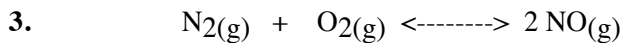*Thermo Test Review ! (Some data is given at the end)*

1. State the <u>first law of thermodynamics.</u>

2. a. State the Second Law of Thermo in word form.
b. How does $\Delta G°_{rxn}$ relate to the entropy change of the universe?

3. $N_{2(g)} + O_{2(g)}$ <-------> $2\,NO_{(g)}$ $\Delta H°_{rxn} = 180.74$ kJ/mole
                                                                       $\Delta S°_{rxn} = 24.7$ J/mole-K

a. Write the heat term into the reaction on the correct side. Is energy absorbed or released by the rxn?
b. Calculate $\Delta G°_{rxn}$ at 25°C
c. Is the rxn spontaneous at 25°C?_____
d. For what temperature range is the reaction spontaneous?
e. Calculate Kp at 7000. Kelvin.
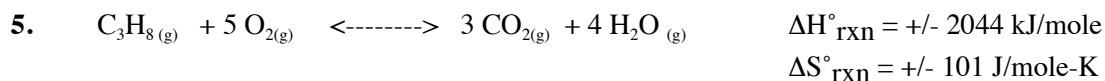f. Which Kp value make sense for this reaction at 8000. Kelvin: 1.29 or 0.775? Explain.
g. Use the Kp value at 8000. Kelvin to calculate the $\Delta G°_{rxn}$ at this temperature.

4. $\quad\quad\quad N_{2(g)} + 2 O_{2(g)} \longleftrightarrow 2 NO_{2(g)}$ $\quad\quad\quad\quad \Delta H°_{rxn} = 67.7$ kJ/mole

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \Delta S°_{rxn} = +/- 121$ J/mole-K

a. Write the heat term into the reaction on the correct side. Is energy absorbed or released by the rxn?

b. Determine the sign of $\Delta S°_{rxn}$.

c. Calculate $\Delta G°_{rxn}$ at 25°C

d. Is the rxn spontaneous at 25°C?_____

e. For what temperature range is the reaction spontaneous?

f. Explain your answer to (e) mathematically.

g. Explain your answer to (e) conceptually.

5. $C_3H_{8\,(g)} + 5\,O_{2(g)} \quad \text{<--------> } \quad 3\,CO_{2(g)} + 4\,H_2O_{\,(g)}$ $\qquad \Delta H°_{rxn} = +/- \ 2044 \text{ kJ/mole}$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \Delta S°_{rxn} = +/- \ 101 \text{ J/mole-K}$

a. Determine the sign of $\Delta S°_{rxn}$. and $\Delta H°_{rxn}$.

b. Write the heat term into the reaction on the correct side. Is energy absorbed or released by the rxn?

c. Calculate $\Delta G°_{rxn}$ at 25°C

d. Is the rxn spontaneous at 25°C?_____

e. For what temperature range is the reaction spontaneous?

f. Explain your answer to (e) mathematically.

g. Explain your answer to (e) conceptually.

h. When propane gas is allowed to mix with oxygen gas at 25°C, no reaction is observed. Does this mean that Keq <1? Explain.

i. What will be the enthalpy change if 10.0 grams of oxygen react?

j. How much energy will be released, if 10.0 grams of oxygen react, at constant pressure?

k. What mass of propane must combust in order to release 645 kJ of energy?

l. A calorimetry experiment is done to determine ΔH of this reaction.

        5.55 grams of propane are combusted while in thermal contact with 2220 grams of water.

        The energy from the reaction causes the water to increase in temperature from 18.4 °C to 45.8 °C.

        Calculate ΔHrxn based on the data including the sign. Use kJ for the energy unit.

        (Ignore the heat capacity of the propane in this problem – we don't know how much its temp changed anyway)

6.

	$\Delta H°_f$ (kJ/mole)	$\Delta G°_f$ (kJ/mole)	$S°_f$ (J/K-mole)
$PCl_{3(g)}$	-288	-270.	312
$PCl_{3(l)}$	-320.	-272	217

Thermodynamic data for $PCl_{3(g)}$ and $PCl_{3(l)}$ are shown above.

Use the data to estimate the normal boiling point of PCl_3.

