1. Which compound is correctly named?

A) HCl (aq) hydrogen chloride
B) H₂S sulfuric acid
C) CoCl₂ cobalt chloride
D) VPO₄ vanadium(III) phosphate
E) NaClO sodium chlorite

2. A radio wave has a frequency of 3.8 x 10¹⁰ s⁻¹. How many photons of this radiation are needed to produce 60.7 J of energy?

A) 2.52 x 10⁻²³ photons
B) 2.41 x 10⁻²⁴ photons
C) 1.74 x 10⁻⁴⁴ photons
D) 1.88 x 10¹⁷ photons
E) Not enough information

3. Rank the emissions in terms of increasing energy:
   I.  n = 5 → n = 4
   II. n = 3 → n = 2
   III. n = 2 → n = 1

A) I < II < III
B) III < II < I
C) II < I < III
D) III < I < II
E) The energies of emissions I, II, and III are all the same

4. Which statement is false?

A) The principle quantum number indicates the energy level and size of an orbital.
B) The only allowed values for the spin quantum number are +½ and − ½.
C) The values for the magnetic quantum number indicate the orientation of the orbitals in space.
D) The value l = 2 indicates a peanut shaped orbital.
E) With an increase in energy level, a new type of orbital becomes available.
5. How many orbitals in an atom can have the designation 5f?

A) 5
B) 7
C) 14
D) 25
E) 50

6. Which statement is true?

A) A 1.0 L sample of 0.200 M Ca(OH)\textsubscript{2} contains 1.20 \times 10^{23} hydroxide ions.
B) In a dilution, the volume of solution remains constant while the moles of solute decreases.
C) There are 124 moles of solute in 145.6 mL of 0.850 M sodium cyanide.
D) To prepare 0.80 L of 0.15 M NaCl, 0.020 L of 5.0 M NaCl must be diluted to a total volume of 800. mL.
E) It takes 21.1 g of KI to make 500.0 mL of 0.254 M KI solution.

7. Boron has two isotopes; one of these is boron-10 with a mass of 10.0129 amu and a percent abundance of 19.91%. If the universal mass of boron is 10.811, what is the mass of the other isotope of boron.

A) 11.01 amu
B) 44.29 amu
C) 14.02 amu
D) 10.90 amu
E) There is not enough information to answer this question.

8. All of the substances below are fertilizers. Which is the richest source of nitrogen on a mass percentage basis?

A) Urea, (NH\textsubscript{2})\textsubscript{2}CO
B) Ammonium nitrate, NH\textsubscript{4}NO\textsubscript{3}
C) Guanidine, HNC(NH\textsubscript{2})\textsubscript{2}
D) Ammonia, NH\textsubscript{3}
E) There is not enough information to answer this question
9. Depicted below is a reaction vessel containing a mixture of H\textsubscript{2}(g) and N\textsubscript{2}(g) before the reaction begins. The filled spheres represent nitrogen and the open spheres represent hydrogen. Given the equation below, which image best represents the vessel after reaction occurs?

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \]

A) ![Image A]
B) ![Image B]
C) ![Image C]
D) ![Image D]
E) ![Image E]
10. How many moles of carbon monoxide are required to react with one mole of O\(_2\)(g) to produce 2 moles of carbon dioxide gas?

A) \(\frac{1}{2}\)
B) 1
C) 2
D) \(\frac{3}{2}\)
E) 3

11. What are the spectator ions in the reaction of sulfuric acid with barium hydroxide?

A) \(\text{Ba}^{2+}\) and \(\text{SO}_4^{2-}\)
B) \(\text{H}^+\) and \(\text{OH}^-\)
C) \(\text{OH}^-\) and \(\text{Ba}^{2+}\)
D) \(\text{H}^+\) and \(\text{SO}_4^{2-}\)
E) There are no spectator ions in this reaction.

12. Which statement best explains why the following ionic radii trend is true?

\[ \text{S}^{2-} > \text{Cl}^- > \text{K}^+ \]

A) \(Z_{\text{eff}}\) increases with the number of electrons.
B) The potassium ion has the least amount of shielding, so \(Z_{\text{eff}}\) is greatest for it.
C) \(Z_{\text{eff}}\) increases with the number of protons.
D) The amount of shielding is equal, but the nucleus of sulfur is least positive resulting in smallest \(Z_{\text{eff}}\).
E) The radii trend above is not correct.

