# Chemical Energy 2

**Objective: Learning about chemical reactions, bond energy and energy released in chemical reaction.**

Key concepts:

- Chemical Formula
- Balancing Chemical Reactions
- Bond Energy
- Energy in Chemical Reactions
- Acids and Bases
- pH Scale

# Chemical Formula Notation

The expression $O_2$ means there are **2** atoms of **O**

The expression $H_2O$ means there are **2** atoms of **H** and one atom of **O**

The expression $H_2SO_4$ means there are **2** atoms of **H**, one atom of **S**, and **4** atoms of **O**

**Chemical Reaction** - Elements can combine to make compounds and represented by Chemical Equations.

**Reactants** ⟶ **Products**

**Reacting substances** — **Newly formed substances**

Example: **Table Salt - Sodium Chloride - NaCl**
Physical and chemical properties of **NaCl** is completely different from properties of individual Na and Cl elements

# Balancing Chemical Equations

**Chemical Equations** are balanced in a similar way to nuclear equations: you just have to make sure that there is the same number of **atoms of each element** on both sides.

**You balance each element separately but …**

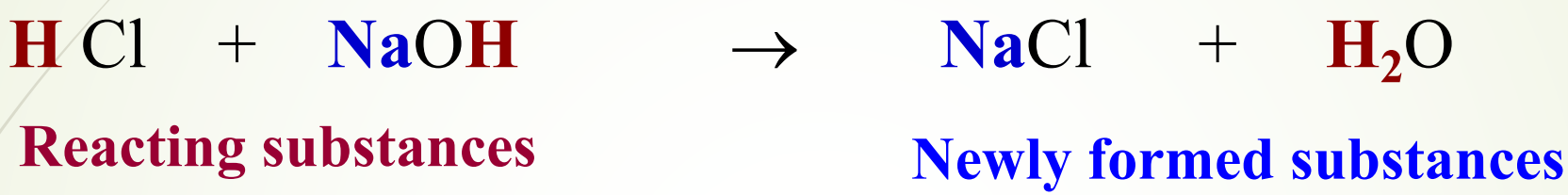
often we have molecules where one atom of one kind **must** be joined with more than one atom of the other kind. **"Make odds even"** is used to deal with this problem, which makes these problems more challenging than nuclear ones.

**You must watch for subscripts** and interpret them correctly to get your element count correct.

***Law of mass conservation in chemical reactions** - Atoms are neither destroyed nor created during chemical reaction (*reactants only rearrange to make new molecules*)

# Balancing Chemical Equations

Example:




Left side (Reactants): 2 **H**, 1 Cl, 1 **Na**, 1 O

Right side (Products): 2 **H**, 1 Cl, 1 **Na**, 1 O

This is a balanced chemical reaction equation!

Remember that the subscript 2 in $H_2O$ means there are two H atoms in this molecule.

# Balancing Chemical Equations

Example:

$H_2(g) + O_2(g) \longrightarrow H_2O\ (g)$ **Not balanced**

**Reactants: 2 H and 2O atoms** **Products: 2 H and 1 O atoms**

$2H_2(g) + 1O_2(g) \longrightarrow 2H_2O\ (g)$ **Balanced**

**Reactants: 4 H and 2O atoms** **Products: 4 H and 2 O atoms**

$NO(g) \longrightarrow N_2O\ (g) + NO_2\ (g)$ **Not balanced**

**Reactants: 1N and 1O atoms** **Products: 3 N and 3 O atoms**

$3\ NO(g) \longrightarrow N_2O\ (g) + NO_2\ (g)$ **Balanced**

**Reactants: 3N and 3O atoms** **Products: 3 N and 3 O atoms**

# Balancing Chemical Equations

Practice:

a) ____$C_2H_2$ + ____$O_2$ ⟶ ____$CO_2$ + ____$H_2O$

b) Balance this equation and determine how many molecules of $H_2$ are formed if 16 molecules of HCl are reacted.

____ Mg + ____ H Cl → ____ $MgCl_2$ + ____ $H_2$

# Balancing Chemical Equations

Practice:

a) $\_\_5\_\_ C_2H_2 + \_\_5\_\_ O_2 \longrightarrow \_\_4\_\_ CO_2 + \_\_2\_\_ H_2O$

**Reactants: 10 H, 10 C and 10 O atoms**

**Products: 10 H, 10 C and 10O atoms**

b) Balance this equation and determine how many molecules of $H_2$ are formed if 16 molecules of HCl are reacted.