7a. Formation of ATP from ADP is not a "spontaneous" reaction.
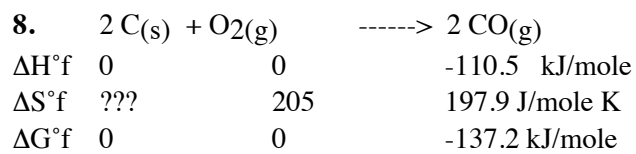So, how can we generate ATP in our body? What reaction do we "couple" together with the formation of ATP? Write the balanced equation for this reaction.

**b.** What is the sign of $\Delta G°$ for each of these processes:
- (1)   1 protein -----> individual amino acids
- (2)   individual amino acids -----> 1 protein
- (3)   a bunch of glucose molecules ----> a "strand" of glycogen polymer
- (4)   85 glucose + 510 O_2 ------> 510 H_2O + 510 CO_2

c. Which of the above reactions are "nonspontaneous?"
Since they are nonspontaneous, how do they happen in your body?

8. $2\,C_{(s)} + O_{2(g)} \quad \text{------>} \quad 2\,CO_{(g)}$

$\Delta H°f$	0	0	-110.5 kJ/mole
$\Delta S°f$	???	205	197.9 J/mole K
$\Delta G°f$	0	0	-137.2 kJ/mole

a. Calculate Kp at 25°C

b. Without using numbers, predict the sign of ΔS_{rxn}.

c. Determine ΔS_{rxn}.

d. Determine $\Delta S_{formation}$ of Carbon

e. For what temperature range is the rxn spontaneous?

9. Combustion of Propene: $2 C_3H_6 (g) + 9 O_2 (g)$ ---------> $6 CO_2 (g) + 6 H_2O (g)$
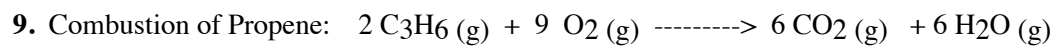
a. Determine ΔH rxn using heats of formation.

b. Write the heat term into the reaction on the correct side. Is energy absorbed or released by this reaction?

c. If 100. grams of propene combust, how much energy will be absorbed or released?

d. Determine the heat of combustion of propene in kJ/gram.

e. Determine ΔH rxn using bond enthalpies.

10. a. Sketch a graph showing temperature vs. heat added for water going from -50.0˚C to 150.0˚C.

b. Calculate the total energy required for part (a) if the mass is 10.0 grams.

11. 50.0 grams of metal at 100.0˚C are placed into 125 mL of water at 4.0˚C, in a "perfect calorimeter." At thermal equilibrium, the metal/water mixture is at a temperature of 6.8˚C. Calculate the specific heat of the metal.

12. $MgSO_{4(s)}$ ------> $Mg^{+2}_{(aq)}$ + $SO_4^{-2}_{(aq)}$
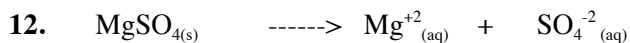
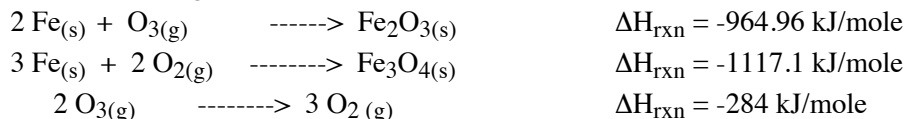An experiment is done to determine ΔH for the above "reaction."
87.3 grams of water and 6.48 grams of magnesium sulfate are each at a temperature of 21.4°C.
The water is placed into a calorimeter. The magnesium sulfate is added to the water, and the mixture is stirred until the $MgSO_4$ completely dissolves. As the salt dissolves, the solution reaches a maximum temperature of
33.3°C.   Calculate ΔH for the "reaction" (so, calculate "ΔH$_{solution}$ of $MgSO_4$") in kJ/mole.
       Assume that the calorimeter contents have a specific heat of 4.184 J/g°C.

