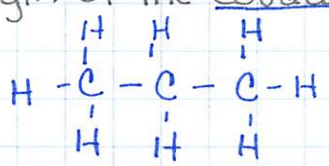
Thermochemistry

the study of the heat energy which is associated w/ chemical reactions and physical changes (like boiling or freezing)

1. energy - the ability to do work or produce heat. It exists in 2 forms.
   - potential energy (PE) - for us this is the energy stored in the chemical bonds of a substance
   - kinetic energy (KE) - related to the constant, random motion of atoms & molecules. The higher a substance's temperature, the faster the particles move & the higher the kinetic energy is

2. Law of Conservation of Energy - In any chemical reaction or physical process, energy cannot be created or destroyed but it can be converted from one form of energy to another. Also called the 1ST Law of Thermodynamics

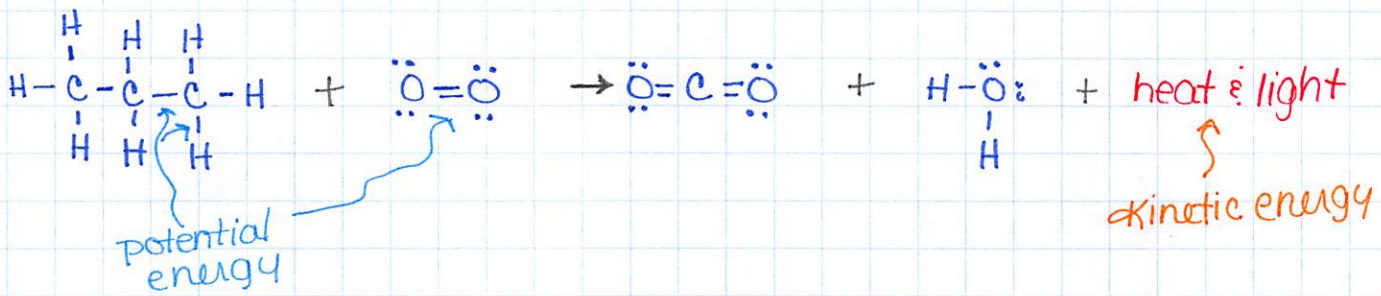
For example: Propane, C_3H_8, has potential energy from the strength of the covalent bonds that hold the molecule together



When propane reacts w/oxgen (like when it's burned in a gas grill) the bonds holding the propane (C_3H_8) break apart and combine w/oxgen to form new compounds, CO_2 & H_2O. The bonds breaking change the potential energy into kinetic energy in the form of heat & light.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + \text{energy (heat \& light)}$$

or



3. Measuring Heat

- **heat** - flow of energy due to a difference in temperature

uses the symbol q (stands for quantity of heat energy)

↳ units for heat

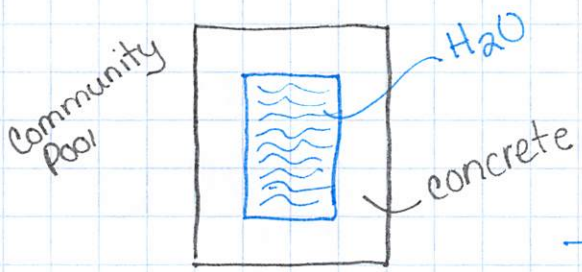
↳ calorie (cal) - defined as the amount of energy needed to raise the temperature of 1g of pure H_2O by 1°C.

↳ Calorie (Cal) - is a kilocarie or 1000 calories. This is the unit used to measure the amount of energy food will give you

↳ joule (J)* - S.I. unit for energy (1 cal. = 4.184 J)
* this is the unit we will use most often

- **specific heat** - amount of heat needed to raise the temperature of 1g of any substance by 1°C. Each substance has its own specific heat.

↳ The higher the specific heat for a substance, the more energy you have to put into it to raise the temperature.
Example.



You go to your local community pool in July. Which is hotter, the water in the pool or the concrete deck surrounding the pool?

specific heat
water = 4.184 J/g °C
concrete = .84 J/g °C

The specific heat of concrete is really low compared to water. That means it does not take that much energy (heat) to make concrete's temperature to increase. Water, on the other hand, has a relatively high specific heat. That means water can absorb alot of energy (heat) before it will change temperature.

Therefore, the concrete gets hotter than the water.

· Calculating heat

$$q = m \cdot C \cdot \Delta T$$

- q → heat (in joules, J)
- m → mass (in grams, g)
- C → specific heat (in J/g°C)
- ΔT → change in temperature

$\Delta T = T_{final} - T_{initial}$ (in °C)

↳ This process can be endothermic or exothermic.

endothermic: q is a positive number b/c heat is being added into the system

$T_{final} > T_{initial}$

exothermic: q is a negative number b/c heat is being released (exiting) the system

$T_{final} < T_{initial}$

Examples $q = m \cdot C \cdot \Delta T$ $\Delta T = T_{final} - T_{initial}$

1. 100.0 g (m) of silver is cooled from 25.0°C ($T_{initial}$) to a temperature of 9.0°C (T_{final}). The specific heat of silver is .240 J/g°C (C). How much heat (?) is released? Is this process endothermic or exothermic?