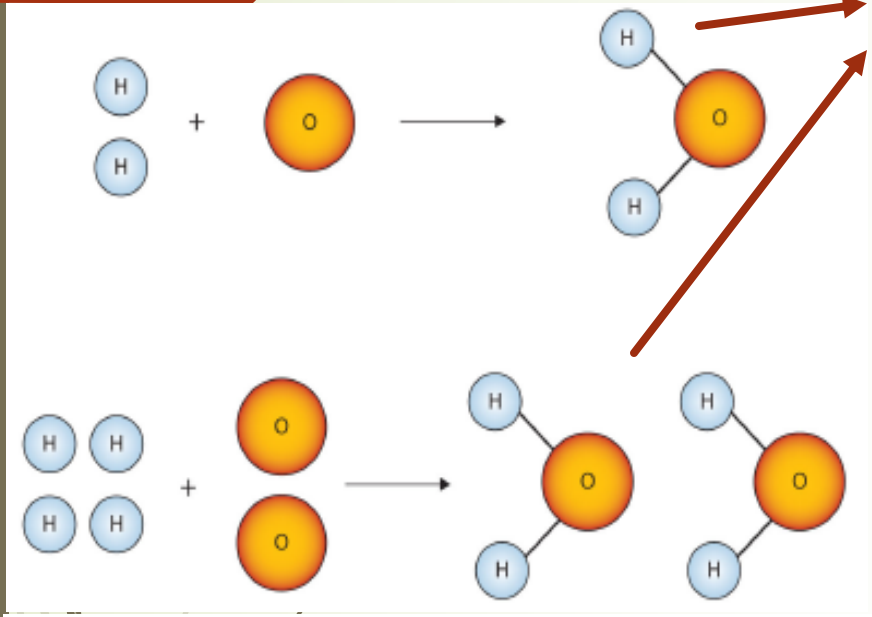
$\_\_2\_\_ Mg + \_\_4\_\_ HCl \rightarrow \_\_2\_\_ MgCl_2 + \_\_2\_\_ H_2$

**Reactants: 2 Mg, 4 Cl and 4 H atoms**

**Products: 2 Mg, 4 Cl and 4 H atoms**

4HCl: 2 $H_2$= 16 HCl: 8 $H_2$

# Quantities in Chemical Reactions



*The ratio of hydrogen atoms to oxygen atoms used to make water molecules is always 2:1, no matter how many water molecules are being made.* It is impossible to organize atoms one at a time! (***Need a new unit***)

- Chemists use a different unit for large number of atoms and molecules. A ***mole*** (mol) represents $6.022 \times 10^{23}$ things, called Avogadro's number. (*Just as a dozen implies 12 things*)
- The word ***mole*** can be used to represent *atoms or molecules*— if we have $6.022 \times 10^{23}$ O atoms, we say we have 1 mol of O atoms. While, 1 $H_2$ molecule contains 2 H atoms, therefore 1 mol of $H_2$ molecules ($6.022 \times 10^{23}$ molecules) has 2 mol of H atoms or ($2 \times 6.022 \times 10^{23}$ atoms).

| 1 Molecule of $C_2H_6O$ Has | 1 Mol of $C_2H_6O$ Has | Molecular Relationships |
|---|---|---|
| 2 C atoms | 2 mol of C atoms | $\frac{2 \text{ mol C atoms}}{1 \text{ mol } C_2H_6O \text{ molecules}}$ or $\frac{1 \text{ mol } C_2H_6O \text{ molecules}}{2 \text{ mol C atoms}}$ |
| 6 H atoms | 6 mol of H atoms | $\frac{6 \text{ mol H atoms}}{1 \text{ mol } C_2H_6O \text{ molecules}}$ or $\frac{1 \text{ mol } C_2H_6O \text{ molecules}}{6 \text{ mol H atoms}}$ |
| 1 O atom | 1 mol of O atoms | $\frac{1 \text{ mol O atoms}}{1 \text{ mol } C_2H_6O \text{ molecules}}$ or $\frac{1 \text{ mol } C_2H_6O \text{ molecules}}{1 \text{ mol O atoms}}$ |

***Using formulas to indicate how many atoms of each element we have in a substance, we can relate the number of moles of molecules to the number of moles of atoms.