13. Given the following:

$2 Fe_{(s)}$ + $O_{3(g)}$ ------> $Fe_2O_{3(s)}$ ΔH$_{rxn}$ = -964.96 kJ/mole
$3 Fe_{(s)}$ + $2 O_{2(g)}$ -------> $Fe_3O_{4(s)}$ ΔH$_{rxn}$ = -1117.1 kJ/mole
$2 O_{3(g)}$ -------> $3 O_{2 (g)}$ ΔH$_{rxn}$ = -284 kJ/mole

Use Hess's Law to calculate ΔH$_{rxn}$ for: $6 Fe_2O_{3(s)}$ ------> $4 Fe_3O_{4(s)}$ + $O_{2(g)}$

14. a. For each of the following phase changes, state whether the ΔH of the phase change is positive or negative, and whether the ΔH of the phase change is positive or negative.

	ΔH	ΔS
melting	_____	_____
freezing	_____	_____
condensation	_____	_____
vaporization	_____	_____
sublimation	_____	_____

b. Which of the phase changes are more "favorable" at high temp than at low temp, and how does this relate to the sign of the ΔH and ΔS?

**c.** Which of the phase changes are more "favorable" at low temp than at high temp, and how does this relate to the sign of the ΔH and ΔS?

10. Which of the following reactions is not thermodynamically favored at low temperatures but becomes favored as the temperature increases?

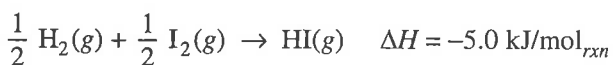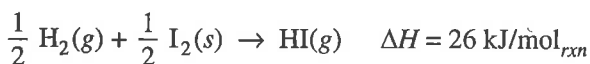| Reaction	$\Delta H°$ (kJ/mol$_{rxn}$)	$\Delta S°$ (J/(mol$_{rxn}$·K))
(A) $2\,CO(g) + O_2(g) \rightarrow 2\,CO_2(g)$	-566	-173
(B) $2\,H_2O(g) \rightarrow 2\,H_2(g) + O_2(g)$	484	90.0
(C) $2\,N_2O(g) \rightarrow 2\,N_2(g) + O_2(g)$	-164	149
(D) $PbCl_2(s) \rightarrow Pb^{2+}(aq) + 2\,Cl^-(aq)$	23.4	-12.5

9. A 100 g sample of a metal was heated to 100°C and then quickly transferred to an insulated container holding 100 g of water at 22°C. The temperature of the water rose to reach a final temperature of 35°C. Which of the following can be concluded?

(A) The metal temperature changed more than the water temperature did; therefore the metal lost more thermal energy than the water gained.

(B) The metal temperature changed more than the water temperature did, but the metal lost the same amount of thermal energy as the water gained.

(C) The metal temperature changed more than the water temperature did; therefore the heat capacity of the metal must be greater than the heat capacity of the water.

(D) The final temperature is less than the average starting temperature of the metal and the water; therefore the total energy of the metal and water decreased.
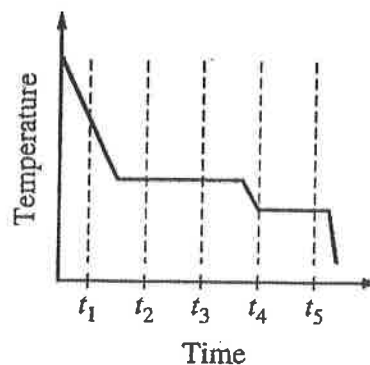

45. The cooling curve above shows how the temperature of a sample varies with time as the sample goes through phase changes. The sample starts as a gas, and heat is removed at a constant rate. At which time does the sample contain the most liquid?

(A) t_1
(B) t_2
(C) t_3
(D) t_4
(E) t_5

$\frac{1}{2}\,H_2(g) + \frac{1}{2}\,I_2(s) \rightarrow HI(g) \quad \Delta H = 26\ kJ/mol_{rxn}$

$\frac{1}{2}\,H_2(g) + \frac{1}{2}\,I_2(g) \rightarrow HI(g) \quad \Delta H = -5.0\ kJ/mol_{rxn}$

64. Based on the information above, what is the enthalpy change for the sublimation of iodine, represented below?

$$I_2(s) \rightarrow I_2(g)$$
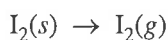
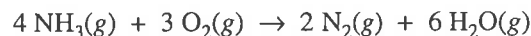(A) 15 kJ/mol$_{rxn}$
(B) 21 kJ/mol$_{rxn}$
(C) 31 kJ/mol$_{rxn}$
(D) 42 kJ/mol$_{rxn}$
(E) 62 kJ/mol$_{rxn}$

Questions 12-14 refer to the following combinations of enthalpy changes (ΔH) and entropy changes (ΔS) for chemical reactions.

