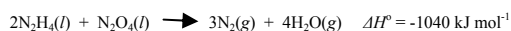


Passage I (Questions 1-10)

Hydrazine (N_2H_4) and methylhydrazines (hydrazine with CH_3 groups substituted for hydrogen atoms) are often used as rocket fuels. These chemicals are easily oxidized to nitrogen by both liquid oxygen and hydrogen peroxide:

**Equation 1**

Safety concerns over the use of liquid oxygen close to rockets have been expressed. Instead, it was recommended that hydrazine be reacted with dinitrogen tetroxide (N_2O_4) to produce gaseous nitrogen and water for rocket propulsion. Equation 2 shows the reaction and the enthalpy change.

**Equation 2**

Additional thermochemical data for hydrazine and dinitrogen tetroxide are given in Table 1.

Table 1: Thermochemical Properties of Hydrazine and Dinitrogen Tetroxide at 298 K

Property	$\text{N}_2\text{H}_4(l)$	$\text{N}_2\text{O}_4(g)$
ΔH_f° (kJ mol ⁻¹)	50.6	9.2
ΔG_f° (kJ mol ⁻¹)	149.2	97.9
S° (J K ⁻¹ mol ⁻¹)	121.2	304.3

Due to the high volatility of hydrazine, it is usually transported as the hydrate ($\text{N}_2\text{H}_4 \cdot \text{H}_2\text{O}$), which can be easily dehydrated to form the anhydrous compound.

At room temperature, hydrazine is a liquid that exists in hydrogen-bonded networks. One method of hydrazine preparation is the Raschig process, which involves the introduction of ammonia into a sodium hypochlorite solution, as shown in Equation 3.

**Equation 3**

Hydrazine and ammonia are bases in aqueous solution. Figure 1 shows the equilibria reactions of ammonia and hydrazine in aqueous solution.

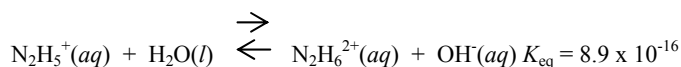
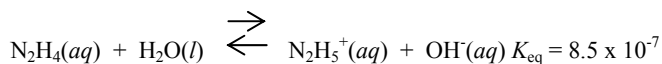
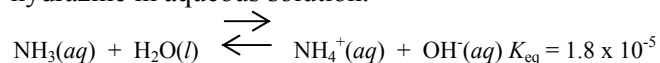
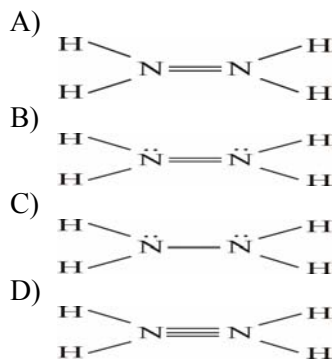


Figure 1 : Equilibria Reactions

1. Which of the following Lewis structures best represents hydrazine?



2. Equation 1 shows the oxidation of hydrazine. What is the oxidation number of the nitrogen atom in hydrazine?

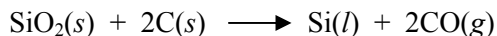
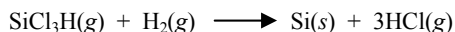
- A) +2
B) +1
C) -1
D) -2

3. How many grams of ammonia are required to make one mole of hydrazine by the Rasching process?
- A) 8.5 g
B) 17.0 g
C) 32.0 g
D) 34.0 g
4. Estimate the percent by weight of hydrazine in its hydrate.
- A) $6.0/50.0 \times 100\%$
B) $18.0/32.0 \times 100\%$
C) $18.0/50.0 \times 100\%$
D) $32.0/50.0 \times 100\%$
5. A group of NASA engineers wanted to increase the amount of gaseous nitrogen and water formed in Equation 2 to promote rocket propulsion. Which of the following suggestions would achieve that objective?
- A) Increase the amount of N_2O_4
B) Use a smaller reaction chamber
C) Decrease the temperature
D) Cover the internal surfaces of the reaction chamber with catalytic carbon
6. $N_2(g) + 2H_2(g) \longrightarrow N_2H_4(l)$
- What is the enthalpy change (ΔH°) for the reaction shown above?
- A) 50.6 kJ mol^{-1}
B) $149.2 \text{ kJ mol}^{-1}$
C) $(149.2 + 298 \times 121.2) \text{ kJ mol}^{-1}$
D) $(149.2 - 50.6) \text{ kJ mol}^{-1}$
7. Since ammonia reacts more vigorously with acids, hydrazine must:
- A) have a smaller acidity constant (K_a) than ammonia.
B) have a smaller basicity constant (K_b) than ammonia.
C) be easily protonated twice to form $N_2H_6^{2+}$.
D) form hydrogen bonds in aqueous solution.
8. The formation of hydrazine from its elements is NOT a spontaneous process at 25°C and 1 atm because:
- A) ΔS° for the reaction is > 0 .
B) ΔH° for the reaction is < 0 .
C) ΔG° for the reaction is > 0 .
D) S° for hydrazine is > 0 .
9. The entropy change (ΔS°) for the reaction shown in Equation 2 is:
- A) < 0 because the moles of gaseous products $>$ the moles of gaseous reactants.
B) < 0 because water is a product of the reaction.
C) > 0 because the moles of gaseous products $>$ the moles of gaseous reactants.
D) > 0 because water is a product of the reaction.
10. Ammonia (in Equation 3) occupies 10 L at 1 atm and 25°C . What volume will it occupy at 500 atm and 25°C .
- A) Exactly 0.020 L
B) More than 0.02 L because of the space occupied by the individual gas molecules.
C) Somewhat more than 0.02 L because of the repulsions between the individual gas molecules.
D) Somewhat more than 0.02 L because of the increased number of collisions with the sides of the reaction chamber.

Passage II (Questions 11-18)

Silicon comprises more than 25% of the earth's crust and provides the structure of most minerals and rocks. It is found normally combined with oxygen in a variety of silicate materials. The most common is silica (SiO_2), which is a network solid with strong bonds between the silicon and oxygen.

