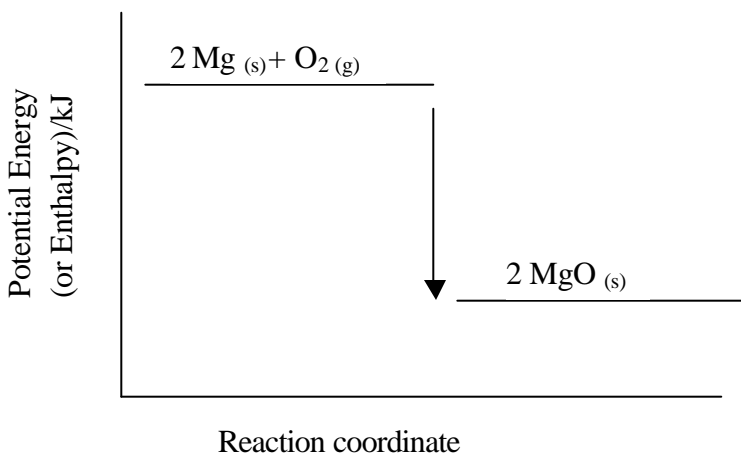## *5. Energetics: Thermochemistry*

<u>Solution further problems.</u>

1. Decrease in the strength and/or the number of bonds causes energy to be released in an exothermic reaction.

2. a)

Reaction coordinate

b) The reaction is exothermic.

c) Reactants.

3. Heat gained by the calorimeter + water sample in calorimeter = − heat lost by 2nd water sample

$\Rightarrow$ (mass of calorimeter X C_p of calorimeter X ΔT) + (mass of water X C_p of water X ΔT) = − (mass of second water sample X C_p of water X ΔT)

$\Rightarrow$ (Heat capacity of calorimeter) (32.6 − 24.1) K + (0.050 kg) (4.18 kJkg^{-1}K^{-1}) (32.6 − 24.1) K
$= -$ (0.050 kg) (4.18 kJkg^{-1}K^{-1}) (32.6 − 41.7) K

$\Rightarrow$ (Heat capacity of calorimeter) (8.5 K) + 1.77 kJ = 1.90 kJ

$\Rightarrow$ Heat capacity of calorimeter = [(1.90 − 1.77) kJ] / 8.5 K

$\Rightarrow$ Heat capacity of calorimeter = 0.01529 kJ K^{-1} = 0.015 kJK^{-1}

4. a) If $\quad$ 2 NO$_{(g)}$ + Cl$_{2(g)}$ → 2 NOCl$_{(g)}$ $\qquad$ ΔH^{θ} = − 77.4 kJ

   then $\quad$ NO$_{(g)}$ + ½ Cl$_{2(g)}$ → NOCl$_{(g)}$ $\qquad$ ΔH^{θ} = − 77.4 kJ / 2 = − 38.7 kJ

   b) $\quad$ 6 NOCl$_{(g)}$ → 6 NO$_{(g)}$ + 3 Cl$_{2(g)}$ $\qquad$ ΔH^{θ} = − 77.4 kJ X 3 = − 232.2 kJ

5. 2Na$_{(s)}$ + 2 S$_{(s)}$ + 3/2 O$_{2 (s)}$ → Na$_2$S$_2$O$_{3(s)}$ $\Delta H = \Delta H_f^q$

6.
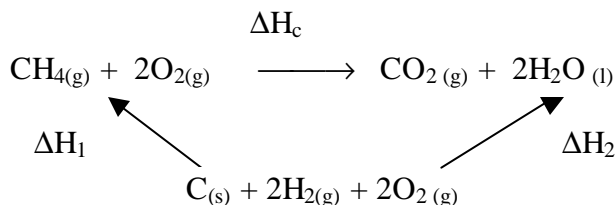
$\Delta H_2 = \Delta H_1 + \Delta H_c$

