$\frac{\quad}{62} = \quad \%$ Name: _____

SCH OA1
Thermodynamics Test

1. For each of the following, label with a + for in increase in potential energy or a - for a decrease in potential energy:

a) $-$ the combustion of methane gas

b) $+$ the formation of diamond deep within the earths crust

c) $-$ formation of ice on a window through a sublimation process

d) $+$ formation of toluene (l)

/20 e) $+$ a reaction in which the reactants have greater forces or attraction than the products

(4) f) $-$ heat energy is absorbed by the water jacket in a bomb calorimeter (consider reactant and product compounds only)

g) $+$ formation of an onion from all necessary raw materials

h) $+$ the conversion of ethyl alcohol to dimethyl ether

i) $-$ deflation of a balloon

f) $+$ build up of electrostatic charge in a thunderhead

2. What is the difference between Q and ΔH? Why are these two quantities equal in magnitude but opposite of sign for a given chemical or physical change? (1 mark per main point)

✓ Q → E_k (chemical kinetic energy)
ΔH → E_p (chemical potential energy)
✓ $\Delta H = -Q$ law of conservation of energy ✓

/4

✓ $E_T = E_k + E_p$
$\Delta E_T = \Delta E_k + \Delta E_p$
$\Delta E_T = 0$ (law of conservation of energy)

(4) $\therefore \quad 0 = \Delta E_k + \Delta E_p$

$\therefore \quad \Delta E_p = -\Delta E_k$

$\Delta H = -Q$

/2

3. Using the summation of heats of formation technique, calculate the heat of reaction in kJ, if $FeSO_4$ (s) is decomposed to form Fe (s) plus sulphur dioxide gas plus oxygen gas. Use the values in the text for help. Now determine the mass of natural gas (CH_4 (g)) in kg that must be combusted to provide enough heat to decompose 750 kg of ferrous sulphate.

(4)

$FeSO_4(s) \rightarrow Fe(s) + SO_2(g) + O_2(g)$ ✓ $\Delta H = ?$

$\Delta H = [\Delta H^\circ_{Fe(s)} + \Delta H^\circ_{SO_2(g)} + \Delta H^\circ_{O_2(g)}] - [\Delta H^\circ_{FeSO_4(s)}]$ ✓

$\Delta H = [0 + (-70.8\,kcal) + 0] - [(-220.5\,kcal)]$

14

$\Delta H = 149.7\,kcal$ ✓

$149.7\,kcal \times \frac{4.184\,kJ}{1\,kcal} = 626.35\,kJ$ ✓

$Q = -\Delta H$ ✓

$Q = -626.35\,kJ/mol\ FeSO_4$

heat absorbed

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ $\Delta H = ?$ ✓

$\Delta H = [\Delta H^\circ_{CO_2(g)} + 2\Delta H^\circ_{H_2O(l)}] - [\Delta H^\circ_{CH_4(g)} + 2\Delta H^\circ_{O_2(g)}]$ ✓

$\Delta H = [(-94.0\,kcal) + 2(-68.3\,kcal)] - [(-17.9\,kcal) + 2(0)]$

$\Delta H = -212.7\,kcal$ ✓

$Q = -\Delta H$

$Q = 212.7\,kcal/mol\ CH_4$ ✓

$750\,kg \times \frac{1000\,g}{1\,kg} \times \frac{1\,mol\ FeSO_4}{151.92\,g\ FeSO_4} \times \frac{*149.7\,kcal}{1\,mol\ FeSO_4} \times \frac{1\,mol\ CH_4}{212.70\,kcal}$

$\times \frac{16.05\,g\ CH_4}{1\,mol\ CH_4} \times \frac{1\,kg}{1000\,g} = 55.767\,kg$

$\therefore$ 55.767 kg of CH_4 is required to decompose 750 kg of $FeSO_4$

* - sign is dropped for convenience, heat required by $FeSO_4$ is provided by CH_4

14

4. Use Hess' Law (The Law of Hess) to prove that the heat of formation of ethyl alcohol (C_2H_5OH (l)) is -66.4 kcal/mol, using:

a) The combustion of dimethyl ether (CH_3OCH_3 (l)) has a heat of reaction of ΔH = -348.6 kcal

b) The straight conversion (i.e. no other compounds present in the reaction) of dimethyl ether (CH_3OCH_3 (l)) to ethyl alcohol (C_2H_5OH (l))has a heat of reaction of -22.1 kcal

c) the formation reaction for CO_2(g)

d) the formation reaction for H_2O(l)

Please write out all four equations and the equation for the formation of ethyl alcohol **before** you attempt the Hessian Law!