The purification of silicon was difficult to achieve. However, when elemental potassium became available in the 19th century, it was used in a silicon purification procedure. Today, crude silicon is produced commercially by the reaction of silica with coke in an electric furnace at 3000°C (see Equation 1). The product is only 98% pure, containing impurities of iron, oxygen, aluminum, and other trace elements. Further purification is achieved by halogenating the silicon, purifying the resulting gas by fractional distillation, and then reducing the halogenated silicon compound (Equations 2 and 3).

**Equation 1****Equation 2****Equation 3**

Pure silicon is a hard, brittle, non-reactive substance with a metallic luster that forms a diamond lattice.

11. Silica in Equation 1 is:

- A) Combusted
- B) Reduced
- C) Oxidized
- D) Carbonated

12. The purification of elemental silicon was difficult to achieve because it:

- A) is a rare element.
- B) is too reactive to isolate easily.
- C) exists in minerals that do not decompose easily.
- D) does not crystallize.

13. Silicon is not as hard as diamond even though it forms a diamond lattice because:

- A) it is in Group IV on the periodic table.
- B) silicon atoms are larger than carbon atoms.
- C) silicon exhibits covalent bonding.
- D) it is in Period 3 on the periodic table.

14. What is the electron configuration for a ground-state silicon atom?

- A) $[\text{Ne}] 3s \uparrow\downarrow 3p \uparrow\uparrow _ _$
- B) $[\text{Ne}] 3s \uparrow\downarrow 3p \uparrow _ \downarrow _$
- C) $[\text{Ne}] 3s \uparrow\downarrow 3p \uparrow\downarrow _ _$
- D) $[\text{Ne}] 3s \uparrow\downarrow 3p \downarrow _ \downarrow _$

15. According to valence shell electron pair repulsion (VSEPR) theory, what is the geometry around silicon in SiCl_3H ?

- A) Linear
- B) Tetrahedral
- C) Trigonal bipyramidal
- D) Octahedral

16. Which of the following elements could best substitute for potassium in the purification of silicon?

- A) H_2
- B) Na
- C) Mg
- D) Ca

17. SiCl_3H has a normal boiling point of 33°C . What are the predominant forces between SiCl_3H molecules?
- A) Ionic forces
 B) Covalent bonds
 C) Hydrogen bonds
 D) van der Waals forces
18. SiCl_3H is purified by fractional distillation. Why does this procedure effect a purification?
- A) SiCl_3H is not soluble in water.
 B) SiCl_3H is decomposed by water.
 C) SiCl_3H has a lower boiling point than the solid impurities.
 D) SiCl_3H has a lower melting point than the impurities.

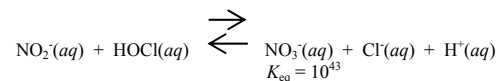
Passage III (Questions 19-28)

The reactions of many *oxyanions* (negatively charged ions that contain oxygen) involve the transfer of oxygen atoms from one ion or molecule to another. These reactions may have very large equilibrium constants (K_{eq}).

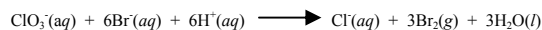
Reaction 1 shows a typical oxyanion reaction in which an oxygen atom is transferred.

**Reaction 1**

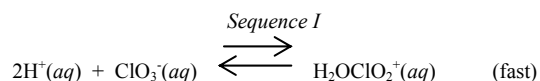
This reaction is extremely slow, despite the large equilibrium constant. The reaction rate can be increased by adding acid to the solution. When added, the acid reacts with OCl^- to form HOCl , which allows the oxygen transfer to take place more quickly. The rate of this reaction, Reaction 2, is first order in both NO_2^- and HOCl .

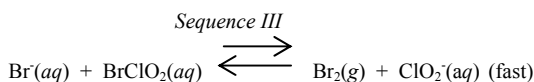
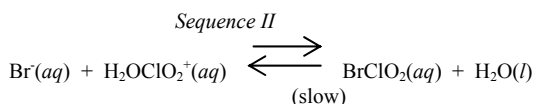
**Reaction 2**

Other oxyanion reactions also take place more quickly in acidic solutions. For example, no observable reaction occurs between ClO_3^- and Br^- in basic solution, but when an acidic solution is used, a redox reaction occurs and Reaction 3 occurs rapidly.

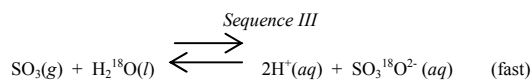
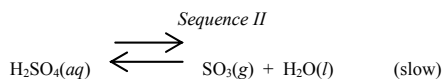
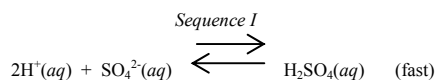
**Reaction 3**

The rate law for Reaction 3 is $k[\text{ClO}_3^-][\text{Br}^-][\text{H}^+]^2$, and the initial sequences of the reaction mechanism are shown below:





The transfer of oxygen-18 between H_2^{18}O and SO_4^{2-} is also more rapid in acid than in neutral solutions of SO_4^{2-} . A reaction mechanism has been proposed for this exchange:



19. Addition of hydrogen to OCl^- in Reactions 1 and 2 reduces the charge on the oxygen atom. This increases the reaction rate because (most probable):

- A) the oxidation number of the oxygen is increased from -2 to 0.
- B) the O-Cl bond is longer, facilitating breaking of the bond.
- C) NO_2^- can attack HOCl easier than OCl^- .
- D) chlorine will be a good leaving species on HOCl.

20. If the rate of formation of Cl^- in Reaction 3 were $1.0 \times 10^{-2} \text{ M/sec}$ at a pH of 1, what would it be at a pH of 2? (Assume that all the other conditions are identical.)

- A) $1 \times 10^{-1} \text{ M/sec}$
- B) $1 \times 10^{-2} \text{ M/sec}$
- C) $2 \times 10^{-2} \text{ M/sec}$
- D) $1 \times 10^{-4} \text{ M/sec}$

21. In the balanced equation of Reaction 3, how many electrons are transferred?

- A) 3
- B) 2
- C) 6
- D) 0

22. Compared to the rate of Reaction 1, the rate of Reaction 2:

- A) is 10^{25} times less.
- B) is 10^{25} times greater.
- C) is 1.58 times greater.
- D) cannot be evaluated without additional information.

