1. When a sample of oxygen gas in a closed container of constant volume is heated until its absolute temperature is doubled, which of the following is also doubled?
   (A) The density of the gas
   (B) The pressure of the gas
   (C) The average velocity of the gas molecules
   (D) The number of molecules per cm³
   (E) The potential energy of the molecules

2. The density of an unknown gas is 4.20 grams per liter at 3.00 atmospheres pressure and 127 °C. What is the molecular weight of this gas?
   \( R = 0.0821 \text{ liter-atm/mole-K} \)
   (A) 14.6  (C) 88.0  (E) 138
   (B) 46.0  (D) 94.1

3. The molality of the glucose in a 1.0-molar glucose solution can be obtained by using which of the following?
   (A) Volume of the solution
   (B) Temperature of the solution
   (C) Solubility of glucose in water
   (D) Degree of dissociation of glucose
   (E) Density of the solution

4. The geometry of the \( \text{SO}_3 \) molecule is best described as
   (A) trigonal planar  \( \text{D) bent} \)
   (B) trigonal pyramidal  \( \text{E) tetrahedral} \)
   (C) square pyramidal

5. Which of the following molecules has the shortest bond length?
   (A) \( \text{N}_2 \)  \( \text{C) Cl}_2 \) \( \text{E) I}_2 \)
   (B) \( \text{O}_2 \)  \( \text{D) Br}_2 \)
6. Equal masses of three different ideal gases, X, Y, and Z, are mixed in a sealed rigid container. If the temperature of the system remains constant, which of the following statements about the partial pressure of gas X is correct?
   (A) It is equal to \( \frac{1}{3} \) the total pressure
   (B) It depends on the intermolecular forces of attraction between molecules of X, Y, and Z.
   (C) It depends on the relative molecular masses of X, Y, and Z.
   (D) It depends on the average distance traveled between molecular collisions.
   (E) It can be calculated with knowledge only of the volume of the container.

7. Which of the following has a zero dipole moment?
   (A) HCN
   (B) NH₃
   (C) SO₂
   (D) NO₂
   (E) PF₃

8. A 27.0-gram sample of an unknown hydrocarbon was burned in excess oxygen to form 88.0 grams of carbon dioxide and 27.0 grams of water. What is a possible molecular formula of the hydrocarbon?
   (A) CH₄
   (B) C₂H₂
   (C) C₃H₈
   (D) C₄H₆
   (E) C₅H₁₀

9. For which of the following molecules are resonance structures necessary to describe the bonding satisfactorily?
   (A) H₂S
   (B) SO₂
   (C) CO₂
   (D) OF₂
   (E) PF₃

10. Which of the following aqueous solutions has the highest boiling point?
    (A) 0.10 M potassium sulfate, K₂SO₄
    (B) 0.10 M hydrochloric acid, HCl
    (C) 0.10 M ammonium nitrate, NH₄NO₃
    (D) 0.10 M magnesium sulfate, MgSO₄
    (E) 0.20 M sucrose, C₁₂H₂₂O₁₁

11. A sample of 9.00 grams of aluminum metal is added to an excess of hydrochloric acid. The volume of hydrogen gas produced at standard temperature and pressure is
    (A) 22.4 liters
    (B) 11.2 liters
    (C) 7.46 liters
    (D) 5.60 liters
    (E) 3.74 liters
Questions 12–15 refer to the following descriptions of bonding in different types of solids.

(A) Lattice of positive and negative ions held together by electrostatic forces
(B) Closely packed lattice with delocalized electrons throughout
(C) Strong single covalent bonds with weak intermolecular forces
(D) Strong multiple covalent bonds (including Pi-bonds) with weak intermolecular forces
(E) Macromolecules held together with strong polar bonds

12. Cesium chloride, $\text{CsCl}(s)$  \( \text{A} \)
13. Gold, $\text{Au}(s)$  \( \text{B} \)
14. Carbon dioxide, $\text{CO}_2(s)$  \( \text{D} \)
15. Methane, $\text{CH}_4(s)$  \( \text{C} \)

16. What mass of Au is produced when 0.0500 mol of $\text{Au}_2\text{S}_3$ is reduced completely with excess $\text{H}_2$?
   (A) 9.85 g  \( \text{B} \) 19.7 g  \( \text{C} \) 24.5 g
   (D) 39.4 g  \( \text{E} \) 48.9 g

17. The cooling curve for a pure substance as it changes from a liquid to a solid is shown above. The solid and the liquid coexist at
   (A) point Q only
   (B) point R only
   (C) all points on the curve between Q and S
   (D) all points on the curve between R and T
   (E) no point on the curve
18. The melting point of MgO is higher than that of NaF. Explanations for this observation include which of the following?

