1. Which ion is planar?
   A) PF$_4^+$
   B) CO$_3^{2-}$
   C) SO$_3^{2-}$
   D) ClO$_4^-$
   E) SCl$_5^-$

2. Of the following, which molecule has the smallest bond angle?
   A) CCl$_4$
   B) PCl$_3$
   C) SO$_2$
   D) Cl$_2$O
   E) BeCl$_2$

3. Upon heating, CaCO$_3$ decomposes to CaO and CO$_2$. What change in the hybridization of carbon occurs in this reaction?
   A) sp to sp$^2$
   B) sp$^2$ to sp$^3$
   C) sp$^3$ to sp
   D) sp$^2$ to sp
   E) no change

Use the following to answer questions 4-6:

Tetracyanoethylene has the skeleton shown here:

From its Lewis structure, determine the following.

4. How many sigma bonds and how many pi bonds are in the molecule?
   A) 5 sigma and 9 pi
   B) 6 sigma and 8 pi
   C) 9 sigma and 7 pi
   D) 9 sigma and 9 pi
   E) 5 sigma and 8 pi

5. How many of the atoms are sp$^2$ hybridized?
   A) 2
   B) 4
   C) 6
   D) 8
   E) 10
6. How many of the atoms are sp hybridized?
   A) 2
   B) 4
   C) 6
   D) 8
   E) 10

7. What is the hybridization of the I atom in the ion IF₄⁻?
   A) sp
   B) sp²
   C) sp³
   D) dsp³
   E) d²sp³

8. Which of the following species has the largest dissociation energy?
   A) O₂
   B) O₂⁻
   C) O₂²⁻
   D) O₂⁺
   E) O₂²⁺

9. Draw the molecular orbital diagram of CO. (use the MO diagram for C)

10. Order the following from shortest to longest bond: C₂, B₂, H₂, N₂
    A) H₂, N₂, C₂, B₂
    B) N₂, C₂, B₂, H₂
    C) C₂, N₂, H₂, B₂
    D) C₂, B₂, H₂, N₂
    E) none of these

11. Which of the following statements is false?
    A) Atoms or molecules with an even number of electrons are diamagnetic.
    B) Atoms or molecules with an odd number of electrons are paramagnetic.
    C) Paramagnetism cannot be deduced from the Lewis structure of a molecule alone.
    D) Paramagnetic molecules are attracted toward a magnetic field.
    E) N₂ molecules are diamagnetic.

12. Which of the following is the correct order of boiling points for NaNO₃, CH₃OH, C₂H₆, and Ne?
    A) Ne < CH₃OH < C₂H₆ < NaNO₃
    B) NaNO₃ < CH₃OH < C₂H₆ < Ne
    C) Ne < C₂H₆ < NaNO₃ < CH₃OH
    D) Ne < C₂H₆ < CH₃OH < NaNO₃
    E) C₂H₆ < Ne < CH₃OH < NaNO₃
13. Which of the following statements is(are) false?
   I. The hexagonal closest-packed structure is ABAB....
   II. A body-centered cubic unit cell has four atoms per unit cell.
   III. For unit cells having the same edge length, a simple cubic structure would have a smaller density than a body-centered cube.
   IV. Atoms in a solid consisting of only one element would have six nearest neighbors if the crystal structure was a simple cubic array.

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

14. How many unit cells share an atom which is located at a corner (or lattice point) of a unit cell?
   A) 8
   B) 4
   C) 2
   D) 1
   E) 6

15. Nickel metal exhibits a fcc structure. The density of Ni metal is 6.84 g/cm$^3$.
   a. What is the radius of a Ni atom in pm? (1 pm = 10$^{-12}$ m)
   b. What fraction of the space in a unit cell is unoccupied?

16. The unit cell in this two-dimensional crystal contains __________ Xs and __________ Os.

   A) 1, 4
   B) 1, 2
   C) 4, 1
   D) 1, 1
   E) none of the above

17. A certain metal fluoride crystallizes in such a way that the fluoride ions occupy simple cubic lattice sites, while the metal atoms occupy the body centers of half the cubes. What is the formula for the metal fluoride?
   A) MF$_2$
   B) M$_2$F
   C) MF
   D) MF$_8$
   E) none of these
18. Which of the compounds below is an example of a covalent network solid?
   A) $S_8(s)$
   B) C(s)
   C) MgO(s)
   D) NaCl(s)
   E) C$_{25}$H$_{52}$(s)

19. Which of the following statements is incorrect?
   A) Molecular solids have high melting points.
   B) The binding forces in a molecular solid include London dispersion forces.
   C) Ionic solids have high melting points.
   D) Ionic solids are insulators.
   E) All of these statements are correct.