23. In addition to the explanation in the passage, the rate of Reaction 2 is different from the rate of Reaction 1 because the formation of HOCl by the protonation of the oxygen:

- A) reduces the electronic repulsion forces between the reactants.
- B) increases the electronic repulsion forces between the reactants.
- C) increases the electronic repulsion forces between the nitrogen atom and the oxygen atom that is being transferred.
- D) reduces the electronic attraction forces between the chlorine atom and the oxygen atom that is being transferred.

24. *Sequence I* of the mechanism of Reaction 3 is a termolecular step because three species collide and react simultaneously to form the product. *Sequence II* is a bimolecular step, which should have a larger collision frequency and should be faster than a termolecular step at the same temperature. Why is *Sequence I* faster than *Sequence II*?

I - $\text{H}_2\text{OClO}_2^+$ is large and bulky;

II - Steps with more cations will react faster;

III - H^+ is smaller than Br^- .

- A) I, only
 B) I and III
 C) I and II
 D) I, II, and III

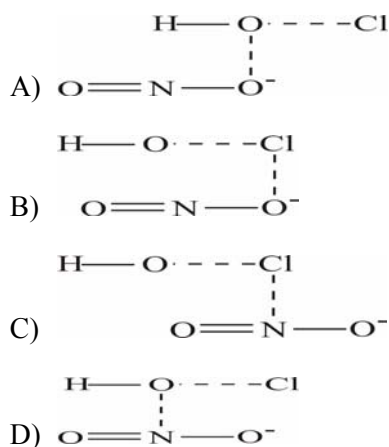
25. Which of the following methods would produce $\text{SO}_3^{18}\text{O}^{2-}$ at the fastest rate?

- A) Bubbling $\text{SO}_3(\text{g})$ through H_2^{18}O .
 B) Bubbling $\text{S}^{18}\text{O}_3(\text{g})$ through H_2^{18}O .
 C) Bubbling $\text{S}^{18}\text{O}_3(\text{g})$ through H_2O .
 D) Reacting $\text{SO}_2^{18}\text{O}(\text{l})$ with H_2^{18}O .

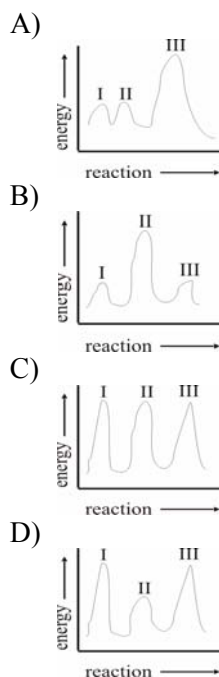
26. Multiple forms of a rate law exist for many reactions. An alternate form of the rate law of Reaction 3 could possibly be:

- A) $\text{rate} = k_{\text{I}}[\text{H}^+]^2[\text{ClO}_3^-]$
 B) $\text{rate} = k_{\text{III}}[\text{Br}^-][\text{BrClO}_2]$
 C) $\text{rate} = k_{\text{II}}[\text{Br}^-][\text{H}_2\text{OClO}_2^+]/[\text{BrClO}_2]$
 D) $\text{rate} = k_{\text{II}}[\text{Br}^-][\text{H}_2\text{OClO}_2^+]$

27. Which of the following represents the most likely transition state for Reaction 2?



28. Which of the following graphs best shows the energy diagram for the Reaction 3 mechanism in the passage?



Passage IV (Questions 29-37)

Colligative properties are solution properties that depend on the concentration of solute particles and not on their nature. They are better-suited to describe general solution dynamics, instead of generalizations such as “like dissolves like” and “the solubility of a solute doubles for every ten-degree rise in temperature”. Since there are various types of colligative properties, various concentration units must be used.

Molarity (M) is best for most stoichiometry problems, molality (m) for boiling point elevation problems, mole fraction (X) for Raoult-law problems, and osmolality for osmotic pressure problems.

Table 1 gives data for two water soluble solutes, ethylene glycol [$C_2H_6O_2(l)$] and lead nitrate [$Pb(NO_3)_2(s)$].

Table 1: Data for Ethylene Glycol and Lead Nitrate

Property	$C_2H_6O_2$	$Pb(NO_3)_2$
Formula Weight	62.1 g/mol	331 g/mol
Specific Gravity	1.116	4.53
Water Solubility at $0^\circ C$	∞	37.7 g/100 mL
Water Solubility at $20^\circ C$	∞	56.5 g/100 mL

Equation 1 shows an alternative form of the van't Hoff equation, which shows how the osmotic pressure (Π) depends on concentration (M) and on the Kelvin temperature (T).

$$\Pi = MRT$$

Equation 1

Note that $R = 0.082 \text{ L atm K}^{-1} \text{ mol}^{-1}$, and the molal freezing-point depression and boiling-point elevation constants for water are $K_f = -1.86^\circ C/m$ and $K_b = 0.52^\circ C/m$, respectively.

29. The increase in the solubility of the lead nitrate as the temperature increases suggests that for lead nitrate:

- A) the enthalpy of solution > 0 .
- B) the nitrate ion forms a complex ion with water.
- C) the hydration is an endothermic process.
- D) lead precipitates.

30. What is the molality of a saturated solution of $Pb(NO_3)_2(aq)$ at $0^\circ C$?

- A) 0.114 m
- B) 0.251 m
- C) 1.14 m
- D) 3.41 m

31. To what extent does a 10.75 m solution of ethylene glycol protect an engine from freezing?

- A) $-5.78^\circ C$
- B) $-12.0^\circ C$
- C) $-20.0^\circ C$
- D) $-45.0^\circ C$

32. Which aqueous solution, 0.1 M lead nitrate or 0.1 M ethylene glycol, lowers the freezing point of water to a greater extent?

