

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?

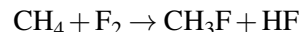
- (A) Melting ice at 0 °C to form liquid water at 0 °C ($\Delta H_{fus} = 330 \text{ J/g}$)
- (B) Boiling liquid acetone at 56 °C to form acetone vapor at 56 °C ($\Delta H_{vap} = 540 \text{ J/g}$)
- (C) Increasing the temperature of liquid glycerin from 20 °C to 120 °C (Specific heat = $2.4 \text{ J/(g}\cdot\text{°C)}$)
- (D) Increasing the temperature of solid copper from 0 °C to 200 °C (Specific heat = $0.40 \text{ J/(g}\cdot\text{°C)}$)

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?

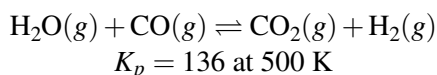


- (A) $-650 \text{ kJ/mol}_{rxn}$
- (B) $-490 \text{ kJ/mol}_{rxn}$
- (C) $+490 \text{ kJ/mol}_{rxn}$
- (D) $+650 \text{ kJ/mol}_{rxn}$

Acid	K_a
$\text{HF}(aq)$	4×10^{-4}
$\text{HC}_2\text{H}_3\text{O}_2(aq)$	2×10^{-5}
$\text{HClO}(aq)$	3×10^{-8}
$\text{HCN}(aq)$	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) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M HF}(aq)$
 (B) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M NaC}_2\text{H}_3\text{O}_2(aq)$
 (C) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M HCN}(aq)$
 (D) $0.10\text{ M HClO}(aq)$ and $0.10\text{ M NaClO}(aq)$



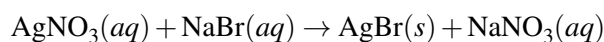
5. A vessel initially contains $\text{H}_2\text{O}(g)$ at a partial pressure of 0.30 atm, $\text{CO}(g)$ at a partial pressure of 0.10 atm, $\text{CO}_2(g)$ at a partial pressure of 1.5 atm, and $\text{H}_2(g)$ at a partial pressure of 10 atm at 500K. Which of the following occurs as the system approaches equilibrium at 500K?

- (A) The partial pressures of $\text{H}_2\text{O}(g)$ and $\text{CO}(g)$ increase because $Q > K_p$.
 (B) The partial pressures of $\text{H}_2\text{O}(g)$ and $\text{CO}(g)$ increase because $Q < K_p$.
 (C) The partial pressures of $\text{CO}_2(g)$ and $\text{H}_2(g)$ increase because $Q > K_p$.
 (D) The partial pressures of $\text{CO}_2(g)$ and $\text{H}_2(g)$ increase because $Q < K_p$.

Data for H_2O	
Specific heat capacity of liquid phase	$4.2\text{ J/(g}\cdot^\circ\text{C)}$
Heat of fusion	330 J/g

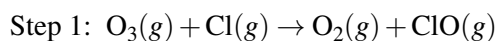
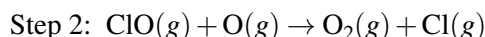
6. A sample of ice at 0°C is added to 100 g of water at 33°C . The mixture is stirred gently until the temperature of the water is 0°C . All the remaining ice is quickly removed. Based on the information in the table above, the mass of ice that melted is closest to

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



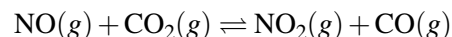
7. A 10.0mL sample of $1.0\text{ M AgNO}_3(aq)$ and a 10.0mL sample of $1.0\text{ M NaBr}(aq)$, both originally at 25°C , are combined in a constant-pressure calorimeter where the reaction represented above occurs. If the final temperature of the mixture is 35°C , what is the value of ΔH for the reaction? (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 $4.2\text{ J/(g}\cdot^\circ\text{C)}$.)

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



8. A proposed mechanism for the destruction of $\text{O}_3(g)$ in the upper atmosphere is represented above. Which of the following is the catalyst in the proposed mechanism?

- (A) $\text{O}(g)$
 (B) $\text{Cl}(g)$
 (C) $\text{ClO}(g)$
 (D) $\text{O}_2(g)$

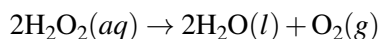


9. Which of the following changes will increase the amount of $\text{NO}_2(g)$ in the equilibrium system represented by the equation above?

- (A) Removing $\text{CO}(g)$ from the system
 (B) Removing $\text{CO}_2(g)$ 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 .



A student carries out an experiment in which a sample of $\text{H}_2\text{O}_2(aq)$ decomposes in the presence of $\text{MnO}_2(s)$. The student measures the volume of $\text{O}_2(g)$ 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 $\text{O}_2(g)$ 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 $\text{MnO}_2(s)$ is not used. Which of the following statements best explains this observation?
- (A) $\text{MnO}_2(s)$ changes the reaction from endothermic to exothermic.
 - (B) $\text{MnO}_2(s)$ shifts the equilibrium position of the reaction from reactant favored to product favored.
 - (C) $\text{MnO}_2(s)$ releases heat in order to start the reaction.
 - (D) $\text{MnO}_2(s)$ provides a reaction pathway with a lower activation energy.
14. A second experiment is done under identical conditions using a higher concentration of $\text{H}_2\text{O}_2(aq)$ in the presence of the same mass of $\text{MnO}_2(s)$. 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	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & \\ & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - \text{N} - \text{H} \\ & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & \\ & & & & & & \\ & & & & & \text{H} & \end{array} $	59
Pentane	$ \begin{array}{ccccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} - \text{H} \\ & & & & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \end{array} $	72
2-propanol	$ \begin{array}{ccccccc} & & & \text{H} & & & \\ & & & & & & \\ & & & \text{O} & & & \\ & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & \\ & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - \text{H} \\ & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & \end{array} $	60
Propanoic acid	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{O} & \\ & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - \text{O} - \text{H} \\ & & & & & & \\ & \text{H} & & \text{H} & & & \end{array} $	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 $\text{C}_3\text{H}_5\text{O}_2^-$
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-} ?

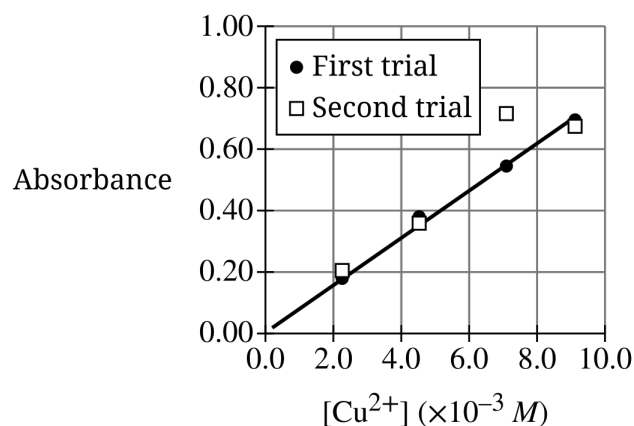
- (A) XSO_4
- (B) X_2SO_4
- (C) $\text{X}_2(\text{SO}_4)_3$
- (D) $\text{X}(\text{SO}_4)_2$

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 $\text{HNO}_2(aq)$ and $\text{NH}_3(aq)$?

- (A) The acid is $\text{HNO}_2(aq)$, and the conjugate base is $\text{NH}_3(aq)$.
- (B) The acid is $\text{HNO}_2(aq)$, and the conjugate base is $\text{NO}_2^-(aq)$.
- (C) The acid is $\text{NH}_4^+(aq)$, and the conjugate base is $\text{NO}_2^-(aq)$.
- (D) The acid is $\text{NH}_3(aq)$, and the conjugate base is $\text{NH}_4^+(aq)$.



21. A student prepared four solutions of known $[\text{Cu}^{2+}]$ 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 $[\text{Cu}^{2+}] \approx 7 \times 10^{-3} M$ in the second trial?

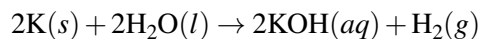
- (A) The cuvette was rinsed with water between measurements.
- (B) A fingerprint was left on the side of the cuvette facing the detector.
- (C) The absorbance was measured at a wavelength where Cu^{2+} has a lower molar absorptivity.
- (D) The cuvette was not filled with the same volume of solution.

Acid	Concentration of Acid (M)	Volume of Sample (mL)	Volume of Standardized NaOH(aq) Added to Reach Equivalence Point (mL)
$\text{HClO}_4(aq)$	0.100	25.0	24.0
$\text{HClO}(aq)$	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 $\text{HClO}_4(aq)$ and $\text{HClO}(aq)$.

Questions 23-24



$$\Delta H^\circ = -393 \text{ kJ/mol}_{\text{rxn}}$$

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

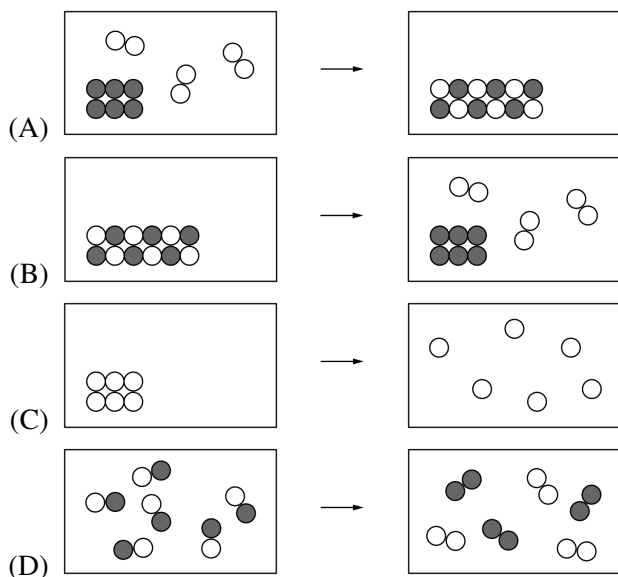
23. Which of the following is true when the 3.9 g of $\text{K}(s)$ has completely reacted?

- (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) $\text{pH} < 7$
- (B) $\text{pH} = 7$
- (C) $\text{pH} > 7$
- (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° ?



26. A 10.0 g sample of $\text{Pb}(\text{NO}_3)_2(s)$ is dissolved in distilled water and an excess of 1.0 M $\text{HCl}(aq)$ is added. The $\text{PbCl}_2(s)$ 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 $\text{Pb}(\text{NO}_3)_2(s)$ was wet.
 (B) The K_{sp} of $\text{PbCl}_2(s)$ is extremely small.
 (C) The precipitate was not dried to a constant mass.
 (D) A 3.0 M $\text{HCl}(aq)$ solution was used instead of a 1.0 M $\text{HCl}(aq)$ solution.



27. The rate law for the reaction represented above is experimentally determined to be $\text{rate} = k[\text{N}_2\text{O}]$. Which of the following best explains why increasing the initial concentration of $\text{N}_2\text{O}(g)$ at a constant temperature increases the reaction rate?

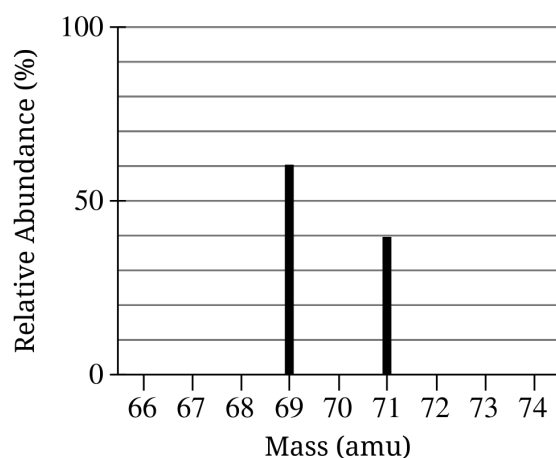
- (A) Molecular collisions become more frequent.
 (B) There is a higher probability of effective molecular collisions.
 (C) The rate constant for the reaction increases.
 (D) The reaction mechanism changes to one that has a lower activation energy.

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.