$q = ?$
$m = 100.0\,g$
$C = .240\ J/g°C$
$\Delta T = 9.0°C - 25.0°C =$
$= -16.0°C$

$q = (100.0\,g)(.240\ J/g°C)(-16.0°C)$
$q = -384\ J$ ← significant figures still apply!

It's exothermic because q is negative

2. How much heat (?) is absorbed by a 3.580×10^6 g (m) piece of granite as it heats throughout the day from -12.9°C ($T_{initial}$) to 41.2°C (T_{final})? The specific heat of granite is .803 J/g°C (C)

$q = ?$
$m = 3.580 \times 10^6\,g$
$C = .803\ J/g°C$
$\Delta T = 41.2°C - -12.9°C$
$= 54.1°C$

$q = (3.580 \times 10^6\,g)(.803\ J/g°C)(54.1°C)$
$q = 155523434\ J = 156000000\ J$ or $1.56 \times 10^8\ J$

It's endothermic because q is positive.

3. When 10.2g (m) of canola oil at 25.0°C (Tinitial) is placed in a wok, 3340 J (q) of heat is required to heat it to a temperature of 196.4°C (Tfinal). What is the specific heat (c) of canola oil?

$q = +3340\ J$ → It's positive because the heat is added.
$m = 10.2\ g$
$c = ?$
$\Delta T = 196.4°C - 25.0°C$
$= 171.4°C$

$q = m \cdot c \cdot \Delta T$

$$c = \frac{q}{m \cdot \Delta T}$$

$$c = \frac{3340\ J}{(10.2\ g \cdot 171.4°C)} = 1.910449127\ J/g°C$$

$= 1.91\ J/g°C$

Try these on your own. Then see the answers on the answer sheet!

4. If the temperature of 34.4g of ethanol increases from 25.0°C to 78.8°C, how much heat has been absorbed by the ethanol. The specific heat of ethanol is 2.44 J/g °C.

5. Calculate the amount of heat released when 5.50g of aluminum is cooled from 95.0°C to 31.2°C. The specific heat of aluminum is .897 J/g°C.

Enthalpy & Thermochemical Equations

↓ the heat (q) of a process at constant pressure.
The symbol for enthalpy is: H
↓
The change in enthalpy of a reaction, ΔH_{rxn} is the change in energy that occurs when bonds are broken in the reactants & new bonds form in the products

$\Delta H_{rxn} = H_{products} - H_{reactants}$

↳ you won't have to calculate this, just understand where ΔH_{rxn} comes from.

↓ Ok, it sounds scary but it's not! It's just a balanced chemical equation (including states of matter) and the change in enthalpy of the reaction, ΔH_{rxn}

Examples

1) reaction in an instant heat pack

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$ $\Delta H_{rxn} = -1625\,kJ$

↑ fairly exothermic, giving off heat

2. reaction in a cold pack

$NH_4NO_3(s) \xrightarrow{H_2O(l)} NH_4^{1+}(aq) + OH^{1-}(aq)$

$\Delta H_{rxn} = +27\,kJ$

endothermic, absorbs heat from your body.

- You can also write thermochemical equations when a substance changes its state of matter (such as boiling or melting)

boiling

enthalpy of vaporization
ΔH_{vap}

Ex) $H_2O(l) \rightarrow H_2O(g)$ $\Delta H_{vap} = +40.7\,kJ$

condensing

enthalpy of condensation
ΔH_{cond}

Ex) $H_2O(g) \rightarrow H_2O(l)$ $\Delta H_{cond} = -40.7\,kJ$

melting

enthalpy of fusion
ΔH_{fus}

Ex) $H_2O(s) \rightarrow H_2O(l)$
$\Delta H_{fus} = +6.01\,kJ$

freezing

enthalpy of solidification
ΔH_{solid}

Ex) $H_2O(l) \rightarrow H_2O(s)$
$\Delta H_{solid} = -6.01\,kJ$

Hess's Law & Calculating Enthalpy Changes

<u>Hess's Law</u>: If you can add 2 or more thermochemical equations to produce a final equation for a reaction, then the sum of the enthalpy changes for the individual reactions is the enthalpy change for the final reaction.

<u>Examples</u>

1. Calculate ΔH_{rxn} for this overall reaction:

$$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$$

given the steps below:

(1) $N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H_1 = 180\,kJ$

(2) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta H_2 = -112\,kJ$

2. Calculate ΔH_{rxn} for this reaction:

$$C_{graphite}(s) \rightarrow C_{diamond}(s)$$

given the steps below:

(1) $C_{graphite}(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_1 = -394\,kJ$

(2) $C_{diamond}(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_2 = -396\,kJ$

3. Calculate ΔH_{rxn} for this reaction:

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

given:

(1) $S(s) + \frac{3}{2} O_2(g) \rightarrow SO_3(g)$ $\Delta H_1 = -395.2\,kJ$

(2) $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ $\Delta H_2 = -198.2\,kJ$

4. Calculate ΔH_{rxn} for this reaction:

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

given:

(1) $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_1 = -393.5\,kJ$

(2) $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$ $\Delta H_2 = -566.0\,kJ$

(3) $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$ $\Delta H_3 = -483.6\,kJ$

Heating Curve

shows what happens, thermodynamically, as a substance is heated and changes states of matter.