(A) $\Delta H > 0,\ \Delta S > 0$
(B) $\Delta H > 0,\ \Delta S < 0$
(C) $\Delta H < 0,\ \Delta S > 0$
(D) $\Delta H < 0,\ \Delta S < 0$
(E) $\Delta H = 0,\ \Delta S < 0$

12. Must be true for a reaction that is spontaneous at all temperatures

13. True for the evaporation of water at 25°C and 1 atm

14. True for the combustion of liquid pentane, $C_5H_{12}(l)$, to form $H_2O(g)$ and $CO_2(g)$ at 1 atm

43. A pure liquid in an open vessel boils at the temperature at which the

(A) molar entropy of the liquid becomes equal to that of the gas
(B) vapor pressure of the liquid becomes equal to the equilibrium pressure at the triple point
(C) vapor pressure of the liquid becomes equal to the atmospheric pressure on the surface of the liquid
(D) molar heat capacity of the liquid becomes equal to that of the gas
(E) average kinetic energy of the liquid molecules becomes equal to that of the gas molecules

$$4 \, NH_3(g) + 3 \, O_2(g) \rightarrow 2 \, N_2(g) + 6 \, H_2O(g)$$

53. If the standard molar heats of formation of ammonia, $NH_3(g)$, and gaseous water, $H_2O(g)$, are -46 kJ/mol and -242 kJ/mol, respectively, what is the value of ΔH°_{298} for the reaction represented above?

(A) -190 kJ/mol$_{rxn}$
(B) -290 kJ/mol$_{rxn}$
(C) -580 kJ/mol$_{rxn}$
(D) $-1,270$ kJ/mol$_{rxn}$
(E) $-1,640$ kJ/mol$_{rxn}$

Questions 34-38

$$K(s) + \frac{1}{2} Cl_2(g) \rightarrow KCl(s) \qquad \Delta H^\circ = -437 \text{ kJ/mol}_{rxn}$$
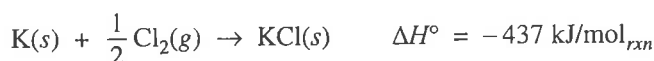
The elements K and Cl react directly to form the compound KCl according to the equation above. Refer to the information above and the table below to answer the questions that follow.

Process	ΔH° (kJ/mol$_{rxn}$)
$K(s) \rightarrow K(g)$	v
$K(g) \rightarrow K^+(g) + e^-$	w
$Cl_2(g) \rightarrow 2 \, Cl(g)$	x
$Cl(g) + e^- \rightarrow Cl^-(g)$	y
$K^+(g) + Cl^-(g) \rightarrow KCl(s)$	z

34. How much heat is released or absorbed when 0.050 mol of $Cl_2(g)$ is formed from $KCl(s)$?

(A) 87.4 kJ is released
(B) 43.7 kJ is released
(C) 43.7 kJ is absorbed
(D) 87.4 kJ is absorbed

35. What remains in the reaction vessel after equal masses of $K(s)$ and $Cl_2(g)$ have reacted until either one or both of the reactants have been completely consumed?

(A) KCl only
(B) KCl and K only
(C) KCl and Cl_2 only
(D) KCl, K, and Cl_2

36. Which of the values of ΔH° for a process in the table is (are) less than zero (i.e., indicate(s) an exothermic process) ?

(A) z only
(B) y and z only
(C) x, y, and z only
(D) w, x, y, and z

37. It is observed that the reaction producing KCl from its elements goes essentially to completion. Which of the following is a true statement about the thermodynamic favorability of the reaction?

(A) The reaction is favorable and driven by an enthalpy change only.
(B) The reaction is unfavorable and driven by an entropy change only.
(C) The reaction is favorable and driven by both enthalpy and entropy changes.
(D) The reaction is unfavorable due to both enthalpy and entropy changes.

$$Cl_2(g) + 2 \, e^- \rightarrow 2 \, Cl^-(g)$$
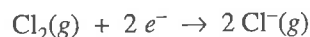
38. Which of the following expressions is equivalent to ΔH° for the reaction represented above?