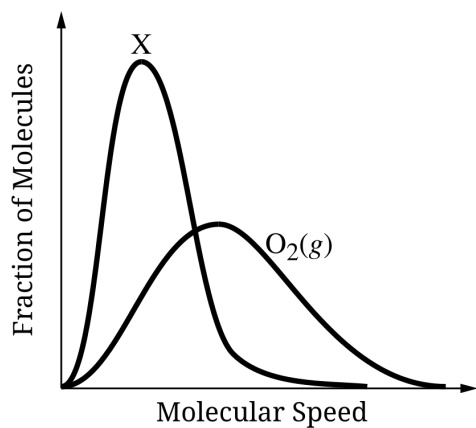
29. A student mixes 100 mL of 0.25 M $\text{HCl}(aq)$ with 200 mL of 0.50 M $\text{HClO}_4(aq)$ and then dilutes the mixture with distilled water to a total volume of 500 mL. The $[\text{H}_3\text{O}^+]$ in the final solution is closest to

- (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) $\text{Br}_2(g)$
- (B) $\text{CH}_4(g)$
- (C) $\text{He}(g)$
- (D) $\text{N}_2(g)$

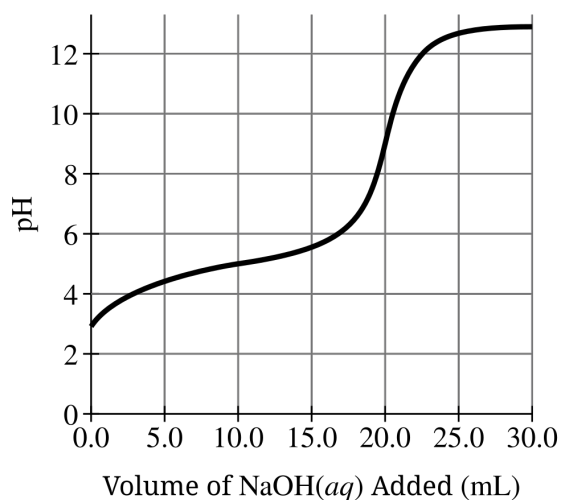
32. The value of K_{sp} for the salt PbF_2 is 3.2×10^{-8} . The $[\text{Pb}^{2+}]$ in a saturated solution of PbF_2 is approximately

- (A) $2 \times 10^{-4} M$
- (B) $4 \times 10^{-4} M$
- (C) $2 \times 10^{-3} M$
- (D) $4 \times 10^{-3} M$

$\text{PCl}_3, \text{Cl}_2, \text{CaCl}_2$

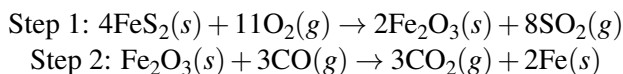
33. Which of the following correctly ranks the substances listed above in order of increasing ionic character in their bonding?

- (A) $\text{Cl}_2, \text{PCl}_3, \text{CaCl}_2$
- (B) $\text{Cl}_2, \text{CaCl}_2, \text{PCl}_3$
- (C) $\text{CaCl}_2, \text{PCl}_3, \text{Cl}_2$
- (D) $\text{CaCl}_2, \text{Cl}_2, \text{PCl}_3$



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?

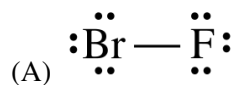
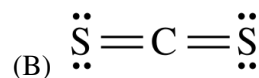
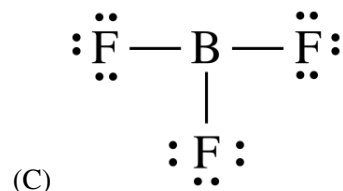
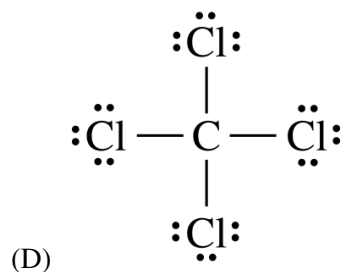
(A) HCN with a K_a value of 5×10^{-10}
 (B) HOCl with a K_a value of 3×10^{-8}
 (C) $\text{CH}_3\text{CH}_2\text{COOH}$ with a K_a value of 1×10^{-5}
 (D) ClCH_2COOH with a K_a value of 1×10^{-3}



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

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

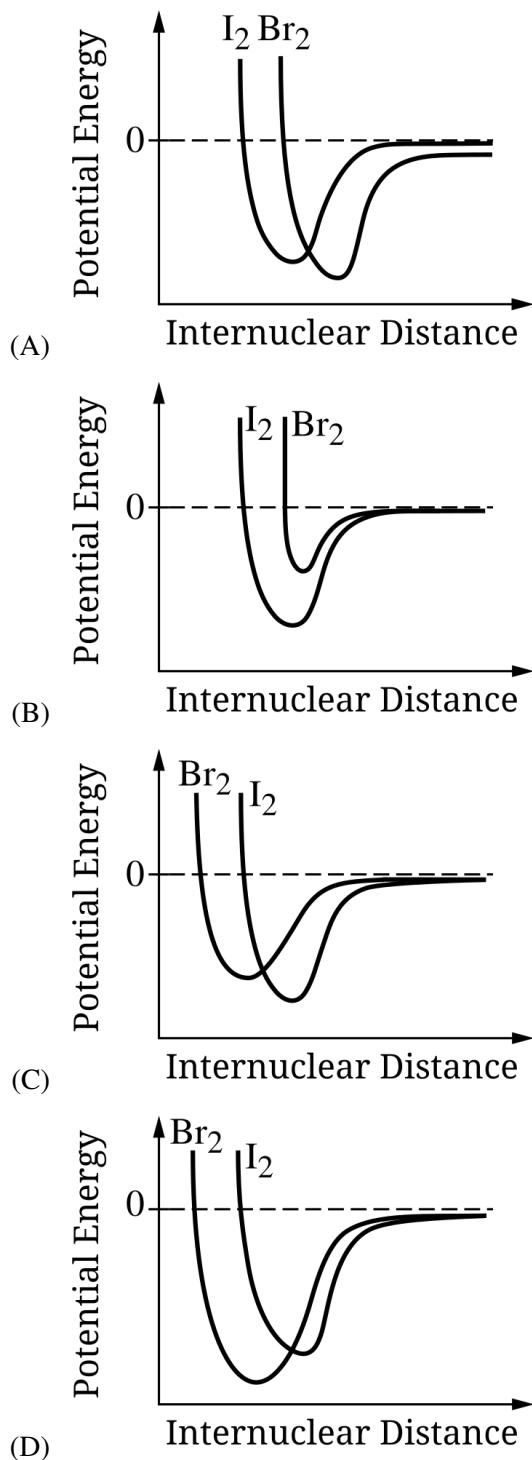


37. A solid is tested in a laboratory to determine its properties. Which of the following provides the best evidence to support the hypothesis that the solid is a metal as opposed to a nonmetal?

- (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?



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

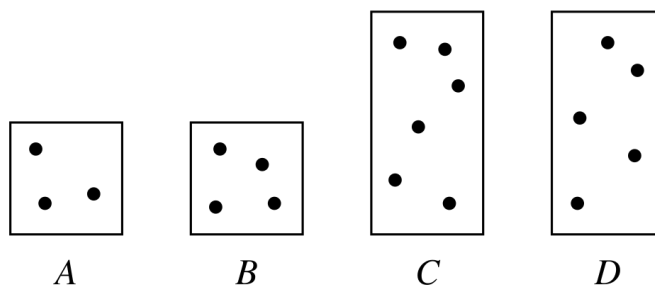
P (atm)	$V_{\text{experimental}}$ (L)	V_{ideal} (L)
0.200	122.2	122.2
2.000	12.17	12.22
8.000	2.925	3.055

40. The pressure of a sample of $\text{NH}_3(g)$ 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?

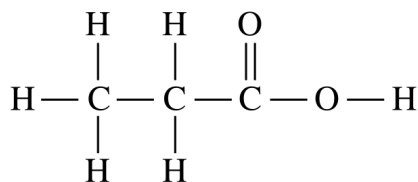
- (A) CO_2
- (B) SO_2
- (C) H_2O
- (D) N_2O



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

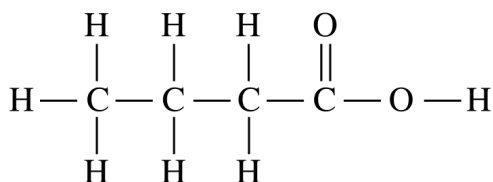
43. A student determines that an unknown compound contains 49 percent C by mass. Which of the following could be the compound?



Propanoic acid

(74 g/mol)

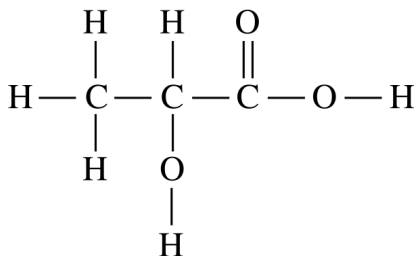
(A)



Butanoic acid

(88 g/mol)

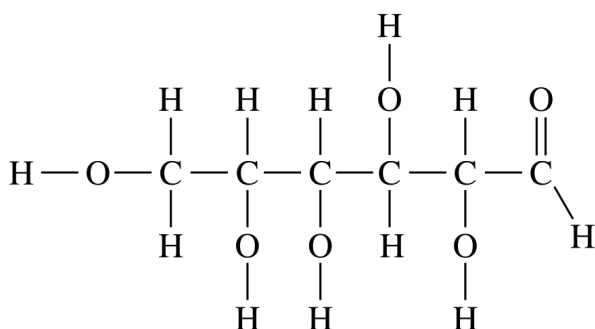
(B)



Lactic acid

(90 g/mol)

(C)



Glucose

(180 g/mol)

(D)

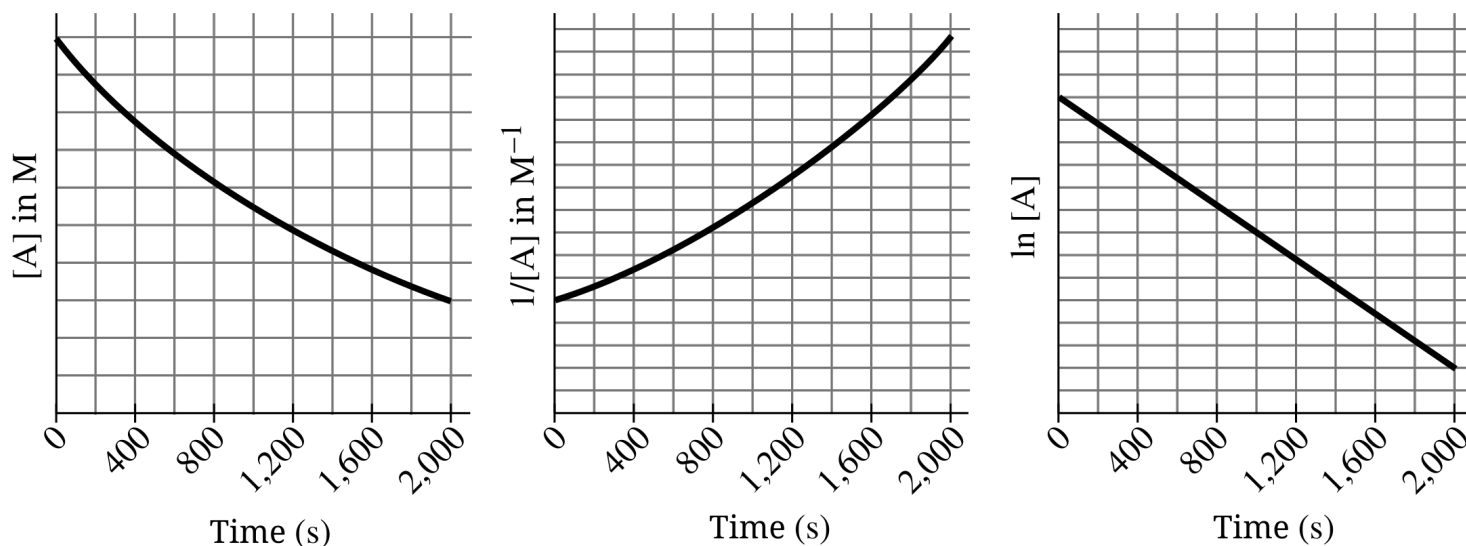
44. At 298 K and 1 atm, Br_2 is a liquid and I_2 is a crystalline solid. Which of the following statements best explains the different physical states of Br_2 and I_2 at 298 K and 1 atm?

- (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 $\text{Br}-\text{Br}$ bond is stronger than the $\text{I}-\text{I}$ bond.
- (D) The $\text{I}-\text{I}$ bond is stronger than the $\text{Br}-\text{Br}$ bond.

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

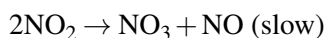
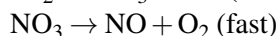
45. Which of the following ranks the compounds listed in the table above in order of increasing solubility?

- (A) $\text{Fe}(\text{OH})_2 < \text{Cu}(\text{OH})_2 < \text{Co}(\text{OH})_2$
- (B) $\text{Fe}(\text{OH})_2 < \text{Co}(\text{OH})_2 < \text{Cu}(\text{OH})_2$
- (C) $\text{Co}(\text{OH})_2 < \text{Fe}(\text{OH})_2 < \text{Cu}(\text{OH})_2$
- (D) $\text{Cu}(\text{OH})_2 < \text{Fe}(\text{OH})_2 < \text{Co}(\text{OH})_2$



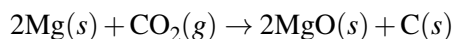
46. A student recorded the rate of decomposition of compound A as a function of time at 45 °C. The experimental data are shown above. What is the rate law for the decomposition of A at this temperature?

- (A) Rate = k
- (B) Rate = $k[A]$
- (C) Rate = $k[A]^2$
- (D) The rate law cannot be determined without additional experimentation.



