Hess's Law Worksheet (Hess Cycles)
Answer key

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

$2C(s) + O_2(g) \rightarrow 2CO(g)$ $\Delta H = -222\ kJ\ mol^{-1}$

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -349\ kJ\ mol^{-1}$

$2CO(g) \rightarrow 2C(s) + O_2(g)$ $\Delta H = +222\ kJ\ mol^{-1}$

$2C(s) + 2O_2(g) \rightarrow 2CO_2(g)$ $\Delta H = -698\ kJ\ mol^{-1}$

$2CO(g) + \cancel{2C(s)} + \cancel{2O_2(g)} \rightarrow \cancel{2C(s)} + \cancel{O_2(g)} + 2CO_2(g)$

$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$ $\boxed{\Delta H = -476\ kJ\ mol^{-1}}$

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② $H_2O(l) \rightarrow H_2O(g)$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ $\Delta H = -572\ kJ\ mol^{-1}$

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$ $\Delta H = -484\ kJ\ mol^{-1}$

$H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H = +286\ kJ\ mol^{-1}$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$ $\Delta H = -242\ kJ\ mol^{-1}$

$H_2O(l) + \cancel{H_2(g)} + \cancel{\frac{1}{2}O_2(g)} \rightarrow \cancel{H_2(g)} + \cancel{\frac{1}{2}O_2(g)} + H_2O(g)$

$H_2O(l) \rightarrow H_2O(g)$ $\boxed{\Delta H = +44\ kJ\ mol^{-1}}$

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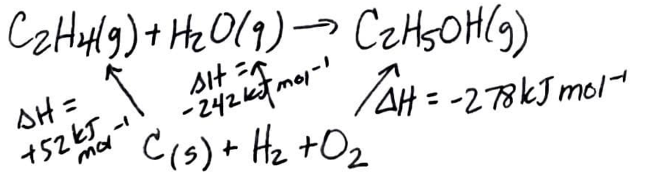
③ $C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(l)$ $H_2O(l) \rightarrow H_2O(g)$ $\Delta H_{rxn} = +44\ kJ\ mol^{-1}$

you can solve this using enthalpies of combustion <u>or</u> enthalpies of formation

Using enthalpies of formation:



$\Delta H_{rxn} = \Sigma\,\Delta H_f(products) - \Sigma\,\Delta H_f(reactants)$

$\Delta H_{rxn} = -278 - (-242 + 52)$

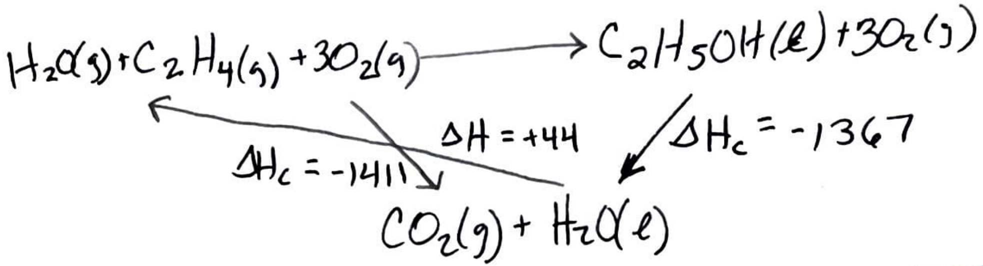
$\boxed{= -88\ kJ\ mol^{-1}}$

③ Continued

using enthalpies of combustion:

$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$ $\Delta H_c = -1411$ kJ mol^{-1}

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$ $\Delta Hc = -1367$ kJ mol^{-1}



$\Delta H_{rxn} = -1411 + 1367 - 44 = \boxed{-88 \text{ kJ mol}^{-1}}$

either way you slice it, it is -88 kJ mol^{-1}!