I. Mg\(^{2+}\) is more positively charged than Na\(^+\).
II. O\(^{2-}\) is more negatively charged than F\(^-\).
III. The O\(^{2-}\) ion is smaller than the F\(^-\) ion.

(A) I only  (B) I and II only  (C) I and III only  (D) II and III only  (E) I, II, and III

19. Types of hybridization exhibited by the C atoms in propene, CH\(_2\)CHCH\(_2\), include which of the following?

I. sp  II. sp\(^2\)  III. sp\(^3\)

(A) I only  (B) III only  (C) I and II only  (D) II and III only  (E) I, II, and III

20. If the temperature of an aqueous solution of NaCl is increased from 20 °C to 90 °C which of the following statements is true?

(A) The density of the solution remains unchanged.
(B) The molarity of the solution remains unchanged.
(C) The molality of the solution remains unchanged.
(D) The mole fraction of solute decreases.
(E) The mole fraction of solute increases.

21. A 1.0 L sample of an aqueous solution contains 0.10 mol of NaCl and 0.10 mol of CaCl\(_2\). What is the minimum number of moles of AgNO\(_3\) that must be added to the solution in order to precipitate all of the Cl\(^-\) as AgCl(s)? (Assume that AgCl is insoluble.)

(A) 0.10 mol  (B) 0.20 mol  (C) 0.30 mol  (D) 0.40 mol  (E) 0.60 mol
22. The ionization energies for element X are listed in the table above. On the basis of the data, element X is most likely to be

(A) Na   (B) Mg   (C) Al   (D) Si   (E) P

23. The phase diagram for a pure substance is shown above. Which point on the diagram corresponds to the equilibrium between the solid and liquid phases at the normal melting point?

(A) A   (B) B   (C) C   (D) D   (E) E

24. Of the following molecules, which has the largest dipole moment?

(A) CO   (B) CO₂   (C) O₂   (D) HF   (E) F₂

25. A rigid metal tank contains oxygen gas. Which of the following applies to the gas in the tank when additional oxygen is added at constant temperature?

(A) The volume of the gas increases.
(B) The pressure of the gas decreases.
(C) The average speed of the gas molecules remains the same.
(D) The total number of gas molecules remains the same.
(E) The average distance between the gas molecules increases.
W + X → Y + Z

26. Gases W and X react in a closed, rigid vessel to form gases Y and Z according to the equation above. The initial pressure of \( W_{(g)} \) is 1.20 atm and that of \( X_{(g)} \) is 1.60 atm. No \( Y_{(g)} \) or \( Z_{(g)} \) is initially present. The experiment is carried out at constant temperature. What is the partial pressure of \( Z_{(g)} \) when the partial pressure of \( W_{(g)} \) has decreased to 1.0 atm?

(A) 0.20 atm  (B) 0.40 atm  (C) 1.0 atm  
(D) 1.2 atm  (E) 1.4 atm

27. On a mountaintop, it is observed that water boils at 90 °C not at 100 °C as at sea level. This phenomenon occurs because on the mountaintop the

(A) equilibrium water vapor pressure is higher due to the higher atmospheric pressure
(B) equilibrium water vapor pressure is lower due to the higher atmospheric pressure
(C) equilibrium water vapor pressure equals the atmospheric pressure at a lower temperature
(D) water molecules have a higher average kinetic energy due to the lower atmospheric pressure
(E) water contains a greater concentration of dissolved gases

28. A 40.0 mL sample of 0.25 M KOH is added to 60.0 mL of 0.15 M Ba(OH)\(_2\). What is the molar concentration of \( OH^{-}_{(aq)} \) in the resulting solution? (Assume that the volumes are additive.)