20. $\Delta H_{\text{vap}}$ for water is 40.7 kJ/mol. Calculate the boiling point of water at 0.500 atm.
   A) 50.0°C
   B) 81.3°C
   C) 98.6°C
   D) 100.0°C
   E) none of these

21. Below is a phase diagram for compound X. You wish to purify a sample of X that was collected at $P = 1.0$ atm and $T = 100$ by subliming it. In order to sublime the sample, you should

   A) increase $P$ to 1.5 atm and then increase $T$ to 300 K.
   B) increase $T$ to 300 K, keeping $P = 1.0$ atm.
   C) lower $P$ to 0.5 atm and then increase $T$ to 200 K.
   D) increase $T$ to 300 K and then lower $P$ to 0.5 atm.
   E) abandon the attempt to sublime X.

22. True of False:
   a. Semiconductors have no gap between the valence and conduction bands.
   b. For most substances, the enthalpy of fusion is greater than the enthalpy of vaporization.
   c. Gold is a good conductor because it has a high melting point.
   d. Water has a higher freezing point at higher pressures.
23. A material is made from Al, Ga, and As. The mole fractions of these elements are 0.25, 0.26, and 0.49, respectively. This material would be
   A) an n-type semiconductor.
   B) a metallic conductor because Al is present.
   C) a p-type semiconductor.
   D) an insulator.
   E) none of these

24. Rank the following compounds according to increasing solubility in water.
   I. CH₃–CH₂–CH₂–CH₃
   II. CH₃–CH₂–O–CH₂–CH₃
   III. CH₃–CH₂–OH
   IV. CH₃–OH
   A) I < III < IV < II
   B) I < II < IV < III
   C) III < IV < II < I
   D) I < II < III < IV

25. Rank the following compounds according to increasing solubility in water.
   I. O₂ at 1 atm, 25°C
   II. O₂ at 10 atm, 25°C
   III. O₂ at 1 atm, 35°C
   A) I < III < II
   B) I < II < III
   C) III < I < II
   D) III < II < I

26. Circle the correct answer
   a. greatest viscosity  
      H₂O CH₂Cl₂ CH₃(CH₂)₄CH₃
   b. highest vapor pressure  
      1-hexene butanal 2-propanol
   c. lowest freezing point  
      0.2 m NaCl 0.1 m CaCl₂ 0.2 m C₆H₁₂O₆
   d. lowest osmotic pressure  
      H₂O 0.2 M FeCl₃ 0.2 M HOCH₂CH₂OH
   e. highest “i” value  
      0.01 m CaCl₂ 0.10 m CaCl₂ 0.01 m NaCl

27. A 52.8-g sample of glucose (a nondissociated, nonvolatile solute with the formula C₆H₁₂O₆) is dissolved in 158.0 g of water. What is the vapor pressure of this solution at 100°C?
   A) 760 torr
   B) 24.6 torr
   C) 735 torr
   D) 570 torr
   E) 190 torr
28. A solution is made by mixing 50.0 g of propanone and 50.0 g of methanol.
   a. What is the pressure of propanone above this solution? (the vapor pressures of pure propanone and methanol are 271 and 143 torr)
   b. The actual vapor pressure of this solution is 161 torr. Draw a diagram showing the vapor pressure as a function of mole fraction of methanol for these solutions.
   c. If propanone and methanol were mixed with both solutions initially at 25 °C, would the final temperature of the solution increase or decrease?

29. Consider a 2.50 M aqueous solution of CaCl$_2$. The density of the solution is 1.15 g/cm$^3$.
   a. What is the freezing point of the solution? ( $k_f = 1.86$ °C kg/mol)
   b. If the solution is left in an open container, will the boiling point increase, decrease or stay the same over time?

30. When a 19.8-g sample of an unknown compound is dissolved in 522.0 g of benzene, the freezing point of the resulting solution is 3.86°C. The freezing point of pure benzene is 5.48°C, and $K_f$ for benzene is 5.12°C/m. Calculate the molar mass of the unknown compound.

