Lesson 3.11 Key

$C(s) + O_2(g) \rightarrow CO_2(g)$ -394 kJ go to next pg (3)

If the above equations (2 & 3) are manipulated, meaning multiplied by a coefficient or reversed, the overall reaction (1) can be obtained.

Follow the steps below to solve any Hess's Law problem.

1. Balance the individual equations
2. If necessary look up standard enthalpies
3. Put a square around the substances that should be reactants. Circle everything that should be products.
4. Flip equations around if necessary to cancel out terms on opposite sides and ensure reactants are reactants and products are products.
5. Changing the equation around requires a sign change of the H of that individual step
6. Sum up the individual steps

$CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$ (1)

$C(s) + \boxed{\frac{1}{2} O_2}(g) \rightarrow \boxed{CO}(g)$ -111 kJ (2)

$C(s) + \boxed{O_2}(g) \rightarrow (CO_2)(g)$ -394 kJ (3)

Checking to ensure all substances that need to be reactants are on the left hand side of the arrow and everything that needs to be products are on the right hand side of the arrow, it is observed that carbon monoxide (CO) needs to be a reactant, therefore reaction number 2 needs to be reversed. Once it is reversed the sign on the heat also needs to be reversed. Also oxygen is on both sides of the equation, but that is okay because only half of a mole is required.

$\boxed{CO}(g) \rightarrow C(s) + \boxed{\frac{1}{2} O_2}(g)$ 111 kJ (2)

$C(s) + \boxed{O_2}(g) \rightarrow (CO_2)(g)$ -394 kJ (3)

Knowing the reactions are balanced the next step would be to cancel like terms on opposite sides of the arrow. Solid carbon is found on opposite sides of the equation and therefore can be cancelled as well as ½ oxygen. Once all like terms have been cancelled the next step is to sum up the reactants and products and the heats of reactions to give the overall reactions.

$\boxed{CO}(g) \rightarrow C(s) + \boxed{\frac{1}{2} O_2}(g)$ 111 kJ (2)

$\cancel{C(s)} + \boxed{\frac{1}{2} O_2}(g) \rightarrow (CO_2)(g)$ -394 kJ (3)

$CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$ -283 kJ (1)

One the reactions have been summed, as well as the heats, the overall heat required to convert carbon monoxide to carbon dioxide is -283 kJ.

To sum it up, Hess's law says that if two or more equations for which the enthalpy is given or otherwise known can be added together to create a target equation, the enthalpy changes can also be summed to find the enthalpy change of the target equation.

Lesson 3.11 Key

HESS'S LAW PRACTICE PROBLEMS

1) Calculate ΔH° for the formation of 1 mol of strontium carbonate (the material that gives the red color in fireworks) from its elements.

$Sr(s) + C(\text{graphite}) + \frac{1}{2} O_2(g) \rightarrow SrCO_3(s)$

The information available is

(1) $Sr(s) + \frac{1}{2} O_2(g) \rightarrow SrO(s)$ $\quad \Delta H° = -592$ kJ

(2) $SrO(s) + CO_2(g) \rightarrow SrCO_3(s)$ $\quad + \Delta H° = -234$ kJ

(3) $C(\text{graphite}) + O_2(g) \rightarrow CO_2(g)$ $\quad + \Delta H° = -394$ kJ

$Sr_{(s)} + C_{(\text{graphite})} + 3/2 O_2 \rightarrow SrCO_3$ $\quad \Delta H° = -1220$ kJ

2) The combination of coal and steam produces a mixture called coal gas, which can be used as a fuel or as a starting material for other reactions. If we assume coal can be represented by graphite, the equation for the production of coal gas is:

$2C(s) + 2H_2O(g) \rightarrow CH_4(g) + CO_2(g)$

Determine the standard enthalpy change for this reaction from the following standard enthalpies of reaction :

(1) $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$ $\quad \Delta H° = 131.3$ kJ $\times 2$

(2) $CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$ $\quad \Delta H° = -41.2$ kJ

(3) $CH_4(g) + H_2O(g) \rightarrow 3H_2(g) + CO(g)$ $\quad \Delta H° = 206.1$ kJ flip

$\Delta H° = 15.3$ kJ

$2C + 2H_2O \rightarrow 2CO + 2H_2$ $\quad \Delta H = 262.6$ kJ

$CO + H_2O \rightarrow CO_2 + H_2$ $\quad \Delta H = -41.2$ kJ

$3H_2 + CO \rightarrow CH_4 + H_2O$ $\quad \Delta H = -206.1$ kJ

3) Find the ΔH for the reaction below, given the following steps and subsequent ΔH values:

$N_2H_4(l) + H_2(g) \rightarrow 2NH_3(g)$

$N_2H_4(l) + CH_4O(l) \rightarrow CH_2O(g) + N_2(g) + 3H_2(g)$ $\quad \Delta H = -37$ kJ

