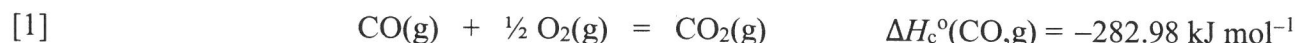


1. Molecules in liquids are packed closely together compared to molecules in gases, so the compressibilities (κ) of liquids are very small compared to those of gases, and it's an excellent approximation to assume liquids are incompressible.

[2]

Explain how liquid incompressibility is used to operate **hydraulic machinery**, such as power brakes and power steering on vehicles, aircraft flaps and rudders, excavators, hammers, presses, lifts, rescue jaws of life, transmissions and many other mechanical devices.

2. The enthalpy of formation of carbon monoxide [$\text{C}(\text{s, graphite}) + \frac{1}{2} \text{O}_2(\text{g}) = \text{CO}(\text{g})$] is difficult to measure directly because of the unwanted side reaction forming CO_2 . However, the standard enthalpies of combustion of graphite and CO are easily measured. At 25 °C:



Use the enthalpy of combustion data to calculate $\Delta H_{\text{fm}}^\circ(\text{CO, g})$ at 25 °C.

3. The **Lingan Generating Station** on Cape Breton Island burns about 4,000 tonnes of coal per day, producing about 25 % of the electricity used by Nova Scotians. The chemical composition of coal is complicated (a highly variable mixture of partially oxidized aromatics and many other compounds), but is reasonably approximated as phenol ($\text{C}_6\text{H}_6\text{O}$). Calculate:

a) the heat released by burning 4,000 tonnes of coal (assumed to be phenol, $\text{C}_6\text{H}_6\text{O}$, molecular weight 94.1 g mol^{-1} , heat of combustion $-3054 \text{ kJ mol}^{-1}$)

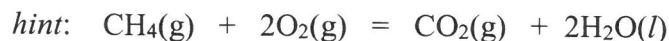
- [4] b) the tonnes of CO_2 gas emitted by burning 4,000 tonnes of coal (assumed to be phenol)



4. Suppose the **Lingan Generating Station** switches from burning coal to burning natural gas.

a) How many tonnes of natural gas (assumed to be methane, CH_4 , molecular weight 16.0 g mol^{-1} , heat of combustion -890 kJ mol^{-1}) must be burned to provide the equivalent heat from burning 4,000 tonnes of coal?

- [4] b) Calculate the tonnes of CO_2 gas emitted by burning the natural gas (assumed to be methane).



5. Rising atmospheric levels of carbon dioxide from the burning of fossil fuels is implicated in global warming, which is predicted to have dangerous consequences. From the point of view of limiting global warming, show that natural gas is a significantly better fuel than coal. (Natural gas is also clean burning: no ash and very low levels of sulfur, mercury and other pollutants.)

[1]

... page 2

6. For the reaction $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) = \text{H}_2\text{O}(\text{l})$

a) calculate q , w , ΔU and ΔH at 25 °C and 1 bar

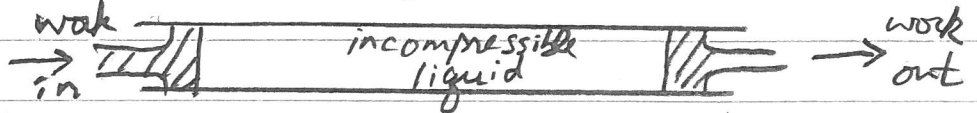
b) calculate q , w , ΔU and ΔH at 100 °C and 1 bar

[8]

Data at 25 °C: $\Delta H_{\text{fm}}^\circ(\text{H}_2\text{O}, \text{l}) = -285.83 \text{ kJ mol}^{-1}$, $C_{\text{pm}}^\circ(\text{H}_2, \text{g}) = 28.82 \text{ J K}^{-1} \text{ mol}^{-1}$,
 $C_{\text{pm}}^\circ(\text{O}_2, \text{g}) = 29.36 \text{ J K}^{-1} \text{ mol}^{-1}$, $C_{\text{pm}}^\circ(\text{H}_2\text{O}, \text{l}) = 75.29 \text{ J K}^{-1} \text{ mol}^{-1}$

Q1 Hydraulic Machinery

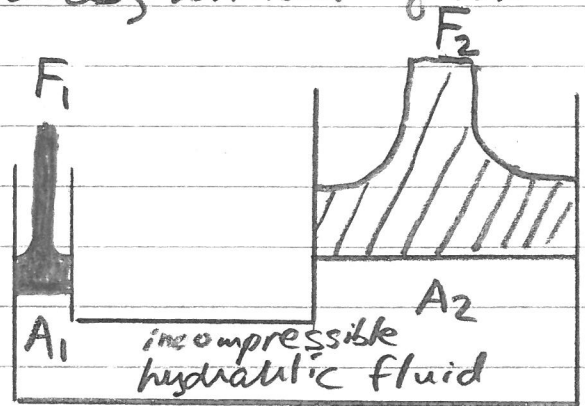
Pumps, cylinders and pistons, and control valves are used to pressurize liquids (hydraulic fluid) and to transmit power through tubes or hoses to do work.