13. Which periodic trend refers to the ability of an atom in a molecule to attract electrons to itself?

A) electron affinity
B) ionization energy
C) polarizability
D) polarizing power
E) electronegativity
14. Which transition metal ion has the electron configuration [Ar]3d^3?
   A) V^{3+}
   B) Mn^{4+}
   C) Cr^{3+}
   D) Fe^{3+}
   E) Ti^{2+}

15. Which is the best resonance structure for the sulfate ion?

   A) ![Resonance Structure A]
   B) ![Resonance Structure B]
   C) ![Resonance Structure C]
   D) ![Resonance Structure D]
   E) ![Resonance Structure E]

16. Which molecule is trigonal pyramidal?
   A) SO_2
   B) AsBr_3
   C) BrF_3
   D) BH_3
   E) CH_2O

17. Which molecule or ion is polar?
   A) XeF_4
   B) PCl_3
   C) CCl_4
   D) I_3^-
   E) BH_3
18. Arrange the following in order of increasing net dipole (dipole moment).

I. \[ \begin{array}{c}
    \text{Cl} \\
    \text{Cl} \\
    \text{C} \\
    \text{Cl} \\
\end{array} \]

II. \[ \begin{array}{c}
    \text{Cl} \\
    \text{C} \\
    \text{Cl} \\
\end{array} \]

III. \[ \begin{array}{c}
    \text{Cl} \\
    \text{C} \\
    \text{Cl} \\
\end{array} \]

A) I < II < III  
B) III < I < II  
C) II < III < I  
D) II < I < III  
E) I < III < II

19. Which best explains the polarity of a bond?

A) Lewis theory  
B) VSEPR  
C) Valence bond theory  
D) Electronegativity  
E) Electron affinity

20. Which statement regarding the following Lewis structure is true?

\[ \begin{array}{c}
    :F: \\
    :F: \\
    :F: \\
\end{array} \]

A) The structure has too many electrons  
B) The structure has no resonance structures.  
C) The formal charge distribution prevents it from contributing significantly to the resonance hybrid.  
D) The structure is wrong because boron cannot have a complete octet.  
E) The structure is missing an overall charge.
21. What atomic orbitals are involved in the pi bond found in \( \text{O}_2 \)?

A) two s orbitals  
B) an s orbital and a p orbitals oriented along the internuclear axis  
C) two p orbitals oriented along the internuclear axis  
D) an s orbital and a p orbital that is perpendicular to the internuclear axis.  
E) two p orbitals that are perpendicular to the internuclear axis

22. How many and what type of atomic orbitals must be combined to account for the tetrahedral shape of \( \text{CH}_4 \)?

A) 2 s orbitals  
B) 4 p orbitals  
C) 8 p orbitals  
D) 1 s and 3 p orbitals  
E) 2 s and 6 p orbitals

23. Which of the following species has a longer bond length and why? \( \text{N}_2 \) or \( \text{N}_2^+ \)

A) \( \text{N}_2 \) has a longer bond because its bond order is smaller  
B) \( \text{N}_2 \) has a longer bond because its bond order is greater  
C) Both species have the same bond length  
D) \( \text{N}_2^+ \) has a longer bond because its bond order is smaller  
E) \( \text{N}_2^+ \) has a longer bond because its bond order is greater

24. What is the molecular orbital electron configuration for \( \text{F}_2^- \)?

A) \((\sigma 2s)^2(\sigma 2s^*)^2(\sigma 2p)^2(\pi 2p)^4(\pi 2p^*)^4(\pi 2p^*)^4\)  
B) \((\sigma 2s)^2(\sigma 2s^*)^2(\sigma 2p)^2(\pi 2p)^4(\pi 2p^*)^3\)  
C) \((\sigma 2s)^2(\sigma 2s^*)^2(\sigma 2p)^2(\pi 2p)^4(\pi 2p^*)^3\)  
D) \((\sigma 2s)^2(\sigma 2s^*)^2(\pi 2p)^4(\sigma 2p)^2(\pi 2p^*)^4(\sigma 2p^*)^3\)  
E) \((\sigma 2s)^2(\sigma 2s^*)^2(\pi 2p)^4(\sigma 2p)^2(\pi 2p^*)^3\)
25. The volume of a sample of ideal gas is 24.8 mL at 1.12 atm. If the pressure of the sample is increased, at constant temperature, to 2.64 atm, then what is the new volume of the sample in liters?

A) 10.5 L  
B) 0.119 L  
C) 0.0566 L  
D) 0.0105 L  
E) 0.00660 L

26. If it takes 1.25 min for 0.010 mol of He to effuse, how long will it take for the same amount of C₂H₆ to effuse under the same conditions?

A) 3.43 min  
B) 2.19 min  
C) 0.456min  
D) 2.74 min  
E) 0.0228 min

27. What mass of potassium chloride forms when 5.25 L of chlorine gas at 0.950 atm and 293 K reacts with 17.0 g of potassium?

A) 30.9 g KCl  
B) 32.4 g KCl  
C) 681 g KCl  
D) 15.4 g KCl  
E) 341 g KCl

28. How many atoms are in one unit cell of the structure below?

A) 1  
B) 2  
C) 3  
D) 4  
E) 9
29. Which substance would you expect to have the lowest boiling point?