$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ $\quad \Delta H = -46$ kJ

$CH_4O(l) \rightarrow CH_2O(g) + H_2(g)$ $\quad \Delta H = -65$ kJ flip

$CH_2O + H_2 \rightarrow CH_4O$ $\quad \Delta H = +65$ kJ

$N_2H_4(l) + H_2(g) \rightarrow 2NH_3$ $\quad \Delta H = -18$ kJ

4) One reaction involved in the conversion of iron ore to the metal is:

$FeO(s) + CO(g) \rightarrow Fe(s) + CO_2(g)$

Calculate the standard enthalpy change for this reaction from the following reactions of iron oxides with carbon monoxide.

$6FeO + 6CO \rightarrow 6Fe + 6CO_2$ $\quad \Delta H = -66$ kJ

So for eqn above, $\Delta H = -66/6 = -11$ kJ

$3Fe_2O_3(s) + CO(g) \rightarrow 2Fe_3O_4(s) + CO_2(g)$ $\quad \Delta H = -47$ kJ flip

$Fe_2O_3 + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$ $\quad \Delta H = -25$ kJ $\times 3$

$\Delta H = 19$ kJ flip $\times 2$

$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$

$2Fe_3O_4 + CO_2 \rightarrow 3Fe_2O_3 + CO$ $\quad \Delta H = +47$ kJ

$3Fe_2O_3 + 9CO \rightarrow 6Fe + 9CO_2$ $\quad \Delta H = -75$ kJ

$6FeO + 2CO_2 \rightarrow 2Fe_3O_4 + 2CO$ $\quad \Delta H = -38$ kJ

$\Delta H = -66$ kJ

$Fe_3O_4 + CO\,(g) \rightarrow 3\,FeO + CO_2\,(g)$ $\Delta H = 19$ kJ

5) Find the ΔH for the reaction below, given the following steps and subsequent ΔH values:

$H_2SO_4(l) \rightarrow SO_3(g) + H_2O(g)$

$\Delta H = 73$ kJ

$H_2S(g) + 2O_2(g) \rightarrow H_2SO_4(l)$ $\Delta H = -235.5$ kJ flip

$H_2S(g) + 2O_2(g) \rightarrow SO_3(g) + H_2O(l)$ $\Delta H = -207$ kJ

$H_2O(l) \rightarrow H_2O(g)$ + $\Delta H = 44$ kJ

$H_2SO_4 \rightarrow H_2S + 2O_2$ $\Delta H = +235.5$ kJ

$H_2S + 2O_2 \rightarrow SO_3 + H_2O(l)$ $\Delta H = -207$ kJ

$H_2O(l) \rightarrow H_2O(g)$ $\Delta H = 44$ kJ

6) Find the ΔH for the reaction below, given the following steps and subsequent ΔH values:

$\frac{1}{2} H_2(g) + \frac{1}{2} Cl_2(g) \rightarrow HCl(g)$

$COCl_2(g) + H_2O(l) \rightarrow CH_2Cl_2(l) + O_2(g)$ $\Delta H = 47.5$ kJ

$2HCl(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) + Cl_2(g)$ $\Delta H = 105$ kJ flip. -105 kJ

$H_2O(l) + Cl_2(g) \rightarrow 2HCl + \frac{1}{2}O_2(g)$

$CH_2Cl_2(l) + H_2(g) + 3/2\,O_2(g) \rightarrow COCl_2(g) + 2H_2O(l)$ + $\Delta H = -402.5$ kJ

$H_2 + Cl_2 \rightarrow 2\,HCl$ $\Delta H = -460$ kJ

so for $\frac{1}{2}H_2 + \frac{1}{2}Cl_2 \rightarrow HCl$, $\Delta H = -460/2 = -230$ kJ

7) Find the ΔH for the reaction below, given the following steps and subsequent ΔH values:

$C_2H_2(g) + 5/2O_2(g) \rightarrow 2CO_2(g) + H_2O(g)$

-283.5 kJ

$C_2H_2 + 2H_2 \rightarrow C_2H_6$

$C_2H_6(g) \rightarrow C_2H_2(g) + 2H_2(g)$ $\Delta H = 283.5$ kJ flip

$2\,H_2O \rightarrow 2\,H_2(g) + O_2(g)$

$H_2(g) + 1/2O_2(g) \rightarrow H_2O(g)$ $\Delta H = 213.7$ kJ flip, x 2 $+427.2$ kJ

$2CO_2(g) + 3H_2O(g) \rightarrow C_2H_6(g) + 7/2\,O_2(g)$ + $\Delta H = 849$ kJ flip -849 kJ

$C_2H_6 + 7/2\,O_2 \xrightarrow{5/2\,O_2} 2\,CO_2 + 3\,H_2O$ (H_2O)