47. A proposed two-step mechanism for the reaction $2\text{NO}_2 \rightarrow 2\text{NO} + \text{O}_2$ is represented. Which of the following rate laws is consistent with the mechanism?

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



$$\Delta H_{\text{rxn}} < 0; \Delta S_{\text{rxn}} < 0 \text{ at } 298\text{K}$$

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)
$\text{Ag}^+ + e^- \rightarrow \text{Ag}$	0.80
$\text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}$	-0.14
$\text{Fe}^{2+} + 2e^- \rightarrow \text{Fe}$	-0.44
$\text{Zn}^{2+} + 2e^- \rightarrow \text{Zn}$	-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) $2\text{Ag}^+ + \text{Sn} \rightarrow 2\text{Ag} + \text{Sn}^{2+}$
 (B) $\text{Sn}^{2+} + 2\text{Ag} \rightarrow \text{Sn} + 2\text{Ag}^+$
 (C) $\text{Fe}^{2+} + \text{Zn} \rightarrow \text{Fe} + \text{Zn}^{2+}$
 (D) $\text{Zn}^{2+} + \text{Fe} \rightarrow \text{Zn} + \text{Fe}^{2+}$

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)
$\text{NaF}(s)$	+0.91
$\text{MgF}_2(s)$	-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?

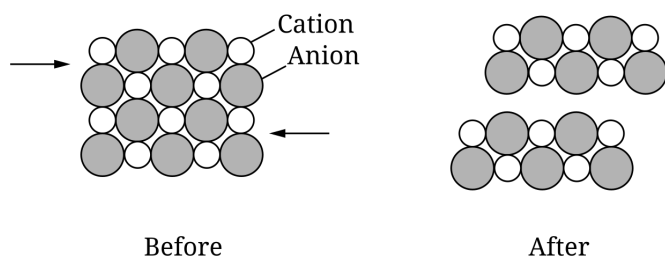
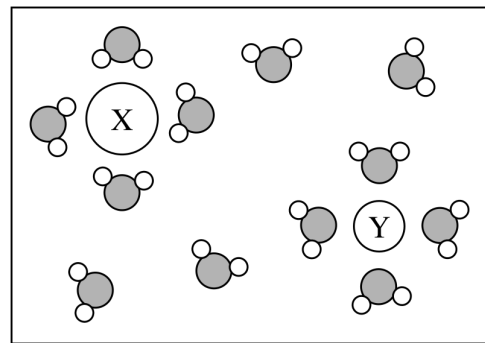
- (A) $\text{NaF}(s)$ only
 (B) $\text{MgF}_2(s)$ only
 (C) Both $\text{NaF}(s)$ and $\text{MgF}_2(s)$
 (D) The solubility of neither $\text{NaF}(s)$ nor $\text{MgF}_2(s)$ will increase.

52. Which of the following identifies the four species that are present in an aqueous solution of the weak acid $\text{H}_2\text{C}_2\text{O}_4$, from the highest to the lowest concentration at equilibrium?

- (A) $\text{H}_3\text{O}^+ > \text{HC}_2\text{O}_4^- > \text{C}_2\text{O}_4^{2-} > \text{H}_2\text{C}_2\text{O}_4$
 (B) $\text{H}_3\text{O}^+ > \text{C}_2\text{O}_4^{2-} > \text{HC}_2\text{O}_4^- > \text{H}_2\text{C}_2\text{O}_4$
 (C) $\text{H}_2\text{C}_2\text{O}_4 > \text{HC}_2\text{O}_4^- > \text{C}_2\text{O}_4^{2-} > \text{H}_3\text{O}^+$
 (D) $\text{H}_2\text{C}_2\text{O}_4 > \text{H}_3\text{O}^+ > \text{HC}_2\text{O}_4^- > \text{C}_2\text{O}_4^{2-}$

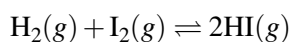
53. A student is given the task of making a calibration curve for $\text{CoCl}_2(aq)$ for use in a spectrophotometry experiment. The student pours a sample of $\text{CoCl}_2(aq)$ of known concentration into a cuvette with a 1.0 cm path length and tries to measure the absorbance at 500 nm, which is the 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



55. A 1.0 mol sample of $\text{H}_2(g)$ and a 1.0 mol sample of $\text{I}_2(g)$ are placed in a previously evacuated 1.0 L container and allowed to reach the equilibrium shown above. If the equilibrium concentration of $\text{HI}(g)$ 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 $\text{Zn}(s)$ in a beaker containing $\text{CuSO}_4(aq)$. 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) $2\text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{Zn}_2\text{SO}_4(aq) + \text{Cu}(s)$
 (B) $\text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{ZnSO}_4(aq) + \text{Cu}(s)$
 (C) $\text{Zn}(s) + \text{Cu}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Cu}(s)$
 (D) $\text{Zn}(s) + \text{Cu}^+(aq) \rightarrow \text{Zn}^+(aq) + \text{Cu}(s)$

Items #58-#60 was not scored.

STOP
END OF SECTION I

CHEMISTRY

SECTION II

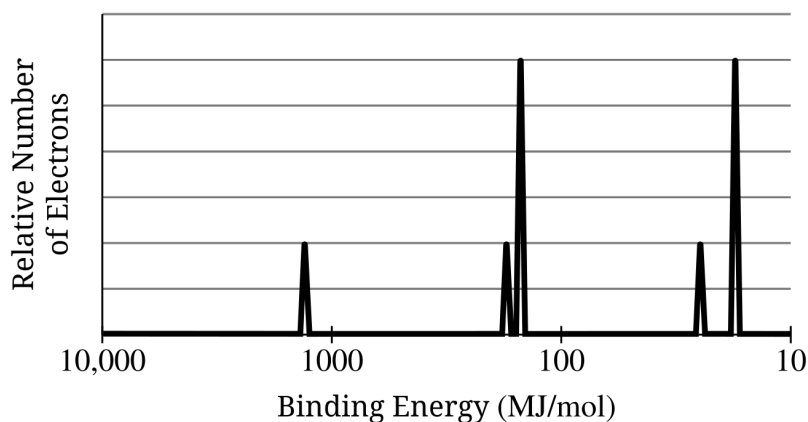
Time—1 hour and 45 minutes

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.

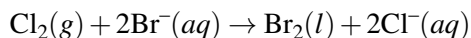
Directions: Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your 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 3s 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, $\text{Br}_2(l)$, is produced in the reaction represented by the following chemical equation.



- (c) A student claims that elemental chlorine, $\text{Cl}_2(g)$, 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)
$\text{Cl}_2(g) + 2\text{Br}^-(aq) \rightarrow \text{Br}_2(l) + 2\text{Cl}^-(aq)$	?
$\text{Cl}_2(g) + 2e^- \rightarrow 2\text{Cl}^-(aq)$	+1.36
$\text{Br}_2(l) + 2e^- \rightarrow 2\text{Br}^-(aq)$	+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 $\Delta H^\circ_{rxn} = -91.2 \text{ kJ/mol}_{rxn}$. Calculate the standard entropy change for the reaction at 298 K. Include units with your answer.

2. Answer the following questions about $\text{C}_2\text{H}_4\text{O}$.

- (a) $\text{C}_2\text{H}_4\text{O}$ (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 $3.00 \times 10^5 \text{ L}$?

Two structures, X and Z, with the molecular formula $\text{C}_2\text{H}_4\text{O}$ are shown in the table below.

Structure	Lewis Dot Diagram
X	
Z	

- (b) Based on VSEPR theory, predict the $\text{H}-\text{C}-\text{H}$ 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.



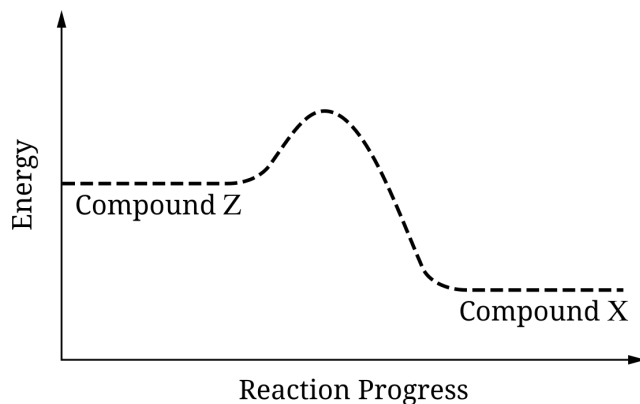
- (d) Write the expression for the equilibrium constant, K_p , in terms of the partial pressures of X and Z.
- (e) For the reaction represented above, the value of the equilibrium constant, K_p , is 3.3×10^{-8} at 25°C . Which would have a greater partial pressure at equilibrium: the reactant, X, or 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)

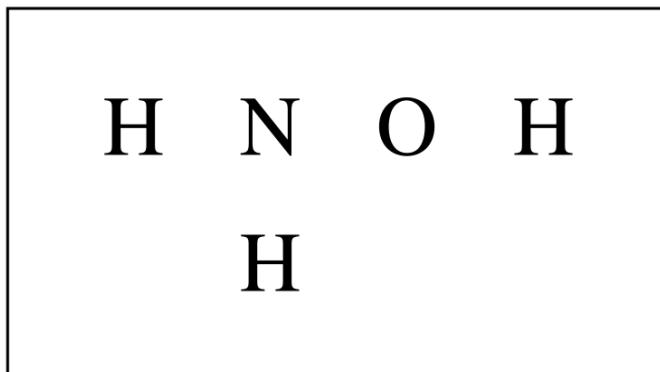
- i. Identify the intermediate in the mechanism, if any.



- 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, $\text{NH}_2\text{OH}(aq)$, is a weak base. Write the balanced net ionic equation for the reaction that occurs when $\text{NH}_2\text{OH}(aq)$ and $\text{HCl}(aq)$ are combined.

A student is preparing to titrate a $\text{NH}_2\text{OH}(aq)$ solution with $\text{HCl}(aq)$. To prepare for the titration, the student places the NH_2OH solution into an Erlenmeyer flask.

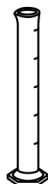
- (c) The titration procedure instructs the student to prepare 100.00 mL of a 0.1000M HCl solution. The stock solution available is 0.5604M HCl. Calculate the volume, in liters, of stock solution required for the dilution.
- (d) Using the following choices, identify the glassware that should be used to deliver the $\text{HCl}(aq)$ with the greatest precision. Circle your choice and provide a brief justification.



Beaker,
50 mL $\pm$ 5 mL



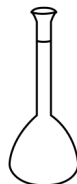
Erlenmeyer
Flask,
50 mL $\pm$ 5 mL



Graduated
Cylinder,
50 mL $\pm$ 0.5 mL



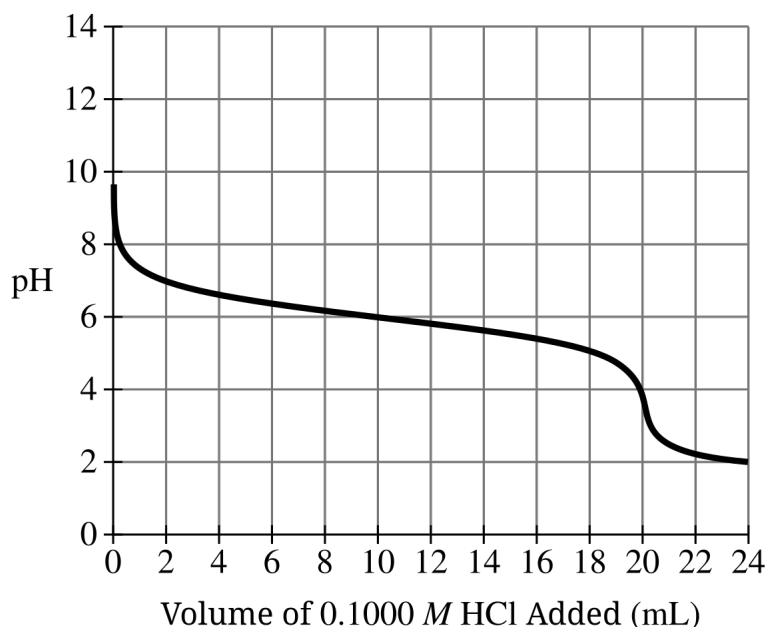
Buret,
50 mL $\pm$ 0.05 mL



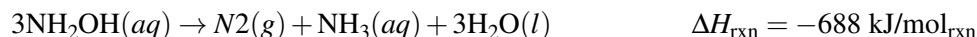
Volumetric
Flask,
50 mL $\pm$ 0.05 mL

- (e) The student titrates a 25.00 mL sample of a NH_2OH solution with 0.1000 M 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



- Based on the data from the titration experiment, estimate the value of $\text{p}K_b$ for NH_2OH .
- Calculate the molar concentration of the 25.00 mL sample of $\text{NH}_2\text{OH}(aq)$.
- 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.



