FORMATION REACTIONS

- A reaction that forms exactly one mole of the specified substance from its elements at their STANDARD STATE at 25C and 1 atm pressure.

$CO_2(g)$: $C(s, graphite) + O_2(g) \longrightarrow CO_2(g)$; $\Delta H = -393.5$ kJ

heat of formation of carbon dioxide ΔH_f° or ΔH_f

"enthalpy of formation"

$CO(g)$: $C(s, graphite) + \frac{1}{2} O_2(g) \rightarrow CO(g)$; $\Delta H = -110.5$ kJ

you may see fractional coefficients in these formation reactions, because you MUST form exactly one mole of the product!

- The heat of formation for an element in its standard state at 25C and 1 atm is ZERO.

$\Delta H^\circ_{f, O_2(g)} = 0$ kJ/mol

- What are formation reactions good for?

... finding enthalpies for more interesting reactions!

Let's say we would like to find the enthalpy of reaction for this equation:

$$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(g);\ \Delta H = ?$$

From A-8, text ↙

Hess' Law: If you add two reactions to get a new reaction, their enthalpies also add.

C_2H_2: $2C(s) + H_2(g) \longrightarrow C_2H_2(g)$ $\Delta H = 226.7$

CO_2: $C(s) + O_2(g) \longrightarrow CO_2(g)$ $\Delta H = -393.5$

H_2O: $H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g)$ $\Delta H = -241.8$

$C_2H_2(g) \longrightarrow 2C(s) + H_2(g)$ $\Delta H = -226.7$

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$$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(l)$$

$$\Delta H = 2(-226.7) + 4(-393.5) + 2(-241.8) = \boxed{-2511\ kJ}$$

Hess' Law using enthalpy of formation:

$$\Delta H = \sum \Delta H_{f,products} - \sum \Delta H_{f,reactants}$$

$$\overset{226.7}{2\,C_2H_2(g)} + \overset{0}{5\,O_2(g)} \longrightarrow \overset{-393.5}{4\,CO_2(g)} + \overset{-241.8}{2\,H_2O(g)};\ \Delta H = ?$$

$$\Delta H = [4(-393.5) + 2(-241.8)] - [2(226.7) + 5(0)]$$

$$= -2511\ kJ$$

* Remember:

- Multiply each enthalpy by its stoichiometric coefficient from the reaction
- Enthalpy of formation of an element at its standard state is zero
- Watch phase labels. You will usually find SEVERAL enthalpies of formation for a given substance in different phases!
- For ionic substances in solution, remember that they exist as free ions, so look up the aqueous IONS!

See Appendix C in the textbook for enthalpy of formation data: p A-8 to A-11

 Example problems:

FORMULA WEIGHTS in g/mol in purple

$$\underset{2.016}{2H_2(g)} + \underset{32.00}{O_2(g)} \longrightarrow \underset{18.02}{2H_2O(g)} \; ; \; \Delta H = -484 \text{ kJ}$$

Calculate the enthalpy change for the combustion of 1.00 kg of hydrogen gas.

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1 - Convert 1.00 kg hydrogen gas to moles. Use FORMULA WEIGHT.
2 - Convert moles hydrogen gas to enthalpy change. Use THERMOCHEMICAL EQUATION

① $2.016 \text{ g } H_2 = \text{mol } H_2$ $\qquad$ $\text{kg} = 10^3 \text{ g}$

② $2 \text{ mol } H_2 = -484 \text{ kJ}$

$$1.00 \text{ kg } H_2 \times \frac{10^3 \text{ g}}{\text{kg}} \times \underset{①}{\frac{\text{mol } H_2}{2.016 \text{ g } H_2}} \times \underset{②}{\frac{-484 \text{ kJ}}{2 \text{ mol } H_2}} = \boxed{-12\bar{0}\,000 \text{ kJ per kg } H_2}$$

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)\ ;\ \Delta H = -906\ kJ$$

What is the enthalpy change when 150. L of nitrogen monoxide are formed by this reaction at 25.0 C and 1.50 atm pressure?

1 - Convert 150. L NO to moles using IDEAL GAS EQUATION
2 - Convert moles NO to enthalpy change using THERMOCHEMICAL EQUATION

(1) $PV = nRT$

$$n = \frac{PV}{RT}$$

$P = 1.50\ atm$ $V = 150.\ L$

$R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$ $T = 25.0°C = 298.2\ K$

$$n_{NO} = \frac{(1.50\ atm)(150.\ L)}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(298.2\ K)} = 9.194822849\ mol\ NO$$

(2) $4\ mol\ NO = -906\ kJ$

$$9.194822849\ mol\ NO \times \frac{-906\ kJ}{4\ mol\ NO} = \boxed{-2080\ kJ}$$

34.086g/mol

Heat of formation / enthalpy of formation!

$$\underset{-20.50}{2H_2S(g)} + \underset{0}{3O_2(g)} \rightarrow \underset{-285.8}{2H_2O(l)} + \underset{-296.8}{2SO_2(g)} \quad] \ \Delta H_f^\circ, \text{kJ/mol (Appendix C)}$$

What is the enthalpy change at standard conditions when 25.0 grams of hydrogen sulfide gas is reacted?

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1 - Calculate the entahlpy change for the reaction as written. Use Hess's Law.
2 - Convert 25.0 grams hydrogen sulfide to moles using FORMULA WEIGHT.
3 - Convert moles hydrogen sulfide to enthalpy change using THERMOCHEMICAL EQUATION.

$$\Delta H = \sum \Delta H^\circ_{f,\text{products}} - \sum \Delta H^\circ_{f,\text{reactants}}$$

(1)
$$= [2(-285.8) + 2(-296.8)] - [2(-20.50) + 3(0)]$$
$$= -1124.2 \text{ kJ}$$

So the THERMOCHEMICAL EQUATION is ...

$$2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g); \ \Delta H = -1124.2 \text{ kJ}$$

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(2) $34.086\text{ g } H_2S = \text{mol } H_2S$ (3) $2 \text{ mol } H_2S = -1124.2 \text{ kJ}$

$$25.0 \text{ g } H_2S \times \frac{\text{mol } H_2S}{34.086 \text{ g } H_2S} \times \frac{-1124.2 \text{ kJ}}{2 \text{ mol } H_2S} = \boxed{-412 \text{ kJ}}$$

propane

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g);\ \Delta H = -2043\ kJ$$

Calculate the volume of propane gas at 25.0 C and 1.08 atm required to provide 565 kJ of heat using the reaction above.

1 - Convert the 565 kJ energy requirement to moles propane using THERMOCHEMICAL EQUATION
2 - Convert moles propane to volume using IDEAL GAS EQUATION

(1) $mol\ C_3H_8 = -2043\ kJ$

Since the reaction is the system here, the energy requirement gets a negatice sign. The reaction gives up this ampunt of energy!

$$-565\ kJ \times \frac{mol\ C_3H_8}{-2043\ kJ} = 0.2765540871\ mol\ C_3H_8$$

(2) $PV = nRT$

$$V = \frac{nRT}{P}$$

$P = 1.08\ atm$ $\quad R = 0.08206\ \frac{L\cdot atm}{mol\cdot K}$

$T = 25.0\ °C = 298.2\ K$

$n = 0.2765540871\ mol\ C_3H_8$

$$V = \frac{(0.2765540871\ mol\ C_3H_8)\left(0.08206\ \frac{L\cdot atm}{mol\cdot K}\right)(298.2\ K)}{(1.08\ atm)}$$

$= 6.27\ L$ of C_3H_8 @ $25.0\ °C$ + $1.08\ atm$

END OF CHAPTER 6