Thermochemistry

Date Planned : __ / __ / __	Daily Tutorial Sheet	Expected Duration : 90 Min
Actual Date of Attempt : __ / __ / __	Level-0	Exact Duration :_____

Very Short Answer Type (1 Mark)

1. The heat of combustion of benzene in a bomb calorimeter (i.e., constant volume) was found to be $3263.9\,\text{kJ mol}^{-1}$ at 25°C. Calculate the heat of combustion of benzene at constant pressure.

2. The molar heat of formation of $NH_4NO_3(s)$ is $-367.54\,\text{kJ}$ and those of $N_2O(g)$ and $H_2O(\ell)$ are $+81.46$ and $-285.78\,\text{kJ}$ respectively at 25°C and 1.0 atmospheric pressure. Calculate ΔH and ΔU for the reaction.

3. 1 g of graphite is burnt in a bomb calorimeter in excess of oxygen at 298 K and 1 atmospheric pressure according to the equation $C(\text{graphite}) + O_2(g) \longrightarrow CO_2(g)$. During the reaction, temperature rises from 298 K to 299 K. If the heat capacity of the bomb calorimeter is 20.7 kJ/K, what is the enthalpy change for the above reaction at 298 K and 1 atm ?

4. Calculate the enthalpy of hydration of anhydrous copper sulphate ($CuSO_4$) into hydrated copper sulphate ($CuSO_4 \cdot 5H_2O$). Given that the enthalpies of solution of anhydrous copper sulphate and hydrated copper sulphate are -66.5 and $+11.7\,\text{kJ mol}^{-1}$ respectively.

5. Calculate the standard enthalpy of formation of SO_3 at 298 K using the following reactions and enthalpies.

$S_8(s) + 8O_2(g) \longrightarrow 8SO_2(g),\ \Delta H^\circ = -2775\,\text{kJ mol}^{-1}$;

$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g),\ \Delta H^\circ = -198\,\text{kJ mol}^{-1}$

6. From the following data at 25°C, calculate the bond energy of O – H bond:

(i) $H_2(g) \longrightarrow 2H(g),\ \Delta H_1 = 104.2\,\text{kcal}$ **(ii)** $O_2(g) \longrightarrow 2O(g),\ \Delta H_2 = 118.4\,\text{kcal}$

(iii) $H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g),\ \Delta H_3 = -57.8\,\text{kcal}$

Short Answer Type-I (2 Marks)

7. A 1.250 g sample of Octane (C_8H_{18}) is burned in excess of oxygen in a bomb calorimeter. The temperature of the calorimeter rises from 294.05 K to 300.78 K. If heat capacity of the calorimeter is 8.93 kJ/K, find the heat transferred to the calorimeter. Also calculate the enthalpy combustion of the sample of octane.

8. 0.16 g of methane was subjected to combustion at 27°C in a bomb calorimeter system. The temperature of the calorimeter system (including water) was found to rise by 0.5°C. Calculate the heat of combustion of methane at (i) constant volume, and (ii) constant pressure. The thermal capacity of the calorimeter system is $17.7\,\text{kJ K}^{-1}$ ($R = 8.314\,\text{J K}^{-1}\,\text{mol}^{-1}$)

9. Calculate enthalpy of formation of methane (CH_4) from the following data :

(i) $C(s) + O_2(g) \longrightarrow CO_2(g),\ \Delta_r H^\circ = -393.5\ kJ\ mol^{-1}$

(ii) $H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(\ell),\ \Delta_r H^\circ = -285.8\ kJ\ mol^{-1}$

(iii) $CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(\ell),\ \Delta_r H^\circ = -890.3\ kJ\ mol^{-1}$

10. Ethylene on combustion gives carbon dioxide and water. Its enthalpy of combustion is 1410.0 kJ / mol. If the enthalpy of formation of CO_2 and H_2O are –393.3 kJ and –286.2 kJ respectively, calculate the enthalpy of formation of ethylene.

11. Calculate the enthalpy of formation of sucrose $(C_{12}H_{22}O_{11})$ from the following data:

(i) $C_{12}H_{22}O_{11} + 12O_2 \longrightarrow 12CO_2 + 11H_2O,\ \Delta H = -5200.7\ kJ\ mol^{-1}$

(ii) $C + O_2 \longrightarrow CO_2,\ \Delta H = -394.5\ kJ\ mol^{-1}$

(iii) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O,\ \Delta H = -285.8\ kJ\ mol^{-1}$

12. Compare quantity of heat produced by the combustion of 1.0 g glucose $(C_6H_{12}O_6)$ with that produced by 1.0g sucrose $(C_{12}H_{22}O_{11})$. Given that the standard heats of formation of CO_2, H_2O glucose and sucrose are $-393.5, -285.9, -1260$ and $-2221\ kJ\ mol^{-1}$ respectively.

13. **(a)** Is the bond energy of all the four $C-H$ bonds in CH_4 molecule equal? If not then why? How is the $C-H$ bond energy then reported?

(b) Same mass of diamond and graphite (both being carbon) are burnt in oxygen. Will the heat produced be same or different? Why?