31. What is the expected osmotic pressure, in torr, of a 0.0100 $M$ solution of NaCl in water at 25°C?
   A) 0.245 torr
   B) 15.6 torr
   C) 372 torr
   D) 186 torr
   E) none of these

32. Which of the following statements is true about coordination complexes?
   A) The metal is a Lewis base and the ligands are Lewis acids.
   B) Only complexes with coordination number 6 are found in nature.
   C) When the ligands approach a transition metal ion in an octahedral field, the $d_{xz}$, $d_{yz}$, and $d_{xy}$ atomic orbitals are affected the least by the ligands.
   D) None of these is true.
   E) All of these are true.

33. How many of the following compounds exhibit geometric isomers?

I. Pt(H$_2$O)$_2$Cl$_2$ (square planar)
II. [Co(H$_2$O)$_2$]Br$_3$
III. [Ni(H$_2$O)$_4$(NO$_2$)$_2$]
IV. K$_2$[CoCl$_4$]

A) 0
B) 1
C) 2
D) 3
E) 4
34. Bipyridine (bipy) is a neutral, bidentate ligand.
a. Name the compound \( K [\text{Mn}(\text{bipy})_2(\text{NO}_2)_2] \)
b. Draw all the stereoisomers of the above compound.
c. If \([\text{Co}(\text{bipy})_3]^{3+}\) is blue and \([\text{Co}(\text{en})_3]^{3+}\) is red, is bipy a stronger or weaker field ligand than ethylenediamine?
d. Which compound in part (c) has more unpaired electrons?

35. A metal ion in a high-spin octahedral complex has two more unpaired electrons than the same ion does in a low-spin octahedral complex. Which of the following could the metal ion be?
   A) \( \text{Ti}^{2+} \)
   B) \( \text{Cu}^{2+} \)
   C) \( \text{Mn}^{2+} \)
   D) \( \text{Co}^{3+} \)
   E) \( \text{Co}^{2+} \)

36. A certain complex ion has a distorted tetrahedral structure in which the ligands closest to the plus and minus z axes are compressed (pushed in closer to the central metal ion). Draw the d orbital splitting diagram.

37. Which of the following names is a correct one?
   A) 3,4-dichloropentane
   B) 1-chloro-2,4-methyl-3-ethylcyclohexane
   C) 1,1-dimethyl-2,2-diethylpentane
   D) \text{cis}-1,3-dimethylbutane
   E) 2-bromo-1-chloro-4,4-diethyloctane

38. Which of the following is \textit{not} a structural isomer of 1-pentene?
   A) 2-pentene
   B) 2-methyl-2-butene
   C) cyclopentane
   D) 3-methyl-1-butene
   E) 1-methyl-cyclobutene

39. \( \text{H}_2\text{CCHCH}_2\text{N(CH}_3)_2 \) is
   A) an alkyne and a secondary amine.
   B) an alkene and a primary amine.
   C) an alkene and a tertiary amine.
   D) an alkyne and a tertiary amine.
   E) none of these

40. How many structural and geometric isomers are there of chloropropene?
   A) 2
   B) 3
   C) 4
   D) 5
   E) more than 5
41. How many structural isomers exist, respectively, for the following: dichlorobenzene, trichlorobenzene, and tetrachlorobenzene?
   A) 2, 3, 4
   B) 2, 3, 3
   C) 2, 4, 4
   D) 3, 3, 4
   E) 3, 3, 3

42. Consider the polymer drawn below:

   \[
   \begin{array}{c}
   \text{CH}_3 \\
   \text{C} - \text{CH}_2 - \text{C} - \text{CH}_2 - \text{C} - \text{CH}_2 \\
   \text{CH}_3 \\
   \end{array}
   \]

   What monomer(s) is (are) needed to produce the above polymer?
   A) methane and propene
   B) 2-methylpropene
   C) 2-butene
   D) 2,4-dimethyl-2-pentene

43. In which of the following lists do all members have a C=O bond?
   A) ester, aldehyde, secondary alcohol, ketone
   B) any alcohol, ether, ester
   C) secondary alcohol, ketone, aldehyde
   D) ester, aldehyde, ketone
   E) carboxylic acid, ether, tertiary alcohol

44. If you were to heat pentanoic acid and 2-butanol with an acid catalyst, which of the following would you most likely discover in your flask?
   A) a ketone
   B) an ester
   C) an amine
   D) an alkane
   E) an aldehyde

45. What is the product of the addition of H₂ to 2-methyl-1-pentene?
   A) 3-methyl-1-pentene
   B) 2-methyl-1-butene
   C) pentane
   D) 2-methylpentane
   E) cyclopentane
46. Which structure represents an optically active aldehyde?

