

## Unit 11 Thermochemistry

**Energy** - measure of the ability to cause change to occur, i.e. work.

Units of energy: Joule (J) = newton x meter or  $J = N \times m$

Types of Energy - five main forms of energy:

**Mechanical (Kinetic and Potential)**

**Chemical**

**Electromagnetic**

**Heat (Thermal)**

**Nuclear**

**Kinetic energy** - energy of motion; depends on both mass and velocity; the faster an object moves, the greater the kinetic energy

**Potential Energy**- amount of energy that is stored.

3 types    **Elastic** e.g. pulling a rubber band back and holding

**Chemical** e.g. burning a match

**Gravitational** e.g. boulder resting on top of a hill

**Chemical energy** - energy stored in the bonds of atoms and molecules

**Electromagnetic Energy**- a form of energy that is reflected or emitted from objects in the form of electrical and magnetic waves that can travel through space; moving electric charges.

**Thermal Energy**- internal energy or thermal energy of a substance is determined by the movement of the molecules and the potential energy of the arrangement of molecules.

**Temperature** - measure of the average kinetic energy of the molecules.

**Heat (q)** - energy transferred from a warmer substance to a colder one by the collisions of molecules.

**calorie** - amount of heat needed to raise 1 g of a substance 1 degree Celsius.

Calorie (food calorie, with a capital C) is 1000 cal (1 kcal)

1 cal = 4.18 joules or 1 kcal = 4180 J

$$\text{specific heat capacity} = \frac{q}{(c_p) \quad m \times \Delta T} = \frac{\text{heat (joules or calories)}}{\text{mass (g)} \times \text{change in } T^{\circ}\text{C}}$$

**Nuclear Energy** -when the nucleus of an atom splits, nuclear energy is

released. Nuclear energy is the most concentrated form of energy.

**Law of Conservation of Energy**- energy can be converted from one form to another, but it can neither be created nor destroyed.

**Heat Energy** - if a substance gets hotter, then something else must get colder.

$$\text{heat}_{\text{lost}} = \text{heat}_{\text{gained}}$$

Temperature measures the average kinetic energy of the particles in a sample of matter:

$$\text{Kinetic Energy} = \frac{1}{2} mv^2$$

### Methods of Energy Transfer

Energy transfer as heat can occur in 3 ways:

**Conduction**- transfer of energy as heat between particles as they collide with a substance or between 2 objects in contact.

**Convection**- transfer of energy by the movement of fluid with different temperature . **Convection current** - cycle of a heated fluid that rises and then cools and falls.

**Radiation**- transfer of energy by electromagnetic waves. This energy transfer does not need any matter since it travels in waves.

### **Main Points**

The Law of Conservation of Energy- energy cannot be created or destroyed. It can only be transferred from one form to another.

Heat is the transfer of energy from the particles of one object to those of another object due to a temperature difference between the two objects.

The transfer of energy always takes place from a substance at a higher temperature to a substance at a lower temperature.

Thermochemical Equation - balanced, stoichiometric chemical equation that includes the enthalpy change,  $\Delta H$

Enthalpy ( $\Delta H$ ) - transfer of energy in a reaction; change in heat.

$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

$$H_{\text{products}} < H_{\text{reactants}} , \Delta H \text{ is negative}$$

$$H_{\text{products}} > H_{\text{reactants}} , \Delta H \text{ is positive}$$

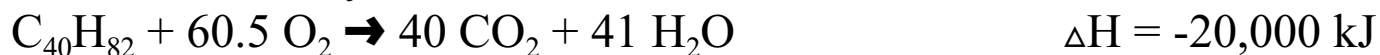
## Writing Thermochemical Equations

For example, Burning one mole of wax releases 20,000 kJ of heat energy.

This could be written as:

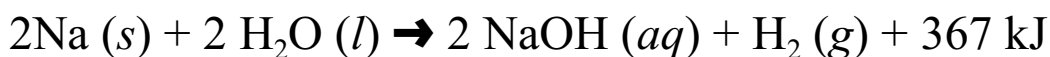


Instead we usually write:

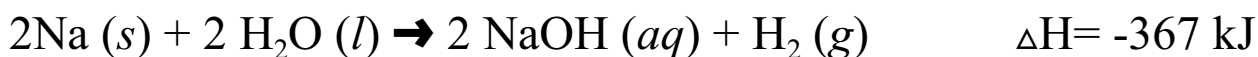


### Example 1

Reacting 2 moles of solid sodium with 2 moles of water to produce 2 mole of aqueous sodium hydroxide and 1 mole of hydrogen gas will release 367 kJ of energy.



*or*



### Example 2

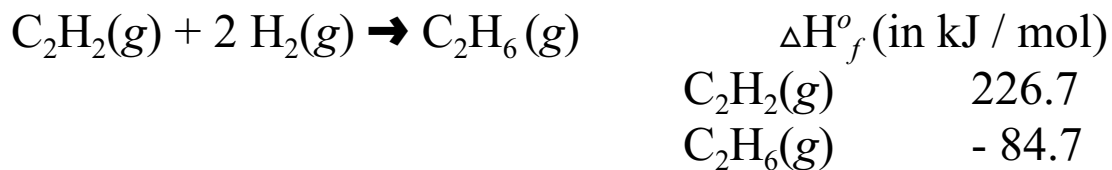
184.6 kJ of energy is needed to produce 1 mole of hydrogen gas and 1 mole of chlorine gas from 2 moles of hydrogen chloride gas.



