41. Which of the following molecules has the shortest bond length?
   (A) N₂  (B) O₂  (C) Cl₂  (D) Br₂  (E) I₂

51. Pi bonding occurs in each of the following species EXCEPT…
   (A) CO₂  (B) C₂H₄  (C) CN⁻  (D) C₆H₆  (E) CH₄

60. Which of the following has a zero dipole moment?
   (A) HCN  (B) NH₃  (C) SO₂  (D) NO₂  (E) PF₅

8. Use the following answers for questions 8 - 9.
   (A) A network solid with covalent bonding
   (B) A molecular solid with zero dipole moment
   (C) A molecular solid with hydrogen bonding
   (D) An ionic solid
   (E) A metallic solid

8. Solid ethyl alcohol, C₂H₅OH
9. Silicon dioxide, SiO₂

80. 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

<table>
<thead>
<tr>
<th>Hydrogen Halide</th>
<th>Normal Boiling Point, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>19</td>
</tr>
<tr>
<td>HCl</td>
<td>−85</td>
</tr>
<tr>
<td>HBr</td>
<td>−67</td>
</tr>
<tr>
<td>HI</td>
<td>−35</td>
</tr>
</tbody>
</table>

18. The liquefied hydrogen halides have the normal boiling points given above. The relatively high boiling point of HF can be correctly explained by which of the following?
   (A) HF gas is more ideal.  (C) HF molecules have a smaller dipole moment.
   (B) HF is the strongest acid.  (D) HF is much less soluble in water.
   (E) HF molecules tend to form hydrogen bonds.

42. The SbCl₅ molecule has trigonal bipyramid structure. Therefore, the hybridization of Sb orbitals should be...
   (A) sp²  (B) sp³  (C) sp²d  (D) sp³d  (E) sp³d²
11. Use these answers for questions 11 - 14.
(A) hydrogen bonding  (B) hybridization  (C) ionic bonding
(D) resonance  (E) van der Waals forces (London dispersion forces)

11. Is used to explain why iodine molecules are held together in the solid state
12. Is used to explain why the boiling point of HF is greater than the boiling point of HBr
13. Is used to explain the fact that the four bonds in methane are equivalent
14. Is used to explain the fact that the carbon-to-carbon bonds in benzene, C₆H₆, are identical

17. The Lewis dot structure of which of the following molecules shows only one unshared pair of valence electron?
(A) Cl₂  (B) N₂  (C) NH₃  (D) CCl₄  (E) H₂O₂

31. The structural isomers C₂H₅OH and CH₃OCH₃ would be expected to have the same values for which of the following? (Assume ideal behavior.)
(A) Gaseous densities at the same temperature and pressure
(B) Vapor pressures at the same temperature  (C) Boiling points
(D) Melting points  (E) Heats of vaporization

47. CCl₄, CO₂, PCl₃, PCl₅, SF₆
Which of the following does not describe any of the molecules above?
(A) Linear  (B) Octahedral  (C) Square planar  (D) Tetrahedral  (E) Trigonal pyramidal

59. Which of the following compounds is ionic and contains both sigma and pi covalent bonds?
(A) Fe(OH)₃  (B) HClO  (C) H₂S  (D) NO₂  (E) NaCN

15. In a molecule in which the central atom exhibits sp³d² 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

32. 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

34. X = CH₃-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
57. 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

62. The electron-dot structure (Lewis structure) for which of the following molecules would have two unshared pairs of electrons on the central atom?

(A) H₂S  (B) NH₃  (C) CH₄  (D) HCN  (E) CO₂

68. Which of the following molecules has a dipole moment of zero?

(A) C₆H₆ (benzene)  (B) NO  (C) SO₂  (D) NH₃  (E) H₂S

8. Questions 8-10 refer to the following diatomic species.

(A) Li₂  (B) B₂  (C) N₂  (D) O₂  (E) F₂

8. Has the largest bond-dissociation energy

9. Has a bond order of 2

10. Contains 1 sigma (σ) and 2 pi (π) bonds

<table>
<thead>
<tr>
<th>Bond</th>
<th>Average Bond Energy (kJ/mole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I---I</td>
<td>150</td>
</tr>
<tr>
<td>Cl---Cl</td>
<td>240</td>
</tr>
<tr>
<td>I---Cl</td>
<td>210</td>
</tr>
</tbody>
</table>

60. I₂(g) + 3 Cl₂(g) → 2 ICl₃(g)

According to the data in the table above, what is the value of ΔH° for the reaction represented above?

(A) −870 kJ  (B) −390 kJ  (C) +180 kJ  (D) +450 kJ  (E) +1,260 kJ

28. The melting point of MgO is higher than that of NaF. Explanations for this observation include which of the following?

I. Mg²⁺ is more positively charged than Na⁺

II. O²⁻ is more negatively charged than F⁻

III. The O²⁻ ion is smaller than the F⁻ ion

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

32. Types of hybridization exhibited by the C atoms in propene, CH₃CHCH₂, include which of the following?

I. sp  II. sp²  III. sp³

(A) I only  (B) III only  (C) I and II only  (D) II and III only  (E) I, II, and III
40. Of the following molecules, which has the largest dipole moment?
(A) CO  (B) CO₂  (C) O₂  (D) HF  (E) F₂

58. 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 gas

68. In which of the following processes are covalent bonds broken?
(A) I₂(s) → I₂(g)  (B) CO₂(s) → CO₂(g)  (C) NaCl(s) → NaCl(l)
(D) C(diamond) → C(g)  (E) Fe(s) → Fe(l)

40. The geometry of the SO₃ molecule is best described as…
(A) trigonal planar  (B) trigonal pyramidal  (C) square pyramidal
(D) bent  (E) tetrahedral

66. Ca, V, Co, Zn, As
Gaseous atoms of which of the elements above are paramagnetic?
(A) Ca and As only  (B) Zn and As only  (C) Ca, V, and Co only
(D) V, Co, and As only  (E) V, Co, and Zn only

Questions 3-5 refer to the following molecules:
(A) CO₂  (B) H₂O  (C) CH₄  (D) C₂H₄  (E) PH₃

3. The molecule with only one double bond.
4. The molecule with the largest dipole moment.
5. The molecule that has trigonal pyramidal geometry.
28. Of the following compounds, which is the most ionic?

(A) SiCl₄  
(B) BrCl  
(C) PCl₃  
(D) Cl₂O  
(E) CaCl₂

53. According to the VSEPR model, the progressive decrease in the bond angles in the series of molecules CH₄, NH₃, and H₂O is best accounted for by the…

(A) increasing strength of the bonds  
(B) decreasing size of the central atom  
(C) increasing electronegativity of the central atom  
(D) increasing number of unshared pairs of electrons  
(E) decreasing repulsion between hydrogen atoms

56. The boiling points of the elements helium, neon, argon, krypton, and xenon increase in that order. Which of the following statements accounts for this increase?

(A) The London (dispersion) forces increase.  
(B) The hydrogen bonding increases.  
(C) The dipole-dipole forces increase.  
(D) The chemical reactivity increases.  
(E) The number of nearest neighbors increases.

AP Chemistry: Atomic Structure
Multiple Choice

22. 1s² 2s² 2p⁶ 3s² 3p³

Atoms of an element, X, have the electronic configuration shown above. The compound most likely formed with magnesium, Mg, is…

(A) MgX  
(B) Mg₂X  
(C) MgX₂  
(D) MgX₃  
(E) Mg₃X₂

43. The elements in which of the following have most nearly the same atomic radius?

(A) Be, B, C, N  
(B) Ne, Ar, Kr, Xe  
(C) Mg, Ca, Sr, Ba  
(D) C, P, Se, I  
(E) Cr, Mn, Fe, Co

58. Which of the following represents the ground state electron configuration for the Mn³⁺ ion? (Atomic number Mn = 25)

(A) 1s² 2s² 2p⁶ 3s² 3p⁶ 3d⁴  
(B) 1s² 2s² 2p⁶ 3s² 3p⁶ 3d⁵ 4s²  
(C) 1s² 2s² 2p⁶ 3s² 3p⁶ 3d² 4s²  
(D) 1s² 2s² 2p⁶ 3s² 3p⁶ 3d⁸ 4s²  
(E) 1s² 2s² 2p⁶ 3s² 3p⁶ 3d³ 4s¹

Use the following answers for questions 1 - 3.