- A) $Pb(NO_3)_2(aq)$ by threefold
- B) $Pb(NO_3)_2(aq)$ by twofold
- C) $C_2H_6O_2(aq)$ by twofold
- D) $C_2H_6O_2(aq)$ by threefold

- 33.** Does either generalization in the passage apply to aqueous solutions of ethylene glycol?
- A) Yes; both generalizations apply.
 - B) No; neither generalization applies.
 - C) Yes; “like dissolves like” only applies.
 - D) Yes; “the solubility of a solute doubles for every ten-degree rise in temperature” only applies.
- 34.** It was observed that the addition of ethylene glycol to water elevated the boiling point of the water. A possible explanation is:
- A) that a chemical reaction occurred producing an organic compound with boiling point of 104.5°C.
 - B) the ethylene glycol forms hydrogen bonds with water and lowers the vapor pressure.
 - C) the solution temperature drops drastically, therefore requiring more energy to initiate boiling.
 - D) the volatility of the water is reduced.
- 35.** If a cell wall separates a hypertonic, interstitial fluid from cellular fluid, will there be an osmotic effect?
- A) Yes; the cell fluid will become less concentrated.
 - B) Yes; the cell fluid will become more concentrated.
 - C) No; osmosis does not apply to biological fluids.
 - D) No; the concentrations are the same on both sides of the wall.
- 36.** What kind of solution results if a chemist equilibrates 39.0 g of lead nitrate in 100 mL of H₂O at 0°C over several days?
- A) A saturated solution with 3.9 g of undissolved salt.
 - B) A saturated solution with 1.3 g of undissolved salt.
 - C) An unsaturated solution.
 - D) A supersaturated solution.
- 37.** What is the mole fraction (X) of lead nitrate in a 10% (wt-wt) aqueous solution?
- A) 0.006
 - B) 0.03
 - C) 0.1
 - D) 0.6
-

Passage V (Questions 38-46)

Ammonia can be prepared by the Haber process in a reversible reaction between H_2 and N_2 in the presence of a mixture of FeO and $\text{Al}_2\text{K}_2\text{O}_4$ (see Reaction 1) under a variety of experimental conditions (see Table 1).

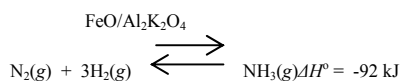
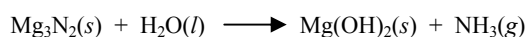
**Reaction 1**

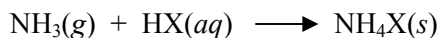
Table 1: Equilibrium Concentrations of $\text{NH}_3(\text{g})$ at Several Temperatures and Pressures

Pressure (atm)	Equilibrium concentration of $\text{NH}_3(\text{g})$ (% by volume)			
	at 200°C	at 400°C	at 600°C	at 800°C
1	15.3	0.44	0.05	0.01
100	80.6	25.1	4.47	1.15
200	85.8	36.3	8.25	2.24
1,000	98.3	80.0	31.5	---

NH_3 can also be prepared by reacting a metal nitride, such as Mg_3N_2 , with H_2O , as summarized by the following unbalanced equation (Reaction 2).

**Reaction 2**

Ammonia and ammonium salts are used as commercial fertilizers. Ammonium salts are prepared by reacting NH_3 with HX (an acid) as shown below (Reaction 3).

**Reaction 3**

The approximate electronegativities of several elements are given in Table 2.

Table 2: Electronegativities of Several Elements

Element	Electronegativity
H	2.20
I	2.66
N	3.04
O	3.44
F	3.98
Br	3.00

38. Is Reaction 1 exothermic under standard conditions?

- A) Yes, because heat must be added to initiate the reaction.
- B) Yes, because the standard enthalpy change is negative.
- C) No, because the percent yield of NH_3 is greatest at high pressure.
- D) No, because the standard enthalpy change is negative.

39. Under similar ambient conditions and concentrations, the most vigorous reaction should occur between NH_3 and:

- A) HI
- B) HF
- C) H_2O
- D) HBr

40. What type of reaction is Reaction 3?

- A) Solvation
- B) Hydrogenation
- C) Neutralization
- D) Oxidation

41. Based on the results reported in Table 1:

- A) a temperature increase reduces the NH_3 yield because the reaction is endothermic.
- B) the rate of change of NH_3 at 800°C is the lowest because iron-based mixtures such as $\text{FeO}/\text{Al}_2\text{K}_2\text{O}_4$, are known to retard the reaction at high temperatures.
- C) increasing the pressure increases the NH_3 yield since the products occupy a smaller volume.
- D) the volume of the reaction chamber has little effect on the NH_3 yield.

42. The most likely role of the $\text{FeO}/\text{Al}_2\text{K}_2\text{O}_4$ mixture used in Reaction 1 is to:

- A) increase the rate of the reaction.
- B) increase the equilibrium constant.
- C) provide energy to facilitate the reaction.
- D) lower the pH of the reaction mixture.

43. If excess $\text{NH}_3(\text{g})$ reacts with $\text{H}_2\text{SO}_4(\text{aq})$, which of the following compounds can be produced?

- A) NH_4SO_4
- B) $\text{NH}_4\text{H}_2\text{SO}_4$
- C) $\text{NH}_4(\text{SO}_4)_2$
- D) $(\text{NH}_4)_2\text{SO}_4$

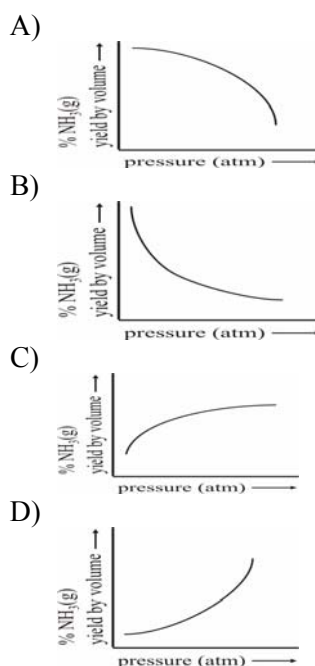
44. What kind of interactions take place between molecules of the product of Reaction 1?

- A) Ionic only
- B) Hydrogen bonding only
- C) Dipole-dipole only
- D) Both hydrogen bonding and dipole-dipole

45. Which of the following ions involved in Reaction 2 is the strongest base?

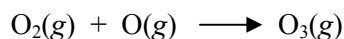
- A) $\text{N}^{3-}(\text{aq})$
- B) $\text{OH}^-(\text{aq})$
- C) $\text{Mg}^{2+}(\text{aq})$
- D) $\text{H}^+(\text{aq})$

46. Which of the following graphs best shows the effect of pressure on the equilibrium percentage yield of $\text{NH}_3(\text{g})$ at 200°C ?



