Energy in Chemistry: Thermochemistry

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Thermochemistry is the study of changes in energy in chemical reaction and the influences of temperature on those changes, i.e it is the study of the transfer of energy in a chemical or physical change.

All energy transferred is in the form of heat at constant pressure.

1. **System**: is the portion of the universe under study.

2. **Surroundings**: is everything in the universe that is not part of the system.

3. **Energy** is defined as the ability to do work.

4. **Heat** is the flow of thermal energy from a warmer object to a cooler one.

5. **Temperature** is a measure of the average thermal energy of a substance.

6. **Heat content** of a substance represents the total of all forms of energy within a substance. It is impossible to measure the total heat content of a substance: the heat content of a substance is constant as long as no energy enters or leaves the substance.

7. The capital letter **H** is the symbol used to represent the heat content (or **enthalpy**) of a substance.

8. Heat or enthalpy is measured in **Joules** (J) or kJ, 1 cal = 4.184 J.

9. Forms of energy: electrical, chemical, light, heat, sound, nuclear, mechanical, etc.

10. Energy can be converted from one form to another.

11. **Law of Conservation of Energy**: energy can not be created or destroyed.
    In other words, energy can only be converted from one form to another, with no net loss or gain.

12. **Molar Enthalpy**: Heat content of one mole of the substance.
    This is a characteristic property of the substance.
    It is the energy stored in the substance during its formation.
    Heat stored, H, can not be measured directly, however, the changes in heat content that occur during a chemical reaction can be measured.
    It is impossible to estimate absolute enthalpies, only enthalpy changes may be determined.

13. **Elements in their standard state,** (i.e at 25 ^{O}C and 101.3 kPa), are regarded as having zero enthalpy, i.e. they are by convention assumed to have a heat content of zero.

14. Chemical reactions involve the breaking and forming of bonds.

15. During a chemical reaction, the chemical bonds in the reactants are broken. Energy is required to break these bonds:

$$A_2 \quad + \quad B_2 \quad \longrightarrow \quad 2\ AB$$

○-○ + □-□ ⟶ 2 ○-□

Energy required to break bonds energy released when bonds are formed

16. The atoms of the reactants come together in new combinations to form new bonds in the products of the reaction. The formation of bonds releases energy.

17. The **energy change, ΔH**, in a chemical reaction is the difference between the energy required to break chemical bonds in the reactants and the energy released by the formation of the bonds in the products.

18. ΔH (delta H) represents the changes in energy of a chemical reaction (i.e. the Heat of reaction) :

$$\Delta H = \text{Enthalpy of the products } (H_{p}) - \text{Enthalpy of the reactants } (H_{r})$$
$$= H_{products} - H_{reactants}$$

[Since most laboratory work is carried out at constant pressure, it is usual to deal with the heat absorbed at constant pressure. This quantity is called the change in enthalpy, ΔH, and it is equal to the heat absorbed at constant pressure:

q = ΔH (at constant pressure) q = the quantity of heat (heat of the reaction)]

19. The change in heat content, (enthalpy), of a reaction, ΔH, is related to:
    (i) the change in the number of bonds breaking and forming, and
    (ii) the strengths of these bond as the reactant form products

20. An **exothermic reaction**:

- has a negative, — ΔH.
- Heat is lost by the substance in a reaction,
- the temperature of the surrounding increases.
- The enthalpy of the products is lower than those of the reactants.
- bonds broken are weaker than the bonds made.
- the products are more stable than the reactants.
- the reaction is self-sustaining.

Sketch of an exothermic reaction:

20. An **endothermic reaction:**

- has a positive, + ΔH.
- Heat is gained by the substance in a reaction,
- the temperature of the surroundings decreases.
- The enthalpy of the products is higher than those of the reactants.
- the bonds broken in the reactants are stronger than the bonds made in the products
- the products are less stable than the reactants.
- the reaction stops once the energy input is stopped, i.e. the reaction is non-sustaining.

Sketch of an Endothermic reaction:

Section B: Specific Heat and Heat Capacity

The energy required to raise one gram of water by 1 ^{O}C is called the **calorie**, this is from the Latin word calor meaning ...

The heat flow associated with a chemical reaction is measured experimentally using a device called a ***calorimeter.***

Calorimetry, the science of measuring heat flow, is observing the temperature change when a body absorbs or releases heat.

Substance differ in their responses to being heated.
One substance might require a great deal of heat to raise its temperature by one degree, while another will exhibit the same temperature change after absorbing relatively little heat.

The magnitude of the heat flow that accompanies an increase in temperature depends upon the mass and the identity of the substance involved.

To determine the amount of heat associated with a known ΔT for a given amount of a substance, it is necessary to know the ***heat capacity, C,*** of that substance. Every object has a heat capacity.