(A) F  
(B) S  
(C) Mg  
(D) Ar  
(E) Mn
1. Forms monatomic ions with $2^-$ charge in solutions
2. Forms a compound having the formula $\text{KXO}_4$
3. Forms oxides that are common air pollutants and that yield acidic solution in water

33. Which of the following conclusions can be drawn from J. J. Thomson's cathode ray experiments?

(A) Atoms contain electrons.
(B) Practically all the mass of an atom is contained in its nucleus.
(C) Atoms contain protons, neutrons, and electrons.
(D) Atoms have a positively charged nucleus surrounded by an electron cloud.
(E) No two electrons in one atom can have the same four quantum numbers.

1. Use these answers for questions 1 - 3.

(A) O   (B) La   (C) Rb   (D) Mg   (E) N

1. What is the most electronegative element of the above?
2. Which element exhibits the greatest number of different oxidation states?
3. Which of the elements above has the smallest ionic radius for its most commonly found ion?

50. In the periodic table, as the atomic number increases from 11 to 17, what happens to the atomic radius?

(A) It remains constant.      (B) It increases only.
(C) It increases, then decreases. (D) It decreases only.
(E) It decreases, then increases.

4. Use these answers for questions 4 - 7.

(A) $1s^2 2s^2 2p^5 3s^2 3p^3$   (B) $1s^2 2s^2 2p^6 3s^2 3p^6$   (C) $1s^2 2s^2 2p^6 2d^{10} 3s^2 3p^6$
(D) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$   (E) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$

4. An impossible electronic configuration
5. The ground-state configuration for the atoms of a transition element
6. The ground-state configuration of a negative ion of a halogen
7. The ground-state configuration of a common ion of an alkaline earth element

1. Use these answers for questions 1-4

(A) Heisenberg uncertainty principle   (B) Pauli exclusion principle   (C) Hund's rule
(D) Shielding effect   (E) Wave nature of matter

1. Can be used to predict that a gaseous carbon atom in its ground state is paramagnetic
2. Explains the experimental phenomenon of electron diffraction
3. Indicates that an atomic orbital can hold no more than two electrons
4. Predicts that it is impossible to determine simultaneously the exact position and the exact velocity of an electron

54. 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.

5. Questions 5-8 refer to atoms for which the occupied atomic orbitals are shown below:

5. Represents an atom that is chemically unreactive
6. Represents an atom in an excited state
7. Represents an atom that has four valence electrons.
8. Represents an atom of a transition metal.

51. Which of the following is a correct interpretation of the results of Rutherford's experiments in which gold atoms were bombarded with alpha particles?
(A) Atoms have equal numbers of positive and negative charges.
(B) Electrons in atoms are arranged in shells.
(C) Neutrons are at the center of an atom.
(D) Neutrons and protons in atoms have nearly equal mass.
(E) The positive charge of an atom is concentrated in a small region.

| Ionization Energies for element X (kJ mol⁻¹) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|     First       |     Second      |     Third       |     Fourth      |     Five        |
| 580             | 1815            | 2740            | 11600           | 14800           |

37. 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

19. Which of the following represents a pair of isotopes?

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)  I.</td>
<td>6 14</td>
</tr>
<tr>
<td>I.</td>
<td>7 14</td>
</tr>
<tr>
<td>(B)  I.</td>
<td>6 7</td>
</tr>
<tr>
<td>I.</td>
<td>14 14</td>
</tr>
<tr>
<td>(C)  I.</td>
<td>6 14</td>
</tr>
<tr>
<td>I.</td>
<td>7 13</td>
</tr>
<tr>
<td>(D)  I.</td>
<td>7 14</td>
</tr>
<tr>
<td>I.</td>
<td>14 28</td>
</tr>
</tbody>
</table>
Questions 1-2
Consider atoms of the following elements. Assume that the atoms are in the ground state.

(A) S  
(B) Ca  
(C) Ga  
(D) Sb  
(E) Br

1. The atom that contains exactly two unpaired electrons.
2. The atom that contains only one electron in the highest occupied energy sublevel.

17. In which of the following groups are the three species isoelectronic, i.e. have the same number of... electrons?

(A) S\(^{2-}\), K\(^+\), Ca\(^{2+}\)  
(B) Sc, Ti, V\(^{2+}\)  
(C) O\(^{2-}\), S\(^{2-}\), Cl\(^-\)  
(D) Mg\(^{2+}\), Ca\(^{2+}\), Sr\(^{2+}\)  
(E) Cs, Ba\(^{2+}\), La\(^{3+}\)

44. Which of the following properties generally decreases across the periodic table from sodium to chlorine?

(A) First ionization energy  
(B) Atomic mass  
(C) Electronegativity  
(D) Maximum value of oxidation number  
(E) Atomic radius

46. The effective nuclear charge experienced by the outermost electron of Na is different than the effective nuclear charge experienced by the outermost electron of Ne. This difference best accounts for which of the following?

(A) Na has a greater density at standard conditions than Ne.  
(B) Na has a lower first ionization energy than Ne.  
(C) Na has a higher melting point than Ne.  
(D) Na has a higher neutron-to-proton ratio than Ne.  
(E) Na has fewer naturally occurring isotopes than Ne.

Name ____________________________

AP Chemistry: Liquids & Solids
Multiple Choice

27. The critical temperature of a substance is the…

(A) temperature at which the vapor pressure of the liquid is equal to the external pressure.
(B) temperature at which the vapor pressure of the liquid is equal to 760 mm Hg.
(C) temperature at which the solid, liquid, and vapor phases are all in equilibrium.
(D) Temperature at which liquid and vapor phases are in equilibrium at 1 atmosphere.
(E) lowest temperature above which a substance cannot be liquefied at any applied pressure.

54. Which of the following statements is always true about the phase diagram of any one-component system?
(A) The slope of the curve representing equilibrium between the vapor and liquid phases is positive.
(B) The slope of the curve representing equilibrium between the liquid and solid phases is negative.
(C) The slope of the curve representing equilibrium between the liquid and solid phases is positive.
(D) The temperature at the triple point is greater than the normal freezing point.
(E) The pressure at the triple point is greater than 1 atmosphere.

21. Which of the following is true at the triple point of a pure substance?
(A) The vapor pressure of the solid phase always equals the vapor pressure of the liquid phase.
(B) The temperature is always 0.01 K lower than the normal melting point.
(C) The liquid and gas phases of the substance always have the same density and are therefore indistinguishable.
(D) The solid phase always melts if the pressure increases at constant temperature.
(E) The liquid phase always vaporizes if the pressure increases at constant temperature.

5. Questions 5-7 refer to the phase diagram on the right of a pure substance.
(A) Sublimation
(B) Condensation
(C) Solvation
(D) Fusion
(E) Freezing

5. If the temperature increases from 10° C to 60° C at a constant pressure of 0.4 atmospheres, which of the processes occurs?

6. If the temperature decreases from 110° C to 40° C at a constant pressure of 1.1 atmospheres, which of the processes occurs?

7. If the pressure increases from 0.5 to 1.5 atmospheres at a constant temperature of 50° C, which of the processes occurs?