④ a) $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$

ΔH_f $CO(g)$: -111 kJ mol^{-1}

ΔH_f $CO_2(g)$: -394 kJ mol^{-1}

ΔH_f $Fe_2O_3(s)$: -822 kJ mol^{-1}

$\Delta H_{rxn} = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})$

$= 3(-394) - (-822 + 3(-111))$

$= -1182 + 822 + 333 = \boxed{-27 \text{ kJ mol}^{-1}}$

b) $4NH_3(g) + SO_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

ΔH_f NH_3: -46.11 kJ mol^{-1}

ΔH_f NO: $+90.7$ kJ mol^{-1}

ΔH_f $H_2O(g)$: -242 kJ mol^{-1}

$\Delta H_{rxn} = (4(90.7) + -242) - (4(-46.11))$

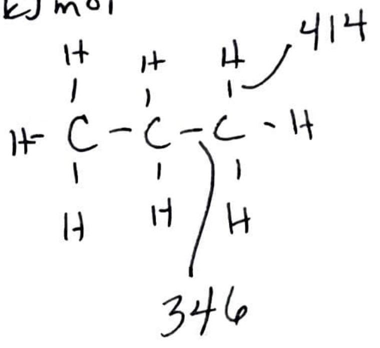
$= 120.8 + 184.44$

$\boxed{= +305.24 \text{ kJ mol}^{-1}}$

⑤ $3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$

$C(s) \rightarrow C(g)$ $\Delta H = +715\,kJ\,mol^{-1}$

$3C(s) + 4(H-H) \rightarrow$



$3(715)\downarrow$ $3C(g)$ 436

$\Delta H_{rxn} = \Sigma$ bonds broken $- \Sigma$ bonds formed

$= [3(715) + 4(436)] - [2(346) + 8(414)]$

$= 3889 - (4004) = \boxed{-115\,kJ\,mol^{-1}}$

⑥ $BrF(g) + F_2(g) \rightarrow BrF_3(g)$

$Br_2(l) + F_2(g) \rightarrow 2BrF(g)$ $\Delta H = x\,kJ$

$Br_2(l) + 3F_2(g) \rightarrow 2BrF_3(g)$ $\Delta H = y\,kJ$

$BrF(g) \rightarrow \frac{1}{2}Br_{2(l)} + \frac{1}{2}F_2(g)$ $\Delta H = -\frac{1}{2}x$

$+\ \frac{1}{2}Br_2(l) + \frac{3}{2}F_{2(g)} \rightarrow BrF_3(g)$ $\Delta H = \frac{1}{2}y$

$BrF(g) + \cancel{\frac{1}{2}Br_2(l)} + \frac{3}{\cancel{2}}F_2(g) \rightarrow \cancel{\frac{1}{2}Br_2(l)} + \cancel{\frac{1}{2}F_2(g)} + BrF_3(g)$

$BrF(g) + F_2(g) \rightarrow BrF_3(g)$ $\boxed{\Delta H = -\frac{1}{2}x + \frac{1}{2}y}$

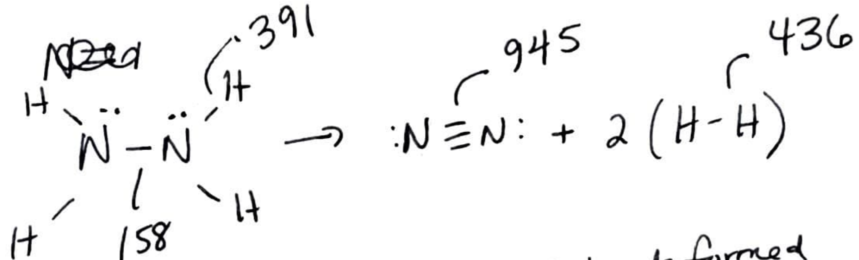
⑦

$$\begin{tikzcd}
CaCO_3(s) \arrow[rr, "\Delta H"] \arrow[dr, "2HCl(aq)"', "\Delta H_1"] \arrow[rr, dashed, bend right=60] & & CaO(s) + CO_2(g) \arrow[dl, "2HCl(aq)", "\Delta H_2"'] \\
& CaCl_2(aq) + H_2O(l) + CO_2(g) &
\end{tikzcd}$$

$\boxed{\Delta H = \Delta H_1 - \Delta H_2}$

⑧

a) $N_2H_4(g) \rightarrow N_2(g) + 2H_2(g)$



$\Delta H_{rxn} = \Sigma$ bonds broken − Σ bonds formed

$= [158 + 4(391)] - [945 + 2(436)]$

$= 1722 - 1817 = \boxed{-95 \text{ kJ mol}^{-1}}$

ΔH_f $N_2H_4(g)$: $+95 \text{ kJmol}^{-1}$

b) ΔH_f $N_2H_4(l)$: $+50.6 \text{ kJ mol}^{-1}$

use ΔH_f Hess Cycle:

$$\begin{tikzcd}
N_2H_4(l) \arrow[rr, "\Delta H_{rxn}"] \arrow[rr, dashed, bend right] & & N_2H_4(g) \\
& N_2(g) + 2H_2(g) \arrow[ul, "+50.6\ \text{kJmol}^{-1}"] \arrow[ur, "+95\ \text{kJmol}^{-1}"'] &
\end{tikzcd}$$

remember, if it goes against the arrow, flip the sign!

$\Delta H^{vap}_{rxn} = -50.6 + 95 = \boxed{+44.4 \text{ kJmol}^{-1}}$

⑨ $C_6H_4(OH)_2(aq) + H_2O_2(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(l)$

a) $C_6H_4(OH)_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g)$ $\Delta H = +177.0 \text{ kJ}$

flip & divide by 2 → $2H_2O(l) + O_2(g) \rightarrow 2H_2O_2(aq)$ $\Delta H = +189.2 \text{ kJ} \Rightarrow -\frac{189.2}{2}$

flip → $H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H = +285.5 \text{ kJ} \Rightarrow -285.5$