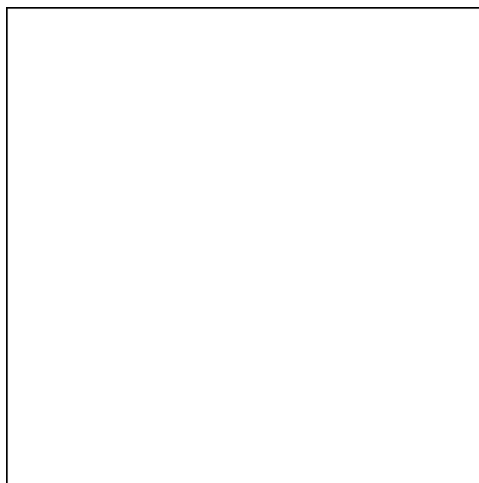
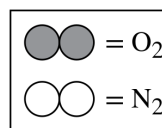
At elevated temperatures, $\text{NH}_2\text{OH}(aq)$ undergoes decomposition according to the equation shown above.

- (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.

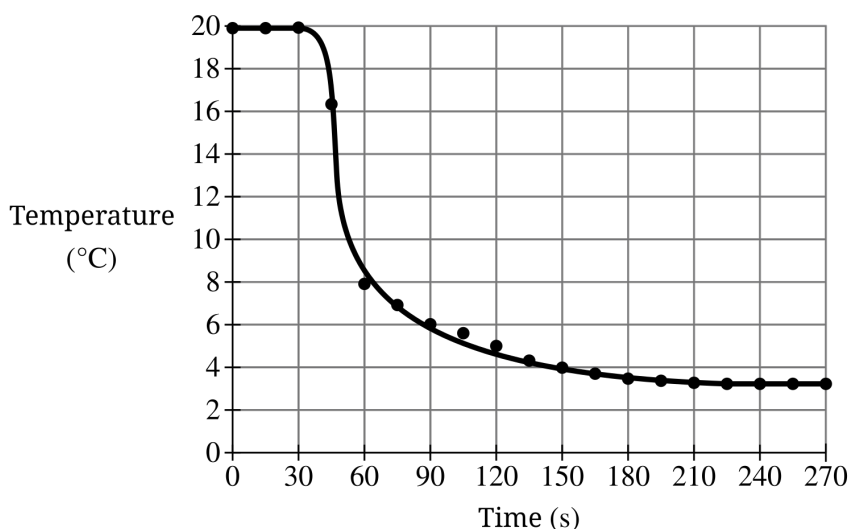


- (d) In this sample, 78% of the molecules are N_2 and 21% of the molecules are O_2 . Calculate the total number of grams of the substance that condenses first.



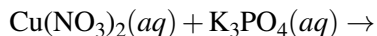
5. A student conducts a calorimetry experiment in which solid baking soda, NaHCO_3 , reacts with excess aqueous citric acid, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, as represented by the equation above. The student places 36.40 g of the $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ solution into a calorimeter 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 $\text{H}_3\text{C}_6\text{H}_5\text{O}_7(aq)$	36.40 g
Mass of $\text{NaHCO}_3(s)$	8.00 g
Total mass of reaction mixture	44.40 g
Initial temperature	19.9 °C
Final temperature	3.2 °C

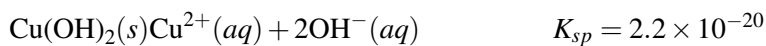


- Calculate the magnitude of q , in joules, for this mixture using the data in the table. Assume that the reaction mixture in the calorimeter has a specific heat capacity of $4.22 \text{ J}/(\text{g} \cdot ^\circ\text{C})$.
- Based on the collisions that occur between particles, explain why the graph shows temperature changing less rapidly as time progresses in the experiment.
- 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.
- The student conducts a second experiment using 36.40 g of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7(aq)$ at an initial temperature of 19.9°C . However, the student adds only 4.00 g of $\text{NaHCO}_3(s)$. 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 $\text{Cu}^{2+}(\text{aq})$ ion, which is important in the environment.



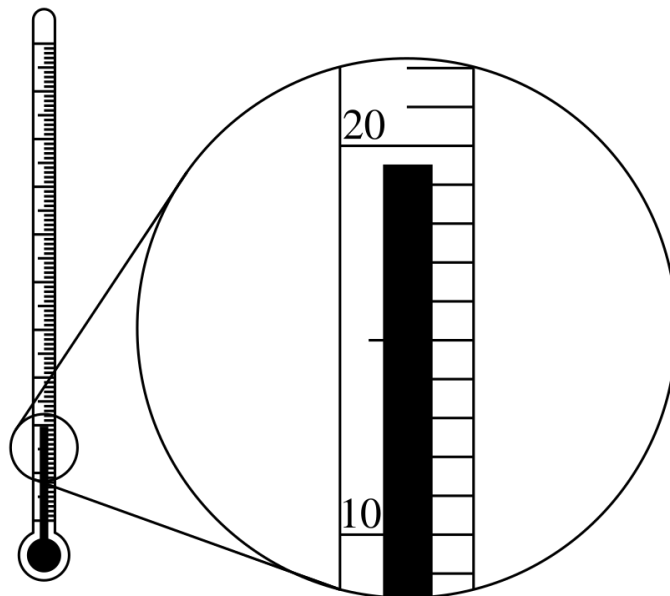
- (a) First, the student carries out a precipitation reaction. A solution of copper(II) nitrate is mixed with a solution of potassium phosphate, as represented above, and a blue precipitate forms. Write the balanced net ionic equation for the process.
- (b) In a separate experiment the student decides to precipitate the $\text{Cu}^{2+}(\text{aq})$ as $\text{Cu}(\text{OH})_2(\text{s})$. To make sure that $\text{Cu}(\text{OH})_2(\text{s})$ will precipitate, the student looks up the K_{sp} value for $\text{Cu}(\text{OH})_2(\text{s})$, as shown below.



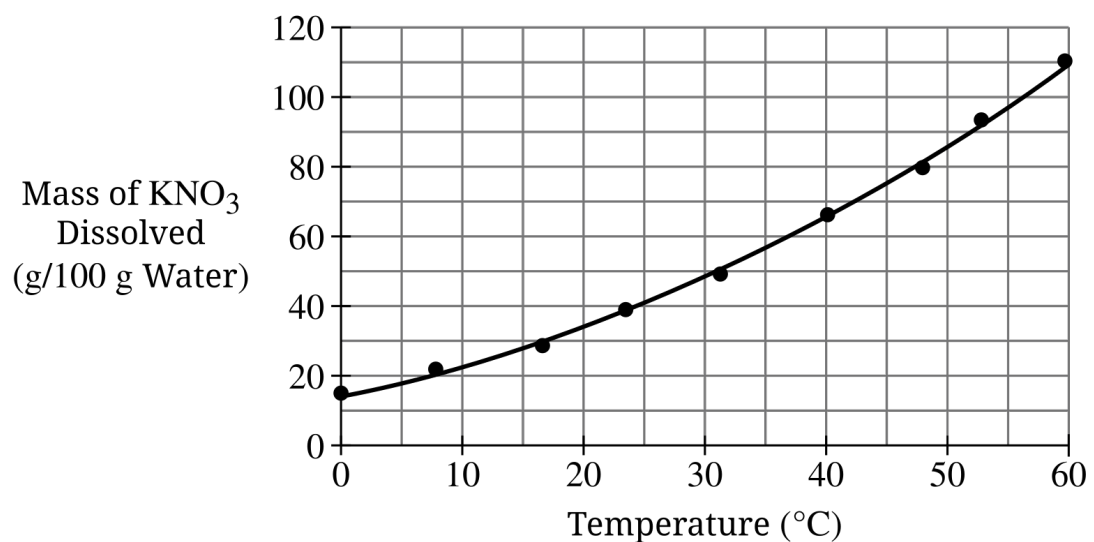
- Write the K_{sp} expression for the dissolving of $\text{Cu}(\text{OH})_2(\text{s})$.
 - Calculate the concentration of $\text{Cu}^{2+}(\text{aq})$ in a saturated $\text{Cu}(\text{OH})_2$ solution in mol/L.
- (c) The student incorrectly proposes that lowering the pH of the saturated $\text{Cu}(\text{OH})_2$ 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

APPENDIX - ANSWERS

AP CHEMISTRY 2022

Multiple-choice key transcribed from the matching supplied source.

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

Items 58-60 were not scored and were omitted in the supplied paper.

The complete supplied set has 57 scored MCQs and 7 FRQs.

Scoring-extract items 58-64 correspond to FRQs 1-7.

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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 $0.^{\circ}\text{C}$ to form liquid water at $0.^{\circ}\text{C}$ ($\Delta H_{fus} = 330 \text{ J/g}$)
- (B) Boiling liquid acetone at $56.^{\circ}\text{C}$ to form acetone vapor at $56.^{\circ}\text{C}$ ($\Delta H_{vap} = 540 \text{ J/g}$)
- (C) Increasing the temperature of liquid glycerin from $20.^{\circ}\text{C}$ to $120.^{\circ}\text{C}$
(Specific heat = $2.4 \text{ J/(g} \cdot ^{\circ}\text{C)}$)
- (D) Increasing the temperature of solid copper from $0.^{\circ}\text{C}$ to $200.^{\circ}\text{C}$
(Specific heat = $0.40 \text{ J/(g} \cdot ^{\circ}\text{C)}$)

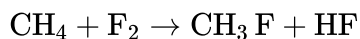
2. Which of the following questions about the components in a mixture could be investigated with a paper chromatography experiment?

- (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?

3.

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

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?



- (A) $-650 \text{ kJ / mol}_{rxn}$
- (B) $-490 \text{ kJ / mol}_{rxn}$
- (C) $+490 \text{ kJ / mol}_{rxn}$
- (D) $+650 \text{ kJ / mol}_{rxn}$

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4.

Acid	K_a
$\text{HF}(aq)$	4×10^{-4}
$\text{HC}_2\text{H}_3\text{O}_2(aq)$	2×10^{-5}
$\text{HClO}(aq)$	3×10^{-8}
$\text{HCN}(aq)$	5×10^{-10}

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) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M HF}(aq)$
 (B) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M NaC}_2\text{H}_3\text{O}_2(aq)$
 (C) $0.10\text{ M HC}_2\text{H}_3\text{O}_2(aq)$ and $0.10\text{ M HCN}(aq)$
 (D) $0.10\text{ M HClO}(aq)$ and $0.10\text{ M NaClO}(aq)$



5. $\text{H}_2\text{O}(g) + \text{CO}(g) \rightleftharpoons \text{CO}_2(g) + \text{H}_2(g)$ $K_p = 136$ at 500 K

A vessel initially contains $\text{H}_2\text{O}(g)$ at a partial pressure of 0.30 atm , $\text{CO}(g)$ at a partial pressure of 0.10 atm , $\text{CO}_2(g)$ at a partial pressure of 1.5 atm , and $\text{H}_2(g)$ at a partial pressure of $10.\text{ atm}$ at 500 K . Which of the following occurs as the system approaches equilibrium at 500 K ?

- (A) The partial pressures of $\text{H}_2\text{O}(g)$ and $\text{CO}(g)$ increase because $Q > K_p$.
 (B) The partial pressures of $\text{H}_2\text{O}(g)$ and $\text{CO}(g)$ increase because $Q < K_p$.
 (C) The partial pressures of $\text{CO}_2(g)$ and $\text{H}_2(g)$ increase because $Q > K_p$.
 (D) The partial pressures of $\text{CO}_2(g)$ and $\text{H}_2(g)$ increase because $Q < K_p$.



6.

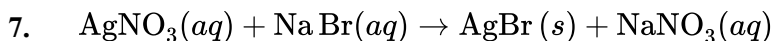
Data for H_2O	
Specific heat capacity of liquid phase	$4.2\text{ J}/(\text{g} \cdot ^\circ\text{C})$
Heat of fusion	330 J/g

A sample of ice at 0°C is added to $100.\text{ g}$ 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

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- (A) 0.13 g
(B) 0.42 g
(C) 1.3 g

(D) 42 g



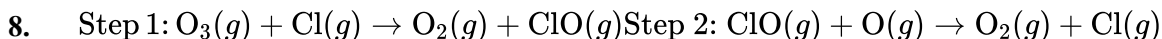
A 10.0 mL sample of 1.0 M $\text{AgNO}_3(aq)$ and a 10.0 mL sample of 1.0 M $\text{NaBr}(aq)$, both originally at 25°C , are combined in a constant-pressure calorimeter where the reaction represented above occurs. If the final temperature of the mixture is 35°C , what is the value of ΔH for the reaction? (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 $4.2 \text{ J}/(\text{g}\cdot^\circ\text{C})$.)

(A) $-84,000 \text{ J}/\text{mol}_{rxn}$

(B) $-84 \text{ J}/\text{mol}_{rxn}$

(C) $+84 \text{ J}/\text{mol}_{rxn}$

(D) $+84,000 \text{ J}/\text{mol}_{rxn}$



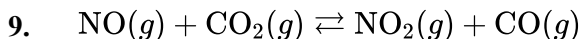
A proposed mechanism for the destruction of $\text{O}_3(g)$ in the upper atmosphere is represented above. Which of the following is the catalyst in the proposed mechanism?