49. Use the following diagram for 49-51.
49. The normal boiling point of the substance represented by the phase diagram shown is…
(A) −15 °C  (B) −10 °C  (C) 140 °C
(D) greater than 140 °C
50. The phase diagram above provides sufficient information for determining the…

(A) entropy change on vaporization.  (B) conditions necessary for sublimation.
(C) deviations from ideal gas behavior of the gas phase.  (D) latent heat of vaporization.
(E) latent heat of fusion.

51. For the substance represented in the diagram, which of the phases is most dense and which is least dense at −15 °C?

<table>
<thead>
<tr>
<th>Most Dense</th>
<th>Least Dense</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Solid</td>
<td>Gas</td>
</tr>
<tr>
<td>(B) Solid</td>
<td>Liquid</td>
</tr>
<tr>
<td>(C) Liquid</td>
<td>Solid</td>
</tr>
<tr>
<td>(D) Liquid</td>
<td>Gas</td>
</tr>
<tr>
<td>(E) The diagram gives no information about densities.</td>
<td></td>
</tr>
</tbody>
</table>

26. Which of the following actions would be likely to change the boiling point of a sample of a pure liquid in an open container?

I. Placing it in a smaller container  
II. Increasing the number of moles of the liquid in the container  
III. Moving the container and liquid to a higher altitude  

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

13. Questions 13-16 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 bonds.) with weak intermolecular forces  
(E) Macromolecules held together with strong polar bonds  

13. Cesium chloride, CsCl (s)  
14. Gold, Au(s)  
15. Carbon dioxide, CO₂(s)  
16. Methane, CH₄(s)

25. The cooling curve for a pure substance as it changes from a liquid to a solid is shown right. 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
39. The phase diagram for a pure substance is shown at the right. 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

Questions 15-16 relate to the graph shown on the right. The graph shows the temperature of a pure substance as it is heated at a constant rate in an open vessel at 1.0 atm pressure. The substance changes from the solid to the liquid to the gas phase.

15. The substance is at its normal freezing point at time…

(A) t₁  (B) t₂  (C) t₃  (D) t₄  (E) t₅

16. Which of the following best describes what happens to the substance between t₄ and t₅?

(A) The molecules are leaving the liquid phase.
(B) The solid and liquid phases coexist in the equilibrium.
(C) The vapor pressure of the substance is decreasing.
(D) The average intermolecular distance is decreasing.
(E) The temperature of the substance is increasing.

29. The best explanation for the fact that diamond is extremely hard is that diamond crystals…

(A) are made up of atoms that are intrinsically hard because of their electronic structures
(B) consist of positive and negative ions that are strongly attracted to each other
(C) are giant molecules in which each atom forms strong covalent bonds with all of its neighboring atoms
(D) are formed under extreme conditions of temperature and pressure
(E) contain orbitals or bands of delocalized electrons that belong not to single atoms but to each crystal as a whole

18. The phase diagram for the pure substance X is shown on the right. The temperature of a sample of pure solid X is slowly raised from 10°C to 100°C at a constant pressure of 0.5 atm. What is the expected behavior of the substance?
(A) It first melts to a liquid and then boils at about 70°C.
(B) It first melts to a liquid and then boils at about 30°C.
(C) It melts to a liquid at a temperature of about 20°C and remains a liquid until the temperature is greater than 100°C.
(D) It sublimes to a vapor at an equilibrium temperature of about 20°C.
(E) It remains a solid until the temperature is greater than 100°C.

32. Which of the following oxides is a gas at 25°C and 1 atm?
(A) Rb₂O  (B) N₂O  (C) Na₂O₂  (D) SiO₂  (E) La₂O₃

48. Sodium chloride is LEAST soluble in which of the following liquids?
(A) H₂O  (B) CCl₄  (C) HF  (D) CH₃OH  (E) CH₃COOH

67. Which of the following describes the changes in forces of attraction that occur as H₂O changes phase from a liquid to a vapor?
(A) H-O bonds break as H-H and O-O bonds form.
(B) Hydrogen bonds between H₂O molecules are broken.
(C) Covalent bonds between H₂O molecules are broken.
(D) Ionic bonds between H⁺ ions and OH⁻ ions are broken.
(E) Covalent bonds between H⁺ ions and H₂O molecules become more effective.

70. Of the following pure substances, which has the highest melting point?
(A) S₈  (B) I₂  (C) SiO₂  (D) SO₂  (E) C₆H₆

68. Liquid naphthalene at 95 °C was cooled to 30 °C, as represented in the cooling curve shown. From which section of the curve can the melting point of naphthalene be determined?
(A) A  (B) B  (C) C  (D) D  (E) E
59. When 70. milliliters of 3.0-molar Na₂CO₃ is added to 30. milliliters of 1.0-molar NaHCO₃ the resulting concentration of Na⁺ is…

(A) 2.0 M  (B) 2.4 M  (C) 4.0 M  (D) 4.5 M  (E) 7.0 M

67. A student wishes to prepare 2.00 liters of 0.100-molar KIO₃ (molecular weight 214). The proper procedure is to weigh out…

(A) 42.8 grams of KIO₃ and add 2.00 kilograms of H₂O
(B) 42.8 grams of KIO₃ and add H₂O until the final homogeneous solution has a volume of 2.00 liters
(C) 21.4 grams of KIO₃ and add H₂O until the final homogeneous solution has a volume of 2.00 liters
(D) 42.8 grams of KIO₃ and add 2.00 liters of H₂O
(E) 21.4 grams of KIO₃ and add 2.00 liters of H₂O

68. A 20.0-milliliter sample of 0.200-molar K₂CO₃ solution is added to 30.0 milliliters of 0.400-molar Ba(NO₃)₂ solution. Barium carbonate precipitates. The concentration of barium ion, Ba²⁺, in solution after reaction is…

(A) 0.150 M  (B) 0.160 M  (C) 0.200 M  (D) 0.240 M  (E) 0.267 M

69. What is the mole fraction of ethanol, C₂H₅OH, in an aqueous solution in which the ethanol concentration is 4.6 molal?

(A) 0.0046  (B) 0.076  (C) 0.083  (D) 0.20  (E) 0.72

72. How many moles of solid Ba(NO₃)₂ should be added to 300. milliliters of 0.20-molar Fe(NO₃)₃ to increase the concentration of the NO₃⁻ ion to 1.0-molar? (Assume that the volume of the solution remains constant.)

(A) 0.060 mole  (B) 0.12 mole  (C) 0.24 mole  (D) 0.30 mole  (E) 0.40 mole

47. Which of the following has the lowest conductivity?

(A) 0.1 M CuSO₄  (B) 0.1 M KOH  (C) 0.1 M BaCl₂  (D) 0.1 M HF  (E) 0.1 M HNO₃

28. Given that a solution is 5 percent sucrose by mass, what additional information is necessary to calculate the molarity of the solution?

I. The density of water   II. The density of the solution   III. The molar mass of sucrose

(A) I only  (B) II only  (C) III only  (D) I and III  (E) II and III
53. If 87 grams of $K_2SO_4$ (molar mass 174 grams) is dissolved in enough water to make 250 milliliters of solution, what are the concentrations of the potassium and the sulfate ions?