Large amounts of power (work per unit time) can be transferred over long distances, without gears or rotating shafts.

Force Multiplication

A small force (F_1) acting on a small piston (area A_1) can generate a much larger force (F_2) on a larger piston (area A_2)

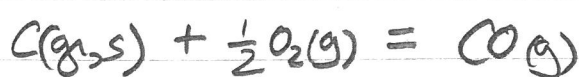
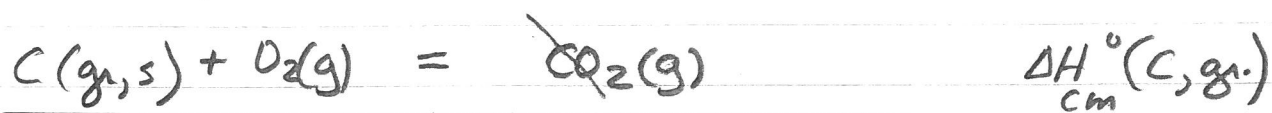


$$\text{hydraulic pressure} = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_2 = \frac{A_2}{A_1} F_1$$

Example: In a hydraulic jack, a small force is used to lift heavy objects

Q2 standard enthalpy of formation of carbon monoxide =



$$\begin{aligned} \Delta H_{\text{fm}}^{\circ}(\text{CO}, \text{g}) &= \Delta H_{\text{cm}}^{\circ}(\text{C}, \text{gr}) - \Delta H_{\text{cm}}^{\circ}(\text{CO}_2, \text{g}) \\ &= -393.51 - (-282.98) \end{aligned}$$

$$\Delta H_{\text{fm}}^{\circ}(\text{CO}, \text{g}) = -110.53 \text{ kJ mol}^{-1}$$

Q3 a) ΔH for burning 4,000 tonnes of phenol: (4.25 × 10⁷ mol)

$$4,000 \text{ tonnes} = (4,000 \times 10^3 \text{ kg}) \left(\frac{10^3 \text{ g}}{\text{kg}} \right) = 4 \times 10^9 \text{ g}$$

$$\Delta H = \left(-3054 \frac{\text{kJ}}{\text{mol}} \right) \left(\frac{4 \times 10^9 \text{ g}}{94.1 \text{ g/mol}} \right) = -1.30 \times 10^{11} \text{ kJ}$$

$$\left(\text{moles of phenol} = \frac{4 \times 10^9 \text{ g}}{94.1 \text{ g/mol}} = 4.25 \times 10^7 \text{ mol} \right)$$



1 mol phenol → 6 mol CO₂

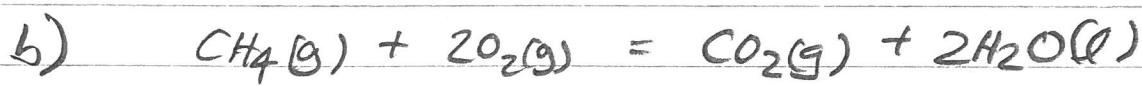
$$\text{moles of CO}_2 \text{ emitted} = 6(4.25 \times 10^7 \text{ mol}) = 2.55 \times 10^8 \text{ mol}$$

$$\text{mass of CO}_2 = (2.55 \times 10^8 \text{ mol}) \left(\frac{44.0 \text{ g}}{\text{mol}} \right) \frac{10^{-6} \text{ tonne}}{\text{g}} = 11,200 \text{ tonnes CO}_2$$

Q4 a) moles of CH_4 to produce heat of combustion
 $= -1.30 \times 10^{11} \text{ kJ}$

$$n = \frac{-1.30 \times 10^{11} \text{ kJ}}{-890 \text{ kJ mol}^{-1}} = 1.46 \times 10^8 \text{ mol}$$

$$\begin{aligned} \text{mass of } \text{CH}_4 \text{ required} &= (1.46 \times 10^8 \text{ mol}) \left(\frac{16.0 \text{ g}}{\text{mol}} \right) = 2.33 \times 10^9 \text{ g} \\ &= (2.33 \times 10^9 \text{ g}) \left(\frac{10^{-6} \text{ tonne}}{\text{g}} \right) = \boxed{2330 \text{ tonnes } \text{CH}_4} \end{aligned}$$