Passage VI (Questions 47-55)

Ozone (O_3) is formed in the upper atmosphere by the following reactions:

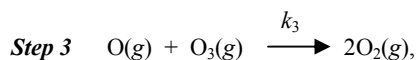
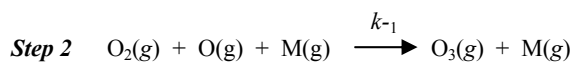
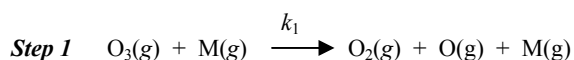
**Reaction 1****Reaction 2**

Reactions 1 and 2 are photochemically reversible, so ozone is removed at a rate that is equal to the rate of its formation, and a steady state concentration is reached. Table 1 summarizes the thermodynamic data for the oxygen species involved in ozone formation.

Table 1: Thermodynamic Properties of Oxygen

Oxygen Species	S (J/mol·K)	ΔH_f (kJ/mol)	ΔG_f (kJ/mol)
O	161.0	247.5	230.1
O_2	205.0	0	0
O_3	238.8	142	163.4

Ozone can be converted to oxygen through the three-step mechanism of Reaction 3.

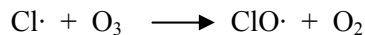
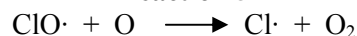


where M is a grain of dust and k is the rate constant.

Reaction 3

The ozone balance has been disturbed, resulting in a net loss of ozone in the upper atmosphere. It is believed that this is due in part to reactions involving chlorofluorocarbons (CFC's) such as CF_3Cl . Although CFC's are typically inert, they can undergo photolysis in the stratosphere and

subsequently assist in the decomposition of ozone according to Reactions 4 – 6.

**Reaction 4****Reaction 5****Reaction 6**

This mechanism is supported by evidence that periodic increases in $ClO\cdot$ in the stratosphere correlate well with times of ozone depletion.

47. A compound that significantly assists in ozone depletion CANNOT be:

- A) a gas.
- B) a radical precursor.
- C) inert in the lower atmosphere.
- D) inert in the upper atmosphere.

48. The chlorine atom in Reaction 5 is very reactive because it has:

- A) an unpaired electron.
- B) an extra electron.
- C) an expanded octet.
- D) a partial negative charge.

49. The grain of dust, M, in the mechanism of Reaction 3 is:

- A) a catalyst
- B) a pollutant
- C) an intermediate
- D) a radical

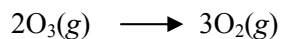
50. Which of the following is the balanced net reaction that is described by Reactions 5 and 6?

- A) $O_3 + O \longrightarrow O_2$
- B) $O_3 + O \longrightarrow 2O_2$
- C) $Cl\cdot + O_3 \longrightarrow Cl\cdot + O + O_2$
- D) $O_3 + ClO\cdot \longrightarrow 2O_2 + Cl\cdot$

51. Does the mechanism of Reaction 3 have a rate-determining step?

- A) Step 1
- B) Step 2
- C) Step 3
- D) No

52. According to Table 1, what is ΔS of the following reaction?

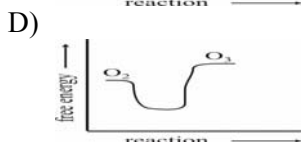
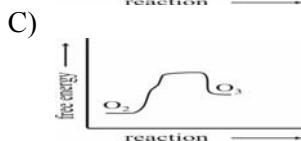
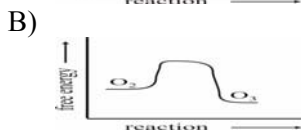
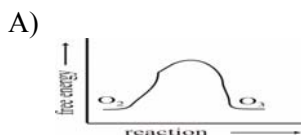


- A) $-33.8 \text{ J/mol}\cdot\text{K}$
- B) $33.8 \text{ J/mol}\cdot\text{K}$
- C) $-137.4 \text{ J/mol}\cdot\text{K}$
- D) $137.4 \text{ J/mol}\cdot\text{K}$

53. From Reactions 4 – 6, what can be determined about the relative concentrations of CFC's and O_2 ?

- A) One equivalent of CFC is required to produce one equivalent of O_2 .
- B) One equivalent of CFC is required to produce two equivalents of O_2 .
- C) A catalytic amount of CFC can produce much O_2 .
- D) The CFC is produced by a catalytic amount O_2 .

54. Based on Table 1, which of the following graphs most accurately depicts the free energy changes during the course of Reactions 1 and 2?



55. Would the overall reaction described by Reactions 1 and 2 and the properties of Table 1 be spontaneous?

- A) Yes, because ΔS is negative.
 - B) No, because the temperature is low.
 - C) No, because ΔG is positive.
 - D) Yes, because ΔH is positive.
-

Passage VII (Questions 56-64)

Transition metals are found within the *d* block of the periodic table. A group of graduate students performed two experiments to study several transition metals.

Experiment A

The students reacted four transition metals with nonmetals and observed the products formed (Table 1).

Table 1: Products of Reacting Transition Metals with Nonmetals

Transition Metal	Nonmetal				
	O ₂ (g)	S(s)	Cl ₂ (g)	Br ₂ (g)	I ₂ (s)
Ni	NiO	NiS	NiCl ₂	NiBr ₂	NiI ₂
Cu	Cu ₂ O, CuO	Cu ₂ S	CuCl ₂	CuBr ₂	CuI
Zn	ZnO	ZnS	ZnCl ₂	ZnBr ₂	ZnI ₂
Ag	Ag ₂ O	Ag ₂ S	AgCl	AgBr	AgI

Experiment B

The students then prepared nitrate solutions of 0.1 M $X(\text{NO}_3)_n(\text{aq})$, where *X* represents a transition metal. Then they prepared the following three reagents:

Reagent 1 0.1 M NaCl(aq)

Reagent 2 0.1 M (NH₄)₂C₂O₄(aq)

Reagent 3 0.1 M Na₂CO₃(aq)

2.0 mL of $X(\text{NO}_3)_n(\text{aq})$ was poured into each of three test tubes. 2.0 mL of NaCl(aq) was added to the first tube, 2.0 mL of (NH₄)₂C₂O₄(aq) was added to the next tube, and 2.0 mL of Na₂CO₃(aq) to the third tube. The students observed whether a precipitate formed and they noted its color (Table 2).