<table>
<thead>
<tr>
<th></th>
<th>[K$^+$]</th>
<th>[SO$_4^{2-}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>0.020 M</td>
<td>0.020 M</td>
</tr>
<tr>
<td>(B)</td>
<td>1.0 M</td>
<td>2.0 M</td>
</tr>
<tr>
<td>(C)</td>
<td>2.0 M</td>
<td>1.0 M</td>
</tr>
<tr>
<td>(D)</td>
<td>2.0 M</td>
<td>2.0 M</td>
</tr>
<tr>
<td>(E)</td>
<td>4.0 M</td>
<td>2.0 M</td>
</tr>
</tbody>
</table>

33. 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

56. A yellow precipitate forms when 0.5 M NaI$_{(aq)}$ is added to a 0.5 M solution of which of the following ions?

(A) Pb$^{2+}_{(aq)}$  (B) Zn$^{2+}_{(aq)}$  (C) CrO$_4^{2-}_{(aq)}$  (D) SO$_4^{2-}_{(aq)}$  (E) OH$^-_{(aq)}$

59. 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

69. What is the final concentration of barium ions, [Ba$^{2+}$], in solution when 100. mL of 0.10 M BaCl$_2_{(aq)}$ is mixed with 100. mL of 0.050 M H$_2$SO$_4_{(aq)}$?

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

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

(A) [PO$_4^{3-}$] < [NO$_3^-$] < [Na$^+$]  (B) [PO$_4^{3-}$] < [Na$^+$] < [NO$_3^-$]  (C) [NO$_3^-$] < [PO$_4^{3-}$] < [Na$^+$]

(D) [Na$^+$] < [NO$_3^-$] < [PO$_4^{3-}$]  (E) [Na$^+$] < [PO$_4^{3-}$] < [NO$_3^-$]

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

(A) Adding dilute Na$_2$S$_{(aq)}$ solution  (B) Adding dilute HCl$_{(aq)}$ solution  (C) Adding dilute NaOH$_{(aq)}$ solution

(D) Adding dilute NH$_3_{(aq)}$ solution  (E) Adding dilute HNO$_3_{(aq)}$ solution

73. The volume of distilled water that should be added to 10.0 mL of 6.00 M HCl$_{(aq)}$ in order to prepare a 0.500 M HCl$_{(aq)}$ solution is approximately…

(A) 50.0 mL  (B) 60.0 mL  (C) 100. mL  (D) 110. mL  (E) 120. mL

Use the following answers for questions 10 - 13.
(A) CO$_3^{2-}$  (B) Cr$_2$O$_7^{2-}$  (C) NH$_4^+$  (D) Ba$^{2+}$  (E) Al$^{3+}$

Assume that you have an "unknown" consisting of an aqueous solution of a salt that contains one of the ions listed above. Which ion must be absent on the basis of each of the following observations of the "unknown"?

10. The solution is colorless.
11. The solution gives no apparent reaction with dilute hydrochloric acid.
12. No odor can be detected when a sample of the solution is added drop by drop to a warm solution of sodium hydroxide.
13. No precipitate is formed when a dilute solution of H$_2$SO$_4$ is added to a sample of the solution.

37. 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

55. At 20 °C, the vapor pressure of toluene is 22 millimeters of mercury and that of benzene is 75 millimeters of mercury. An ideal solution, equimolar in toluene and benzene, is prepared. At 20 °C, what is the mole fraction of benzene in the vapor in equilibrium with this solution?
(A) 0.23  
(B) 0.29  
(C) 0.50  
(D) 0.77  
(E) 0.83

84. Which of the following aqueous solutions has the highest boiling point?
(A) 0.10 M potassium sulfate, K$_2$SO$_4$  
(B) 0.10 M hydrochloric acid, HCl  
(C) 0.10 M ammonium nitrate, NH$_4$NO$_3$  
(D) 0.10 M magnesium sulfate, MgSO$_4$  
(E) 0.20 M sucrose, C$_{12}$H$_{22}$O$_{11}$

27.
I. Difference in temperature between freezing point of solvent and freezing point of solvent and freezing point of solution
II. Molal freezing point depression constant, K$_f$, for solvent

In addition to the information above, which of the following gives the minimum data required to determine the molecular mass of a nonionic substance by the freezing point depression technique?

(A) No further information is necessary.  
(B) Mass of solute  
(C) Mass of solute and mass of solvent  
(D) Mass of solute and volume of solvent  
(E) Mass of solute, mass of solvent, and vapor pressure of solvent

28. 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.
the solid has a high energy of hydration.

71. A solution of toluene (molecular weight 92.1) in benzene (molecular weight 78.1) is prepared. The mole fraction of toluene in the solution is 0.100. What is the molality of the solution?
(A) 0.100 m  (B) 0.703 m  (C) 0.921 m  (D) 1.28 m  (E) 1.42 m

14. Which of the following is lower for a 1.0-molar aqueous solution of any solute than it is for pure water?
(A) pH  (B) Vapor pressure  (C) Freezing point  (D) Electrical conductivity  (E) Absorption of visible light

44. Which of the following solutions has the lowest freezing point?
(A) 0.20 m C₆H₁₂O₆, glucose  (B) 0.20 m NH₄Br  (C) 0.20 m ZnSO₄
(D) 0.20 m KMnO₄  (E) 0.20 m MgCl₂

31. 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.

43. A sample of 61.8 g of H₃BO₃, a weak acid is dissolved in 1,000 g of water to make a 1.0-molal solution. Which of the following would be the best procedure to determine to molarity of the solution? (Assume no additional information is available.)
(A) Titration of the solution with standard acid  (B) Measurement of the pH with a pH meter
(C) Determination of the boiling point of the solution  (D) Measurement of the total volume of the solution
(E) Measurement of the specific heat of the solution

75. Which of the following pairs of liquids forms the solution that is most ideal (most closely follows Raoult's law)?
(A) C₈H₁₈(l) and H₂O(l)  (B) CH₃CH₂CH₂OH(l) and H₂O(l)
(C) CH₃CH₂CH₂OH(l) and C₈H₁₈(l)  (D) C₆H₁₄(l) and C₈H₁₈(l)  (E) H₂SO₄(l) and H₂O(l)

67. Substances X and Y that were in a solution were separated in the laboratory using the technique of fractional crystallization. This fractional crystallization is possible because substances X and Y have different...
(A) boiling points  (B) melting points  (C) densities  (D) crystal colors  (E) solubilities

35. A solution is made by dissolving a nonvolatile solute in pure solvent. Compared to the pure solvent, the solution...
(A) has a higher normal boiling point.
(B) has a higher vapor pressure.
(C) has the same vapor pressure.
(D) has a higher freezing point.
(E) is more nearly ideal.
45. What is the mole fraction of ethanol, C\textsubscript{2}H\textsubscript{5}OH, in an aqueous solution that is 46 percent ethanol by mass? (The molar mass of C\textsubscript{2}H\textsubscript{5}OH is 46 g; the molar mass of H\textsubscript{2}O is 18 g.)

(A) 0.25  (B) 0.46  (C) 0.54  (D) 0.67  (E) 0.75

26. Approximately what mass of CuSO\textsubscript{4}·5H\textsubscript{2}O (250 g mol\textsuperscript{-1}) is required to prepare 250 mL of 0.10 M copper (II) sulfate solution?

(A) 4.0 g  (B) 6.2 g  (C) 34 g  (D) 85 g  (E) 140 g

38. A 0.10 M aqueous solution of sodium sulfate, Na\textsubscript{2}SO\textsubscript{4}, is a better conductor of electricity than a 0.10 M aqueous solution of sodium chloride, NaCl. Which of the following best explains this observation?

(A) Na\textsubscript{2}SO\textsubscript{4} is more soluble in water than NaCl is.
(B) Na\textsubscript{2}SO\textsubscript{4} has a higher molar mass than NaCl has.
(C) To prepare a given volume of 0.10 M solution, the mass of Na\textsubscript{2}SO\textsubscript{4} needed is more than twice the mass of NaCl needed.
(D) More moles of ions are present in a given volume of 0.10 M Na\textsubscript{2}SO\textsubscript{4} than in the same volume of 0.10 M NaCl.
(E) The degree of dissociation of Na\textsubscript{2}SO\textsubscript{4} in solution is significantly greater than that of NaCl.

