Answer Key:

1. Which of the following is not a state function? **[2]**
   (a) Energy (b) Enthalpy **(c) Work** (d) Pressure (e) Volume (f) Helmholtz Free Energy

2. At constant pressure and volume and at 300 K, a reaction has $\Delta G = 0.15$, while at 3000 K, a reaction has $\Delta G = 20.$ What can we conclude about this reaction? **[2]**
   (a) The reaction will be spontaneous at 100K (b) There is a change in state of matter
   (c) The reaction will be spontaneous at 200K **(d)** $\Delta H < 0$

3. Which of the following elements could have a negative heat of fusion at 1 atm pressure? **[2]**
   (a) Hydrogen **(b) Helium** (c) Lithium (d) Beryllium (e) Iodine (f) Phosphorous

4. A system of ideal nitrogen gas is compressed at constant temperature. What are the signs of work and heat in this compression? (W,Q) = **[2]**
   (a) (+,+) **(b) (+,-)** (c) (-,+) (d) (-,-)

5. What is the high temperature limiting molar heat capacity of diatomic gases (R = gas constant)? **[2]**
   (b) R (c) 3R/2 (d) 2R (e) 5R/2 (f) 3R **(g) 7R/2** (h) 4R (i) 9R/2 (j) 5R (k) 4R/3 (l) 8R/3

6. From the definition of entropy and the second law of thermodynamics, derive the fact that spontaneous reactions will only occur when $\Delta G \leq 0$ [You may assume constant pressure] **[3: 1pt use of 2nd law, 1pt substitution, 1 pt conclusion]**
   $0 \leq \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} = \Delta S - \Delta H/T \Leftrightarrow \Delta H - T\Delta S = \Delta G \leq 0$

7. A calorimeter at $23^{\circ}C$ has a heat capacity of $100\ J/C^{\circ}$ and is filled with 30.1 mL of water at $30^{\circ}C$. Afterwards, a piece of 2.01 g iron (heat capacity: 0.45 J/(g C)) at $700^{\circ}C$ is dropped into the calorimeter. Find the final temperature after equilibrium is established. Assume no heat is lost. **[3]**

   32.67 C

8. Explain why humans can and still exist, despite the laws of thermodynamics. **[2: 1 pt increase entropy, 1 pt activity example]**
   Though humans are highly ordered, they are creating more entropy on the universe through activities such as food digestion.

9. According to the Dulong–Petit law, the molar heat capacity of many elements is $3R$, where R is the gas constant. **[4: 1pt a, 1pt b, 2pts c]**
   (a). Calculate the molar heat capacity of iron, given that its heat capacity is 0.45 J/(g K)
   25.13 J/(mol K)

   (b). Calculate the molar heat capacity of water, given that its heat capacity is 4.2 J/(g K)
   75.6 J/(mol K)

   (c). Explain the cause(s) of any significant deviations from the Dulong-Petit law from parts (a) and (b). If there are no significant deviations, then do not answer this question.
   Hydrogen bonding and more degrees of freedom in H2O due to more atoms

10. If 1 g iron at 100 K is dissolved into a beaker with 1 g water at 200 K, then what will be the final temperature after equilibrium is established? **[2]**

    190.41 K

11. [Tiebreaker] For an ideal gas, it is well known that $C_p - C_v = nR$, where n is the moles of substance, and C_p and C_v are the molar heat capacities at constant pressure and constant volume, respectively. Given that the internal energy of an ideal gas only depends on temperature, prove the above relation between C_p and C_v. **[3: 1pt manipulation C_p, 1 pt manipulation and justification C_v, 1 pt conclusion]**
    $C_p = (\frac{\partial H}{\partial T})_P = (\frac{\partial U}{\partial T})_P + (\frac{\partial (PV)}{\partial T})_P = (\frac{\partial U}{\partial T})_P + nR$
    $C_v = (\frac{\partial U}{\partial T})_V = (\frac{\partial U}{\partial T})_P$ as the internal energy only depends on temperature,
    Thus $C_p - C_v = nR$

12. [Tiebreaker] 1 mol of an ideal gas is at a temperature of 300 K, and inside of an expandable 1 L container. If the container started increasing by 1 L/sec, and temperature is kept constant throughout this expansion, then at what rate is the container's pressure changing when the container is at 10 L? Assume no loss of energy or loss of molecules. **[3: 1 pt gas law manipulation, 1 pt substitution, 1 pt derivative]**
    PV = nRT
    PV = 0.0821 * 300 * 1 = 24.63 which implies P = 24.63/V
    Taking derivatives we obtain dP/dT = -24.63/V^2 * dV/dT
    Plugging in known values V = 10 L, dV/dT = 1 L/s we obtain that pressure is decreasing at a rate of 0.2463 atm/sec.

