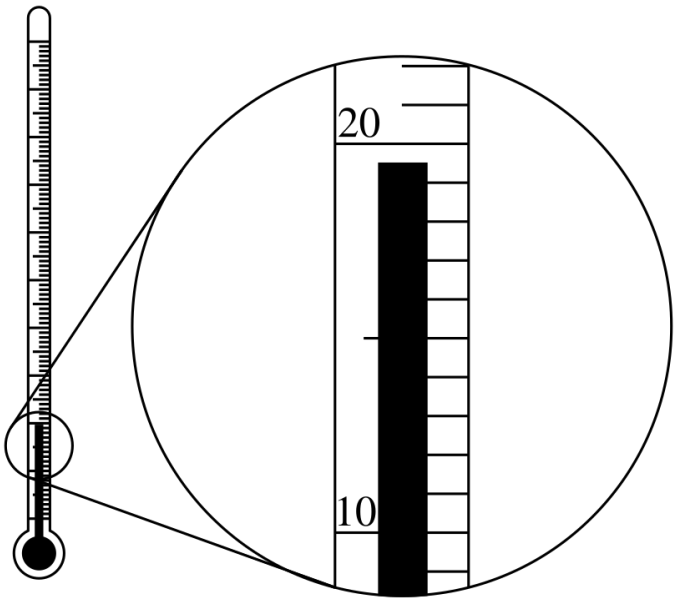
i. Write the K_{sp} expression for the dissolving of $Cu(OH)_2(s)$.

ii. Calculate the concentration of $Cu^{2+}(aq)$ in a saturated $Cu(OH)_2$ solution in mol/L.

(c) The student incorrectly proposes that lowering the pH of the saturated $Cu(OH)_2$ solution will increase the amount of precipitate that forms. Explain why the student is incorrect.

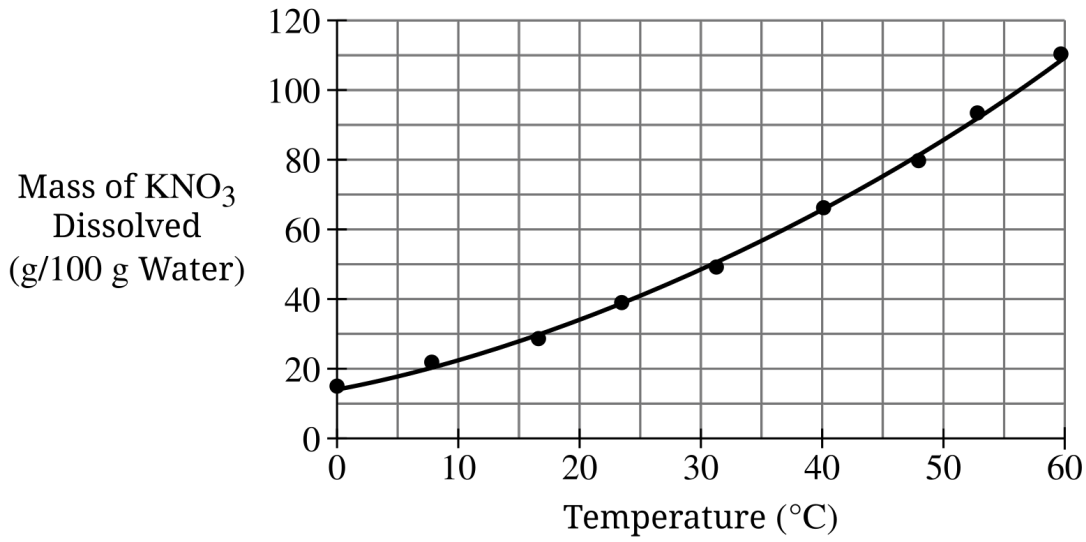
7. A student conducts a solubility experiment with potassium nitrate, KNO_3, in water by identifying the temperature at which various masses of KNO_3 will completely dissolve.

   (a) At room temperature, H_2O is a liquid and KNO_3 is a solid. The student incorrectly claims that this is because potassium and nitrate ions experience stronger dispersion forces than H_2O molecules. In terms of the types of attractive forces, explain why the student is incorrect.



   (b) In one of the trials, the student reads the initial temperature of the water using the Celsius thermometer above. Record this temperature to the appropriate number of significant figures.

   (c) At the temperature indicated on the thermometer, the student adds the solid KNO_3 to the sample of water and begins to stir the mixture. Explain the effect of stirring on the maximum amount of solid that can dissolve in the water.



The graph above summarizes the data collected by the student.

(d) Another student places 38.1 grams of KNO_3 into 100.0 g of water at the temperature measured in part (b), stirs the mixture, and observes that the solid does not dissolve completely. The student plans to heat the mixture and states that the solid will completely dissolve before the mixture reaches 30°C. Do you agree with the claim? Justify your answer with information from the graph.

STOP
END OF EXAM