39. On the basis of the solubility curves shown, the greatest percentage of which compound can be recovered by cooling a saturated solution of that compound from 90°C to 30°C?

(A) NaCl
(B) KNO\textsubscript{3}
(C) K\textsubscript{2}CrO\textsubscript{4}
(D) K\textsubscript{2}SO\textsubscript{4}
(E) Ce\textsubscript{2}(SO\textsubscript{4})\textsubscript{3}

69. If 200. mL of 0.60 M MgCl\textsubscript{2}(aq) is added to 400. mL of distilled water, what is the concentration of Mg\textsuperscript{2+}(aq) in the resulting solution? (Assume volume are additive.)

(A) 0.20 M  (B) 0.30 M  (C) 0.40 M  (D) 0.60 M  (E) 1.2 M

Name ____________________________
21. 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

23. 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 L-atm / mole-K)

(A) 14.6  
(B) 46.0  
(C) 88.0  
(D) 94.1  
(E) 138

39. 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 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.

50. Two flexible containers for gases are at the same temperature and pressure. One holds 0.50 grams of hydrogen and the other holds 8.0 grams of oxygen. Which of the following statements regarding these gas samples is FALSE?

(A) The volume of the hydrogen container is the same as the volume of the oxygen container.  
(B) The number of molecules in the hydrogen container is the same as the number of molecules in the oxygen container.  
(C) The density of the hydrogen sample is less than that of the oxygen sample.  
(D) The average kinetic energy of the hydrogen molecules is the same as the average kinetic energy of the oxygen molecules.  
(E) The average speed of the hydrogen molecules is the same as the average speed of the oxygen molecules.

52. 3 Ag(s) + 4 HNO₃ ⇄ 3 AgNO₃ + NO(g) + 2 H₂O

The reaction of silver metal and dilute nitric acid proceeds according to the equation above. If 0.10 moles of powdered silver is added to 10.0 milliliters of 6.0-molar nitric acid, the number of moles of NO gas that can be formed is...

(A) 0.015 mole  
(B) 0.020 mole  
(C) 0.030 mole  
(D) 0.045 mole  
(E) 0.090 mole

78. When the actual gas volume is greater than the volume predicted by the ideal gas law, the explanation lies in the fact that the ideal gas law does NOT include a factor for molecular...

(A) volume  
(B) mass  
(C) velocity  
(D) attractions  
(E) shape
72. A compound is heated to produce a gas whose molecular weight is to be determined. The gas is collected by displacing water in a water-filled flask inverted in a trough of water. Which of the following is necessary to calculate the molecular weight of the gas, but does NOT need to be measured during the experiment?
(A) Mass of the compound used in the experiment  (B) Temperature of the water in the trough  
(C) Vapor pressure of the water  (D) Barometric pressure  
(E) Volume of water displaced from the flask

85. 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

16. A gaseous mixture containing 7.0 moles of nitrogen, 2.5 moles of oxygen, and 0.50 mole of helium exerts a total pressure of 0.90 atmospheres. What is the partial pressure of the nitrogen?
(A) 0.13 atm  (B) 0.27 atm  (C) 0.63 atm  (D) 0.90 atm  (E) 6.3 atm

24. A sample of 0.010 moles of oxygen gas is confined at 127 °C and 0.80 atmosphere. What would be the pressure of this sample at 27 °C and the same volume?
(A) 0.10 atm  (B) 0.20 atm  (C) 0.60 atm  (D) 0.80 atm  (E) 1.1 atm

30. Hydrogen gas is collected over water at 24 °C. The total pressure of the sample is 755 millimeters of mercury. At 24 °C, the vapor pressure of water is 22 millimeters of mercury. What is the partial pressure of the hydrogen gas?
(A) 22 mm Hg  (B) 733 mm Hg  (C) 755 mm Hg  (D) 760 mm Hg  (E) 777 mm Hg

32. A 2.00-liter sample of nitrogen gas at 27 °C and 600. millimeters of mercury is heated until it occupies a volume of 5.00 liters. If the pressure remains unchanged, the final temperature of the gas is...
(A) 68 °C  (B) 120 °C  (C) 477 °C  (D) 677 °C  (E) 950. °C

40. \(2 \text{K} + 2 \text{H}_2\text{O} \rightarrow 2 \text{K}^+ + 2 \text{OH}^- + \text{H}_2\)

When 0.400 moles 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  (B) 2.24 liters  (C) 3.36 liters  (D) 4.48 liters  (E) 6.72 liters

62. As the temperature is raised from 20 °C to 40 °C, the average kinetic energy of neon atoms changes by a factor of...
(A) \(\frac{1}{2}\)  (B) \(\sqrt{313/293}\)  (C) 313/293  (D) 2  (E) 4

24. A sample of 0.0100 moles of oxygen gas is confined at 37 °C and 0.216 atmospheres. 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

74. Which of the following gases deviates most from ideal behavior?
A) \(\text{SO}_2\)  B) \(\text{Ne}\)  C) \(\text{CH}_4\)  D) \(\text{N}_2\)  E) \(\text{H}_2\)
33. A hydrocarbon gas with an empirical formula CH₂ has a density of 1.88 grams per liter at 0 °C and 1.00 atmospheres. A possible formula for the hydrocarbon is…
(A) CH₂ (B) C₂H₄ (C) C₃H₆ (D) C₄H₈ (E) C₅H₁₀

37. A sample of 3.0 grams of an ideal gas at 121°C and 1.0 atmospheres pressure has a volume of 1.5 liters. Which of the following expressions is correct for the molar mass of the gas? (R = 0.082 L-atm / mole-K)
(A) [(0.082)(394)] / [(3.0)(1.0)(1.5)]
(B) [(1.0)(1.5)] / [(3.0)(0.082)(394)]
(C) [(0.082)(1.0)(1.5)] / [(3.0)(394)]
(D) [(3.0)(0.082)(394)] / [(1.0)(1.5)]
(E) [(3.0)(0.082)(1.5)] / (1.0)(394)]

39. Samples of F₂ gas and Xe gas are mixed in a container of fixed volume. The initial partial pressure of the F₂ gas is 8.0 atmospheres and that of the Xe gas is 1.7 atmospheres. When all of the Xe gas reacted, forming a solid compound, the pressure of the unreacted F₂ gas was 4.6 atmospheres. The temperature remained constant. What is the formula of the compound?
(A) XeF (B) XeF₃ (C) XeF₄ (D) XeF₆ (E) XeF₈

40. The system shown in the picture 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

45. A sample of an ideal gas is cooled from 50.0 °C to 25.0 °C in a sealed container of constant volume. Which of the following values for the gas will decrease?
I. The average molecular mass of the gas
II. The average distance between the molecules
III. The average speed of the molecules
(A) I only (B) II only (C) III only (D) I and III (E) II and III

64. At 25 °C, a sample of NH₃ (molar mass 17 grams) effuses at the rate of 0.050 moles per minute. Under the same conditions, which of the following gases effuses at approximately one-half that rate?
(A) O₂ (molar mass 32 grams) (B) He (molar mass 4.0 grams) (C) CO₂ (molar mass 44 grams)
(D) Cl₂ (molar mass 71 grams) (E) CH₄ (molar mass 16 grams)
Pressure of $O_2(g)$ above $H_2O(l)$ (atm) | Temperature of $H_2O(l)$ °(C)  
---|---
(A) 5 | 80  
(B) 5 | 20  
(C) 1 | 80  
(D) 1 | 20  
(E) 0.5 | 20

52. Under which of the following sets of conditions could the most $O_2(g)$ be dissolved in $H_2O(l)$?

23. A hot-air balloon, shown at the right, rises. Which of the following is the best explanation for this observation?
(A) The pressure on the walls of the balloon increases with increasing temperature.
(B) The difference in temperature between the air inside and outside the balloon produces convection currents.
(C) The cooler air outside the balloon pushes in on the walls of the balloon.
(D) The rate of diffusion of cooler air is less than that of warmer air.
(E) The air density inside the balloon is less than that of the surrounding air.