Table 2: Results of adding Reagents to Transition Metal Solutions

Transition Metal Nitrate	Color of precipitate		
	NaCl(aq)	(NH ₄) ₂ C ₂ O ₄ (aq)	Na ₂ CO ₃ (aq)
Ni(NO ₃) ₂ (aq)	*	*	green
Cu(NO ₃) ₂ (aq)	*	aqua	blue
Zn(NO ₃) ₂ (aq)	*	white	white
Cd(NO ₃) ₂ (aq)	white	white	white
AgNO ₃ (aq)	white	colorless	yellow

* indicates that no precipitate formed.

Finally, the students added 2.0 mL of 1.0 M HNO₃(aq) to each tube containing a precipitate. In all but two cases, the precipitate disappeared when HNO₃(aq) was added. The precipitate remained in the tube that contained AgNO₃(aq) and NaCl(aq) and in the tube that contained AgNO₃(aq) and (NH₄)₂C₂O₄(aq).

56. When the Zn(NO₃)₂(aq) solution is mixed with the Na₂CO₃(aq) solution, Zn(NO₃)₂ was in excess. What was the maximum mass of white substance produced?

- A) 0.02 g
- B) 0.03 g
- C) 0.04 g
- D) 0.06 g

57. Cu attains a different oxidation state when it reacts with Cl₂(g) than when it reacts with I₂(s) because Cl₂(g):

- A) has a higher boiling point than I₂(s).
- B) has a lower boiling point than I₂(s).
- C) attracts electrons more strongly than I₂(s).
- D) attracts electrons less strongly than I₂(s).

58. What was the most likely identity of the precipitate that formed when $\text{NaCl}(aq)$ was added to $\text{Cd}(\text{NO}_3)_2(aq)$?
- $\text{Cd}_2\text{Cl}(s)$
 - $\text{CdCl}(s)$
 - $\text{CdCl}_2(s)$
 - $\text{CdCl}_3(s)$
59. The precipitate remained in the tube that contained $\text{AgNO}_3(aq)$ and $\text{NaCl}(aq)$ when $\text{HNO}_3(aq)$ was added because:
- Na inhibited a chemical reaction.
 - Cl^- is the conjugate base of $\text{HCl}(aq)$.
 - silver compounds cannot react with $\text{HNO}_3(aq)$.
 - more precipitate was actually formed upon the addition of $\text{HNO}_3(aq)$.
60. If Cd is reacted with S, what is the most likely oxidation state of Cd in the product?
- +1
 - +2
 - +4
 - +6
61. When a strip of Zn is placed into very cold $\text{H}_2\text{O}(l)$, no change is observed. However, when that same strip of Zn is placed into a solution of $\text{HNO}_3(aq)$, a gas evolves. What is the most likely identity of the gas?
- $\text{NO}(g)$
 - $\text{CO}_2(g)$
 - $\text{H}_2(g)$
 - $\text{O}_3(g)$
62. Which of the following will occur if the acidity of a saturated solution of $\text{Cu}(\text{OH})_2$ is increased?
- The K_{sp} will decrease and additional $\text{Cu}(\text{OH})_2$ will dissolve.
 - The K_{sp} will remain unchanged and additional $\text{Cu}(\text{OH})_2$ will dissolve.
 - The K_{sp} will decrease and additional $\text{Cu}(\text{OH})_2$ will precipitate.
 - The K_{sp} will remain unchanged and additional $\text{Cu}(\text{OH})_2$ will precipitate.
63. In Experiment B, is the boiling point of $\text{Zn}(\text{NO}_3)_2(aq)$ higher than that of $\text{AgNO}_3(aq)$?
- Yes, because the solute in $\text{Zn}(\text{NO}_3)_2(aq)$ is ionic, whereas the solute in $\text{AgNO}_3(aq)$ is not.
 - Yes, because the solute in $\text{Zn}(\text{NO}_3)_2(aq)$ dissociates into three ions, and the solute in $\text{AgNO}_3(aq)$ dissociates into two ions.
 - No, because the solute in $\text{Zn}(\text{NO}_3)_2(aq)$ has a higher molecular weight than the solute in $\text{AgNO}_3(aq)$.
 - No, because $\text{Zn}(\text{NO}_3)_2(aq)$ contains fewer grams of solute than does $\text{AgNO}_3(aq)$.
64. When a strip of Cu is placed in $\text{AgNO}_3(aq)$, a new metal forms on the surface of the Cu strip. This occurs because Cu is:
- reduced and Ag is oxidized.
 - reduced and Ag^+ is oxidized.
 - oxidized and Ag is reduced.
 - oxidized and Ag^+ is reduced.
-

Passage VIII (Questions 65-73)

A general chemist conducted several experiments in which an unknown substance, *Y*, was reacted with various quantities of Ti. Samples of the resulting products were found to contain 0%, 1%, 3%, and 5% Ti, and were referred to as YT-0, YT-1, YT-3, and YT-5, respectively.

Experiment 1

The solubilities of the YT's were determined by adding a fixed amount of each to two different solvents, tetrahydrofuran, THF [(CH₂)₄O] and toluene [CH₃(CH)₅C]. These two solvents are organic in nature and have ringed structures. The results are shown in Table 1.

Table 1: Percent Solubility of XT Samples

Compound	Amount of sample that dissolves (%)	
	THF	Toluene
YT-0	32	35
YT-1	35	38
YT-3	50	53
YT-5	60	65

Experiment 2

The YT's were placed under N₂(g), then heated to 1500°C, cooled, and reheated. The mass of each sample was recorded at various temperatures during the process (see Table 2).

Table 2: Effects of Temperature Change on the Mass of YT Samples

Temperature (°C)	Mass of Sample (g)	
	YT-0	YT-1, 3, and 5*
20	1.0	1.0
700	0.8	0.8
1200	0.8	0.8
1500	0.8	1.1
20	0.8	0.8
1200	0.8	0.8
1500	0.8	1.1

* YT-1, 3, and 5 responded the same way.

65. Which of the following conclusions on YT solubility is the most consistent with the data presented in Table 1?

- A) The solubility of YT's in THF decreases as the percentage of Ti increases.
- B) The solubility of YT's in toluene decreases as the percentage of Ti increases.
- C) YT's are more soluble in THF than in toluene.
- D) YT's are more soluble in toluene than in THF.