(A) 0.10 M  (B) 0.19 M  (C) 0.28 M  
(D) 0.40 M  (E) 0.55 M

\[ \text{NH}_4\text{NO}_3(s) \rightarrow \text{N}_2\text{O}(g) + 2 \text{H}_2\text{O}(g) \]

29. A 0.03 mol sample of \( \text{NH}_4\text{NO}_3(s) \) is placed in a 1 L evacuated flask, which is then sealed and heated. The \( \text{NH}_4\text{NO}_3(s) \) decomposes completely according to the balanced equation above. The total pressure in the flask measured at 400 K is closest to which of the following? (The value of the gas constant, \( R \), is 0.082 L atm mol\(^{-1}\) K\(^{-1}\).)

(A) 3 atm  (B) 1 atm  (C) 0.5 atm  
(D) 0.1 atm  (E) 0.03 atm

\[ \text{C}_2\text{H}_4(g) + 3 \text{O}_2(g) \rightarrow 2 \text{CO}_2(g) + 2 \text{H}_2\text{O}(g) \]

30. For the reaction of ethylene represented above, \( \Delta H \) is -1,323 kJ. What is the value of \( \Delta H \) if the combustion produced liquid water \( \text{H}_2\text{O}(l) \), rather than water vapor \( \text{H}_2\text{O}(g) \)? (\( \Delta H \) for the phase change \( \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(l) \) is -44 kJ mol\(^{-1}\).)

(A) -1,235 kJ  (B) -1,279 kJ  (C) -1,323 kJ  
(D) -1,367 kJ  (E) -1,411 kJ
31. Equal numbers of moles of He(g), Ar(g), and Ne(g) are placed in a glass vessel at room temperature. If the vessel has a pinhole-sized leak, which of the following will be true regarding the relative values of the partial pressures of the gases remaining in the vessel after some of the gas mixture has effused?

(A) \( P_{He} < P_{Ar} < P_{Ne} \)  
(B) \( P_{Ne} < P_{Ar} < P_{He} \)  
(C) \( P_{Ne} < P_{Ar} < P_{He} \)  
(D) \( P_{Ar} < P_{Ne} < P_{He} \)  
(E) \( P_{Ne} = P_{Ar} = P_{He} \)

32. What is the final concentration of barium ions, \([\text{Ba}^{2+}]\), in solution when 100 mL of 0.10 \( M \) \( \text{BaCl}_2(aq) \) is mixed with 100 mL of 0.050 \( M \) \( \text{H}_2\text{SO}_4(aq) \)?

(A) 0.00 \( M \)  
(B) 0.012 \( M \)  
(C) 0.025 \( M \)  
(D) 0.075 \( M \)  
(E) 0.10 \( M \)

33. When 100 mL of 1.0 \( M \) \( \text{Na}_3\text{PO}_4 \) is mixed with 100 mL of 1.0 \( M \) \( \text{AgNO}_3 \), a yellow precipitate forms and \([\text{Ag}^+]\) becomes negligibly small. Which of the following is a correct listing of the ions remaining in solution in order of increasing concentration?

(A) \([\text{PO}_4^{3-}] < [\text{NO}_3^-] < [\text{Na}^+]\)  
(B) \([\text{PO}_4^{3-}] < [\text{Na}^+] < [\text{NO}_3^-]\)  
(C) \([\text{NO}_3^-] < [\text{PO}_4^{3-}] < [\text{Na}^+]\)  
(D) \([\text{Na}^+] < [\text{NO}_3^-] < [\text{PO}_4^{3-}]\)  
(E) \([\text{Na}^+] < [\text{PO}_4^{3-}] < [\text{NO}_3^-]\)

34. In a qualitative analysis for the presence of \( \text{Pb}^{2+} \), \( \text{Fe}^{2+} \), and \( \text{Cu}^{2+} \) ions in aqueous solution, which of the following will allow the separation of \( \text{Pb}^{2+} \) from the other ions at room temperature?