44. 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 increase.  
(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.

53. $W(g) + X(g) \rightarrow Y(g) + Z(g)$
Gas W and X react in a closed, rigid vessel to form Gas 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

60. $NH_4NO_3(s) \rightarrow N_2O(g) + 2 H_2O(g)$  
(Container Volume = 1.0 L)
A 0.03 mol sample of $NH_4NO_3(s)$ 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? ($R = 0.08 \text{ L-atm / mole-K}$)
(A) 3 atm  
(B) 1 atm  
(C) 0.5 atm  
(D) 0.1 atm  
(E) 0.03 atm

64. 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) $P_{He} < P_{Ne} < P_{Ar}$  
(B) $P_{He} < P_{Ar} < P_{Ne}$  
(C) $P_{Ne} < P_{Ar} < P_{He}$  
(D) $P_{Ar} < P_{He} < P_{Ne}$  
(E) $P_{He} = P_{Ar} = P_{Ne}$
Questions 8-10 refer to the following gases at 0°C and 1 atm:
(A) Ne
(B) Xe
(C) O₂
(D) CO
(E) NO

8. Has an average atomic or molecular speed closest to that of N₂ molecules at 0°C and 1 atm.
9. Has the greatest density.
10. Has the greatest rate of effusion through a pinhole.

20. A flask contains 0.25 mol of SO₂(g), 0.50 mole of CH₄(g), and 0.50 mole of O₂(g). The total pressure of the gases in the flask is 800 mm Hg. What is the partial pressure of the SO₂(g) in the flask?
(A) 800 mm Hg
(B) 600 mm Hg
(C) 250 mm Hg
(D) 200 mm Hg
(E) 160 mm Hg

66. A 2 L container will hold about 4 g of which of the following gases at 0°C and 1 atm?
(A) SO₂
(B) N₂
(C) CO₂
(D) C₄H₈
(E) NH₃

Name ____________________________

AP Chemistry: Thermodynamics
Multiple Choice
(You may use a calculator.)

47. CH₄(g) + 2 O₂(g) → CO₂(g) + 2 H₂O(l); \( \Delta H_{\text{rxn}} = -889.1 \text{ kJ} \)
\( \Delta H_f^\circ \text{H}_2\text{O(l)} = -285.8 \text{ kJ/mole} \)  \( \Delta H_f^\circ \text{CO}_2(g) = -393.3 \text{ kJ/mole} \)

What is the standard heat of formation of methane, \( \Delta H_f^\circ \text{CH}_4(g) \), as calculated from the data above?
(A) \(-210.0 \text{ kJ/mole}\)  (B) \(-107.5 \text{ kJ/mole}\)  (C) \(-75.8 \text{ kJ/mole}\)  (D) \(75.8 \text{ kJ/mole}\)  (E) \(210.0 \text{ kJ/mole}\)

48. Which of the following is a graph that describes the pathway of reaction that is endothermic and has high activation energy?
25.

\[
\begin{align*}
\text{H}_2(g) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{H}_2\text{O}(l) & \Delta H^\circ &= x \\
2 \text{Na}(s) + \frac{1}{2} \text{O}_2(g) & \rightarrow \text{Na}_2\text{O}(s) & \Delta H^\circ &= y \\
\text{Na}(s) + \frac{1}{2} \text{O}_2(g) + \frac{1}{2} \text{H}_2(g) & \rightarrow \text{NaOH}(s) & \Delta H^\circ &= z
\end{align*}
\]

Based on the information above, what is the standard enthalpy change for the following reaction?
\[
\text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2 \text{NaOH}(s)
\]
(A) \(x + y + z\)
(B) \(x + y - z\)
(C) \(x + y - 2z\)
(D) \(2z - x - y\)
(E) \(z - x - y\)

30. The energy diagram for the reaction \(X + Y \rightarrow Z\) is shown. The addition of a catalyst to this reaction would cause a change in which of the indicated energy differences?

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

19. Which of the following best describes the role of the spark from the spark plug in an automobile engine?

(A) The spark decreases the energy of activation for the slow step.
(B) The spark increases the concentration of the volatile reactant.
(C) The spark supplies some of the energy of activation for the combustion reaction.
(D) The spark provides a more favorable activated complex for the combustion reaction.
(E) The spark provides the heat of vaporization for the volatile hydrocarbon.

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

For the reaction of ethylene represented above, \(\Delta H = -1,323 \text{ kJ}\). 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 \(-44 \text{ kJ mol}^{-1}\).)
25.  $3 \text{C}_2\text{H}_2(\text{g}) \rightarrow \text{C}_6\text{H}_6(\text{g})$

What is the standard enthalpy change, $\Delta H^\circ$, for the reaction represented above?
($\Delta H^\circ_f$ of $\text{C}_2\text{H}_2(g)$ is 230 kJ mol$^{-1}$; $\Delta H^\circ_f$ of $\text{C}_6\text{H}_6(g)$ is 83 kJ mol$^{-1}$)

(A) $-607$ kJ  (B) $-147$ kJ  (C) $-19$ kJ  (D) +19 kJ  (E) +773 kJ

83. $\text{NH}_3(\text{g}) + 2 \text{CH}_4(\text{g}) + 5/2 \text{O}_2(\text{g}) \leftrightarrow \text{H}_2\text{NCH}_2\text{COOH}_{(\text{s})} + 3 \text{H}_2\text{O}_{(\text{l})}$

At constant temperature, $\Delta H$, the change in enthalpy for the reaction above is equal to...

(A) $\Delta E - (11/2)RT$  (B) $\Delta E - (7/2)RT$  (C) $\Delta E + RT$  (D) $\Delta E + (7/2)RT$  (E) $\Delta E (11/2)RT$

AP Chemistry: Organic Chemistry
Multiple Choice

77. Which of the following compounds exhibits optical isomerism?

(A)  

(B)  

(C)  

(D)  

(E)  

43. Which of the following pairs of compounds are isomers?

(A) $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_3$ and $\text{CH}_3-\text{CH}-\text{CH}_3$

(B) $\text{CH}_3-\text{O}-\text{CH}_3$ and $\text{CH}_3-\text{C}-\text{CH}_3$

(C) $\text{CH}_3-\text{OH}$ and $\text{CH}_3-\text{CH}_2-\text{OH}$

(D) $\text{CH}_4$ and $\text{CH}_2=\text{CH}_2$
29. The organic compound represented above is an example of...

(A) an organic acid  (B) an alcohol  (C) an ether  (D) an aldehyde  (E) a ketone

62. 

Which of the following structural formulas represents an isomer of the compound that has the structural formula represented above?

1. Which of the following is the correct electron-dot formula for water?
2. Which of the following is the correct electron-dot formula for carbon dioxide?