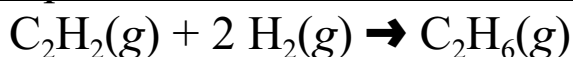
*or*



## How to write Thermochemical equations using Standard Heat of Formations



Write the equation for the heat of formation of  $\text{C}_2\text{H}_6(g)$



1 mol of  $\text{C}_2\text{H}_2(g)$  and 1 mol  $\text{C}_2\text{H}_6(g)$

And

$$\Delta H^{\circ}_{\text{rxn}} = [\Delta H^{\circ}_f \text{ products}] - [\Delta H^{\circ}_f \text{ reactants}]$$

$$\Delta H^{\circ}_{\text{rxn}} = [\text{C}_2\text{H}_6(g)] - [\text{C}_2\text{H}_2(g)]$$

Therefore

$$\Delta H^{\circ}_{\text{rxn}} = [-84.7 \text{ kJ/mol}] - [226.7 \text{ kJ/mol}] = -331.4 \text{ kJ/mol}$$

### Endothermic/ Exothermic equations

Depending on the sign of  $\Delta H^{\circ}$ , the reaction can either be exothermic or endothermic.

Exothermic reactions release heat from the system to the surroundings so the temperature will rise.

$\Delta H^{\circ}$  will be **negative** because the reaction loses heat.

$\Delta H^{\circ}$  can be written into the chemical equation as a **product**.

Endothermic reactions absorb heat from the surroundings into the system so the temperature will decrease.

$\Delta H^{\circ}$  will be **positive** because the reaction absorbs heat.

$\Delta H^{\circ}$  can be written into the chemical equation as a **reactant**.

### Example 3

How much energy does it take to raise the temperature of 50 g of aluminum ( $c_p = 0.9025 \text{ J/g}^{\circ}\text{C}$ ) by  $10^{\circ}\text{C}$ ?

Using  $Q = m \times c_p \times (T_f - T_i)$

$$Q = (50\text{g}) (0.9025 \text{ J/g}^{\circ}\text{C}) (10^{\circ}\text{C})$$

$$Q = 451.3 \text{ J}$$

### Example 4

If we add 30 J of heat to lead ( $c_p = 0.1276 \text{ J/g}^{\circ}\text{C}$ ) with a mass of 10 g, how much will its temperature increase?

Using  $Q = m \times c_p \times \Delta T$

$$30\text{J} = (10\text{g}) (0.1276 \text{ J/g}^{\circ}\text{C}) (\Delta T)$$

$$23.5^{\circ}\text{C} = \Delta T$$

**Calorimetry** - science of measuring the heat of chemical reactions or physical changes. To do calorimetry, heat of combustion and mass must be given OR during a calorimetry procedure, the heat released during a chemical or physical change is transferred to another substance, such as water, which undergoes a temperature change.

### Example 5

Propane is a commonly used fuel. 1 mol of  $\text{C}_3\text{H}_8$  releases 2,220 kJ of heat during combustion. The molar mass of  $\text{C}_3\text{H}_8$  is 44.1 g/mol. How much heat is released if a firework contains 67.8 g of  $\text{C}_3\text{H}_8$ ?

1st step: convert grams  $\text{C}_3\text{H}_8$  to moles  $\text{C}_3\text{H}_8$

$$67.8 \text{ g C}_3\text{H}_8 \quad 1 \text{ mol C}_3\text{H}_8 \\ \times \frac{\text{-----}}{44.1 \text{ g C}_3\text{H}_8} = 1.54 \text{ mol C}_3\text{H}_8$$

2nd step: use the heat of combustion of propane to calculate energy (heat) released

$$1.53 \text{ mol C}_3\text{H}_8 \quad 2,220 \text{ kJ} \\ \times \frac{\text{-----}}{1 \text{ mol}} = 3413.06 \text{ kJ} \quad \therefore >3410 \text{ kJ released}$$

For heat transferred to another object, the equation is:  $-Q_1 = Q_2$   
One will be losing energy ( $-Q_1$ ), the other will be gaining energy ( $Q_2$ ).

### Example 6

175 grams of hot aluminum ( $100^\circ\text{C}$ ) is dropped into an insulated cup that contains 40.0 mL of ice cold water ( $0^\circ\text{C}$ ). Determine the final temperature,  $T_f$ .

1<sup>st</sup> set up expressions for energy released and energy absorbed.

$$\begin{array}{ll} -Q_1 = - (175 \text{ g}) (0.900 \text{ J/g}^\circ\text{C}) (T_f - 100^\circ\text{C}) & \text{for aluminum} \\ Q_2 = (40.0 \text{ g}) (4.184 \text{ J/g}^\circ\text{C}) (T_f - 0.0^\circ\text{C}) & \text{for cold water} \end{array}$$

2<sup>nd</sup> put the expressions together, i.e.  $-Q_1 = Q_2$

$$- (175 \text{ g}) (0.900 \text{ J/g}^\circ\text{C}) (T_f - 100^\circ\text{C}) = (40.0 \text{ g}) (4.184 \text{ J/g}^\circ\text{C}) (T_f - 0^\circ\text{C})$$

3<sup>rd</sup> solve for  $T_f$

$$- 157.5 (T_f - 100^\circ\text{C}) = 167.4 (T_f - 0.0^\circ\text{C})$$

$$- 157.5 T_f + 15750^\circ\text{C} = 167.4 T_f$$

$$15750^\circ\text{C} = 324.9 T_f \quad \therefore T_f = 48.5^\circ\text{C}$$