Section 2: Physical Properties

13. A 10 mL solution of CuCl2 in water is diluted to 1 L. If the freezing point of the first solution, before dilution, is -5.58 C, then find the freezing point of the solution after dilution. **[2]**
    -0.0558 C

14. Which of the following would have the highest boiling point? **[2]**
    (a) n-octane (b) water (c) sodium chloride (d) diamond (e) 2-propanol

15. Which of the following salts would produce a colorless solution when dissolved? **[2]**
    (a) $Zn(NO_3)_2$ (b) $K_2Cr_2O_7$ (c) $BaSO_4$ (d) $CuCl_2$ (e) $KMnO_4$ (f) NaI

16. An unknown metal is subjected to a flame test and produces a crimson red color. It is then combined with AgCl in solution and the resulting solution precipitates out Ag. Adding excess KNa2PO4 to this solution results in the formation of another precipitate. What is this metal? **[2]**
    (a) Li (b) Na (c) K (d) Au (e) Ca (f) Mg (g) Sr

17. Caesium Fluoride adopts a cubic close packed lattice structure in its crystal form, with unit cell length of 624 angstroms. Find its density. **[3]**
    [4 * 132.91 + 4 * 19]/[6.022 * 10^23]/[624*10^[-10]]^3 = 4.13 g/cm^3

18. Which of the following compounds, when combined together, would likely produce a non-brittle compound? **[2]**
    (a) $NaNO_3 + KCl$ (b) $CF_3SO_3H + NaH$ (c) $Ag + Mg(OH)_2$ (d) $AgNO_3 + CuCl_2$

19. Which of the following solids would easily sublime? (circle all that apply) **[2, 0.5 pts for each correct selection]**
    (a) CO_2 (b) Naphthalene (c) I_2 (d) p-Toluenesulfonic acid

20. Which of the following liquids would have the highest dielectric constant? **[2]**
    (a) Benzene (b) Diethyl ether [ethoxyethane] (c) Water (d) HCl

21. Explain how a mixture of the following liquids could be separated: **[2: miscibility, distillation]**
    Ammonia, Water, Lauric Acid (bp 300 C), Benzene
    $Mixture \Rightarrow Ammonia/H_2O + Lauric\ Acid/Benzene\ by\ miscibility \Rightarrow Full\ separation\ with\ distillation$
22. Explain how a mixture of iron, gold, and pulverized balsa wood can be separated. **[2: magnetism, density]**
    Magnetism -> Separate Iron
    Density test with water -> Separate gold/balsa wood

23. Vulcanization of rubber is a common process used in order to make rubber much more elastic than natural rubber. It makes cross-linked polymers with disulfide/multisulfide bridges. How does this process make it more elastic? **[2: flexibility, snapping back]**
    Sulfide bridges are somewhat flexible and can stretch. Afterwards, the cross-linking makes it “snap back” to its original shape.

24. Dichromate ions can be converted to chromate ions through an acid catalyst. Provide a way to qualitatively see that this change has occurred. (Be specific) **[1]**
    Change from orange to yellow color

25. A solution of a non-electrolyte, x, contains 42 grams of x per kilogram of water and freezes at -1.46°C. What is the molecular weight of x? **[2]**
    54 g/mol

26. A piece of silver foil has a width of 2.00 cm and is 0.00200 in. thick. If the density of silver is 10.5 g/cm3, how long of a strip should be cut to obtain 1.00 g of the metal? **[2]**
    9.37 cm

27. Which substance is most soluble in water? **[2]**
    (a) glucose **(b) ethanol** (c) octanol (d) benzene (e) 1-methylcyclopropene