Give reasons for the following:

Short Answer Type-II (3 Marks)

14. Calculate the bond energy of $C-H$ bond, given that the heat of formation of CH_4, heat of sublimation of carbon and heat of dissociation of H_2 are $-74.8 + 719.6$ and $435\ kJ\ mol^{-1}$ respectively.

15. Use the following data to calculate $\Delta_{lattice}H^o$ for NaBr. $\Delta_{sub}H^o$ for sodium metal $= 108.4\ kJ\ mol^{-1}$, ionization enthalpy of sodium $= 496\ kJ\ mol^{-1}$, electron gain enthalpy of bromine $= -325\ kJ\ mol^{-1}$, bond dissociation enthalpy of bromine $= 192\ kJ\ mol^{-1}$, $\Delta_f H^o$ for $NaBr(s) - 360.1\ kJ\ mol^{-1}$.

16. Show that the reaction $CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ at 300 K is spontaneous and exothermic, when the standard entropy change is –0.094 kJ mol^{-1} K^{-1}. The standard Gibbs energies of formation for CO_2 and CO are –394.4 and –137.2 kJ mol^{-1}, respectively.

17. The heat of neutralization of (i) $CHCl_2 - COOH$ by NaOH is 12830 cal, (ii) HCl by NaOH is 13680 cal and (iii) NH_4OH by HCl is 12270 cal. What is the heat of neutralization of dichloro acetic acid by NH_4OH? Calculate the heats of ionization of dichloro acetic acid and NH_4OH.

18. A natural gas may be assumed to be a mixture of CH_4 and C_2H_6 only. On complete combustion of 10 L of the gas at STP, the heat evolved was 474.6 kJ. Assuming $\Delta H_{c(CH_4)}$ = – 894 kJ/mol and $\Delta H_{C(C_2H_6)}$ = – 1560 kJ/mole. Calculate the % by volume of each gas in the mixture.

19. The enthalpy of evaporation of water at 373 K is 40.67 kJ mol^{-1}. What will be the enthalpy of evaporation at 353 K and 393 K if average molar heats at constant pressure in this range for water in liquid and vapour states are 75.312 and 33.89 JK^{-1} mol^{-1} respectively?

Long Answer Type (5 Marks)

20. Classify the following processes as exothermic or endothermic.

(A) Burning of match stick

(B) Melting of ice

(C) Molten metal solidifies

(D) Reaction between Na and H_2O

(E) Rubbing alcohol evaporates

21. Using the data (all value in kilocalories per mole at 25^oC) given below. Calculate the bond energy of C - C and C - H bonds.

$\Delta H^o_{C\ (Ethane)}$ = – 372

$\Delta H^o_{C\ (Propane)}$ = – 530

$\Delta H_{C\ (Graphite)\ -\ C(g)}$ = 172

Bond energy of H – H = 104

$\Delta H_f{}^o_{H_2O(l)}$ = – 68

$\Delta H_f{}^o_{CO_{2(g)}}$ = – 94

22. Using the data given below (all values are in kcal mol^{-1} at 25°C), calculate the bond energies of C—C and C—H bonds.

ΔH^o (combustion) of ethane = – 372.0

$\Delta H°$ (combustion) of propane = – 530.0

ΔH^o for $C(s) \longrightarrow C(g)$ = 172.0

Bond energy of H—H bond = 104.0

$\Delta_f H^o$ of H_2O = 68.0 ; $\Delta_f H^o$ of $CO_2(g)$ = –94.0

23. Standard enthalpy of formation of $C_3H_7NO_2(s)$, $CO_2(g)$ and $H_2O(l)$ are 133.57, –94.05, and –68.32 kcal mol^{-1} respectively. Standard enthalpy of combustion of CH_4 at 25^oC is –212.8 kcal mol^{-1}. Calculate ΔH^o for the reaction:

$$2CH_4 + CO_2 + \frac{1}{2}N_2 \longrightarrow C_3H_7NO_2(s) + \frac{1}{2}H_2$$

Calculate ΔU for combustion of $C_3H_7NO_2(s)$.

24. Whenever an acid is neutralized by a base, the net reaction is

$$H^{\oplus}(aq) + \bar{O}H(aq) \longrightarrow H_2O(l);\ \Delta H = -57.1\ kJ$$

Calculate the heat evolved for the following experiments?

(a) 0.50 mol of HCl solution is neutralized by 0.50 mol of NaOH solution.

(b) 0.50 mol of HNO_3 solution is mixed with 0.30 mol of KOH solution

(c) 100 mL of 0.2 M HCl is mixed with 100 mL of 0.3 M NaOH solution

(d) 400 mL of 0.2 M H_2SO_4 is mixed with 600 mL of 0.1 M KOH solution

25. The standard entropy change for reaction $CO(g) + \frac{1}{2}(O_2) \longrightarrow CO_2(g)$ at 300 K is $-0.094\ kJ\ mol^{-1}\ K^{-1}$. The standard Gibb's free energies of formation of CO_2 and CO are -394.4 and $-137.2\ kJ\ mol^{-1}$ respectively. What is effect of temperature on spontaneity of reaction ?