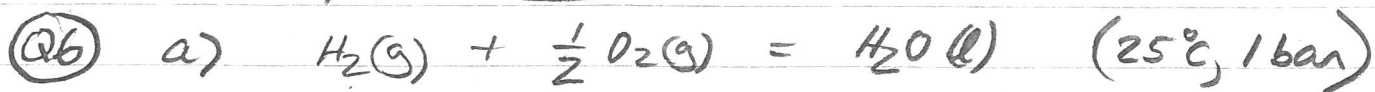
burning one mole CH_4 produces one mole CO_2

$$\text{moles of } \text{CO}_2 \text{ emitted} = 1.46 \times 10^8 \text{ mol}$$

$$\begin{aligned} \text{mass of } \text{CO}_2 \text{ emitted} &= (1.46 \times 10^8 \text{ mol}) \left(\frac{44.0 \text{ g}}{\text{mol}} \right) \\ &= 6.42 \times 10^9 \text{ g} \\ &= (6.42 \times 10^9 \text{ g}) (10^{-6} \text{ tonne g}^{-1}) \\ &= \boxed{6420 \text{ tonnes } \text{CO}_2} \end{aligned}$$

Q5 Natural gas is the better fuel. Significantly less (43%, 6,420 tonnes vs 11,200 tonnes from coal) CO_2 . Burning coal produces 74% more CO_2 !

$$\Delta n_g = -\frac{3}{2} \text{ mol} \quad (\text{"lose" } 1.5 \text{ moles of gas})$$



ΔH° and q

$$\Delta H^\circ = \Delta H_f^\circ(\text{products}) - \Delta H_f^\circ(\text{reactants})$$

$$= \Delta H_{fm}^\circ(\text{H}_2\text{O}, \text{l}) - \Delta H_{fm}^\circ(\text{H}_2, \text{g}) - \frac{1}{2} \Delta H_{fm}^\circ(\text{O}_2, \text{g})$$

H₂, O₂ are elements

$$\Delta H^\circ = -285.83 \text{ kJ mol}^{-1} - 0 - \frac{1}{2}(0)$$

$$= q_p \quad (\text{pressure constant at 1 bar})$$

work

$$W = -\int p_{\text{ext}} dV = -\int p dV = -p \int dV = -p \Delta V$$

$$= -p (V_{\text{products}} - V_{\text{reactants}}) \quad (\text{volume of liquid water negligibly small})$$

$$= -p [V_m(\text{H}_2\text{O}, \text{l}) - V_m(\text{H}_2, \text{g}) - \frac{1}{2} V_m(\text{O}_2, \text{g})]$$

$$= -p [-V_m(\text{H}_2, \text{g}) - \frac{1}{2} V_m(\text{O}_2, \text{g})] = \frac{3}{2} p V_m(\text{ideal gas})$$

$$= \frac{3}{2} RT \quad (= -\Delta n_g RT = -(-\frac{3}{2} \text{ mol}) RT)$$

$$= \frac{3}{2} (8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298.15 \text{ K}) = \boxed{3720 \text{ J}}$$

W

internal energy

internal energy change:

$$\Delta U = q + W = -285.83 \text{ kJ} + 3.72 \text{ kJ}$$

$$\Delta U = -282.11 \text{ kJ}$$

(Q6 cont.)



b) calculate q , w , ΔU and ΔH for $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) = \text{H}_2\text{O}(\text{l})$
at 100 °C Need to calculate ΔH° at 373.15 K (100 °C)

$$T_1 = 298.15 \text{ K} \quad \Delta H^\circ(T_1) \\ (25^\circ \text{C}) \quad \text{known}$$

$$T_2 = 373.15 \text{ K} \\ \Delta H^\circ(T_2) ?$$

$$\begin{aligned} \Delta C_p^\circ &= C_p^\circ(\text{products}) - C_p^\circ(\text{reactants}) \\ &= [C_{p,m}(\text{H}_2\text{O}, \text{l}) - C_{p,m}(\text{H}_2, \text{g}) - \frac{1}{2} C_{p,m}(\text{O}_2, \text{g})] \\ &= [75.29 - 28.82 - \frac{1}{2}(29.36)] \text{ J K}^{-1} \end{aligned}$$

$$\Delta C_p^\circ = 31.79 \text{ J K}^{-1}$$

$$\begin{aligned} \Delta H^\circ(T_2) &= \Delta H^\circ(T_1) + \int_{T_1}^{T_2} \Delta C_p^\circ dT \\ &= \Delta H^\circ(T_1) + \Delta C_p^\circ \int_{T_1}^{T_2} dT \end{aligned}$$

must assume ΔC_p° is constant, no other information given

$$= \Delta H^\circ(T_1) + \Delta C_p^\circ(T_2 - T_1)$$

$$\begin{aligned} & \text{(from a)} \\ &= -285,830 \text{ J} + (31.79 \text{ J K}^{-1})(373.15 - 298.15) \text{ J} \end{aligned}$$

$$= (-285,830 + 2384) \text{ J} = -283,440 \text{ J}$$

$$\Delta H^\circ = -283.44 \text{ kJ}$$

from a)

$$= q \quad (\text{pressure constant at 1 bar})$$

$$w = \frac{3}{2} RT = \frac{3}{2} (8.314) 373.15 = 4653 \text{ J}$$

$$\Delta U = q + w = (-283.44 + 4.65) \text{ kJ} = -278.79 \text{ kJ}$$