$C_2H_2 + 5/2\,O_2 \rightarrow 2\,CO_2 + H_2O$ $\Delta H = -705$ kJ

8) Find the ΔH for the reaction below, given the following steps and subsequent ΔH values:

$HCl(g) + NaNO_2(s) \rightarrow HNO_2(l) + NaCl(s)$

$\Delta H = -79$ kJ

$2NaCl(s) + H_2O(l) \rightarrow 2HCl(g) + Na_2O(s)$ $\Delta H = 507$ kJ flip

$NO(g) + NO_2(g) + Na_2O(s) \rightarrow 2NaNO_2(s)$ $\Delta H = -427$ kJ flip

$NO(g) + NO_2(g) \rightarrow N_2O(g) + O_2(g)$ $\Delta H = -43$ kJ

$2HNO_2(l) \rightarrow N_2O(g) + O_2(g) + H_2O(l)$ $\Delta H = 34$ kJ flip

$2\,HCl + Na_2O \rightarrow 2\,NaCl + H_2O$ $\Delta H = -507$ kJ

$2\,NaNO_2 \rightarrow NO + NO_2 + Na_2O$ $\Delta H = +427$ kJ

$NO + NO_2 \rightarrow N_2O + O_2$ $\Delta H = -43$ kJ

$N_2O + O_2 + H_2O \rightarrow 2\,HNO_2$ + $\Delta H = -34$ kJ

$2\,HCl + 2\,NaNO_2 \rightarrow 2\,NaCl + 2\,HNO_2$ $\Delta H = -157$ kJ

so for $HCl + NaNO_2 \rightarrow NaCl + HNO_2$ $\Delta H = -157/2 = -79$ kJ

9) Calculate the standard enthalpy change for this reaction from the combustion of Zn (g) with oxygen:

$$Zn\,(s) + 1/8\,S_8\,(s) + 2\,O_2\,(g) \rightarrow ZnSO_4\,(s)$$

$Zn\,(s) + 1/8\,S_8\,(s) \rightarrow ZnS\,(s)$ $\quad \Delta H = -183.92$ kJ

$ZnS + \frac{3}{2}O_2 \rightarrow ZnO + SO_2$ (2 O_2) $\quad \Delta H = -463.77$ kJ

~~$2\,ZnS\,(s) + 3\,O_2\,(g) \rightarrow 2\,ZnO\,(s) + 2\,SO_2\,(g)$~~ $\quad$ ~~$\Delta H = -927.54$ kJ~~ $\div 2$

$SO_2 + 1/2\,O_2 \rightarrow SO_3$

~~$2\,SO_3\,(g) \rightarrow 2\,SO_2\,(g) + O_2\,(g)$~~ $\quad$ ~~$\Delta H = -196.04$ kJ~~ flip, $\div 2$ $\quad \Delta H = -98.02$ kJ

$ZnO\,(s) + SO_3\,(g) \rightarrow ZnSO_4\,(s)$ $\quad \Delta H = -230.32$ kJ

$Zn + 1/8\,S_8 + 2\,O_2 \rightarrow ZnSO_4$ $\quad \Delta H = -976.03$ kJ

10) You are given the following data:

$P_4(s) + 6\,Cl_2(g) \rightarrow 4\,PCl_3(g)$	$\Delta H = -1225.6$ kJ	
$P_4(s) + 5\,O_2(g) \rightarrow P_4O_{10}(s)$	$\Delta H = -2967.3$ kJ	flip
$PCl_3(g) + Cl_2(g) \rightarrow PCl_5(g)$	$\Delta H = -84.2$ kJ	flip, $\times 6$
$PCl_3(g) + 1/2\,O_2(g) \rightarrow Cl_3PO(g)$	$\Delta H = -285.7$ kJ	$\times 10$

Calculate ΔH for the following reaction.

$$P_4O_{10}(s) + 6\,PCl_5(g) \rightarrow 10\,Cl_3PO(g)$$

~~$P_4 + 6\,Cl_2 \rightarrow 4\,PCl_3$~~ $\quad \Delta H = -1225.6$ kJ

$P_4O_{10} \rightarrow$ ~~P_4~~ $+$ ~~$5\,O_2$~~ $\quad \Delta H = +2967.3$ kJ

$6\,PCl_5 \rightarrow$ ~~$6\,PCl_3$~~ $+$ ~~$6\,Cl_2$~~ $\quad \Delta H = +505.2$ kJ

~~$10\,PCl_3 + 5\,O_2 \rightarrow 10\,Cl_3PO$~~ $\quad \Delta H = -2857$ kJ

$P_4O_{10} + 6\,PCl_5 \rightarrow 10\,Cl_3PO$ $\quad \Delta H = -610.1$ kJ

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