(A) $\text{O}(g)$

(B) $\text{Cl}(g)$

(C) $\text{ClO}(g)$

(D) $\text{O}_2(g)$



Which of the following changes will increase the amount of $\text{NO}_2(g)$ in the equilibrium system represented by the equation above?

(A) Removing $\text{CO}(g)$ from the system

(B) Removing $\text{CO}_2(g)$ from the system

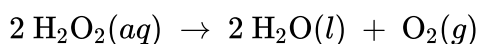
(C) Increasing the volume of the reaction vessel

(D) Decreasing the volume of the reaction vessel



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



A student carries out an experiment in which a sample of $\text{H}_2\text{O}_2(aq)$ decomposes in the presence of $\text{MnO}_2(s)$. The student measures the volume of $\text{O}_2(g)$ 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 $\text{O}_2(g)$ 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?

2022 Form I

- (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 $\text{MnO}_2(s)$ is not used. Which of the following statements best explains this observation?
- (A) $\text{MnO}_2(s)$ changes the reaction from endothermic to exothermic.
- (B) $\text{MnO}_2(s)$ shifts the equilibrium position of the reaction from reactant favored to product favored.
- (C) $\text{MnO}_2(s)$ releases heat in order to start the reaction.
- (D) $\text{MnO}_2(s)$ provides a reaction pathway with a lower activation energy. ✓
14. A second experiment is done under identical conditions using a higher concentration of $\text{H}_2\text{O}_2(aq)$ in the presence of the same mass of $\text{MnO}_2(s)$. 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
-

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Substance	Structural Formula	Molar Mass (g/mol)
Propylamine	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & \\ & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - \text{N} - \text{H} \\ & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & \end{array} $	59
Pentane	$ \begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} - \text{H} \\ & & & & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \end{array} $	72
2-propanol	$ \begin{array}{ccccc} & & \text{H} & & \\ & & & & \\ & & \text{O} & & \\ & & & & \\ & \text{H} & & \text{H} & \\ & & & & \\ \text{H} & - \text{C} & - & \text{C} & - \text{C} - \text{H} \\ & & & & \\ & \text{H} & & \text{H} & \text{H} \end{array} $	60
Propanoic acid	$ \begin{array}{ccccc} & \text{H} & & \text{H} & & \text{O} \\ & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} - \text{O} - \text{H} \\ & & & & & \\ & \text{H} & & \text{H} & & \end{array} $	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 $\text{C}_3\text{H}_5\text{O}_2^-$

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

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- (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

18.

**Ionization
Energies**

(kJ / mol)

First	590
Second	1150
Third	4910
Fourth	6490

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) $\text{X}_2(\text{SO}_4)_3$
- (D) $\text{X}(\text{SO}_4)_2$

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

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20. Which of the following correctly identifies a Brønsted-Lowry conjugate acid-base pair in a solution prepared by mixing together $\text{HNO}_2(aq)$ and $\text{NH}_3(aq)$?

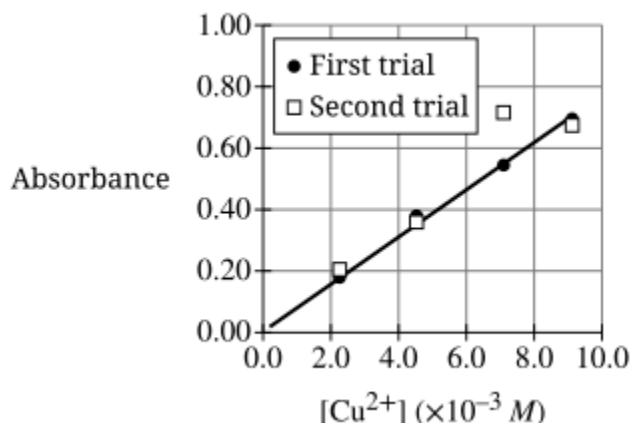
(A) The acid is $\text{HNO}_2(aq)$, and the conjugate base is $\text{NH}_3(aq)$.

(B) The acid is $\text{HNO}_2(aq)$, and the conjugate base is $\text{NO}_2^-(aq)$. ✓

(C) The acid is $\text{NH}_4^+(aq)$, and the conjugate base is $\text{NO}_2^-(aq)$.

(D) The acid is $\text{NH}_3(aq)$, and the conjugate base is $\text{NH}_4^+(aq)$.

21.



A student prepared four solutions of known $[\text{Cu}^{2+}]$ 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 $[\text{Cu}^{2+}] \approx 7 \times 10^{-3} M$ 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.

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22.

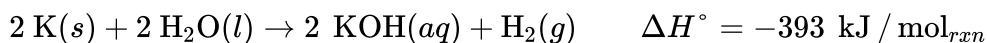
Acid	Concentration of Acid (<i>M</i>)	Volume of Sample (mL)	Volume of Standardized NaOH(<i>aq</i>) Added to Reach Equivalence Point (mL)
HClO ₄ (<i>aq</i>)	0.100	25.0	24.0
HClO(<i>aq</i>)	0.200	25.0	?

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 25.0 mL 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 HClO₄(*aq*) and HClO(*aq*).

When 3.9 g 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

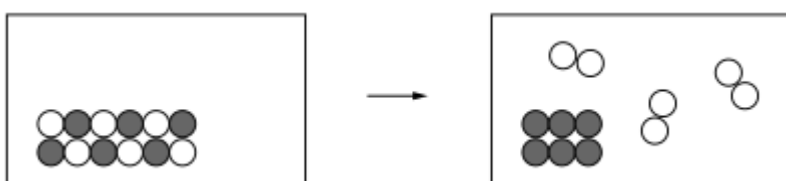


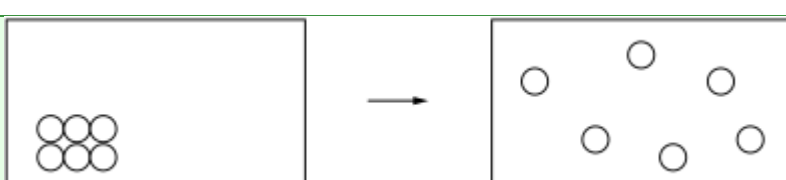
(D) The pH of the water cannot be determined without additional information.

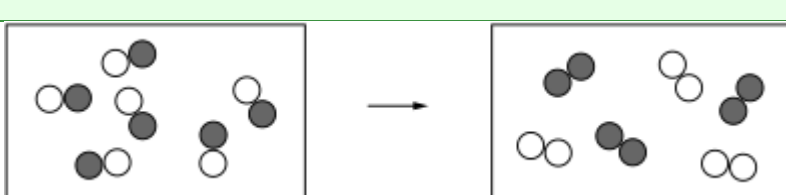
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25. Which of the following pairs of diagrams represents the change with the greatest positive value of ΔS° ?

(A) 

(B) 

(C) 

(D) 

26. A 10.0 g sample of $\text{Pb}(\text{NO}_3)_2(s)$ is dissolved in distilled water and an excess of $1.0\text{ M HCl}(aq)$ is added. The $\text{PbCl}_2(s)$ 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 $\text{Pb}(\text{NO}_3)_2(s)$ was wet.
- (B) The K_{sp} of $\text{PbCl}_2(s)$ is extremely small.
- (C) The precipitate was not dried to a constant mass.
- (D) A $3.0\text{ M HCl}(aq)$ solution was used instead of a $1.0\text{ M HCl}(aq)$ solution.

27. $2\text{N}_2\text{O}(g) \rightarrow 2\text{N}_2(g) + \text{O}_2(g)$

The rate law for the reaction represented above is experimentally determined to be $\text{rate} = k[\text{N}_2\text{O}]$. Which of the following best explains why increasing the initial concentration of $\text{N}_2\text{O}(g)$ 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.

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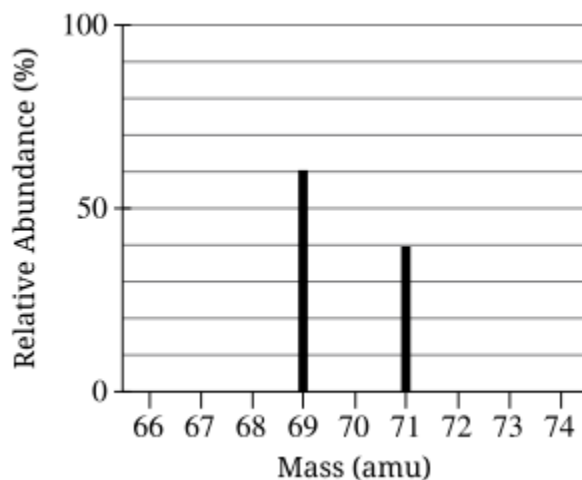
28. A sample of an ideal gas in a sealed container occupies a volume of 50.0 L at 200 K. The temperature of the gas is changed to 400 K, and the pressure doubles. Which of the following must occur and why?

(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 $\text{HCl}(aq)$ with 200. mL of 0.50 M $\text{HClO}_4(aq)$ and then dilutes the mixture with distilled water to a total volume of 500. mL. The $[\text{H}_3\text{O}^+]$ in the final solution is closest to

(A) 0.0025 M
(B) 0.12 M
(C) 0.25 M ✓
(D) 0.75 M

30.

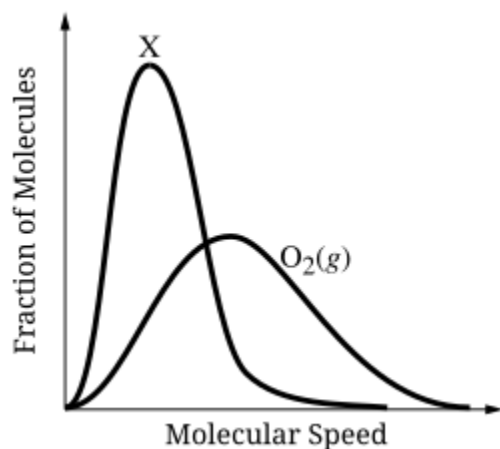


The mass spectrum of an element is represented above. Which of the following is most likely the identity of the element?

(A) Ga ✓
(B) Ge
(C) Tm
(D) Lu

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31.



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

(A) Br₂(g)

(B) CH₄(g)

(C) He(g)

(D) N₂(g)



32. The value of K_{sp} for the salt PbF₂ is 3.2×10^{-8} . The $[\text{Pb}^{2+}]$ in a saturated solution of PbF₂ is approximately

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

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

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

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



33.

PCl₃, Cl₂, CaCl₂

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

(A) Cl₂, PCl₃, CaCl₂

(B) Cl₂, CaCl₂, PCl₃

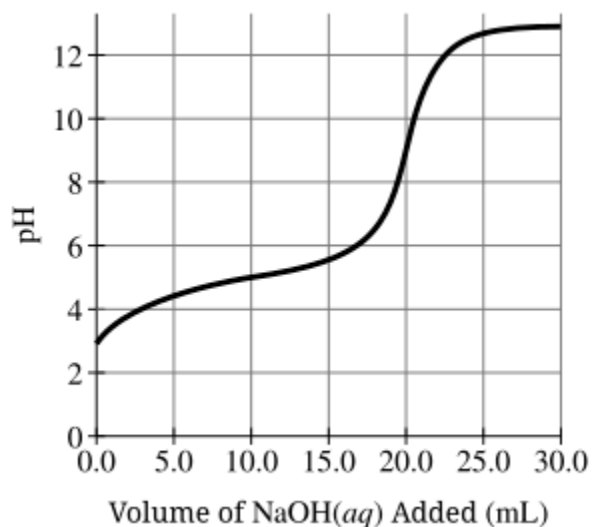
(C) CaCl₂, PCl₃, Cl₂

(D) CaCl₂, Cl₂, PCl₃



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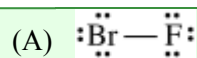
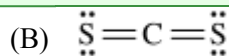
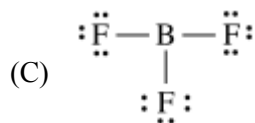
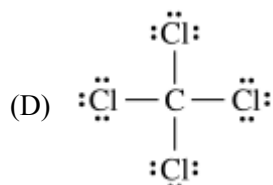
34.



A 0.10 M solution of a weak acid is titrated with $0.10\text{ M NaOH}(aq)$. 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) $\text{CH}_3\text{CH}_2\text{COOH}$ 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?



36. Step 1: $4\text{FeS}_2(s) + 11\text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s) + 8\text{SO}_2(g)$
 Step 2: $\text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 3\text{CO}_2(g) + 2\text{Fe}(s)$

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

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(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.