# Quantities in Chemical Reactions

Example : If a sample consists of 2.5 mol of ethanol (C2H6O), how many moles of carbon atoms, hydrogen atoms, and oxygen atoms does it have?

| 1 Molecule of $C_2H_6O$ Has | 1 Mol of $C_2H_6O$ Has | Molecular Relationships |
|---|---|---|
| 2 C atoms | 2 mol of C atoms | $\frac{2\text{ mol C atoms}}{1\text{ mol }C_2H_6O\text{ molecules}}$ or $\frac{1\text{ mol }C_2H_6O\text{ molecules}}{2\text{ mol C atoms}}$ |
| 6 H atoms | 6 mol of H atoms | $\frac{6\text{ mol H atoms}}{1\text{ mol }C_2H_6O\text{ molecules}}$ or $\frac{1\text{ mol }C_2H_6O\text{ molecules}}{6\text{ mol H atoms}}$ |
| 1 O atom | 1 mol of O atoms | $\frac{1\text{ mol O atoms}}{1\text{ mol }C_2H_6O\text{ molecules}}$ or $\frac{1\text{ mol }C_2H_6O\text{ molecules}}{1\text{ mol O atoms}}$ |

Solution: We apply the appropriate conversion factor for each element:

$$2.5\text{ mol }C_2H_6O\text{ molecules} \times \frac{\mathbf{2\text{ mol C atoms}}}{1\text{ mol }C_2H_6O\text{ molecules}} = \mathbf{5\text{ mol C atoms}}$$

$$2.5\text{ mol }C_2H_6O\text{ molecules} \times \frac{6\text{ mol H atoms}}{1\text{ mol }C_2H_6O\text{ molecules}} = 15\text{ mol H atoms}$$

$$2.5\text{ mol }C_2H_6O\text{ molecules} \times \frac{1\text{ mol O atoms}}{1\text{ mol }C_2H_6O\text{ molecules}} = 2.5\text{ mol O atoms}$$

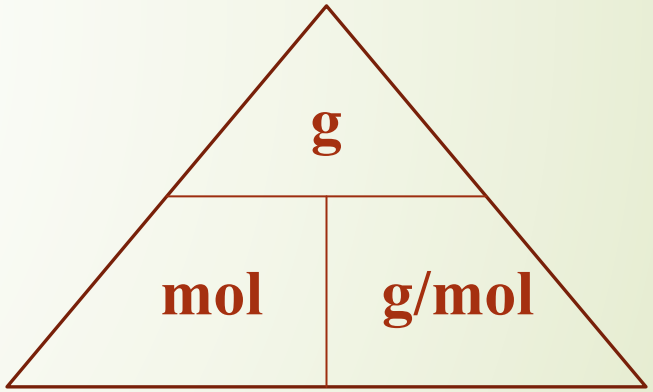
# Quantities in Chemical Reactions

- It is useful to associate atomic mass with a mass in grams. It has been found that 1.01g H, 14g N, 16 g O, 23 g Na or 35.45 g Cl have $6.02 \times 10^{23}$ atoms (1 mole).
- The mass of one mole is called "molar mass". For example: 1 mol C = 12.01 g C (atomic mass of C is 12.01!). This can also be expressed as 12.01 g/mol.

**Converting between grams and moles:**

If we are given the # of grams of a compound we can determine the # of moles, & vise-versa. In order to convert from one to the other you must first calculate molar mass

g = mol x g/mol
mol = g ÷g/mol




This can be represented in an "*equation triangle*"