A) 
\[
\begin{align*}
&\text{CH}_3\text{CH}_2\text{C} - \text{C} - \text{OH} \\
&\text{CH}_3
\end{align*}
\]

B) 
\[
\begin{align*}
&\text{H} \\
&\text{CH}_3\text{CH}_2\text{C} - \text{C} - \text{CHO} \\
&\text{CH}_3
\end{align*}
\]

C) 
\[
\begin{align*}
&\text{O} \\
&\text{CH}_3 - \text{CH} - \text{C} - \text{CH}_3 \\
&\text{CH}_3
\end{align*}
\]

D) 
\[
\begin{align*}
&\text{CH}_3 \\
&\text{CH}_3\text{C} - \text{CH}_2 - \text{CHO} \\
&\text{CH}_3
\end{align*}
\]

E) 
\[
\begin{align*}
&\text{H} \\
&\text{CH}_3\text{CH}_2\text{C} - \text{C} - \text{NH}_2 \\
&\text{CH}_3
\end{align*}
\]

47. Draw and name:
   a. an ester that’s an isomer of butanoic acid
   b. a secondary amine that’s an isomer of triethylamine
   c. a primary alcohol that’s an isomer of diethyl ether

48. a. What is the general structure of an amino acid?
   b. Draw two possible dipeptides of alanine (R=CH\textsubscript{3}) and serine (R=CH\textsubscript{2}OH).

49. Which of the following is the best description of a protein?
   A) an alternating chain of amino acids and nucleic acids
   B) a chain of amino acids connected by ester bonds
   C) two antiparallel chains of nucleic acids connected by hydrogen bonding
   D) a chain of amino acids formed by condensation polymerization
   E) a chain of nucleotides connected by phosphodiester bonds

50. Which types of processes are likely when the proton-to-neutron ratio in a nucleus is too large?

I. α decay
II. β decay
III. positron production
IV. electron capture

A) I, II
B) II, III
C) III, IV
D) II only
E) IV only
51. The nuclide $^{224}_{86}$Rn is radioactive. When one of these atoms decays, a series of $\alpha$- and $\beta$-particle emissions occurs, taking the atom through many transformations to end up as an atom of $^{208}_{82}$Pb. How many $\alpha$ particles are emitted in converting $^{224}_{86}$Rn into $^{208}_{82}$Pb?

A) 6
B) 8
C) 2
D) 214
E) 4

52. When the Pu-244 nucleus is struck with a neutron, the Ga-80 and Sm-160 nuclei are produced, along with some neutrons. How many neutrons are emitted?

A) 2
B) 3
C) 4
D) 5
E) 6

53. The half-life for electron capture for $^{40}_{19}$K is 1.3 billion years. What will be the $^{40}_{19}$K / $^{40}_{18}$Ar ratio in a rock that is 4.5 billion years old?

A) 0.091
B) 11.
C) 0.10
D) 10.
E) 0.36

54. Which element has the highest binding energy per nucleon?

A) C
B) Fe
C) U
D) Pb
E) O

55. Fresh rainwater or surface water contains enough tritium ($^3_H$) to show 5.5 decompositions per minute per 100. g of water. Tritium has a half-life of 12.3 years. You are asked to check a vintage wine claimed to have been produced in 1947. How many decompositions per minute should you expect to observe in 50. g of that wine?

A) 0.0013
B) 0.023
C) 1.7
D) 0.063
E) 181

56. Calculate $\Delta E$ in kilojoules per mole for the reaction

$^{230}_{90}$Th $\rightarrow$ $^{4}$He $+ ^{1}_{1}$Ra

Atomic masses: $^{230}_{90}$Th = 230.0332 amu, $^4$He = 4.00260 amu, $^1$Ra = 226.02544 amu.

A) $-4.6 \times 10^8$ kJ/mol
B) $-2.4 \times 10^8$ kJ/mol
C) 0
D) $+2.4 \times 10^6$ kJ/mol
E) $+4.6 \times 10^8$ kJ/mol