03W-F

Name: ____________________

$\overline{\quad}$ / 61 = %

TEST #2

THERMODYNAMICS

1. Each of the following examples involve a change in enthalpy. Label as + for an increase in potential energy and - for a decrease in potential energy Do not guess! One half mark deducted for each wrong answer!

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(6)

a) __+__ The lake thaws slowly in the spring.
b) __-__ When two particular solutions are mixed together the average temperature increases
~~c) ____ In a fission reaction , the total mass of the products is significantly less than the total mass of the reactants.~~
d) __-__ Sulphuric acid is dissolved in water.
e) __-__ The products of a reaction have greater attractive forces than the reactants.
f) __-__ After a reaction, the forces of attraction between the atoms involved has undergone a net increase.
g) __-__ The condensation of any liquid.
h) __+__ $H_2O(g) + C(s) = CO(g) + H_2(g)$ $\Delta H = 31.4$ kcal
i) __+__ Photosynthesis
j) __-__ The formation of water from its elements at 25 C and 1 atmosphere pressure.

2. Use heats of formation directly (i.e. not Hess Law) to calculate the heat of reaction for:

$$3CuO(s) + 2NH_3(g) \Longrightarrow 3Cu(s) + 3H_2O(l) + N_2(g) \quad \Delta H = ?$$

Use your answer to determine:
a) the heat released in kJ if 500 g of Cu(s) is recovered
b) the heat released in kcal if 1.5 L of nitrogen gas is recovered at S.T.P. (22.414 L of gas = 1 mol of gas)

(6)

$$\Delta H = [3\Delta H^\circ_{Cu(s)} + 3\Delta H^\circ_{H_2O(l)} + \Delta H^\circ_{N_2(g)}] - [3\Delta H^\circ_{CuO(s)} + 2\Delta H^\circ_{NH_3(g)}]$$ ✓

$$\Delta H = [3(0) + 3(-285.8\text{ kJ}) + 0] - [3(-157.3\text{ kJ}) + 2(-45.9\text{ kJ})]$$ ✓

$$\Delta H = -293.7\text{ kJ}$$ ✓

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a) $500\text{ g Cu} \times \frac{1\text{ mol Cu}}{63.54\text{ g Cu}} \times \frac{293.7\text{ kJ}}{3\text{ mol Cu}} = 770.38\text{ kJ}$ ✓

$Q = -\Delta H$ ✓

$Q = 293.7\text{ kJ}$

b) $1.5\text{ L } N_2 \times \frac{1\text{ mol } N_2}{22.414\text{ L } N_2} \times \frac{293.7\text{ kJ}}{1\text{ mol } N_2} \times \frac{1\text{ kcal}}{4.184\text{ kJ}} = 4.698\text{ kcal}$ ✓

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3. 30 L of water in a bomb calorimeter is warmed from 20.00 °C to 23.94 °C when 10 g of butane (C_4H_{10}) is reacted with sufficient oxygen to allow complete combustion. Use this information plus appropriate heats of formation (i.e. values for carbon dioxide, water and oxygen) to derive the heat of formation for the compound butane in kJ per mol. Check this answer with the heat of formation value for butane found in the table to see if the information in the question is correct.

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$Q = mc\Delta T$ ✓

$Q = 30\,000 g \times 4.184 J/g°C \times 3.94°C$

$Q = 494\,54.88 J$

$Q = 494.5488 kJ$ ✓

$\frac{494.5488 kJ}{10 g\ C_4H_{10}} \times \frac{58.14 g\ C_4H_{10}}{1 mol\ C_4H_{10}} = 2875.307 kJ/mol$ ✓✓

$\Delta H = -Q$

$\Delta H = -2875.307 kJ$ ✓

$C_4H_{10}(g) + \frac{13}{2}O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$ ✓ $\Delta H = -2875.307 kJ$ ✓

$\Delta H = [4\Delta H°_{CO_2(g)} + 5\Delta H°_{H_2O(l)}] - [\Delta H°_{C_4H_{10}(g)} + 13/2\ \Delta H°_{O_2(g)}]$ ✓