A) CH₄  
B) SiH₄  
C) CH₃Cl  
D) SiH₂Cl₂  
E) CH₃F

30. If a unit cell of an ionic compound has A cations at the corners and the face centers and X anions in the centers of the unit cells of the edges, what is the empirical formula of the compound?

A) A₄X₃  
B) A₆X₃  
C) A₄X₂  
D) A₃X₄  
E) A₃X₃

31. An element crystallizes in a face-centered cubic unit cell has a density of 1.45 g/cm³. The edge length of its unit cell is 4.52 x 10⁻⁸ cm. What is the approximate atomic mass of the element in g/mol?

A) 3.35 g/mol  
B) 9.87 g/mol  
C) 20.2 g/mol  
D) 80.7 g/mol  
E) Not enough information

32. If expanding gases in a car engine do 451 J of work on the pistons, and the system loses 325 J to the surroundings as heat, calculate the change in internal energy (ΔU) in J.

A) +136 J  
B) -776 J  
C) -96 J  
D) -126 J  
E) +802 J
33. A layer of copper lining a skillet weighs 125 g. What is the specific heat capacity of the copper if 13.3 kJ heat is needed to raise the temperature of the copper from 25°C to 300°C?

A) 9.40 J/g°C  
B) 2.56 J/g°C  
C) 0.387 J/g°C  
D) 0.000387 J/g°C  
E) 29.26 J/g°C

34. For which species is the enthalpy of formation NOT zero?

A) Na(s)  
B) Cl₂(g)  
C) N₂(g)  
D) H₂O(g)  
E) None of the above

35. Consider two metals A and B. The specific heat capacity of A has a greater value than that of B. Which statement is true?

A) More heat is required to raise the same mass of metal B by 1°C than metal A.  
B) Given the same amount of heat energy and the same mass of both metals, the temperature of A will rise more than the temperature of B.  
C) If the same mass of both metals, beginning at the same initial temperature, are each placed on a table, then metal B will reach room temperature faster.  
D) If the metals, both at different temperatures, are placed in contact with each other, metal A will exhibit a greater temperature change than metal B.  
E) None of these statements are true.

36. What is the change in entropy of the surroundings for the following process at 25°C?

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \quad \Delta H^o = -92.6 \text{ kJ/mol} \]

A) +311 J/K  
B) -311 J/K  
C) +3220 J/K  
D) -371 J/K  
E) -27.4 J/K
37. A 100.0 mL sample of 0.500 M HCl was mixed with 100.0 mL of 0.500 M NaOH in a coffee-cup calorimeter. The initial temperature of both solutions was room temperature, 22.50°C and the final temperature of the mixture was 25.86°C. If no heat is lost to the surroundings or the calorimeter, then what is the enthalpy of reaction? The specific heat capacity of water is 4.184 J/g°C, and the density of the solution is 1.00 g/mL.

   A) -2.81 kJ/mol  
   B) +56.2 kJ/mol  
   C) +2.81 kJ/mol  
   D) -5.62 kJ/mol  
   E) -56.2 kJ/mol

38. In the question above, you were told to assume that no heat was lost to the surroundings or calorimeter. What can you assume about the value of ΔH if C_{cal} were greater than 0?

   A) The value of ΔH is not affected by a non-zero C_{cal}.  
   B) The value of ΔH becomes zero.  
   C) The real absolute value of ΔH would be greater than calculated in question 36.  
   D) The real absolute value ΔH would be less than calculated in question 36.  
   E) Without the value of C_{cal}, there is not enough information.

39. Determine the standard enthalpy of formation for C_2H_2 from its elements given the information below.

   \[ 2\text{C(graphite)} + \text{H}_2(g) \rightarrow \text{C}_2\text{H}_2(g) \quad \Delta H^o = ? \]

   Given:
   - C(graphite) + O_2(g) → CO_2(g) \quad ΔH^o = -383.5 kJ/mol
   - \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \rightarrow \text{H}_2\text{O(l)} \quad ΔH^o = -285.8 kJ/mol
   - 2\text{C}_2\text{H}_2(g) + 5 \text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 2\text{H}_2\text{O(l)} \quad ΔH^o = -2598.8 kJ/mol

   A) +226.6 kJ/mol  
   B) +246.6 kJ/mol  
   C) +1930 kJ/mol  
   D) -3650 kJ/mol  
   E) -1830 kJ/mol
40. Which processes lead to an increase in entropy? Treat all gases as ideal.

I. The pressure of 1 mole of oxygen gas is allowed to double isothermally.
II. Carbon dioxide is allowed to expand isothermally to 10 times its original volume.
III. The temperature of 1 mol of helium is increased by 25°C at constant pressure.
IV. Nitrogen gas is compressed isothermally to half its original volume.