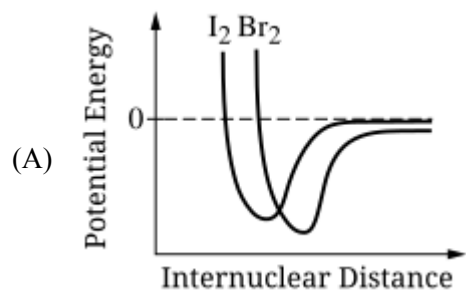
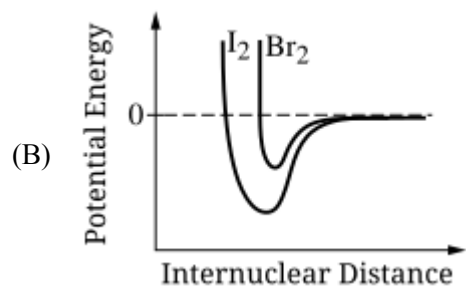
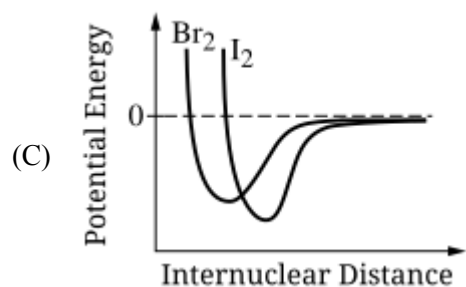
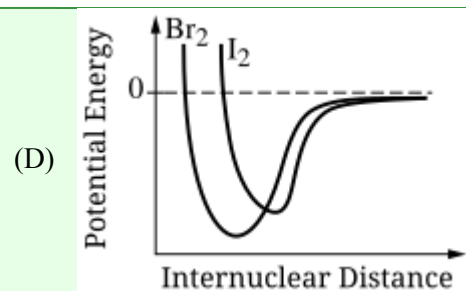
(C) It has a high melting point (1700°C).(D) It has the same density as aluminum (2.7 g/mL).

38.

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

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

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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

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40.

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

The pressure of a sample of $\text{NH}_3(g)$ 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?

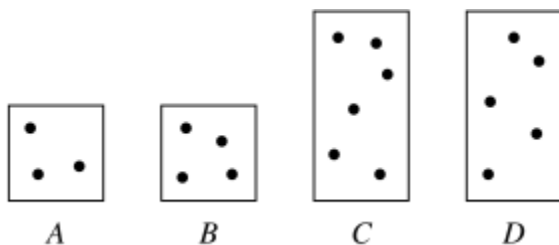
(A) CO_2

(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 ✓

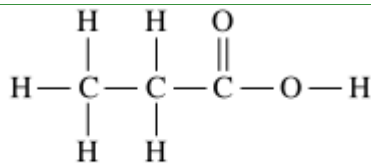
(C) C

(D) D

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

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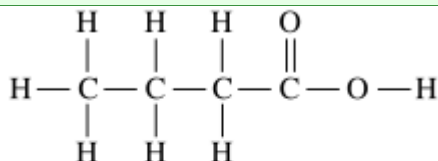
(A)



Propanoic acid
(74 g/mol)

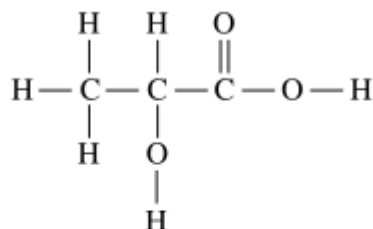


(B)



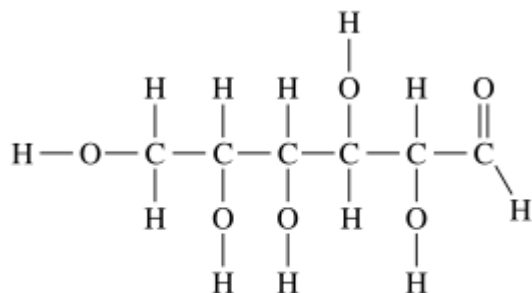
Butanoic acid
(88 g/mol)

(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 $\text{Br}-\text{Br}$ bond is stronger than the $\text{I}-\text{I}$ bond.

(D) The $\text{I}-\text{I}$ bond is stronger than the $\text{Br}-\text{Br}$ bond.

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- 45.
- | Compound | K_{sp} |
|--------------------------|-----------------------|
| $\text{Fe}(\text{OH})_2$ | 4.9×10^{-17} |
| $\text{Cu}(\text{OH})_2$ | 1.6×10^{-19} |
| $\text{Co}(\text{OH})_2$ | 1.1×10^{-15} |
- Which of the following ranks the compounds listed in the table above in order of increasing solubility?
- (A) $\text{Fe}(\text{OH})_2 < \text{Cu}(\text{OH})_2 < \text{Co}(\text{OH})_2$
- (B) $\text{Fe}(\text{OH})_2 < \text{Co}(\text{OH})_2 < \text{Cu}(\text{OH})_2$
- (C) $\text{Co}(\text{OH})_2 < \text{Fe}(\text{OH})_2 < \text{Cu}(\text{OH})_2$
- (D) $\text{Cu}(\text{OH})_2 < \text{Fe}(\text{OH})_2 < \text{Co}(\text{OH})_2$ ✓

- 46.
-
- Three graphs showing the decomposition of compound A over time at 45°C. The x-axis for all graphs is Time (s) from 0 to 2,000. The first graph shows $[\text{A}]$ in M decreasing from approximately 1.0 to 0.4. The second graph shows $1/[\text{A}]$ in M^{-1} increasing from approximately 1.0 to 2.5. The third graph shows $\ln [\text{A}]$ decreasing from approximately 0 to -1.0.

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) $\text{Rate} = k$
- (B) $\text{Rate} = k[\text{A}]$ ✓
- (C) $\text{Rate} = k[\text{A}]^2$
- (D) The rate law cannot be determined without additional experimentation.
47. $2\text{NO}_2 \rightarrow \text{NO}_3 + \text{NO}$ (slow)
- $\text{NO}_3 \rightarrow \text{NO} + \text{O}_2$ (fast)

A proposed two-step mechanism for the reaction $2\text{NO}_2 \rightarrow 2\text{NO} + \text{O}_2$ is represented. Which of the following rate laws is consistent with the mechanism?

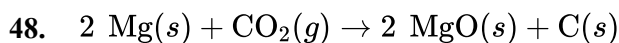
2022 Form I

(A) $\text{rate} = k[\text{NO}_3]$

(B) $\text{rate} = k[\text{NO}_2]^2$ ✓

(C) $\text{rate} = k[\text{NO}_2]^2[\text{NO}_3]$

(D) $\text{rate} = k \frac{[\text{NO}]^2[\text{O}_2]}{[\text{NO}_2]^2}$



$\Delta H_{\text{rxn}}^\circ < 0; \Delta G_{\text{rxn}}^\circ < 0 \text{ at } 298\text{K}$

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

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

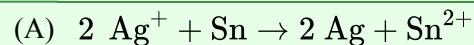
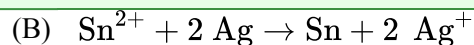
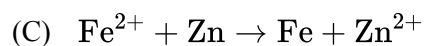
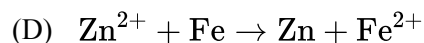
(B) At 298 K, it is driven by entropy only.

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

(D) It is thermodynamically favorable at all temperatures.

49.

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

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}° ?

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.

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51.

Compound	$\Delta H_{\text{solution}}$ (kJ / mol)
NaF(s)	+0.91
MgF ₂ (s)	−18

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) MgF₂(s) only

(C) Both NaF(s) and MgF₂(s)

(D) The solubility of neither NaF(s) nor MgF₂(s) will increase.

52. Which of the following identifies the four species that are present in an aqueous solution of the weak acid H₂C₂O₄, from the highest to the lowest concentration at equilibrium?

(A) H₃O⁺ > HC₂O₄[−] > C₂O₄^{2−} > H₂C₂O₄

(B) H₃O⁺ > C₂O₄^{2−} > HC₂O₄[−] > H₂C₂O₄

(C) H₂C₂O₄ > HC₂O₄[−] > C₂O₄^{2−} > H₃O⁺

(D) H₂C₂O₄ > H₃O⁺ > HC₂O₄[−] > C₂O₄^{2−}



53. A student is given the task of making a calibration curve for CoCl₂(aq) for use in a spectrophotometry experiment. The student pours a sample of CoCl₂(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 1.5 cm path length

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

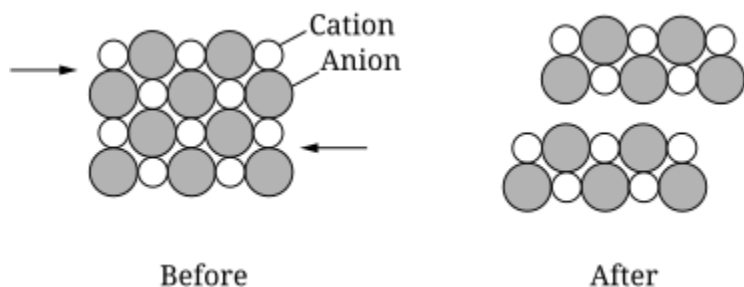
(C) Diluting a measured volume of the solution to a new known volume using distilled water



(D) Pouring some solution out of the cuvette

2022 Form I

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

55. $\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g)$

A 1.0 mol sample of $\text{H}_2(g)$ and a 1.0 mol sample of $\text{I}_2(g)$ are placed in a previously evacuated 1.0 L container and allowed to reach the equilibrium shown above. If the equilibrium concentration of $\text{HI}(g)$ is 0.40 M, which of the following is the value of the equilibrium constant?

(A) 0.16

(B) 0.25

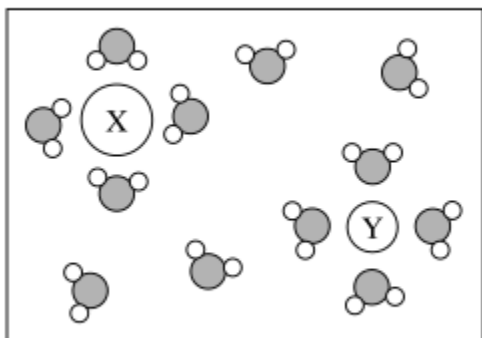
(C) 0.44

(D) 1.0



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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 $\text{Zn}(s)$ in a beaker containing $\text{CuSO}_4(aq)$. 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) $2 \text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{Zn}_2\text{SO}_4(aq) + \text{Cu}(s)$

(B) $\text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{ZnSO}_4(aq) + \text{Cu}(s)$

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

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

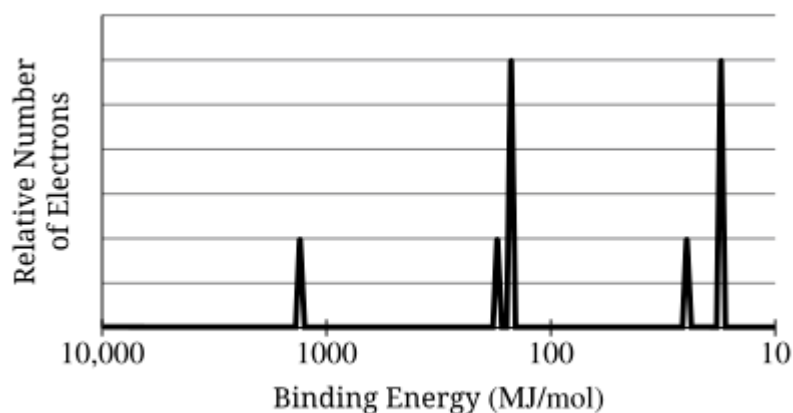


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58. For parts of the free response question that require calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Examples and equations may be included in your answers where appropriate.

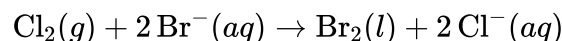
Bromine is the only nonmetal that exists as a liquid at room temperature and 1 atm.

- (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 $3s$ 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, $\text{Br}_2(l)$, is produced in the reaction represented by the following chemical equation.



- (c) A student claims that elemental chlorine, $\text{Cl}_2(g)$, 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.

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Reaction	E° (V)
$\text{Cl}_2(g) + 2 \text{Br}^-(aq) \rightarrow \text{Br}_2(l) + 2 \text{Cl}^-(aq)$	?
$\text{Cl}_2(g) + 2 e^- \rightarrow 2 \text{Cl}^-(aq)$	+1.36
$\text{Br}_2(l) + 2 e^- \rightarrow 2 \text{Br}^-(aq)$	+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 $\text{kJ} / \text{mol}_{rxn}$) for the reaction between chlorine gas and bromide ions.

(f) At 298K, 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 $\Delta H_{rxn}^\circ = -91.2 \text{ kJ/mol}_{rxn}$. Calculate the standard entropy change for the reaction at 298K. Include units with your answer.

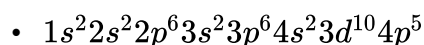
Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

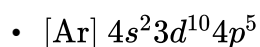


0	1
---	---

The response provides a correct answer.