$-2875.307 kJ = [4(-393.5 kJ) + 5(-285.8 kJ)] - [\Delta H°_{C_4H_{10}(g)} + 13/2(0)]$

$\Delta H°_{C_4H_{10}(g)} = -127.69 kJ$ ✓

✓

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4. Use Hess' Law to determine the heat of formation of p-nitrotoluene ($C_7H_7O_2N(l)$) in kcal given:

(1) $C_7H_8(l) + HNO_3(l) \Rightarrow C_7H_7O_2N(l) + H_2O(l)$ $\Delta H = -47.25$ kcal

(2) $C_7H_8(l) + 9O_2(g) \Rightarrow 7CO_2(g) + 4H_2O(l)$ $\Delta H = -943.1$ kcal

(3) $NO_2(g) + H_2O(l) \Rightarrow HNO_3(l) + \frac{1}{2}H_2(g)$ $\Delta H = 18.8$ kcal

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Table values for the formation reactions of $CO_2(g)$, $H_2O(l)$ and $NO_2(g)$

(4) $C(s) + O_2(g) \Rightarrow CO_2(g)$ ✓ $\Delta H = -393.5$ kJ $\Rightarrow -94.05$ kcal

(5) $H_2(g) + \frac{1}{2}O_2(g) \Rightarrow H_2O(l)$ ✓ $\Delta H = -285.8$ kJ $\Rightarrow -68.31$ kcal ✓

(6) $\frac{1}{2}N_2(g) + O_2(g) \Rightarrow NO_2(g)$ $\Delta H = +33.2$ kJ $\Rightarrow +7.93$ kcal

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find $7C(s) + \frac{7}{2}H_2(g) + O_2(g) + \frac{1}{2}N_2(g) \Rightarrow C_7H_7O_2N(l)$ ✓

✓ (1) ~~$C_7H_8(l)$~~ + ~~$HNO_3(l)$~~ $\Rightarrow C_7H_7O_2N(l)$ + ~~$H_2O(l)$~~ $\Delta H = -47.25$ kcal

rev (2) ~~$7CO_2(g)$~~ + ~~$4H_2O(l)$~~ $\Rightarrow$ ~~$C_7H_8(l)$~~ + ~~$9O_2(g)$~~ ✓ $\Delta H = 943.1$ kcal

(3) ~~$NO_2(g)$~~ + ~~$H_2O(l)$~~ $\Rightarrow$ ~~$HNO_3(l)$~~ + $\frac{1}{2}H_2(g)$ ✓ $\Delta H = 18.8$ kcal

9 (6) $\frac{1}{2}N_2(g) + O_2(g) \Rightarrow$ ~~$NO_2(g)$~~ ✓ $\Delta H = 7.93$ kcal

7×(4) $7C(s)$ + ~~$7O_2(g)$~~ $\Rightarrow$ ~~$7CO_2(g)$~~ $\Delta H = -658.35$ kcal

4×(5) $\frac{7}{2}$ ~~4~~ $H_2(g)$ + ~~$2O_2(g)$~~ $\Rightarrow$ ~~$4H_2O(l)$~~ $\Delta H = -273.24$ kcal

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$7C(s) + \frac{7}{2}H_2(g) + O_2(g) + \frac{1}{2}N_2(g) \Rightarrow C_7H_7O_2N(l)$ $\Delta H = -9.01$ kcal ✓

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5. From the following information and <u>Hess' Law</u>, calculate the heat of formation of CaO in kJ

a) $CaO(s) + 2HCl(aq) \Rightarrow CaCl_2(s) + H_2O(l)$ $\Delta H = ?$

15.00 g of CaO was reacted in 5 L of an HCl solution.* A change in temperature of 3.35 °C was noted

(6)

b) $Ca(s) + 2HCl(aq) \Rightarrow CaCl_2(s) + H_2(g)$ $\Delta H = ?$

12.00 g of Ca was reacted in 5 L of an HCl solution.* A change in temperature of 8.75 °C was noted.

c) $H_2(g) + \frac{1}{2}O_2(g) \Rightarrow H_2O(l)$ $\Delta H = -285.6$ kJ/mol

* consider these solution to have the same heat capacity as water (4.184 J/g°C) and ignore any mass contributions from the addition of CaO and Ca