A) I and IV
B) I only
C) III and IV
D) II and III
E) I and II

41. Which statement regarding the graph is true?

A) Regions A, C, and E represent phase changes.
B) No heat is exchanged in regions B and D.
C) ΔH_vap is much larger than ΔH_fus for this substance.
D) The freezing point of the substance is -25°C.
E) None of these statements are true.
42. Calculate the molar heat of fusion for benzene given the following data:

\[ \Delta S_{\text{fus}} = 39.1 \text{ J/mol} \cdot \text{K} \]
\[ \Delta S_{\text{vap}} = 87.8 \text{ J/mol} \cdot \text{K} \]
\[ \Delta H_{\text{vap}} = 33.9 \text{ kJ/mol} \]

Normal melting point = 5.5°C
Normal boiling point = 80.1°C

A) 31.0 kJ/mol
B) 7.11 kJ/mol
C) 140. kJ/mol
D) 10.9 kJ/mol
E) 215 kJ/mol

43. Use the information from question 42 to determine the Gibbs free energy for the evaporation of benzene.

A) 0 kJ/mol
B) 2.90 kJ/mol
C) 3.10 \times 10^4 \text{ kJ/mol}
D) 64.9 kJ/mol
E) Not enough information

44. For which of these processes is \( \Delta S \) positive?

I. \( \text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl(s)} \)
II. sublimation
III. \( 2\text{O}_3(g) \rightarrow 3\text{O}_2(g) \)
IV. condensation

A) I and IV
B) II and III
C) II and IV
D) II only
E) III and IV
45. Which statement best explains why water freezes only at or below 0°C at atmospheric pressure.

A) Freezing is an endothermic process with an increase in entropy.
B) Freezing is an exothermic process with decrease in entropy.
C) The sign of ΔG for the process is always positive.
D) Freezing is an endothermic process with a decrease in entropy.
E) Freezing is an exothermic process with an increase in entropy.

46. The density of a 2.45 M aqueous solution of methanol (CH₃OH, molar mass = 32.04 g/mol) is 0.976 g/mL. What is the molality of the solution?

A) 2.45 m
B) 0.0314 m
C) 3.18 m
D) 2.51 m
E) 2.73 m

47. By how much does the vapor pressure change when 218 g of glucose (non-volatile solute, molar mass = 180.2 g/mol) is dissolved in 460.0 mL of water at 30°C. At this temperature, the vapor pressure of pure water is 31.82 torr, and the density of water is 1.00 g/mL.

A) The vapor pressure decreases by 1.4 torr
B) The vapor pressure increases by 1.4 torr
C) The vapor pressure decreases by 30.4 torr
D) The vapor pressure increases by 30.04 torr
E) The vapor pressure does not change.

48. Which statement is true?

A) CH₃OH has a higher vapor pressure than CH₄ at a given temperature.
B) Boiling points tend to decrease with increasing strength of intermolecular forces.
C) Boiling point and melting point follow opposite trends with respect to intermolecular forces.
D) The easier it is for molecules to escape the liquid phase to the gas phase, the greater the vapor pressure will be.
E) H₂O has a lower boiling point than CH₄.
49. Molecule A has \( i = 1 \) while molecule B has \( i = 2 \). The molality of an aqueous solution of molecule A is exactly half that of molecule B. Which statement is true?

A) The solution of molecule B will result in a higher freezing point.
B) The solution of molecule A will result in a lower vapor pressure.
C) The osmotic pressure of solution A is greater than that of B.
D) The two solutions have the same boiling point.
E) The boiling point, freezing point, osmotic pressure, and vapor pressure cannot be calculated without knowing the identities of the molecules.

50. A solution is prepared by dissolving 35.0 g of hemoglobin (Hb) in enough water to make 1.00L of solution. If the osmotic pressure of the solution is 0.0132 atm at 25°C, then what is the molar mass of hemoglobin?

A) 108 g/mol
B) 65100 g/mol
C) 2270000 g/mol
D) 0.00926 g/mol
E) 1.54 x 10^{-5} g/mol

51. The freezing point depression of an aqueous 0.100 \( m \) solution of MgSO\(_4\) is 0.225°C. What is the van’t Hoff factor? The K\(_f\) for water is 1.86°C/m.

A) 1
B) 2
C) 6
D) 1.2
E) Not enough information

52. For a given solution, which of the following concentration values will change as temperature changes?

A) mass percent
B) molarity
C) mole fraction
D) molality
E) none of these choices is correct
53. Consider the following reaction:

\[ A + B \rightarrow C + D \quad \Delta G_{\text{rxn}} = -200 \text{ kJ} \]

Based on this information, which of the following statements can be made about the reaction?

I. The reaction is spontaneous.
II. The products are more stable than the reactants.
III. The reaction is exothermic.
IV. The reactants are labile.

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