$C_6H_4(OH)_2(aq) + H_2O_2(aq) + \cancel{H_2(g)} + \cancel{\tfrac{1}{2}O_2(g)} \rightarrow C_6H_4O_2(aq) + \cancel{H_2(g)} + H_2O(l) + \cancel{\tfrac{1}{2}O_2(g)} + H_2O(l)$

$C_6H_4(OH)_2(aq) + H_2O_2(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(l)$

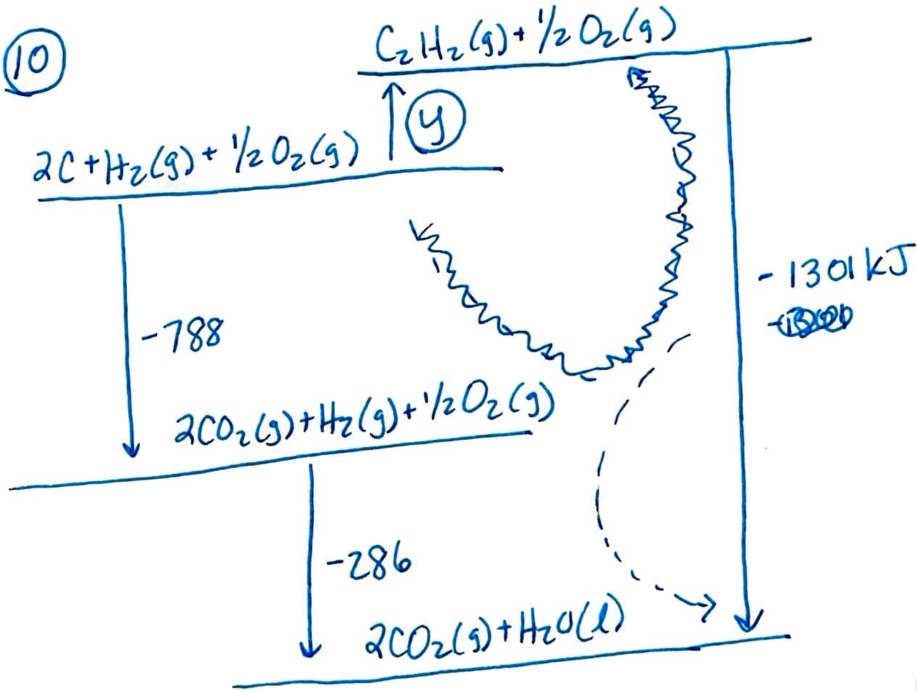
$\Delta H_{rxn} = +177 - 94.6 - 285.5 = \boxed{-203.1 \text{ kJ}}$

b) $q = +203.1 \text{ kJ}$ $m = 850 \text{ g}$ $T_1 = 21.8°C$ $\Delta H = -q$

$+203{,}100 \text{ J} = 850(4.184)(T_2 - 21.8)$

$57.11 = T_2 - 21.8$ $\boxed{T_2 = 78.9°C}$

⑩



everything against the arrow, flip the sign!

~~y = +788 + 286~~ $-y - 788 - 286 = -1301$

$-y = -1301 + 788 + 286$

$-y = -227$

$\boxed{y = +227\text{ kJ}}$

⑪ a. ΔH_{hyd} $MgSO_4$ dissolved in water (represented by ΔH_1 on the Hess cycle)

mol anhydrous $MgSO_4$: $3.0\cancel{g} \times \dfrac{1\text{ mol}}{120.38\text{g}} = \boxed{0.0250\text{ mol } MgSO_4}$

b. $q = mc\Delta T$

$q = 50.0\text{g}(4.184)(9.7\text{K})$

$= 2.029\text{ kJ}$ $\quad \Delta H_1 = -2.029\text{kJ}/0.0250\text{mol} = \boxed{-81.2\text{ kJ mol}^{-1}}$

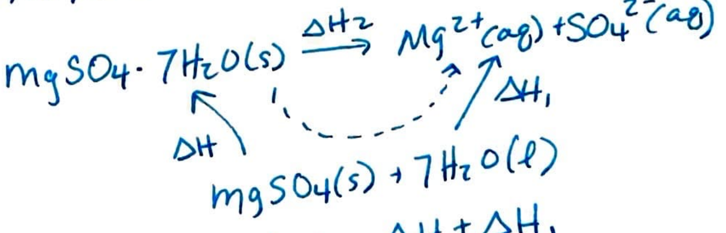
c. $\Delta H_2 = +18\text{ kJ mol}^{-1}$

~~+18~~ ~~81.2 + ΔH_1~~

$+18 = -\Delta H - 81.2$

$-\Delta H = +99.2$

$\boxed{\Delta H = -99.2\text{kJ mol}^{-1}}$



$\Delta H_2 = -\Delta H + \Delta H_1$

d. % error $= \dfrac{-103 - (-99.2)}{-103} \times 100 = \boxed{3.7\%}$

e)
- loss of heat leads to a lower calculated ΔH
- incomplete rxn
- rxn not done @ STP
- absorption of heat by calorimeter