$\Delta H_c = \Delta H_2 - \Delta H_1$

Where, $\Delta H_1 = \Delta H_f^q [CH_{4(g)}] = (1\ mol)(-75\ kJ\ mol^{-1}) = -75\ kJ$

$\Delta H_2 = (2\ mol)\ \Delta H_f^q [H_2O_{(l)}] + (1\ mol)\ \Delta H_f^q [CO_{2(g)}]$

$= (2\ mol)\ X\ (-285.83\ kJ\ mol^{-1}) + (1\ mol)(-393.51\ kJ\ mol^{-1})$

$\Delta H_2 = -956.17\ kJ$

$\Delta H_c = -956.17\ kJ - (-75\ kJ)$

$\Delta H_c = -890.17\ kJ$

$\boxed{\Delta H_c = -8.90\ X\ 10^2\ kJ\ mol^{-1}\ (mol^{-1}\ \text{obtained from the equation})}$

7. $M_R (C_5H_{10}O_5) = 155.15$

Heat gained by the calorimeter and contents = heat capacity X ΔT

$= (15.8\ kJ/°C)\ (210.54 - 20.00)\ °C$

$= 3010.532\ kJ$

$\Delta H = -$ heat energy gained by calorimeter and its contents

$\Delta H = -3010\ kJ$

$\left(\dfrac{3010\ kJ}{0.548\ g\ C_5H_{10}O_5} \right) \left(\dfrac{155.15\ g\ C_5H_{10}O_5}{1\ mol\ C_5H_{10}O_5} \right) = 852343\ kJ\ mol^{-1}$

$\boxed{\Delta H_c = -8.52\ X\ 10^5\ kJ\ mol^{-1}}$

8. $Cl_{2\ (g)} \rightarrow 2Cl_{(g)}$ ΔH = bond enthalpy

$[\ \frac{1}{2}\ Cl_{2\ (g)} \rightarrow Cl_{(g)}$ ΔH = enthalpy of atomization]

9. (a)

$$\Delta H_{rxn}$$

$$CH_{4(g)} + Cl_{2(g)} \xrightarrow{\hspace{2cm}} CH_3Cl_{(g)} + HCl_{(g)}$$

ΔH_1 ↘   ↗ ΔH_2

$$C_{(g)} + 4H_{(g)} + 2Cl_{(g)}$$
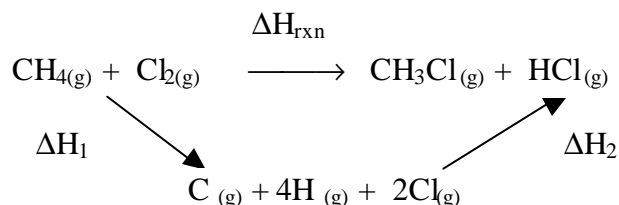
$\Delta H_{rxn} = \Delta H_1 + \Delta H_2$

where, ΔH_1 = bond breaking

$= (4\ mol)\ E(C\text{-}H) + (1\ mol)\ E(Cl\text{-}Cl)$

$= (4\ mol)\ (412\ kJ\ mol^{-1} + (1\ mol)\ (242\ kJ\ mol^{-1})$

$= 1890\ kJ$

ΔH_2 = bond making

$= (3mol)\ E(C\text{-}H) + (1\ mol)\ E(C\text{-}Cl) + (1\ mol)\ E(H\text{-}Cl)$

$= (3\ mol)(-412\ kJ\ mol^{-1}) + (1\ mol)(-338\ kJ\ mol^{-1}) + (1\ mol)(-431\ kJ\ mol^{-1})$

$= -2005\ kJ$

$\Delta H_{rxn} = (1890 - 2005)\ kJ = -115\ kJ$

$\boxed{\Delta H_{rxn} = -115\ kJ\ mol^{-1}\ (mol^{-1}\ \text{from the equation})}$