OR



Part B(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

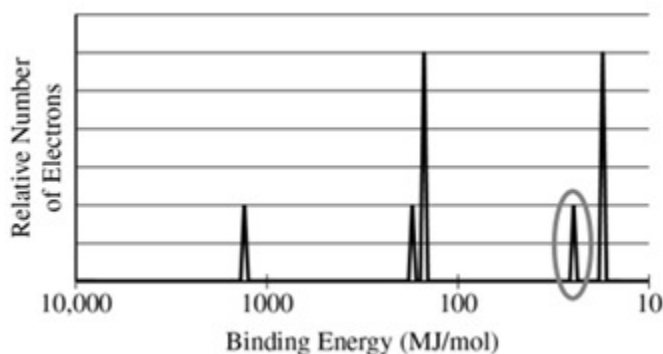


0	1
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The response provides the correct answer.

- The second peak from the right is circled.



Part B(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0

1

The response provides the correct answer and a valid explanation.

- Shifted to the left. Kr has a higher nuclear charge than Br does (36 versus 35), so the peaks for the core electrons of Kr would be shifted toward higher binding energies (to the left on the graph).

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0

1

The response provides the correct answer and a valid explanation.

- Agree. This is a correct statement because the oxidation number of chlorine is being reduced from 0 to -1 .

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0

1

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The response provides the correct calculated value.

$$E_{cell}^{\circ} = E_{cathode}^{\circ} - E_{anode}^{\circ}$$

$$E_{cell}^{\circ} = 1.36 - 1.07 = +0.29 \text{ V}$$

Part E

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
---	---	---

The response meets **both** of the following criteria.

- ☐ The response provides the correct number of electrons.
 - 2 electrons
- ☐ The response provides the correct calculated value, consistent with part (d).
 - $\Delta G_{rxn}^{\circ} = -nFE_{cell}^{\circ} = -\left(\frac{2 \text{ mol } e^{-}}{1 \text{ mol}_{rxn}}\right)\left(\frac{96,485 \text{ coulombs}}{1 \text{ mol } e^{-}}\right)\left(\frac{0.29 \text{ J}}{1 \text{ coulomb}}\right)$
 - $\Delta G_{rxn}^{\circ} = -56,000 \text{ J/mol}_{rxn} = -56 \text{ kJ/mol}_{rxn}$

Part F

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides the correct answer and a valid justification, consistent with part (e).

- Yes, this is a thermodynamically favorable reaction at 298 K because the standard Gibbs free energy change is a negative term.

Part G

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
---	---	---

2022 Form I

The response meets **both** of the following criteria.

- ☐ The response provides the correct calculated value, consistent with part (e).

$$\Delta G_{rxn}^{\circ} = \Delta H_{rxn}^{\circ} - T \Delta S_{rxn}^{\circ}$$

$$\Delta S_{rxn}^{\circ} = \frac{\Delta H_{rxn}^{\circ} - \Delta G_{rxn}^{\circ}}{T} = \left(\frac{-91.2 \text{ kJ/mol}_{rxn} - (-56 \text{ kJ/mol}_{rxn})}{298 \text{ K}} \right) \left(\frac{1000 \text{ J}}{\text{kJ}} \right)$$

$$\Delta S_{rxn}^{\circ} = -120 \text{ J/(K} \cdot \text{mol}_{rxn})$$

- ☐ The response provides the correct units.

$$\text{J/(K} \cdot \text{mol}_{rxn})$$

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59. For parts of the free response question that require 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. Examples and equations may be included in your answers where appropriate.

Answer the following questions about $\text{C}_2\text{H}_4\text{O}$.

- (a) $\text{C}_2\text{H}_4\text{O}$ (molar mass 44.06g/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 $3.00 \times 10^5 \text{L}$?

Two structures, X and Z, with the molecular formula $\text{C}_2\text{H}_4\text{O}$ are shown in the table.

Structure	Lewis Dot Diagram
X	
Z	

- (b) Based on VSEPR theory, predict the $\text{H} - \text{C} - \text{H}$ 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 1atm, and they react according to the following equation.
- $$\text{X} \rightleftharpoons \text{Z}$$
- (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

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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.

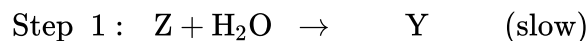
Option 2 :

The partial pressure of product **Z** is greater.

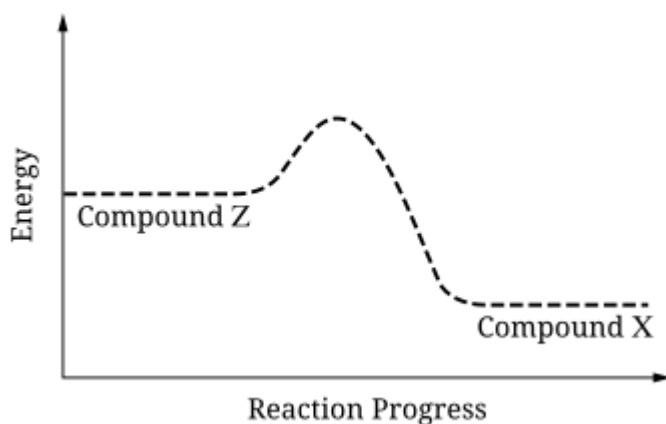
(f) An empty vessel is filled with compound **X** and sealed shut. The initial pressure of compound **X** is 0.55 atm. Calculate the partial pressure of compound **Z** in the vessel after equilibrium is established at constant temperature.

(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.



(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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

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0	1
---	---

The response provides the correct calculated value.

- $(8.17 \times 10^{-6} M)(3.00 \times 10^5 \text{ L}) = 2.451 \text{ mol}$
 $2.451 \text{ mol} \times \frac{44.06 \text{ g}}{1 \text{ mol}} = 108 \text{ g}$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides the correct answer.

- 109.5°

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides a correct explanation.

- In resonance structures, the connectivity of atoms must remain the same; only electron arrangements change. In the case of X and Z, a hydrogen atom in molecule X has been moved to a different position in molecule Z, so X and Z cannot be resonance structures of each other.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides the correct expression.

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$$\bullet K_p = \frac{P_Z}{P_X}$$

Part E

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides the correct answer and a valid justification.

- Option 1 is circled.

The value of K_p is less than 1. At equilibrium, the partial pressure of the reactant is greater than the partial pressure of the product.

Part F

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides the correct calculated value.

$$\bullet K_p = \frac{P_Z}{P_X}$$

$$3.3 \times 10^{-8} = \frac{P_Z}{(0.55 \text{ atm} - P_Z)} \approx \frac{P_Z}{(0.55 \text{ atm})}$$

$$P_Z = (3.3 \times 10^{-8})(0.55 \text{ atm}) = 1.8 \times 10^{-8} \text{ atm}$$

Part G

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
---	---

The response provides a correct answer and a valid justification.

- K_p will remain the same. Only a temperature change can alter the value of K .

OR

2022 Form I

- K_p will remain the same. Changing the volume of the container does not change the K_p value.

Part H(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct answer.

- Y is an intermediate.

Part H(ii)

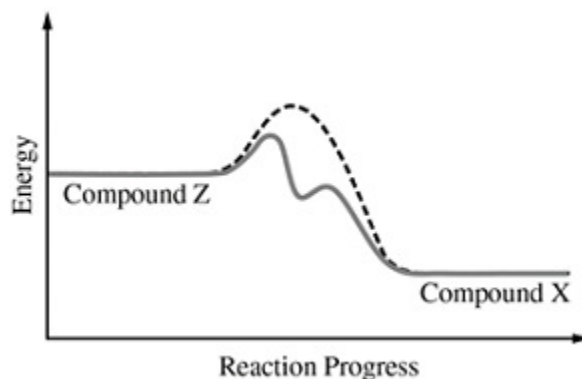
Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
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The response does not meet **any** of the following criteria.

- ☐ The response shows the correct starting and ending points.
 - The curve begins and ends at the same energies as the original curve, with an initial activation energy depicted.
- ☐ The response shows a curve with the correct shape.
 - The curve should have two local maxima, with the first step having a larger E_a than the second step (and smaller than the E_a of the uncatalyzed reaction).

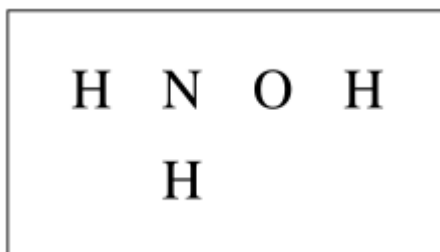


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60. For parts of the free response question that require calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Examples and equations may be included in your answers where appropriate.

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.

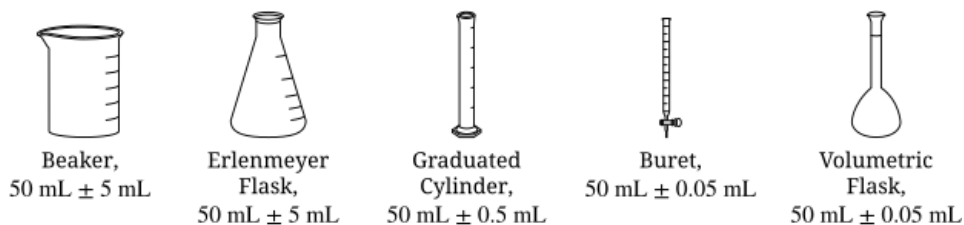


- (b) Hydroxylamine, $\text{NH}_2\text{OH}(aq)$, is a weak base. Write the balanced net ionic equation for the reaction that occurs when $\text{NH}_2\text{OH}(aq)$ and $\text{HCl}(aq)$ are combined.

A student is preparing to titrate a $\text{NH}_2\text{OH}(aq)$ solution with $\text{HCl}(aq)$. 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 100.00mL of a 0.1000M HCl solution. The stock solution available is 0.5604M HCl . Calculate the volume, in liters, of stock solution required for the dilution.

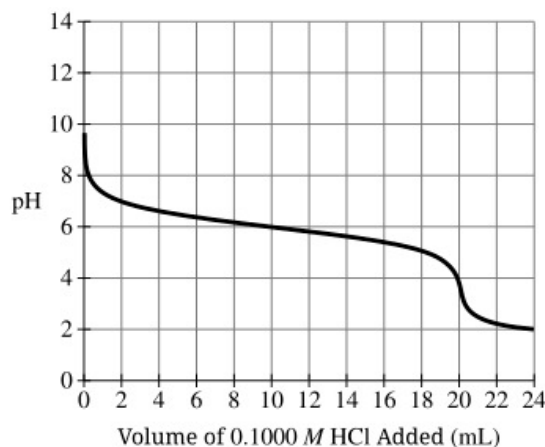
- (d) Using the following choices, identify the glassware that should be used to deliver the $\text{HCl}(aq)$ with the greatest precision. Circle your choice and provide a brief justification.



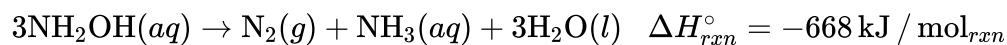
- (e) The student titrates a 25.00mL sample of a NH_2OH solution with 0.1000M HCl . The student monitors the pH during the experiment and creates the following titration curve. Selected data are given in the table.

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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 $\text{NH}_2\text{OH}(aq)$.
- (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.



At elevated temperatures, $\text{NH}_2\text{OH}(aq)$ undergoes decomposition according to the equation shown.

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

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

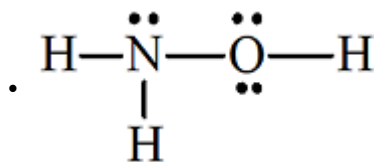


0

1

The response provides the correct answer.

2022 Form I



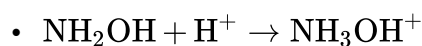
Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

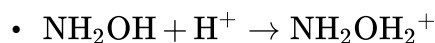


0	1
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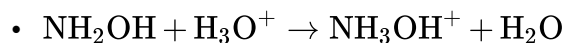
The response provides a correct balanced equation.



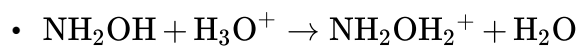
OR



OR



OR



Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct calculated value.

- $V_1 = \frac{M_2 V_2}{M_1} = \frac{(0.1000 \text{ M})(0.10000 \text{ L})}{0.5604 \text{ M}} = 0.01784 \text{ L}$

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

2022 Form I



0	1
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The response provides the correct answer and a valid justification.

- The buret is the best choice to dispense volume precisely, because it can be used to dispense a variety of different volumes to the nearest 0.05 mL.

Part E(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct calculated value.

- The halfway point in the titration occurs when approximately 10 mL of titrant is added. At the half-equivalence point, the pH of the solution equals the pK_a of the conjugate acid, NH_3OH^+ . According to the table, the pH is 6.03, so $pK_a + pK_b = 14.00$

$$pK_b = 14.00 - 6.03 = 7.97$$

OR

- Based on the graph, the pH at the half-equivalence point is approximately 6.0, so $pK_a + pK_b = 14.00$.

$$pK_b = 14.0 - 6.0 = 8.0$$

Part E(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
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The response meets **both** of the following criteria.

☐

The response provides the correct volume.

- 20.00 mL of 0.1000 M HCl is required to reach the equivalence point.