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a) $Q = mc\Delta T$ ✓

$Q = 5000g \times 4.184 J/g°C \times 3.35°C$

$Q = 70082$ J

$Q = 70.082$ kJ ✓

b) $Q = mc\Delta T$ ✓

$Q = 5000g \times 4.184 J/g°C \times 8.75°C$

$Q = 183050$ J

$Q = 183.050$ kJ ✓

$\frac{70.082 kJ}{15.00 g CaO} \times \frac{56.08 g CaO}{1 mol CaO} = 262.01$ kJ/mol ✓

$\Delta H = -Q$

$\Delta H = -262.01$ kJ/mol CaO ✓

$\frac{183.050 kJ}{12.00 g Ca} \times \frac{40.08 g Ca}{1 mol Ca} = 611.39$ kJ/mol ✓

$\Delta H = -Q$

$\Delta H = -611.39$ kJ/mol Ca ✓

∴ ① $CaO(s) + 2HCl(aq) \Rightarrow CaCl_2(s) + H_2O(l)$ $\Delta H = -262.01$ kJ

∴ ② $Ca(s) + 2HCl(aq) \Rightarrow CaCl_2(s) + H_2(g)$ $\Delta H = -611.39$ kJ

③ $H_2(g) + \frac{1}{2}O_2(g) \Rightarrow H_2O(l)$ $\Delta H = -285.6$ kJ

find $Ca(s) + \frac{1}{2}O_2(g) \Rightarrow CaO$ $\Delta H = ?$

rev ① ~~$CaCl_2$~~ (s) + ~~$H_2O(l)$~~ $\Rightarrow CaO(s)$ + ~~$2HCl$~~ (aq) $\Delta H = 262.01$ kJ ✓

② $Ca(s)$ + ~~$2HCl$~~ (aq) $\Rightarrow$ ~~$CaCl_2$~~ (s) + ~~H_2~~ (g) ✓ $\Delta H = -611.39$ kJ

③ ~~H_2~~ (g) + $\frac{1}{2}O_2(g) \Rightarrow$ ~~$H_2O(l)$~~ ✓ $\Delta H = -285.6$ kJ

$Ca(s) + \frac{1}{2}O_2(g) \Rightarrow CaO(s)$ $\Delta H = -634.98$ kJ

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6. Calculate the amount of heat energy required to convert 355 g of ice at -25 °C to steam at 250 °C. The following data should be of assistance:

Molar Heat of Fusion (melting) of Ice: 6.02 kJ/mol @ 0 °C
Molar Heat of Vaporization of water: 40.6 kJ/mol @ 100 °C
Specific Heat Capacity of Ice: 4.69 J/g°C
Specific Heat Capacity of Water: 4.184 J/g°C
Specific Heat Capacity of Steam: 3.43 J/g°C
Answer: 1291 kJ (Note: this answer is the sum of five different calculations)

(6)

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ice @ -25°C → ice @ 0°C

$Q = mc\Delta T$

$Q = 355g \times 4.69\ J/g°C \times 25°C$

$Q = 41623.75\ J$

$Q = 41.624\ kJ$

ice @ 0°C → water @ 0°C

$355g \times \frac{1mol}{18.02g} \times \frac{6.02\ kJ}{1mol}$

$= 118.596\ kJ$

water @ 0°C → water @ 100°C

$Q = mc\Delta T$

$Q = 355g \times 4.184\ J/g°C \times 100°C$

$Q = 148532\ J$

$Q = 148.532\ kJ$

water @ 100°C → steam @ 100°C

$355g \times \frac{1mol}{18.02g} \times \frac{40.6\ kJ}{1mol}$

$= 799.834\ kJ$

steam @ 100°C → steam at 250°C

$Q = mc\Delta T$

$Q = 355g \times 3.43\ J/g°C \times 150°C$

$Q = 182648\ J$

$Q = 182.648\ kJ$

total heat =

41.624 kJ
118.596 kJ
148.532 kJ
799.834 kJ
182.648 kJ

1291.123 kJ

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