(b)

$$\Delta H_{rxn}$$
$$CH_2{=}CH_{2\,(g)} + H_2O_{(l)} \longrightarrow CH_3CH_2OH_{(g)}$$

ΔH_1 \qquad\qquad $2C_{(g)} + 6H_{(g)} + O_{(g)}$ \qquad ΔH_2
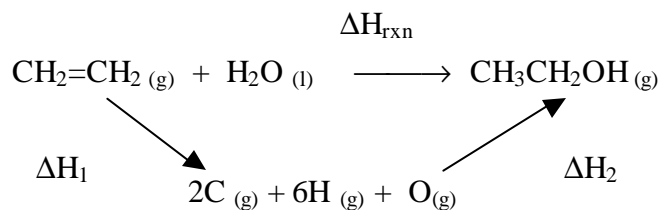
$\Delta H_{rxn} = \Delta H_1 + \Delta H_2$

where, ΔH_1 = bond breaking

$\quad$ = (4 mol) E(C-H) + (1 mol) E(C=C) + (2 mol) E(H-O)

$\quad$ = (4 mol) (412 kJ mol^{-1}) + (1 mol)(612 kJ mol^{-1}) + (2 mol) (463 kJ mol^{-1})

$\quad$ = 3186 kJ

ΔH_2 = bond making = (5 mol) E(C-H) + (1 mol) E(C-C) + (1 mol) E(C-O) + (1 mol) E(O-H)

$\quad$ = (5 mol) X (− 412 kJ mol^{-1}) + (1 mol)(−348 kJ mol^{-1}) + (1 mol)(−360 kJ mol^{-1}) + (1 mol) (−463 kJ mol^{-1})

$\quad$ = − 3231 kJ

$\Delta H_{rxn} = (3186 − 3231)$ kJ = − 45 kJ

10.

Reaction coordinate
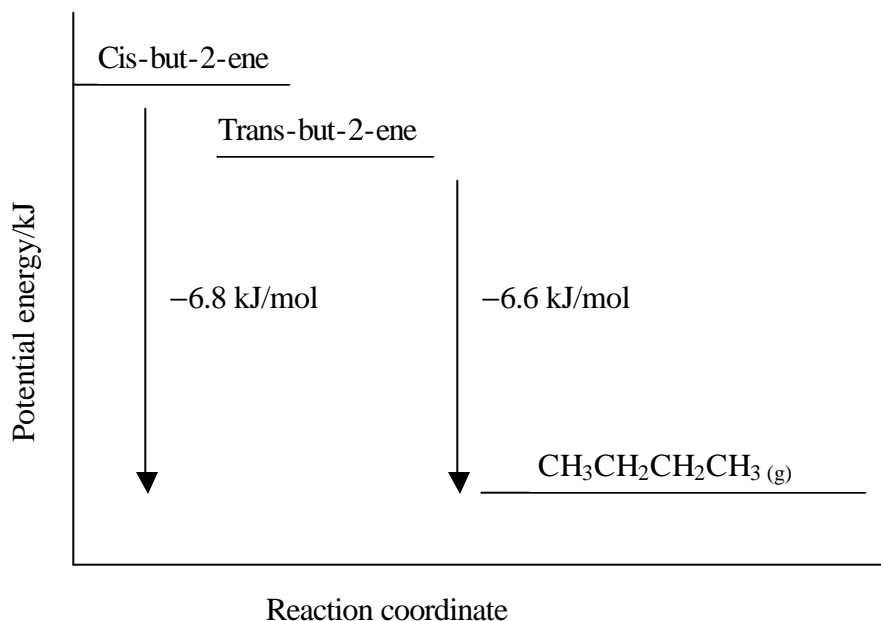
Trans-but-2-ene is thermodynamically more stable. Because hydrogenation of trans-but-2-ene give off less heat than cis-but-2-ene, it can be said that the former is at a lower potential energy than the latter and therefore more stable as depicted above.