(A) $x + y$
(B) $x - y$
(C) $x + 2y$
(D) $\frac{x}{2} - y$

this is mostly a Quantum Question.

DATA!!!   **Bond Enthalpies: (kJ per mole of bonds broken)**

Cl-Cl: 242   H- O : 463   C-O : 358   C=O: 799   O-O : 146

C-H: 413   C-C: 348   C=C: 614   C≡C: 839   O=O: 495

Enthalpy of formation: (kJ per mole)

C3H6(g) 20.0   CO2(g) -393.5   H2O(l) -285.8   H2O(g) -241.8   CaCl2(s) -791.4

specific heat (cal/g°C) H_2O(s) 0.50   H2O(l) 1.00 H_2O(g) 0.48

heat of fusion for water: 79.9 cal/g   **heat of vaporization for water:** 540. cal/g

<u>**Answers:**</u>   **1.** Energy is conserved.   **2.** See the key on the website.

3. a. Write +180.74 kJ on the left, since rxn absorbs energy
b. 173.4 kJ/mole   c. no   d. spont above 7317 K   e. Kp = 0.874
f. Kp(Keq) = 1.26. It is spontaneous above 7317 Kelvin so Kp must be greater than 1 at 8000 K.
g. -16.9 kJ/mole.

4. a. Write +67.7 kJ on the left, since energy is absorbed by rxn.
b. negative, since delta n gas = -1; moles of gas decrease.
c. 103.8 kJ/mole.   d. no   e. it is not spont. for any temperature.   f/g. See the key on the website!

5a. ΔS is positive since moles of gas increase from 6 to 7. ΔH must be negative since it is a combustion rxn;
combustion is exo.
b. write the + 2044 kJ on the right, since the rxn releases energy. **c.** -2074 kJ.   **d.** yes!
e. spont. for ANY temp.   **f/g/h** see answer key online
i.   -128 kJ   **j.** + 128 kJ   **k.** 13.9 g   **l.** q_{H2O} = 60828 cal ---> ΔHrxn = - 2020 kJ/mole.

6. ΔHvap = 32 kJ/mole. ΔSvap = 95 J/mol-K. BP = 336.84 K --> 64°C.

7a. We "couple" the formation (regeneration) of ATP with cellular respiration. C.R. has a negative ΔG°,
which can compensate for the positive ΔG°for ATP formation… the combined ΔG° (of ATP formation together
with C.R.) will be negative.   C.R. Equation: $C_6H_{12}O_6$ +   6 O_2 -----> 6 CO_2 + 6 H_2O
b. negative for (1) and (4). Positive for (2) and (3).
c. (2) and (3) are non spontaneous.
These will need to happen at the same time as some ATP breaks down to ADP
(since ATP --> ADP has a negative ΔG°.)

8. a. (ΔG = -274.4 kJ/mole).   Kp = 1.26 x 10^{48}.
b. ΔS°rxn is **<u>positive</u>**, since the moles of gas increase during the reaction (from 1 mole gas on the left to 2
moles gas on the right).   **c.** 179 J/mole-Kelvin   **d.** 5.8 J/mole-K   **e.** Spontaneous for all temps.

9.a. -3851.8 kJ   b. write +3851.8 kJ on right side, since energy is released.   c. 4580 kJ released.
d. 45.767 kJ/g   e. 11335 kJ - 15144 kJ = -3809 kJ

10a. see website.   **10b.** 250 + 799 + 1000 + 5400 + 240 = 7689 ---> 7690 cal   **11.** 0.075 cal/g°C.

12. $q_{solution}$ = $m_{solution}c_{solution}\Delta T_{solution}$ = 4669.27 J ----> ΔHrxn = -86.7 kJ/mole.   **13.** 469 kJ/mole.

14. melting, vaporization, and sublimation have positive ΔH and ΔS, so are more favorable at high temp.
    condensation and freezing have negative ΔH and ΔS, so are more favorable at low temp.

Multiple Choice Answers:
10 = B   9 = B   64 = E   45 = D   12 = C   13 = A   14 = C
43 = C   53 = D   34 = C   35 = C   36 = B   37 = A   38 = C