Example Problems for Lecture 15

Summary of Hess's Law

- A reaction and its reverse have equal magnitude, opposite sign ΔH values
  If A → B has ΔH = 100 kJ, then B → A has ΔH = –100 kJ
- If you multiply a reaction by a factor, then you multiply the ΔH by the same factor
  If A → B has ΔH = 100 kJ, then 2A → 2B has ΔH = 200 kJ
- When you add two reactions, you add the ΔH values
  If A → B has ΔH = 100 kJ, and C → D has ΔH = 50 kJ,
  then A + C → B + D has ΔH = 100 + 50 kJ = 150 kJ

You can use Hess's Law to calculate ΔH for a reaction of interest if you can sum other reactions to equal the reaction of interest.

1. Calculate ΔH for the reaction

$$2\,C\,(s) + H_2\,(g) \rightarrow C_2H_2\,(g)$$

given the following chemical equations and their respective enthalpy changes.

$$C_2H_2\,(g) + \frac{5}{2}\,O_2\,(g) \rightarrow 2\,CO_2\,(g) + H_2O\,(l) \quad \Delta H = -1299.6\,kJ$$

$$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g) \quad \Delta H = -393.5\,kJ$$

$$H_2\,(g) + \frac{1}{2}\,O_2\,(g) \rightarrow H_2O\,(l) \quad \Delta H = -285.8\,kJ$$

In summary:

$$2\,CO_2\,(g) + H_2O\,(l) \rightarrow C_2H_2\,(g) + \frac{5}{2}\,O_2\,(g) \quad \Delta H = +1299.6\,kJ$$

$$2\,C\,(s) + 2\,O_2\,(g) \rightarrow 2\,CO_2\,(g) \quad \Delta H = -787.0\,kJ$$

$$H_2\,(g) + \frac{1}{2}\,O_2\,(g) \rightarrow H_2O\,(l) \quad \Delta H = -285.8\,kJ$$

Draw an enthalpy diagram to illustrate this.

2. Calculate ΔH for the reaction

$$\mathrm{NO}\,(g) + \mathrm{O}\,(g) \rightarrow \mathrm{NO_2}\,(g)$$

given the following information

$$\mathrm{NO}\,(g) + \mathrm{O_3}\,(g) \rightarrow \mathrm{NO_2}\,(g) + \mathrm{O_2}\,(g) \quad \Delta H = -198.9\ kJ$$

$$\mathrm{O_3}\,(g) \rightarrow \frac{3}{2}\mathrm{O_2}\,(g) \quad \Delta H = -142.3\ kJ$$

$$\mathrm{O_2}\,(g) \rightarrow 2\,\mathrm{O}\,(g) \quad \Delta H = +495.0\ kJ$$

Draw an enthalpy diagram to illustrate this.

Answer: –304.1 *kJ*

You can use a special category of reactions, called *formation reactions*, as the reactions that are summed to equal an overall reaction.

Enthalpy of Formation

An enthalpy of formation, ΔH_f^o, is defined as the enthalpy change for the reaction in which a compound is made from its constituent elements with all substances in their standard states.

Standard enthalpies of formation are measured under standard conditions (25°C and 1.00 atm pressure) and they are reported per mole of the substance.

TABLE 5.3 Standard Enthalpies of Formation, ΔH_f°, at 298 K

Substance	Formula	ΔH_f° (kJ/mol)	Substance	Formula	ΔH_f°(kJ/mol)
Acetylene	$C_2H_2(g)$	226.7	Hydrogen chloride	HCl(g)	−92.30
Ammonia	$NH_3(g)$	−46.19	Hydrogen fluoride	HF(g)	−268.60
Benzene	$C_6H_6(l)$	49.0	Hydrogen iodide	HI(g)	25.9
Calcium carbonate	$CaCO_3(s)$	−1207.1	Methane	$CH_4(g)$	−74.80
Calcium oxide	CaO(s)	−635.5	Methanol	$CH_3OH(l)$	−238.6
Carbon dioxide	$CO_2(g)$	−393.5	Propane	$C_3H_8(g)$	−103.85
Carbon monoxide	CO(g)	−110.5	Silver chloride	AgCl(s)	−127.0
Diamond	C(s)	1.88	Sodium bicarbonate	$NaHCO_3(s)$	−947.7
Ethane	$C_2H_6(g)$	−84.68	Sodium carbonate	$Na_2CO_3(s)$	−1130.9
Ethanol	$C_2H_5OH(l)$	−277.7	Sodium chloride	NaCl(s)	−410.9
Ethylene	$C_2H_4(g)$	52.30	Sucrose	$C_{12}H_{22}O_{11}(s)$	−2221
Glucose	$C_6H_{12}O_6(s)$	−1273	Water	$H_2O(l)$	−285.8
Hydrogen bromide	HBr(g)	−36.23	Water vapor	$H_2O(g)$	−241.8

Practice writing formation reactions for several of the compounds in the table above.

3. Use standard enthalpies of formation to calculate the enthalpy of reaction for the combustion of ethanol, C_2H_5OH (*l*).

Standard enthalpies of formation

$$\Delta H_f^o\left[H_2O(l)\right] = -285.83\ {}^{kJ}\!/_{mol}$$

$$\Delta H_f^o\left[CO_2(g)\right] = -393.5\ {}^{kJ}\!/_{mol}$$

$$\Delta H_f^o\left[C_2H_5OH(l)\right] = -277.7\ {}^{kJ}\!/_{mol}$$

In summary (shortcut):

$$\Delta H_{rxn}^o = \sum_{products} n\,\Delta H_f^o - \sum_{reactants} m\,\Delta H_f^o$$ where *n* and *m* are stoichiometric coefficients