

Review

Energy transfer based on conservation of energy

1. Energy transfer between substances is equal.
2. Direction of energy transfer is opposite.

$$\Delta E_1 = q_1 = -q_2 = -\Delta E_2$$

Energy transfer for physical processes

ΔE = amount of substance x cost for that substance.

1. Change in temperature:

$$q = mc\Delta T \quad (\text{or } q = nC\Delta T)$$

2. Change in phase:

$$q = m\Delta H \quad (\text{or } n\Delta H)$$

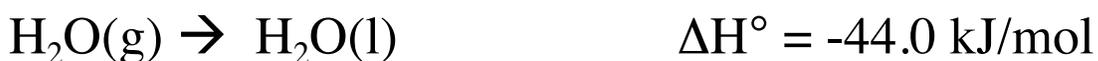
Energy vs. enthalpy

ΔE = change in energy = energy transfer (all conditions).

ΔH = change in enthalpy = energy transfer at constant pressure (usual lab conditions of atmospheric pressure).

Standard enthalpy change (ΔH°) is based on a chemical equation (mole ratio) at standard conditions of 1 bar of pressure and 25°C.

For example,



$^\circ$ = pressure of 1 bar and T of 25°C (very close to atmospheric pressure of 1 atm and room temperature, i.e., typical lab conditions)

ΔH° = standard enthalpy change for a process

Energy transfer for chemical processes (Section 6.6)



$\Delta H^\circ = -2220 \text{ kJ/mol}$ (per mole of ???)

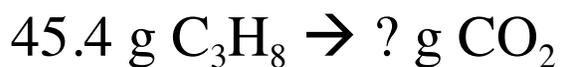
2220 kJ is released for every 1 mol C_3H_8 and 5 mol O_2 and 3 mol CO_2 and 4 mol H_2O .

Practice applying the mole ratio concept:

How many grams of CO₂ are produced when 45.4 g propane are burned? How many kJ of energy are produced?

MM (C₃H₈) = 44.064 g/mol)

MM (CO₂) = 44.010 g/mol



Example: conservation of energy

How much water can be heated from 20.0 °C to 100.0 °C by burning 45.4 g propane (C₃H₈)?

Example: conservation of energy
45.4 g propane (C_3H_8) are burned, and the heat is used to melt 6.00×10^3 g of ice starting at 0.00°C . What is the final temperature of the water? (Hint: two steps – melt the ice, then heat the water; this problem requires 3 calculations)

Experimentally finding amount of energy transfer (Section 6.8)

Conduct a chemical reaction in aqueous solution, and measure the change in temperature of the solution.

0.800 g of Mg are added to 250.0 mL of aqueous solution containing excess HCl to produce hydrogen gas. The solution temperature increases from 23.4 to 37.9 °C.

1. Calculate the energy transfer (energy change) for the solution: $mc\Delta T$.

$$q_{\text{solution}} =$$

2. Conserve energy.

$$q_{\text{reaction}} =$$

3. Divide by the moles from the chemical reaction.

$$\text{moles} = n =$$

$$\frac{q_{\text{reaction}}}{n} =$$



$$\Delta H^\circ =$$

Types of energy transfer (ΔE)

ΔE = amount of substance x cost for that substance.

1. Change in temperature: $mc\Delta T$ ($nC\Delta T$)

2. Change in phase: $m\Delta H$ ($n\Delta H$)

3. Change in chemicals: $n\Delta H$

(m = mass, n = moles)

Enthalpy changes are measured for many different processes.

ΔH_{rxn} = enthalpy change for a chemical reaction

The following symbols are actually ΔH_{rxn} :

ΔH_{comb} combustion rxn

ΔH_{f} formation rxn

ΔH_{soln} dissolving rxn ($\Delta H_{\text{dissolution}}$)

many more ...

Enthalpy changes are measured for physical processes, too.

ΔH_{dil} dilution

ΔH_{vap} evaporation (vaporization)

ΔH_{fus} melting

many more ...

Enthalpy is a state function.

State function: a property that depends only on the present state, not on the changes that took place between the present state and any past state.

Path function: a property that depends on how changes between two states take place.

Example:

Wallet A has \$20. Wallet B has \$20.

What is the financial state of each wallet?

Wallet A had \$100, but \$80 was spent on groceries. Wallet B was empty, but \$20 was put inside. What is the path of each wallet to reach the current state?

Reaching a state (financial or enthalpy) is independent of the path to reach the state.

Because changes in enthalpy are changes in a state function, we can use any pathway to calculate the change in enthalpy.

Hess's Law: ΔH for a process is equal to the sum of ΔH for any set of steps, i.e., for any path that equals the overall process.

Hess's Law applies to any set of reactions.