(a) \( \cdot \text{O}=:\text{C}=: \)
(b) \( =\text{O}::=\text{C}=: \)
(c) \( =\text{O}::\text{C}=O \)
(d) \( =\text{O}::=\text{C}=O \)

3. Which of the following represents the correct formula for aluminum oxide?

(a) \( \text{AlO} \)
(b) \( \text{Al}_2\text{O}_3 \)
(c) \( \text{AlO}_2 \)
(d) \( \text{Al}_2\text{O} \)

4. Which of the bonds, shown by the dash, has the greatest polarity?

(a) \( \text{H-Cl} \)
(b) \( \text{H-NH}_2 \)
(c) \( \text{H-OH} \)
(d) \( \text{H-SH} \)

5. What is the major attraction between water molecules in the solid physical state?

(a) dipole-dipole interactions
(b) electrostatic interactions between charged atoms
(c) hydrogen-bonds
(d) physical entanglement of the molecules

6. Which of the following is the correct name for \( \text{NaHCO}_3 \)?

(a) sodium hydrogen carbonate
(b) sodium acetate
(c) nitrogen hydrogen carbonate
(d) sodium hydrogen carbon trioxide

7. What is the formal charge of the oxygen atom of the following compound?

\[
\begin{array}{c}
\text{H} \quad \text{O} \quad \text{H} \\
\text{H} \\
\end{array}
\]

(a) +3
(b) +1
(c) -2
(d) -3

8. The molecule \( \text{N}_2 \) is isoelectronic with...

(a) \( \text{O}_2 \)
(b) \( \text{F}_2 \)
(c) \( \text{NO} \)
(d) \( \text{CN}^- \)
9. In which of the following compounds does ionic bonding predominate?

(a) NH₄Cl  
(b) CO₂  
(c) CH₄  
(d) LiBr

10. Which of the following molecules contains only one non-bonding pair of valence electrons?

(a) NH₄⁺  
(b) HCN  
(c) C₂H₄  
(d) N₂

11. The following electron-dot formulas for carbon dioxide both satisfy the octet rule for all of the atoms. Which of these structures is the better structure and why is this the case?

\[ \cdot\text{O}≡\text{C}≡\cdot\quad \cdot\text{O}≡\text{C}−\cdot \]

A  
B  
(a) "A" is the better structure because there is no formal charge on any of the atoms.  
(b) "A" is the better structure because all the bonds and non-bonding electron pairs are arranged in a symmetrical pattern.  
(c) "B" is the better structure because there are opposite formal charges on the two oxygen atoms which attract each other and give the molecule a lower energy.  
(d) "B" is the better structure because the bond energies of a single bond and a triple bond are higher than the bond energies of two double bonds.

12. Which of the following gases would be most soluble in water?

(a) N₂  
(b) NH₃  
(c) CH₄  
(d) CO₂

13. Which of the following compounds should have the highest boiling point?

(a) NH₃  
(b) CH₄  
(c) H₂O  
(d) HF

1. What is the energy of one mole of light that has a wavelength of 400 nm?

(a) 4.97 x 10⁻²⁸ J  
(b) 4.97 x 10⁻¹⁹ J  
(c) 2.99 x 10⁻⁴ J  
(d) 2.99 x 10⁵ J

2. Helium can be singly ionized by losing one electron to become the He⁺ cation. Which of the following
statements is true concerning this helium cation?
(a) The line spectrum of this helium cation will resemble the line spectrum of a hydrogen atom.
(b) The line spectrum of this helium cation will resemble the line spectrum of a lithium cation.
(c) The line spectrum of this helium cation will remain the same as for unionized helium.
(d) The line spectrum of this helium cation will resemble the line spectrum of a lithium atom.

3. Which of the following atoms has the largest diameter?
(a) F
(b) Cl
(c) Br
(d) I

4. Which of the following ions has the smallest diameter?
(a) O^{2-}
(b) Na^{+}
(c) F
(d) Al^{3+}

5. Which of the following elements has the greatest electronegativity?
(a) Si
(b) P
(c) N
(d) O

6. Which element would have the greater difference between the first ionization energy and the second ionization energy?
(a) potassium
(b) calcium
(c) Both should have the same differences because they are in the same period of the periodic table.

7. Which element would have the higher electron affinity?
(a) chlorine
(b) bromine
(c) Both should have the same electron affinity because they are in the same group of the periodic table and both will gain only 1 electron.

Name ____________________________
AP Chemistry: Stoichiometry
Multiple Choice
(You may use a calculator.)

44. What number of moles of O_2 is needed to produce 14.2 grams of P_4O_{10} from P? (Molar Mass P_4O_{10} = 284)
(A) 0.0500 mole  (B) 0.0625 mole  (C) 0.125 mole  (D) 0.250 mole  (E) 0.500 mole
73. 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) C₄H₃  (D) C₄H₆  (E) C₄H₁₀

23. How many grams of calcium nitrate, Ca(NO₃)₂, contains 24 grams of oxygen atoms?
(A) 164 grams  (B) 96 grams  (C) 62 grams  (D) 50. grams  (E) 41 grams

25. The simplest formula for an oxide of nitrogen that is 36.8 percent nitrogen by weight is…
(A) N₂O  (B) NO  (C) NO₂  (D) N₂O₃  (E) N₂O₅

39. When a hydrate of Na₂CO₃ is heated until all the water is removed, it loses 54.3 percent of its mass. The formula of the hydrate is…
(A) Na₂CO₃ · 10 H₂O  (B) Na₂CO₃ · 7 H₂O  (C) Na₂CO₃ · 5 H₂O  (D) Na₂CO₃ · 3 H₂O  (E) Na₂CO₃ · H₂O

19. In which of the following compounds is the mass ratio of chromium to oxygen closest to 1.6 to 1.0?
(A) CrO₃  (B) CrO₂  (C) CrO  (D) Cr₂O  (E) Cr₂O₃

72. After completing an experiment to determine gravimetrically the percentage of water in a hydrate, a student reported a value of 38 percent. The correct value for the percentage of water in the hydrate is 51 percent. Which of the following is the most likely explanation for this difference?
A) Strong initial heating caused some of the hydrate sample to spatter out of the crucible.
B) The dehydrated sample absorbed moisture after heating.
C) The amount of the hydrate sample used was too small.
D) The crucible was not heated to constant mass before use.
E) Excess heating caused the dehydrated sample to decompose.

45. The alkenes are compounds of carbon and hydrogen with the general formula CₙH₂ₙ. If 0.561 gram of any alkene is burned in excess oxygen, what number of moles of H₂O is formed?
(A) 0.0400 mole  (B) 0.0600 mole  (C) 0.0800 mole  (D) 0.400 mole  (E) 0.800 mole

37. CH₃CH₂COOH(l) + O₂(g) → CO₂(g) + H₂O(l)
How many moles of O₂ are required to oxidize 1 mole of CH₃CH₂COOH according to the reaction represented above?
(A) 2 moles  (B) 5/2 moles  (C) 3 moles  (D) 7/2 moles  (E) 9/2 moles

67. BrO₃⁻ + 5 Br⁻ + 6 H⁺ ⇌ 3 Br₂ + 3 H₂O
If 25.0 milliliters of 0.200-molar BrO₃⁻ is mixed with 30.0 milliliters of 0.450-molar Br⁻ solution that contains a large excess of H⁺, the amount of Br₂ formed, according to the equation above, is…
(A) 5.00 x 10⁻³ mole  (B) 8.10 x 10⁻³ mole  (C) 1.35 x 10⁻² mole  (D) 1.50 x 10⁻² mole  (E) 1.62 x 10⁻² mole
56. It is suggested that \( \text{SO}_2 \) (molar mass 64 grams), which contributes to acid rain, could be removed from a stream of waste gas by bubbling the gas through 0.25-molar KOH, thereby producing \( \text{K}_2\text{SO}_3 \). What is the maximum mass of \( \text{SO}_2 \) that could be removed by 1,000 liters of the KOH solution?

(A) 4.0 kg    (B) 8.0 kg    (C) 16 kg    (D) 20. kg    (E) 40. kg

59. When a 1.25-gram sample of limestone was dissolved in acid, 0.44 gram of \( \text{CO}_2 \) was generated. If the rock contained no carbonate other than \( \text{CaCO}_3 \), what was the percent of \( \text{CaCO}_3 \) by mass in the limestone?