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- ☐ The response provides the correct calculated value of concentration.

$$\begin{aligned} & 0.02000 \text{ L HCl} \times \frac{0.1000 \text{ mol HCl}}{1 \text{ L}} \times \frac{1 \text{ mol NH}_2\text{OH}}{1 \text{ mol HCl}} = 0.002000 \text{ mol NH}_2\text{OH} \\ \text{Concentration of NH}_2\text{OH} &= \frac{0.002000 \text{ mol}}{0.02500 \text{ L}} = 0.08000 \text{ M} \end{aligned}$$

Part E(iii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct explanation.

- If a more concentrated HCl solution is used to titrate the same amount of base, the volume of acid required to reach the equivalence point would be smaller, not greater. Therefore, using the stock solution could not have caused this error in the second trial.

Part F

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1	2
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The response meets **both** of the following criteria.

- ☐ The response provides the correct calculated value of moles of reaction.

$$8.00 \text{ g NH}_2\text{OH} \times \frac{1 \text{ mol NH}_2\text{OH}}{33.03 \text{ g NH}_2\text{OH}} \times \frac{1 \text{ mol}_{rxn}}{3 \text{ mol NH}_2\text{OH}} = 0.0807 \text{ mol}_{rxn}$$

- ☐ The response provides the correct calculated value of heat produced.

$$0.0807 \text{ mol}_{rxn} \times \frac{-668 \text{ kJ}}{1 \text{ mol}_{rxn}} = -53.9 \text{ kJ. Therefore, 53.9 kJ are produced.}$$

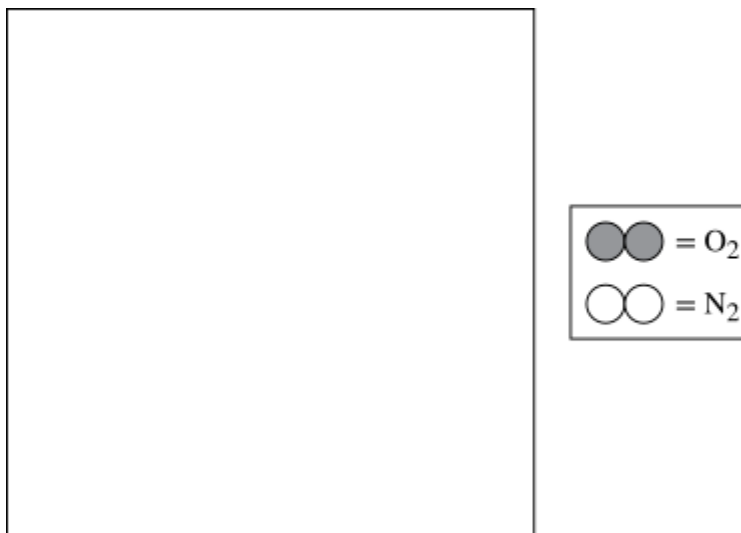
2022 Form I

61. For parts of the free response question that require 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. Examples and equations may be included in your answers where appropriate.

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

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

- (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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

2022 Form I



0	1
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The response provides the correct calculated value.

- $PV = nRT$

$$n = \frac{PV}{RT} = \frac{(1.30 \text{ atm})(2.00 \text{ L})}{(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(295 \text{ K})} = 0.107 \text{ mol}$$

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct answer and a valid justification.

- O_2 will condense first. Both N_2 and O_2 have only dispersion forces as their intermolecular forces. Because O_2 has more electrons, it has a higher polarizability. Therefore, O_2 will have stronger dispersion forces and thus will condense at the higher temperature.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

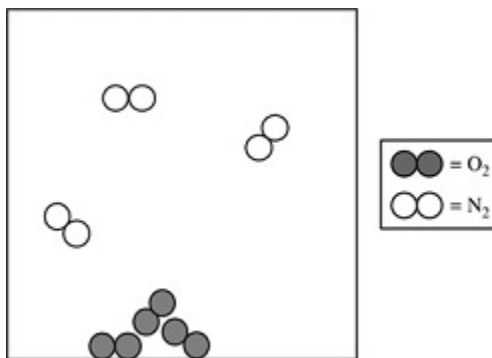


0	1
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The response provides a correct diagram, consistent with part (b).

- Diagram should show one substance is a gas and the other substance is a liquid.

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Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0

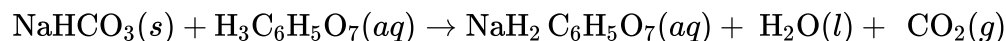
1

The response provides the correct calculated value, consistent with part (b).

- $(0.21)(0.107 \text{ mol})(32.00 \text{ g/mol}) = 0.72 \text{ g O}_2$

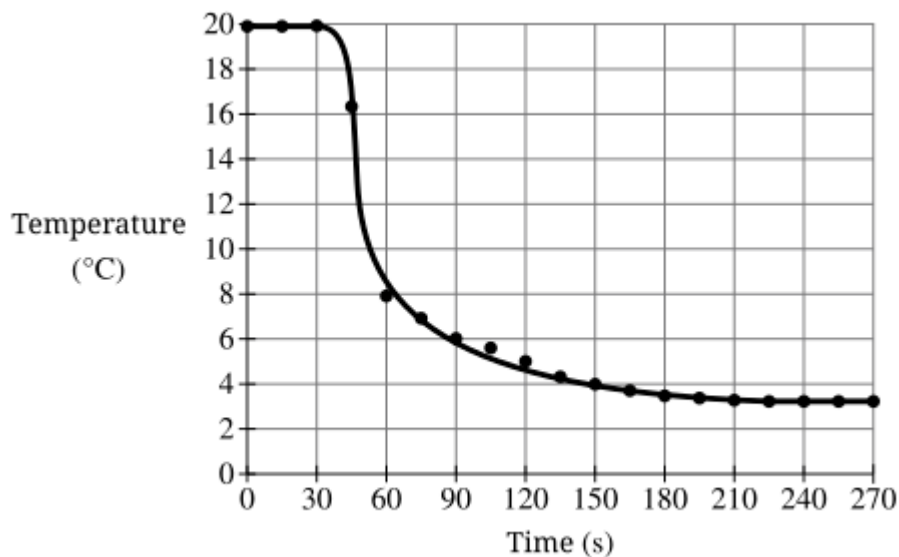
2022 Form I

62. For parts of the free response question that require 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. Examples and equations may be included in your answers where appropriate.



A student conducts a calorimetry experiment in which solid baking soda, NaHCO_3 , reacts with excess aqueous citric acid, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, as represented by the equation above. The student places 36.40 g of the $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ 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 $\text{H}_3\text{C}_6\text{H}_5\text{O}_7(aq)$	36.40 g
Mass of $\text{NaHCO}_3(s)$	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 $4.22 \text{ J}/(\text{g} \cdot ^\circ\text{C})$.
- (b) Based on the collisions that occur between particles, explain why the graph shows temperature changing less rapidly as time progresses in the experiment.

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(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 $\text{H}_3\text{C}_6\text{H}_5\text{O}_7(aq)$ at an initial temperature of 19.9°C . However, the student adds only 4.00 g of $\text{NaHCO}_3(s)$. 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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct calculated value.

- $q = (44.40 \text{ g})(4.22 \text{ J}/(\text{g} \cdot ^\circ\text{C}))(3.2^\circ\text{C} - 19.9^\circ\text{C})$

$q = -3130 \text{ J}$. Therefore, the magnitude of q is 3130 J.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct explanation.

- As the reaction progresses, a lower concentration of the reactant particles remains in the solution, resulting in

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fewer collisions and a reduced rate of temperature change.

OR

- As the temperature decreases, collisions between reactant particles occur less frequently and with less force. Since energy must be absorbed for the reaction to occur, having a lower temperature in the solution means fewer particles will achieve the energy requirements to produce products.

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct claim.

- Heat transfers from the surroundings into the system.

Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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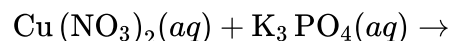
The response provides a correct prediction.

- Less than. The temperature change will be smaller because less of the limiting reactant is present, resulting in a smaller thermal energy transfer (smaller value of q).

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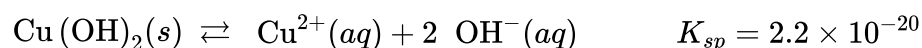
63. For parts of the free response question that require calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Examples and equations may be included in your answers where appropriate.

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



(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 $\text{Cu}^{2+}(aq)$ as $\text{Cu}(\text{OH})_2(s)$. To make sure that $\text{Cu}(\text{OH})_2(s)$ will precipitate, the student looks up the K_{sp} value for $\text{Cu}(\text{OH})_2(s)$, as shown below.



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

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

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

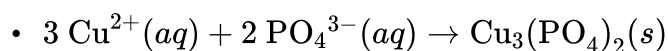
Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct balanced equation (state symbols not required).



Part B(i)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

2022 Form I



0	1
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The response provides the correct expression.

- $K_{sp} = [\text{Cu}^{2+}][\text{OH}^-]^2$

Part B(ii)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct calculated value consistent with part (b)(i).

- $K_{sp} = [\text{Cu}^{2+}][\text{OH}^-]^2$

$$2.2 \times 10^{-20} = (x)(2x)^2$$

$$[\text{Cu}^{2+}] = x = 1.8 \times 10^{-7} M$$

OR

- $K_{sp} = [\text{Cu}^{2+}][\text{OH}^-]^2$

$$2.2 \times 10^{-20} = (x)(1.0 \times 10^{-7} + 2x)^2$$

$$[\text{Cu}^{2+}] = x = 1.4 \times 10^{-7} M$$

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct explanation.

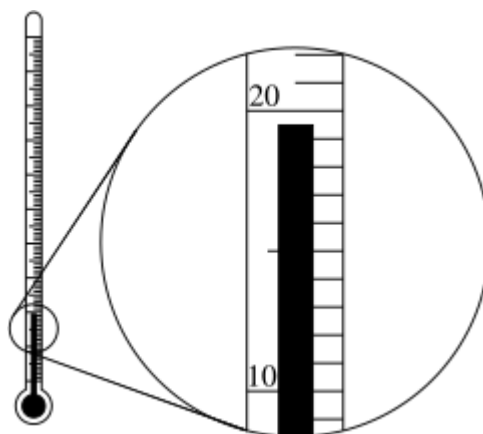
- The amount of precipitate will decrease, not increase. When the pH is lowered, the excess H^+ will react with OH^- , reducing $[\text{OH}^-]$ and therefore allowing additional Cu^{2+} and OH^- ions to enter solution, which increases the solubility of $\text{Cu}(\text{OH})_2$.

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64. For parts of the free response question that require 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. Examples and equations may be included in your answers where appropriate.

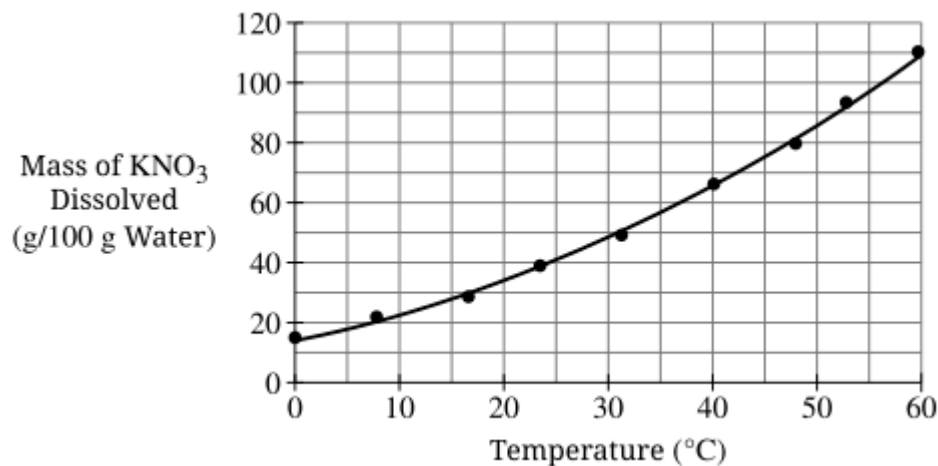
A student conducts a solubility experiment with potassium nitrate, KNO_3 , in water by identifying the temperature at which various masses of KNO_3 will completely dissolve.

(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.



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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.

Part A

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct explanation.

- Dispersion forces are weaker than the ionic bonds present in KNO_3 , and dispersion forces are not the dominant attractive force that leads to the properties of ionic compounds; dispersion forces of attraction are more relevant between molecules in molecular compounds.

Part B

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct answer.

- 19.5°C

Part C

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides a correct explanation.

- The stirring will not affect the maximum amount of KNO_3 that will dissolve (which depends on the equilibrium between the solid and the dissolved ions), only the rate at which the solid dissolves.

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Part D

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.



0	1
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The response provides the correct answer and justification.

- Agree. According to the graph, the maximum solubility at 30°C should be approximately 48 g so 38.1 g is not enough solute to make a saturated solution at this temperature, so the solid should completely dissolve.