Application 1: $\Delta H_{\text{rxn}} = \Delta H_1 + \Delta H_2 + \Delta H_3 \dots$

Example:

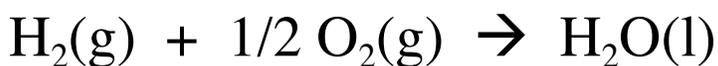


1. $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
 $\Delta H^\circ = -802 \text{ kJ/mol}$
2. $\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{O}(\text{g})$ $\Delta H^\circ = +44 \text{ kJ/mol}$

Formation reaction: a reaction between elements in their most stable forms at 25 °C and 1 bar to produce 1 mole of a chemical substance.

ΔH_f° = standard enthalpy of formation, the enthalpy change for a formation reaction.

The formation reaction for water:



$$\Delta H_f^\circ (\text{H}_2\text{O}, \text{l}) = -285.8 \text{ kJ/mol}$$

Hess's Law applies to any set of reactions, including formation reactions.

Application 2:

$$\Delta H_{\text{rxn}}^\circ = \sum n \Delta H_f^\circ (\text{products}) - \sum n \Delta H_f^\circ (\text{reactants}).$$

Example:



$$\Delta H_f^\circ (\text{CH}_4, \text{g}) = -74.6 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{O}_2, \text{g}) = 0 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{CO}_2, \text{g}) = -393.5 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{H}_2\text{O}, \text{l}) = -285.83 \text{ kJ/mol}$$

$$\Delta H_{\text{rxn}} = \sum n \Delta H_f^\circ (\text{products}) - \sum n \Delta H_f^\circ (\text{reactants})$$

Additional notes on Hess's Law

1. ΔH_f° (element, most stable form) = 0 kJ/mol

Examples:

C(s, graphite), O₂(g), H₂(g) => $\Delta H_f^\circ = 0$.

Not C(s, diamond), O₃(g), H(g).

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

Can be asked to solve for ΔH_{rxn} , ΔH_f° of a product, or ΔH_f° of a reactant.

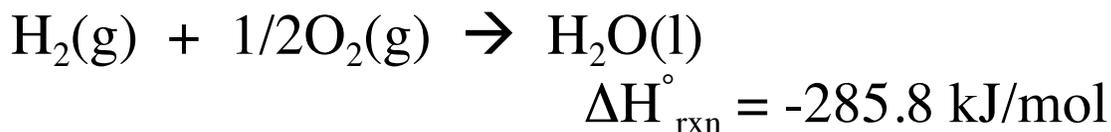
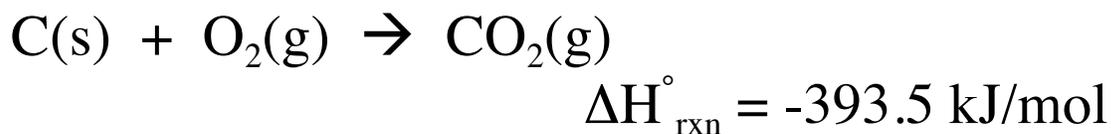
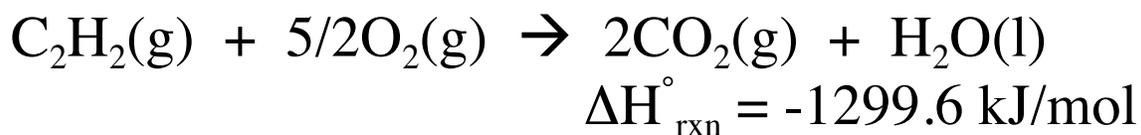
3. $\Delta H_{\text{rxn}} = \Delta H_1 + \Delta H_2 + \Delta H_3 \dots$

Can be asked to solve for ΔH_{rxn} , ΔH_1 , etc.

Practice: conservation of energy

How many grams of propane are needed to boil 1.00 L of water with an initial temperature of 20.0 °C? (Hint: two steps – heat the water, then boil it; this problem requires 3 calculations)

Practice: Hess's Law App. 1: path of reactions



Practice: Hess's Law App. 2: formation values



What is $\Delta H_{\text{rxn}}^\circ$?

$$\Delta H_{\text{f}}^\circ (\text{CH}_4, \text{g}) = -74.6 \text{ kJ/mol}$$

$$\Delta H_{\text{f}}^\circ (\text{H}_2\text{O}, \text{g}) = -241.83 \text{ kJ/mol}$$

$$\Delta H_{\text{f}}^\circ (\text{H}_2\text{O}, \text{l}) = -285.83 \text{ kJ/mol}$$

$$\Delta H_{\text{f}}^\circ (\text{CO}, \text{g}) = -110.5 \text{ kJ/mol}$$

$$\Delta H_{\text{f}}^\circ (\text{H}_2, \text{g}) = 0 \text{ kJ/mol}$$