(A) 35%    (B) 44%    (C) 67%    (D) 80%    (E) 100%

26. \( \ldots \cdot \text{C}_{10}\text{H}_{12}\text{O}_4\text{S}_{(s)} \rightarrow \ldots \cdot \text{CO}_2(g) + \ldots \cdot \text{SO}_2(g) + \ldots \cdot \text{H}_2\text{O}_{(g)} \)

When the equation above is balanced and all coefficients are reduced to their lowest whole-number terms, the coefficient for \( \text{O}_2(g) \) is...

(A) 6    (B) 7    (C) 12    (D) 14    (E) 28

55. \( 10 \text{HI} + 2 \text{KMnO}_4 + 3 \text{H}_2\text{SO}_4 \rightarrow 5 \text{I}_2 + 2 \text{MnSO}_4 + \text{K}_2\text{SO}_4 + 8 \text{H}_2\text{O} \)

According to the balanced equation above, how many moles of HI would be necessary to produce 2.5 mol of \( \text{I}_2 \), starting with 4.0 mol of \( \text{KMnO}_4 \) and 3.0 mol of \( \text{H}_2\text{SO}_4 \)?

A) 20  B) 10  C) 8.0  D) 5.0  E) 2.5

24. A compound contains 1.10 mol of K, 0.55 mol of Te, and 1.65 mol of O. What is the simplest formula of this compound?

(A) KTeO  
(B) KTe_2O  
(C) K_2TeO_3  
(D) K_2TeO_6  
(E) K_4TeO_6

31. \( \text{CS}_2(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{SO}_2(\text{g}) \)

What volume of \( \text{O}_2(\text{g}) \) is required to react with excess \( \text{CS}_2(\text{l}) \) to produce 4.0 L of \( \text{CO}_2(\text{g}) \)? (Assume all gases are measured at 0°C and 1 atm.)

(A) 12 L  
(B) 22.3 L  
(C) 1/3 \times 22.4 L  
(D) 2 \times 22.4 L  
(E) 3 \times 22.4 L

52. Propane gas, \( \text{C}_3\text{H}_8 \), burns in excess oxygen gas. When the equation for this reaction is correctly balanced and all coefficients are reduced to their lowest whole-number terms, the coefficient for \( \text{O}_2 \) is...

(A) 4    (B) 5    (C) 7    (D) 10    (E) 22
58. \[ 2 \text{N}_2\text{H}_4(\text{g}) + \text{N}_2\text{O}_4(\text{g}) \rightarrow 3\text{N}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{g}) \]

When 8.0 g of N\(_2\)H\(_4\) (32 g mol\(^{-1}\)) and 92 g of N\(_2\)O\(_4\) (92 g mol\(^{-1}\)) are mixed together and react according to the equation above, what is the maximum mass of H\(_2\)O that can be produced?

(A) 9.0 g    (B) 18 g    (C) 36 g    (D) 72 g    (E) 144 g

60. \[ 2 \text{H}_2\text{O}(\text{l}) + 4 \text{MnO}_4^-(\text{aq}) + 3 \text{ClO}_2^-(\text{aq}) \rightarrow 4 \text{MnO}_2(\text{s}) + 3 \text{ClO}_4^-(\text{aq}) + 4 \text{OH}^-\text{(aq)} \]

According to the balanced equation above, how many moles of ClO\(_2^-(\text{aq})\) are needed to react completely with 20. mL of 0.20 M KMnO\(_4\) solution?

(A) 0.0030 mol    (B) 0.0053 mol    (C) 0.0075 mol    (D) 0.013 mol    (E) 0.030 mol

1. A 100 g sample of water at 25 °C and 1 atm. of pressure ___?___ than 100 g of water that has recently been heated to 100 °C from 0 °C and then cooled to 25 °C at 1 atm. of pressure.

(a) has more internal energy than
(b) has less internal energy than
(c) has the same internal energy as

2. If a system loses 250 kJ of heat at the same time that it is doing 500 kJ of work, what is the change in the internal energy of the system?

(a) +250 kJ
(b) -250 kJ
(c) +750 kJ
(d) -750 kJ

3. If 1.45 J of heat are added to a 2.00 g sample of aluminum metal and the temperature of the metal increases by 0.798 °C, what is the specific heat of aluminum?

(a) 0.579 J/g deg
(b) 0.909 J/g deg
(c) 1.68 J/g deg
(d) 3.63 J/g deg

4. Water has a specific heat of 4.184 J/g deg while glass (Pyrex) has a specific heat of 0.780 J/g deg. If 10.0 J of heat is added to 1.00 g of each of these, which will experience the larger increase of temperature?

(a) glass
(b) water
(c) They both will experience the same change in temperature since only the amount of a substance relates to the increase in temperature.
5. How many PopTarts\(^\oplus\) are needed to convert 1,000.0 g of water at 20.0 °C to steam at 100.0 °C? One PopTart is equal to 800,000 J of energy...wow!

(a) 0.419 PopTart  
(b) 2.83 PopTarts  
(c) 3.25 PopTarts

6. The heat of combustion for 1 mole of carbon to carbon dioxide is -410 kJ. How many kJ of heat would be liberated from the complete combustion of 60.0 g of carbon?

(a) -82 kJ  
(b) -2050 kJ  
(c) -24,600 kJ

7. Given the following data at 1 atm of pressure and 25.0 °C...

\[ \Delta H^\circ_{\text{formation}} = +64.4 \text{ kJ/mole for Cu}^{2+} \]

\[ \Delta H^\circ_{\text{formation}} = -152.4 \text{ kJ/mole for Zn}^{2+} \]

\[ \Delta H^\circ_{\text{formation}} = 0 \text{ for both Zn and Cu because these are in the most stable state.} \]

Calculate the standard heat of reaction for...

\[ \text{Zn (s) + Cu}^{2+} (aq) \rightarrow \text{Zn}^{2+} (aq) + \text{Cu (s)} \]

(a) -217 kJ/mole  
(b) +217 kJ/mole  
(c) -88.0 kJ/mole  
(d) +88.0 kJ/mole

8. A 1.00 g sample of NH\(_4\)NO\(_3\) is decomposed in a bomb calorimeter. The temperature of the calorimeter increases by 6.12 K. The heat capacity of the system is 1.23 kJ/g\(\Delta\)deg. What is the molar heat of decomposition for ammonium nitrate?

(a) -7.53 kJ/mole  
(b) -16.1 kJ/mole  
(c) -398 kJ/mole  
(d) -602 kJ/mole

9. A sample of 10.6 g of KNO\(_3\) was dissolved in 251.0 g of water at 25 °C in a calorimeter. The final temperature of the solution was 21.5 °C. What is the molar heat of solution of KNO\(_3\)? Assume the C\(_{sp}\) of the solution is 4.184 J/g\(\Delta\)deg and that the calorimeter does not gain or lose heat.

(a) +3830 J/mole  
(b) -3830 J/mole  
(c) +36,500 J/mole  
(d) -36,500 J/mole

10. What is the molar enthalpy of reaction for the combustion of methane? The balanced chemical equation and the bond energies for the various bonds in the reactants and products are...
\[ \text{CH}_4 (g) + 2 \text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2 \text{H}_2\text{O} (g) \]

- \( \text{O} = \text{O} \) \( 498 \text{ kJ/mole} \)
- \( \text{C} - \text{O} \) \( 358 \text{ kJ/mole} \)
- \( \text{O} - \text{H} \) \( 463 \text{ kJ/mole} \)
- \( \text{C} = \text{O} \) \( 732 \text{ kJ/mole} \)
- \( \text{C} - \text{H} \) \( 413 \text{ kJ/mole} \)

- (a) +80 kJ/mole
- (b) -284 kJ/mole
- (c) +668 kJ/mole
- (d) -668 kJ/mole