66. Which of the following statements is true about the stability of the toluene and THF molecule?

- A) Delocalization and double bonds make toluene more stable than THF.
- B) The oxygen atom makes THF more stable than toluene.
- C) The oxygen atom in THF increases ring strain, making THF less stable than toluene.
- D) All molecules with seven carbons, such as toluene, are always less stable than atoms with four carbons, such as THF.

67. Electrons in which of the following orbitals of Ti can form bonds with Substance Y?

- A) 2s
- B) 3d
- C) 4p
- D) 5f

68. The loss in weight as YT's are heated from 20°C to 700°C most likely occurs because:

- A) hydrogen bonds are formed.
- B) XT's are ionized.
- C) nuclei emit protons.
- D) volatile components are released.

69. Which of the following elements, if reacted with Substance Y, will most likely yield compounds with the same properties as the YT's described in the passage?
- A) Sc
 - B) Cr
 - C) Zr
 - D) Mo
70. Which of the two solvents will have the higher boiling point?
- A) THF, because THF forms hydrogen bonds with water, but toluene does not.
 - B) THF, because THF forms stronger hydrogen bonds with water than does toluene.
 - C) Toluene, because toluene contains double bonds, but THF does not.
 - D) Toluene, because toluene has a higher molecular weight than does THF.
71. Which of the following is the orbital hybridization of O in THF?
- A) sp^2
 - B) sp^3
 - C) sp^3d^2
 - D) s^2p^2
72. The principal quantum number of Ti is 4. This is a measure of which of the following?
- A) Approximate radial size of the Ti electron cloud.
 - B) Approximate shape of the Ti electron cloud.
 - C) Number of valence electrons that orbit the Ti nucleus.
 - D) Number of protons and neutrons found in the nucleus of the Ti atom.
73. Most metals tend to combine with non-metals through ionic reactions, such as Ti with oxygen, to form titanium oxide, TiO. What would be the most stable electronic configuration of the titanium ion, Ti^{2+} ?
- A) $[Ar]4s^23d^2$
 - B) $[Ar]4s^2$
 - C) $[Ar]4s^24d^2$
 - D) $[Ar]3d^2$
-

Passage IX (Questions 74-82)

Elements are unique because atoms of any given element differ from all others. The location of an atom on the periodic table may make it possible for a chemist to predict the behavior of the element. Atomic properties, such as the ionization energies, the electron affinities, and the electronegativities may be compared qualitatively based on the position of the elements on the periodic table. Table 1 shows the electronegativities of certain main-group elements.

Table 1: Electronegativities of Selected Elements

I	II	III	IV	V	VI	VII
Li 1.0	Be 1.5	B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2	Al 1.5	Si 2.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8
Rb 0.8	Sr 1.0	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5

Chemical bonds are commonly classified as ionic or covalent. Most ionic compounds are solids at room temperature. Some covalent compounds are solids, but many are liquids and gases. The vast majority of covalent compounds are comprised exclusively of nonmetallic elements, whereas binary ionic compounds are made up of a metal and non-metal. Aqueous solutions of ionic compounds conduct electricity, whereas those of covalent compounds do not. The atomic properties of the bonded atoms provide information about the nature of a chemical bond.

74. Why does the electronegativity typically increase from left to right in Table 1?

- A) The atoms become larger from left to right.
- B) The shielding effect on valence electrons is reduced from left to right.
- C) The degree of paramagnetism increases from left to right.
- D) The electron affinity typically becomes more negative from left to right.

75. With respect to bonding and electrical conductivity, respectively, sulfur hexafluoride, $\text{SF}_6(\text{g})$, would be described as:

- A) covalent and a nonconductor.
- B) ionic and a nonconductor.
- C) covalent and a conductor.
- D) ionic and a conductor.

76. Ionic bonding involves the transfer of electrons. Which metal in the following compounds required the least amount of energy to liberate electrons?

- A) MgS
- B) AlBr_3
- C) RbCl
- D) Li_2O

77. Where are nonmetals found in the periodic table?

- A) Right side
- B) Left side
- C) Top half
- D) Bottom half

78. Which of the following statements must be true?

- A) The ionization energy for metals are low, and the electron affinity of non-metals are high.
- B) The atomic radius increases when an electron is lost.
- C) Longer covalent bonds require more energy to break than smaller covalent bonds.
- D) Covalent bonds tend to be stronger than ionic bonds.

79. Which of the following pairs of compounds provides an example of ionic and covalent bonding, respectively?

- A) HBr(g) and NaCl(s)
- B) NaCl(s) and NaI(s)
- C) NaI(s) and NaCl(s)
- D) NaCl(s) and HBr(g)

80. Which of the following compounds has the most ionic character?

- A) KBr(s)
- B) CsCl(s)
- C) NaI(s)
- D) RbBr(s)

81. Which of the following statements is consistent with the incorrect conclusion that HCl is an ionic compound?

- A) It is a gas at room temperature.
- B) A 1 M solution freezes below 0°C.
- C) A 1 M solution conducts electricity.
- D) It is composed of two non-metals.

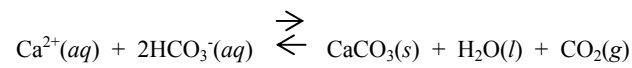
82. Which of the following solids has the highest melting point?

- A) NaCl(s)
- B) CsF(s)
- C) KI(s)
- D) LiCl(s)

Passage X (Questions 83-91)

Water hardness is a phenomenon in which calcium and other ions form insoluble compounds with ordinary soap. Ground water originating from limestone regions may contain calcium in the form of CaCO₃. The high solubility of CaCO₃ in acidic solutions (due to conversion to soluble Ca(HCO₃)₂) is responsible for water hardness in these regions.

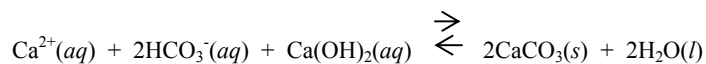
Acidic groundwater can be “softened” by simply boiling, which results in the removal of calcium ions, as shown in Reaction 1.



Reaction 1

The precipitated calcium carbonate is then removed by filtration.