(A) Adding dilute \( \text{Na}_2\text{S(aq)} \) solution  
(B) Adding dilute \( \text{HCl(aq)} \) solution  
(C) Adding dilute \( \text{NaOH(aq)} \) solution  
(D) Adding dilute \( \text{NH}_3(aq) \) solution  
(E) Adding dilute \( \text{HNO}_3(aq) \) solution

35. Which of the following is lower for a 1.0–molar aqueous solution of any solute than it is for pure water?

(A) \( \text{pH} \)  
(B) Vapor pressure  
(C) Freezing point  
(D) Electrical conductivity  
(E) Absorption of visible light
36 In a molecule in which the central atom exhibits sp^3d^6 hybrid orbitals, the electron pairs are directed toward the corners of
(A) a tetrahedron
(B) a square-based pyramid
(C) a trigonal bipyramid
(D) a square
(E) an octahedron

37 A sample of 0.0100 mole of oxygen gas is confined at 37 °C and 0.216 atmosphere. What would be the pressure of this sample at 15 °C and the same volume?
(A) 0.0876 atm  (B) 0.175 atm
(C) 0.201 atm  (D) 0.233 atm
(E) 0.533 atm

38 CH₃CH₂OH boils at 78°C and CH₃OCH₃ boils at −24 °C, although both compounds have the same composition. This difference in boiling points may be attributed to a difference in
(A) molecular mass  (B) density
(C) specific heat  (D) hydrogen bonding
(E) heat of combustion

39 A hydrocarbon gas with an empirical formula CH₄ has a density of 1.88 grams per liter at 0 °C and 1.00 atmosphere. A possible formula for the hydrocarbon is
(A) CH₂  (B) C₂H₄  (C) C₃H₆
(D) C₄H₈  (E) C₅H₁₀

40 X. CH₃–CH₂–CH₂–CH₂–CH₃
Y. CH₃–CH₂–CH₂–CH₂–OH
Z. HO–CH₂–CH₂–CH₂–OH

Based on concepts of polarity and hydrogen bonding, which of the following sequences correctly lists the compounds above in the order of their increasing solubility in water?
(A) Z < Y < X  (B) Y < Z < X
(C) Y < X < Z  (D) X < Z < Y
(E) X < Y < Z
41. The system shown above is at equilibrium at 28 °C. At this temperature, the vapor pressure of water is 28 millimeters of mercury. The partial pressure of O₂(g) in the system is

(A) 28 mm Hg  (B) 56 mm Hg
(C) 133 mm Hg  (D) 161 mm Hg
(E) 189 mm Hg

42. A strip of metallic scandium, Sc, is placed in a beaker containing concentrated nitric acid. A brown gas rapidly forms, the scandium disappears, and the resulting liquid is brown–yellow but becomes colorless when warmed. These observations best support which of the following statements?

(A) Nitric acid is a strong acid.
(B) In solution scandium nitrate is yellow and scandium chloride is colorless.
(C) Nitric acid reacts with metals to form hydrogen.
(D) Scandium reacts with nitric acid to form a brown gas.
(E) Scandium and nitric acid react in mole proportions of 1 to 3.

43. All of the following statements concerning the characteristics of the halogens are true EXCEPT:

(A) The first ionization energies (potentials) decrease as the atomic numbers of the halogens increase.
(B) Fluorine is the best oxidizing agent.
(C) Fluorine atoms have the smallest radii.
(D) Iodine liberates free bromine from a solution of bromide ion.
(E) Fluorine is the most electronegative of the halogens.

44. What volume of 0.150–molar HCl is required to neutralize 25.0 milliliters of 0.120–molar Ba(OH)₂?

(A) 20.0 mL  (B) 30.0 mL
(C) 40.0 mL  (D) 60.0 mL  (E) 80.0 mL
45 Molecules that have planar configurations include which of the following?
I. BCl₃  II. CHCl₃  III. NCl₃

(A) I only  (B) III only  
(C) I and II only  (D) II and III only  
(E) I, II, and III

Questions 46-48

a. O  c. Rb  e. N  
b. La  d. Mg

46. What is the most electronegative element?  

47. Which element exhibits the greatest number of different oxidation states?  

48. Which of the elements above has the smallest ionic radius for its most commonly found ion?

49. Which of the following is probably true for a solid solute with a highly endothermic heat of solution when dissolved in water?
   a. The solid has a low lattice energy.  
   b. As the solute dissolves, the temperature of the solution increases.  
   c. The resulting solution is ideal.  
   d. The solid is more soluble at higher temperatures.  
   e. The solid has a high energy of hydration.

50. 2 K + 2 H₂O → 2K⁺ + 2 OH⁻ + H₂
   When 0.400 mole of potassium reacts with excess water at standard temperature and pressure as shown in the equation above, the volume of hydrogen gas produced is
   a. 1.12 liters  c. 3.36 liters  e. 6.72 liters  
   b. 2.24 liters  d. 4.48 liters