(4)

① $CH_3OCH_3(\ell) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(\ell)$ $\Delta H = -348.6$ kcal

② $CH_3OCH_3(\ell) \rightarrow C_2H_5OH(\ell)$ $\Delta H = -22.1$ kcal

③ $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -94.0$ kcal

④ $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(\ell)$ $\Delta H = -68.3$ kcal

Find $2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(\ell)$

---

② $CH_3OCH_3(\ell) \rightarrow C_2H_5OH(\ell)$ $\Delta H = -22.1$ kcal

rev ① $2CO_2(g) + 3H_2O(\ell) \rightarrow CH_3OCH_3(\ell) + 3O_2(g)$ $\Delta H = 348.6$ kcal

2 x ③ $2C(s) + 2O_2(g) \rightarrow 2CO_2(g)$ $\Delta H = -188.0$ kcal

3 x ④ $3H_2(g) + \frac{3}{2}O_2(g) \rightarrow 3H_2O(\ell)$ $\Delta H = -204.9$ kcal

---

$2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(\ell)$ $\Delta H = -66.4$ kcal

$\frac{3}{2} - \frac{6}{2} = \frac{1}{2}$

8

8

5. When ammonium nitrate is mixed with water, the resulting solution quickly becomes very cold. Why? (1 mark per major point)

4

- heat energy is absorbed, $\Delta H = +$
- heat energy is converted to chemical potential energy
- particles are on average further apart and less attracted
- entropy is the driving force

3

6. What are the two fundamental driving forces in thermodynamics?

4

- tendency toward minimum energy (1st Law of Thermody)
- tendency toward maximum randomness (2nd Law of Thermody)

2

7. Given that:

a) $\Delta G = \Delta H - T\Delta S$ where: ΔG = Gibb's free energy (J)
ΔH = Enthalpy (J)
T = temperature (K) ~~or °C~~
ΔS = Entropy

4

b) $\Delta G < 0$ for a spontaneous reaction

c) ΔH value is 10 times more significant than the ΔS value

State what the sign (+ or −) is for each of the following situations:

Situation	ΔH sign	ΔS sign
evaporation of any liquid to a gas	+	+
combustion of a hydrocarbon	−	+ *
solidification of a liquid to a crystal solid	−	−
dissolving of a salt in water becomes cold	+	+
dissolving of a salt in water becomes hot	−	+

5

Note that this question tests your understanding of chemical potential energy in the ΔH column and your understanding of entropy in the ΔS column.

* best condition for spontaneous reaction

10

8. Given that the combustion of 22.0 g of acetic acid (CH_3COOH (l)) is able to warm 4 L of water from 20.000 °C to 39.066 °C, calculate the heat of formation of acetic acid. (Use kcal)

(4)

$Q = mc\Delta T$ ✓

$Q = 4000_g \times 1.000\ cal/g°C \times 19.066°C$

$Q = 76264\ cal$

$Q = 76.264\ kcal$

/6

$$\frac{76.264\ kcal}{22.0\ g\ CH_3COOH} \times \frac{60.06\ g\ CH_3COOH}{1\ mol\ CH_3COOH} = 208.2\ kcal/mol\ CH_3COOH$$ ✓

$\Delta H = -Q$ ✓

$\Delta H = -208.2 kcal$

$\therefore\ CH_3COOH(l) + 2O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)\quad \Delta H = -208.2kcal$ ✓

$\Delta H = [2\Delta H^\circ_{CO_2(g)} + 2\Delta H^\circ_{H_2O(l)}] - [\Delta H^\circ_{CH_3COOH(l)} + 2\Delta H^\circ_{O_2(g)}]$ ✓

$-208.2kcal = [2(-94.0kcal) + 2(-68.3kcal)] - [\Delta H^\circ_{CH_3COOH} + 2(0)]$

$-208.2\ kcal = -324.6\ kcal - \Delta H^\circ_{CH_3COOH}$

$\Delta H^\circ_{CH_3COOH} = -116.40\ kcal$ ✓

If the values in this question are correct the answer you should get is -116.4 kcal!!!

6

Bonus:

Given the following values at 25 °C and 1 atm pressure:

$\Delta H^{\circ}_{H_2O(l)} = -68.32$ kcal
$\Delta H^{\circ}_{H_2O(g)} = -57.80$ kcal
$S^{\circ}_{H_2O(l)} = 16.72$ cal
$S^{\circ}_{H_2O(g)} = 45.11$ cal

(4)

Calculate the temperature above which the physical change of

$H_2O(l) \Rightarrow H_2O(g)$

becomes spontaneous!!!

$\Delta H = \Delta H^{\circ}_{H_2O(g)} - \Delta H^{\circ}_{H_2O(l)}$

$\Delta H = -57.80\,kcal - (-68.32\,kcal)$

$\Delta H = 10.52\,kcal$

$\Delta H = 10520\,cal$

$\Delta S = S^{\circ}_{H_2O(g)} - S^{\circ}_{H_2O(l)}$

$\Delta S = 45.11\,cal - 16.72\,cal$

$\Delta S = 28.39\,cal$ *

$\Delta G = \Delta H - T\Delta S$

$\Delta G < 0$ for a spontaneous event

$\therefore \quad \Delta H - T\Delta S < 0$

$\Delta H < T\Delta S$

if ΔS is positive *

$\frac{\Delta H}{\Delta S} < T$

$\therefore \quad T > \frac{10520\,cal}{28.39\,cal}$

$T > 370.55\,K$ close!! ☺

4