Chemistry Chapter 12 – Chemical Thermodynamics – AP Questions

These are HIGHLY probable
2. 3) C6H5OH(s) + 7 O2(g) ---> 6 CO2(g) + 3H2O(l)

When a 2.000-gram sample of pure phenol, C6H5OH(s), is completely burned according to the equation above, 64.98 kilojoules of heat is released. Use the information in the table below to answer the questions that follow.

Substance Standard Heat of
Formation, DH°f,
at 25°C (kJ/mol) Absolute Entropy, S°,
at 25°C (J/mol-K)
C(graphite) DH°f = 0.00 S° = 5.69
CO2(g) DH°f = -395.5 S° = 213.6
H2(g) DH°f = 0.00 S° = 130.6
H2O(l) DH°f = -285.85 S° = 69.91
O2(g) DH°f = 0.00 S° = 205.0
C6H5OH(s) DH°f = ? S° = 144.0

(a) Calculate the molar heat of combustion of phenol in kilojoules per mole at 25°C.

(b) Calculate the standard heat of formation, DH°f, of phenol in kilojoules per mole at 25°C.

(c) Calculate the value of the standard free-energy change, DG° for the combustion of phenol at 25°C.

(d) If the volume of the combustion container is 10.0 liters, calculate the final pressure in the container when the temperature is changed to 110°C. (Assume no oxygen remains unreacted and that all products are gaseous.)

ANSWER:
(a) 2.000g x (1 mol / 94.113 g) = 0.02125 mol phenol (one point)

Heat released per mole = 64.98kJ / 0.02125mol = 3,058 kJ/mol (one point)

or, DHcomb = - 3,058 kJ/mol

Units not necessary

(b) DHcomb = - 3,058 kJ/mol (one point)

- 3,058 kJ = [6 (-395.5) + 3 (-285.85)] - [DDH°f phenol] (one point)

DH°f phenol = - 161 kJ (one point)

One point earned for correct sign of heat of combustion, one point for correct use of moles/coefficients, and one point for correct substitution

(c)DS° = [3 (69.91) + 6 (213.6)] - [7 (205.0) + 144.0 = - 87.67 J/K (one point)

DG° = DH° - TDS° = 3,058 kJ - (298 K) (-0.08767 kJ/K) = -3,032 kJ (one point)

Units not necessary; no penalty if correct except for wrong DHcomb from part (a)

(d) moles gas = 9 x [moles from part (a)] = 9 (0.02125 mol0 = 0.1913 moles gas (one point)

P = (nRT) / V = [(0.193 mol) (0.0821 L atm mol¯1K¯1) (383 K)] / 10.0 L = 0.601 atm (one point)

Units necessary; no penalty for using Celsius temperature if also lost point in part (c) for same error

4. Propane, C3H8, is a hydrocarbon that is commonly used as fuel for cooking.

(a) Write a balanced equation for the complete combustion of propane gas, which yields CO2(g) and H2O(l)

(b) Calculate the volume of air at 30°C and 1.00 atmosphere that is needed to burn completely 10.0 grams of propane. Assume that air is 21.0 percent O2 by volume.

(c) The heat of combustion of propane is -2,220.1 kJ/mol. Calculate the heat of formation, DH°f, of propane given that DH°f of H2O(l) = -285.3 kJ/mol and DH°f of CO2(g) = -393.5 kJ/mol.

(d) Assuming that all of the heat evolved in burning 30.0 grams of propane is transferred to 8.00 kilograms of water (specific heat = 4.18 J/g · K), calculate the increase in temperature of the water.

ANSWER:
a) one point

C3H8 + 5 O2 --> 3 CO2 + 4 H2O

ignore phases (even when wrong)
multiples are OK
if balanced wrong, parts b and c should be consistent

---

b) four points

10.0 g C3H8 x (1 mol C3H8 / 44.1 g C3H8) = 0.227 mol C3H8

0.227 mol C3H8 x (5 mol O2 / 1 mol C3H8) = 1.13 mol O2

V = [(1.13 mol O2) (0.0821 L atm mol¯1 K¯1) (303K)] ÷ 1.00 atm = 28.1 L O2

28.1 L O2 x (100 L air / 21.0 L O2) = 134 L air

Note: answer must be consistent with part a

---

c) two points

[delta]H°rxn = [sigma] [delta]H°f (products) - [sigma] [delta]H°f (reactants)

-2,220.1 kJ = [4 (-285.3kJ) + 3 (-393.5 kJ))] - [5 (0 kJ) + [delta]H°f (C3H8)]

-2,220.1 kJ = -1,141.2 kJ - 1,180.5 kJ - [deelta]H°f (C3H8)

-2,220.1 kJ = -2,321.7 kJ - [delta]H°f (C3H88)

-101.6 kJ = [delta]H°f (C3H8)

answer should be consistent with part a
1 point deducted if negative sign missing from answer
1 point deducted if -2,220.1 kJ substituted for [delta]H°f (C3H8)
no points earned if coefficients are inconsistent and not set equal to [delta]H°

---

d) two points

30.0 g C3H8 x (1 mol C3H8 / 44.1 g C3H8) x (2,220.1 kJ / 1 mol C3H8) = 1.51 x 103 kJ

1.51 x 103 kJ = 1.51 x 106 J = (8,000 g) (4.18 J g¯1 K¯1) ([delta]T)

45.1 K (or °C) = [delta]T

must correctly substitute into q = mCp[delta]T for 1 point
1 point earned if q value wrong but [delta]T consistent

10. Compound DH°f (kilocalories/mole) S° (calories/mole K)
H_2O (l) - DH°f = 68.3 S° = 16.7
CO_2 (g) - DH°f = 94.1 S° = 51.1
O_2 (g) DH°f = 0.0 S° = 49.0
C_3H_8 (g) DH°f = ? S° = 64.5

When 1.000 gram of propane gas, C_3H_8, is burned at 25 °C and 1.00 atmosphere, H_2O(l) and CO_2(g) are formed with the evolution of 50.33 kilojoules.