An alternative method of achieving the same result is to add calcium hydroxide to the water, which permits removal of the calcium hydrogen carbonate by Reaction 2.



Reaction 2

This method is preferred for reducing water hardness on a large scale because of the large fuel cost of boiling.

83. A student measured the concentration of calcium ions in a sample of water and found that it was $1.6 \times 10^{-7} M$. What is the concentration ppm?

- A) 0.006
- B) 0.014
- C) 0.028
- D) 0.056

- 84.** Reaction 1 is an effective means of decreasing the hardness of an acidic water sample because it:
- A) increases the pH and decreases the solubility of CaCO_3 .
 - B) decreases the pH and decreases the solubility of CaCO_3 .
 - C) increases the pH and converts HCO_3^- to water.
 - D) decreases the pH and removes Ca^{2+} from solution.
- 85.** What is the effect of a high level of atmospheric CO_2 on the hardness of water in limestone regions?
- A) It would lower the pH and increase the solubility of CaCO_3 .
 - B) It would raise the pH and increase the solubility of CaCO_3 .
 - C) It would lower the pH and decrease the solubility of CaCO_3 .
 - D) It would raise the pH and decrease the solubility of CaCO_3 .
- 86.** How many grams of CaCO_3 would be formed in Reaction 1 if the CO_2 evolved occupies 11.2 L at STP?
- A) 0.5
 - B) 11.2
 - C) 50
 - D) 100
- 87.** The equation of Reaction 2 is which type of reaction?
- A) Carbonation
 - B) Hydroxylation
 - C) Neutralization
 - D) Hydration
- 88.** If the pH of the water sample were high such that all the carbonate is present as CO_3^{2-} , what would be the concentration of Ca^{2+} ? (The K_{sp} of CaCO_3 is 4.8×10^{-9})
- A) $(4.8 \times 10^{-9})^2 M$
 - B) $(4.8 \times 10^{-9})^{1/2} M$
 - C) $4.8 \times 10^{-9} M$
 - D) $(4.8 \times 10^{-9})^{1/3} M$
- 89.** The addition of excess Ca^{2+} to a solution containing Ca^{2+} and CO_3^{2-} ions causes CaCO_3 to precipitate because:
- A) K_{sp} for CaCO_3 would increase due to the increase in $[\text{Ca}^{2+}]$.
 - B) K_{sp} for CaCO_3 would decrease due to the increase in $[\text{Ca}^{2+}]$.
 - C) $[\text{CO}_3^{2-}]$ would increase to maintain K_{sp} .
 - D) $[\text{CO}_3^{2-}]$ would decrease to maintain K_{sp} .
- 90.** Which of the following about the calcium ion is correct?
- A) It is a monovalent ion.
 - B) It is neutral toward water.
 - C) Hydrated calcium ions are acidic.
 - D) It will react violently with gaseous oxygen to form calcium oxide.
- 91.** The calcium ion is isoelectronic with which atom?
- A) K
 - B) Kr
 - C) Ar
 - D) Mg
-

Passage XI (Questions 92-100)

Archaeobacteria are a special type of bacteria found in environments that have harsh climatic conditions, such as salt lakes or very acidic or alkaline hot springs. *Chemoautotrophs* are a type of archaeobacteria that obtain energy by a redox reaction. Methanogens, a type of chemoautotroph, produce methane by metabolizing CO_2 . The bond energy of $\text{C}=\text{O}$ in CO_2 is 803 kJ/mol, and the $\text{C}-\text{H}$ bond energy in CH_4 is 414 kJ/mol.

Table 1 shows the chemical formula of some species that are typically found in environments where archaeobacteria thrive.

Table 1: Chemical Species

Species	Formula
Methane	CH_4
Glycine	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$
Potassium hydroxide	KOH
Sulfuric acid	H_2SO_4
Carbon dioxide	CO_2
Methanol	CH_3OH
Sodium chloride	NaCl
Hydrogen sulfide	H_2S

The methane found in swamp gas is a byproduct of methanogens, which are also found in a symbiotic association with a variety of cellulose-digesting organisms, including cows and termites. Carbon-14 isotopic analysis suggests that methane found deep in the earth's crust might have been produced by archaeobacteria.

92. Scientists are most likely to find which compound listed in Table 1 in an alkaline lake?

- A) NaCl
- B) CH_3OH
- C) H_2SO_4
- D) KOH

93. Which statements are true?

- I The bonds in CO_2 are stronger than those in CH_4 .
- II The bonds in CO_2 are longer than those in CH_4 .
- III The geometry of CO_2 is linear, and that of CH_4 is tetrahedral.

- A) I and II
- B) I and III
- C) II and III
- D) I, II, and III

94. What pair of compounds found in Table 1 can form extensive networks of intermolecular hydrogen bonds with both participating?

- A) Methane and methanol
- B) Methane and glycine
- C) Glycine and methanol
- D) Methanol and carbon dioxide

95. How does an atom of carbon-14 differ from the most abundant isotope of carbon?

- A) By one proton
- B) By two protons
- C) By one neutron
- D) By two neutrons

96. Glycine, methanol, and potassium hydroxide all contain a $-\text{OH}$ group. Are they different types of compounds?

- A) Yes, because glycine is an acid, potassium hydroxide is a base, and methanol can be either an acid or base.
- B) Yes, because glycine and potassium hydroxide are bases, and methanol can be either an acid or base.
- C) Yes, because glycine is an acid, potassium hydroxide is a base, and methanol is a base.
- D) No, all three species are bases.

97. If an archaebacterial species lives in a pool that is 0.01 M HCl(aq), what is the pH of the water?

- A) 12
- B) 6
- C) 2
- D) 0.01

98. Which of the following compounds has the same geometry as methane?

- A) H₂S
- B) CO₂
- C) XeF₄
- D) SiCl₄

99. Glycine passes through a very low pH membrane channel in which form?

- A) H₂N-CH₂-COOH
- B) H₃N⁺-CH₂-COOH
- C) H₂N-CH₂-COO⁻
- D) H₃N⁺-CH₂-COO⁻

100. Like oxygen atoms in methanogens, which of the following elements can act as an electron acceptor?

- A) S
 - B) He
 - C) H₂
 - D) Fe
-