Definition: **Heat Capacity**: the amount of heat energy required to raise the temperature of a given amount of a substance by one degree:

$$\textbf{Heat Capacity, C} = \frac{\textbf{Heat Absorbed, or released by an object, Q}}{\textbf{Increase in Temperature, } \Delta \textbf{ T}}$$

Also, since the heat required will depend on the amount of substance being heated, i.e. the mass of the substance, thus the quantity of the substance must be specified.

Thus the **units for heat capacity** are usually given as **J/ ^{O}C.g or J/ mol °C .**

Heat Capacity is an extensive property because it depends directly on the amount of substance.

In contrast, an intensive property is not related to the amount of substance, ex. temperature.

Since heat capacity of a substance varies with its mass, scientists use **specific heat capacity, c**, to compare various substances.

Specific Heat, c: is the amount of heat required to raise the temperature of one gram of material by one degree (J/g K)

$$\text{Specific Heat, c} = \frac{\text{Heat Capacity, C}}{\text{Mass, m}} \qquad \text{Units: J/g.}^{O}\text{C or J / g. K}$$

$$\text{Specific Heat, c} = \frac{\text{Heat Absorbed, Q}}{\text{(Mass, m) x (Change in Temperature, } \Delta \text{ T)}}$$

Therefore,

Heat Energy, **Q = (Mass, m) x (Specific Heat, c) x (Change in Temperature, ΔT)**

In symbols: $\mathbf{Q = m\, c\, \Delta T}$

Sometimes it is more useful to express specific heats in terms of the **molar heat capacity**.

Simply defined the molar heat capacity is the energy required to raise the temperature of one mole of material one degree Celsius or one Kelvin.

Molar Heat capacity = specific heat x molar mass (J/mol ^{O}C, J/mol.K)

Water is an excellent liquid for use in hot water bottles because of its high specific heat capacity, (4.18 Jg^{-1} K^{-1}). This means that it can absorb a lot of heat energy with only a small increase in its temperature. Water can also release a lot of heat energy with only a small decrease in temperature. Large bodies of water such as lakes moderate the temperature of the area around them, because they absorb a great deal of heat from the air during the summer and give off heat to the air in the winter.

For a given temperature rise above room temperature, water stores almost twice as much heat as, for example, ethanol, whose specific heat capacity is only 2.4 J g^{-1} K^{-1}

Practice Calculations:

1. When 2.71 x 10^2 J of energy is absorbed by a cup of tea, its temperature rises by 8.30 ^{O}C
   What is the heat capacity of the cup of tea?

2. A gold ring with a mass of 5.5 g changes temperature form 25.0 to 28.0^{O}C, how much energy in Joules has it absorbed. (c = 0.129 J/g ^{O}C for gold)

3. If 25.6 g of aluminium absorbs 0.5571 kJ of heat, its temperature rises by 42.6^{O}C. What was the original temperature of the aluminium? (c = 0.902 J/g^{O}C for Al)

4. A chemist is working with copper, silver, and gold. The mass of each sample is 10.0 g. Determine which metal reaches the highest temperature when a heat change of 10.0 J occurs in each sample.
   (c (copper) = 0.385 J/g.^{O}C , c (silver) = 0.237 J/g.^{O}C, c (gold) = 0.130 J/g.^{O}C)

5. Calculate the heat required to raise the temperature of 2.0 kg of copper from 20.0 ^{O}C to 80.0 ^{O}C.
   (c (copper) = 0.385 J/g.^{O}C)

Problems: HEAT CAPACITY and SPECIFIC HEAT

1. Which kind of substances experiences the larger increase in temperature when it absorbs 100 J, something with a high or low specific heat? Explain.

2. What is the name of the thermal property whose values can have the following units?
(A) J g^{-1} $^{O}C^{-1}$ (B) J mol^{-1} $^{O}C^{-1}$ (C) J $^{O}C^{-1}$

3. Which kind of substance needs more energy to undergo an increase of 5 ^{O}C, something with a high or with a low specific heat? Explain

4. When 1.5 x 10^3 J of heat energy is absorbed by a beaker of water, its temperature rises by 3.10 °C, What is the heat capacity of the beaker of water?

5. If 10.5 g of iron, at 25.0 °C, absorbs 128 J of heat, what will be the final temperature of the metal? (The specific heat of iron is 0.499J/g °C.)

6. The specific heat capacity of aluminium is 0.900 J/ g °C.
   a. How much energy is needed to raise the temperature of a 8.50 x 10^2 g block of aluminium from 22.8°C to 94.6°C

   b. What it the heat capacity of aluminium per mole?

7. In order to determine how much heat paraffin gives off on burning, a candle flame is used to heat some water in a calorimeter. The following data is obtained:

Mass of water in calorimeter	350 g
Initial mass of candle	150 g
Final mass of candle	112 g
Initial temperature of water	15°C
Final temperature of water	23°C

Calculate:
(a) the temperature rise,
(b) the heat absorbed by the water in the calorimeter,
(c) the mass of paraffin burned and
(d) the approximate value of the heat in J/g.
Ignore the energy absorbed by the calorimeter.