(a) Write a balanced equation for the combustion reaction.

(b) Calculate the molar enthalpy of combustion, DH°comb , of propane.

(c) Calculate the standard molar enthalpy of formation, DH°f , of propane gas.

(d) Calculate the entropy change, DS°comb , for the combustion reaction and account of the sign of DS°comb.

GOOD QUESTION, NO ANSWER YET

These are probable

---

5. 2 C_4H_{10}(g) + 13 O_2(g) ------> 8 CO_2(g) + 10 H_2O(l)

The reaction represented above is spontaneous at 25 °C. Assume that all reactants and products are in their standard states.

(a) Predict the sign of DS° for the reaction and justify your prediction.

(b) What is the sign of DG° for the reaction? How would the sign and magnitude of DG° be affected by an increase in temperature to 50 °C? Explain your answer.

(c) What must be the sign of DH° for the reaction at 25°C? How does the total bond energy of the reactants compare to that of the products?

(d) When the reactants are placed together in a container, no change is observed even though the reaction is known to be spontaneous. Explain this observation.

ANSWER:
a) one point

[delta]S < 0

The number of moles of gaseous products is less than the number of moles of gaseous reactant

OR

a liquid is formed from gaseous reactants.

----

b) one point

[delta]G < 0

[delta]G becomes less negative as the temperature is increased since [delta]S < 0 and [delta]G = [delta]H - T[delta]S. The term - T[delta]S adds a positive number to [delta]H.

---

c) one point

[delta]H < 0

The bond energy of the reactants is less than the bond energy of the products.

---

d) one point

The reaction has a high activation energy

OR

is kinetically slow,

OR

a specific neuton of the needs for a catalyst or spark.

(a) State the physical significance of entropy.

(b) From each of the following pairs of substances, choose the one expected to have the greater absolute entropy. Explain your choice in each case. Assume 1 mole of each substance.

(1) Pb(s) or C(graphite) at the same temperature and pressure
(2) He(g) at 1 atmosphere or He(g) at 0.05 atmosphere, both at the same temperature
(3) $H_2O(l)$ or $CH_3CH_2OH(l)$ at the same temperature and pressure
(4) Mg(s) at 0 °C or Mg(s) at 150 °C, both at the same pressure.

ANSWER:
a) 2 points

Entropy (S) is a measure of randomness or disorder in a system.

b) 6 points

(4 selections at 1/2 point each and 4 accompanying explanations at 1 point each.) Selection
(1) Pb(s) Pb has metallic bonding and is soft; atoms have large amplitude of vibration; C has atoms more localized by strong covalent bonds and is a more ordered element.
(2) He (0.05 atm) At lower pressure (greater volume) atoms have more space in which to move.
(3) $CH_3CH_2OH(l)$ Ethanol is a molecule with more atoms and thus more vibrations; water has fewer atoms and is more localized by hydrogen-bonding.
(4) Mg (150°) At higher temperature, atoms have more kinetic energy and vibrate faster and further, i.e., greater randomness occurs.

In part (a), partial credit of 1 point was allowed for confusing S with [delta]S, but writing correctly in terms of "change in randomness" or "tendency toward greater randomness." In the explanations of part (b), 1/2 point was credited for correct empirical relationships involving S as a function of P or T, or mentioning relative melting-points in parts (1), (3), and (4).

---

9. $PCl_5(g)$ -----> $PCl_3(g) + Cl_2(g)$

For the reaction above, DH° = +22.1 kilocalories per mole at 25 °C.

(a) Does the tendency of reactions to proceed to a state of minimum energy favor the formation of the products of this reaction? Explain.

(b) Does the tendency of reactions to proceed to a state of maximum entropy favor the formation of the products of this reaction? Explain.

(c) State whether an increase in temperature drives this reaction to the right, to the left, or has no effect. Explain.

(d) State whether a decrease in the volume of the system at constant temperature drives this reaction to the right, to the left, or has no effect. Explain.

ANSWER:
Four effects and 4 explanations valued at 1 point each.

a) No, the reactant is favored. Treaction is endothermic and products are at highter energy than the reactant.

----

b) Yes, products are favored. [delta]S > O as 2 moles of gas are produced form 1 mole of gas.

----

c) Right, products are favored. For the system at constant pressure: absorption of heat favors the products. An argument using LeChatelier's principle can be used with heat considered as a reactant; or T[delta]S favors products as [delta]G becomes more negative. For the system at constant volume: products are favored but increase in the yield of products results in an increase in pressure which would drive the reaction to the left.

No points were deducted for students who mentioned both the thermodynamic effect and the counteractiong pressure effect at constant volume but were uncertain as to which effect is larger. Students who considered a system at constant volume and stated only that the increase in pressure would drive the reaction to the left received half credit.

----

d) Left, the reactant is favored. A decrease in the volume would increase the pressure and the strain is relieved by the reverse reaction which produces 1 mole of gas from 2 moles of gas.