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
or "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:

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

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

C_2H_2: $2C(s) + H_2(g) \longrightarrow C_2H_2(g)$ $\quad \Delta H = 227.4$

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

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

$C_2H_2(g) \longrightarrow \cancel{2C(s)} + \cancel{H_2(g)}$ $\quad \Delta H = -227.4$

$C_2H_2(g) \longrightarrow \cancel{2C(s)} + \cancel{H_2(g)}$ $\quad \Delta H = -227.4$

$\cancel{C(s)} + O_2(g) \longrightarrow CO_2(g)$ $\quad \Delta H = -393.5$

$\cancel{C(s)} + O_2(g) \longrightarrow CO_2(g)$ $\quad \Delta H = -393.5$

$\cancel{C(s)} + O_2(g) \longrightarrow CO_2(g)$ $\quad \Delta H = -393.5$

$\cancel{C(s)} + O_2(g) \longrightarrow CO_2(g)$ $\quad \Delta H = -393.5$

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

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

$$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(g)\ \ \Delta H = \boxed{-2512.4\ kJ}$$

$$2(-227.4) + 4(-393.5) + 2(-241.8) =$$

* Enthalpy of formation data taken from Openstax Chemistry Appendix G

Hess' Law using enthalpy of formation:

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

$$\overset{227.4}{2C_2H_2(g)} + \overset{0}{5O_2(g)} \longrightarrow \overset{-393.5}{4CO_2(g)} + \overset{-241.8}{2H_2O(g)}\ ;\ \Delta H = ?$$

$$\Delta H = 4(-393.5) + 2(-241.8) - 2(227.4) - 5(0)$$

$$= -2512.4\ kJ$$

See Appendix G in the Openstax textbook for enthalpy of formation data!

* 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!

Example problems:

FORMULA WEIGHTS in g/mol in purple

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

Calculate the enthalpy change for the combustion of 1000 g of hydrogen gas.

---

1) Convert 1000. g hydrogen gas to moles. Use FORMULA WEIGHT.
2) Convert moles hydrogen gas to enthalpy change.

① 2.016 g H_2 = mol H_2 ② 2 mol H_2 = −484 kJ

$$1000.\ g\ H_2 \times \underset{①}{\frac{mol\ H_2}{2.016\ g\ H_2}} \times \underset{②}{\frac{-484\ kJ}{2\ mol\ H_2}} = \boxed{-120000\ kJ} \text{ per } 1000\ g\ H_2$$

34.086g/mol

$$\overset{-20.6}{2H_2S(g)} + \overset{0}{3O_2(g)} \rightarrow \overset{-285.8}{2H_2O(l)} + \overset{-296.8}{2SO_2(g)}$$ (Data from Appendix G!)

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

First, let's find the enthalpy change for the reaction as written using Hess's Law and enthalpy of formation (Appendix G) $\Delta H = \sum \Delta H_{f,\,products} - \sum \Delta H_{f,\,reactants}$

$$\Delta H = 2(-285.8) + 2(-296.8) - 2(-20.6) - 3(0) = -1124.0\ kJ$$

$$2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)\ ;\ -1124.0\ kJ$$

Now, we solve the problem like our other thermochemical equation examples!

1) Convert 25.0 grams hydrogen sulfide gas to moles. Use FORMULA WEIGHT.
2) Convert moles hydrogen sulfide gas to enthalpy change. Use THERMOCHEMICAL EQUATION.

1 $34.086\,g\ H_2S = mol\ H_2S$ 2 $2\ mol\ H_2S = -1124.0\ kJ$

$$25.0\,g\ H_2S \times \underbrace{\frac{mol\ H_2S}{34.086\,g\ H_2S}}_{1} \times \underbrace{\frac{-1124.0\ kJ}{2\ mol\ H_2S}}_{2} = \boxed{-412\ kJ}$$