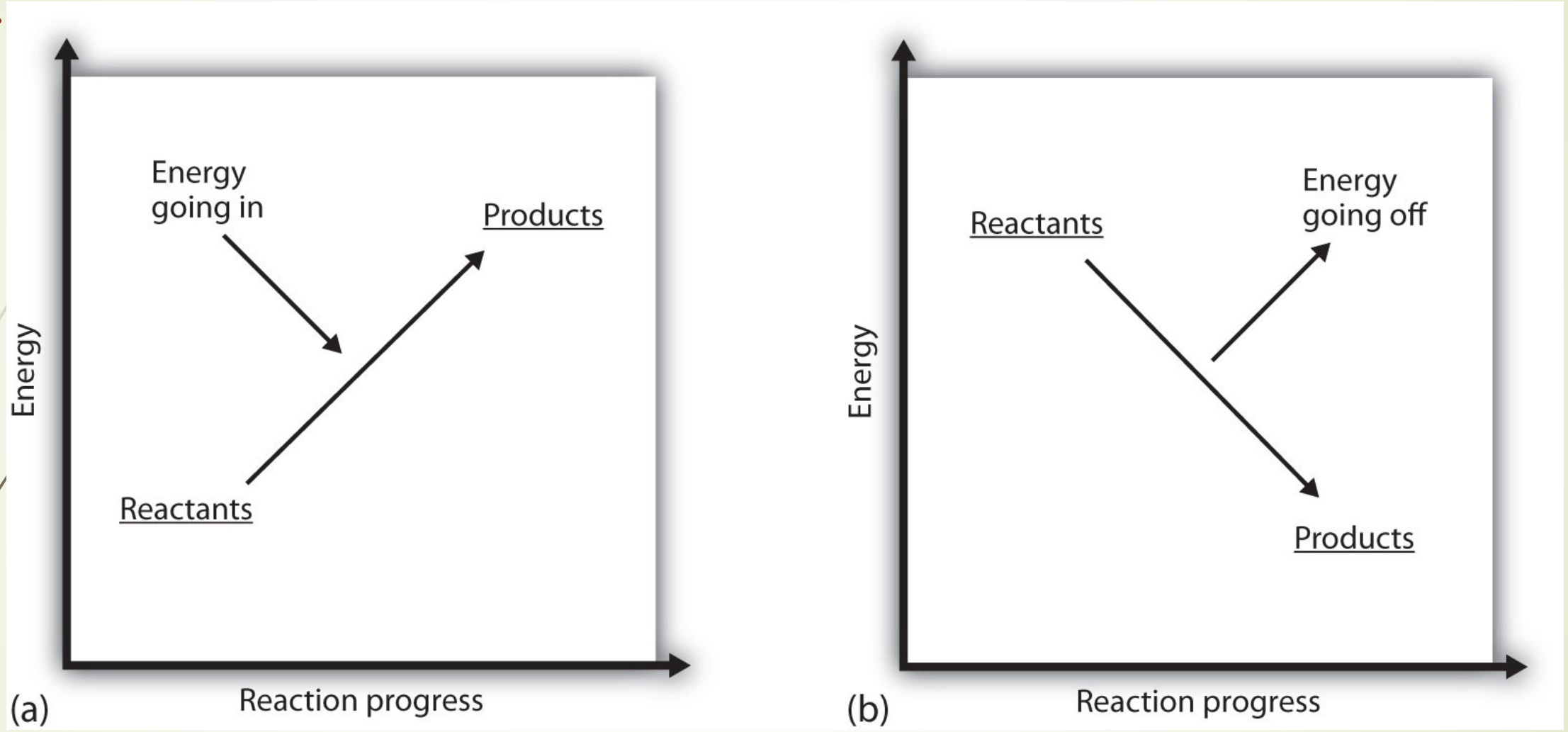
| Formula | g/ mol | g | mol |
|---|---|---|---|
| NaCl | | 58.45 | |
| HCl | | | 0.5 |
| $HNO_3$ | | 53.15 | |

# Bond Energy

- *Energy is always required to break a bond. Energy is released when a bond is made.*
- When atoms combine to make a compound, energy is always given off, and the compound has a lower overall energy.
- Bonds between certain specific elements usually have a characteristic energy, called the **bond energy**, that is needed to break the bond. The same amount of energy was liberated when the atoms made the chemical bond in the first place.
- Chemical Reactions Can Be Either ***Exothermic*** or ***Endothermic.***
- ***Exothermic*** Reaction involves ***Net Release*** of Energy. Exothermic reactions give off energy, so energy is a product and written with the products
- ***Endothermic*** Reaction involves ***Net Absorption*** of Energy. Endothermic reactions require energy, so energy is a reactant and written with the reactant.

| Bond type | Energy kJ/mol |
|---|---|
| Br–Br | 193 |
| C–Br | 288 |
| C–C | 348 |
| C=C | 614 |
| C≡C | 839 |
| C–Cl | 330 |
| C–F | 488 |
| C–H | 413 |
| C–I | 216 |
| C–N | 308 |
| C–O | 360 |
| C=O | 799 |
| C–S | 272 |
| Cl–Cl | 243 |
| F–F | 158 |
| H–Br | 366 |
| H–Cl | 432 |
| H–F | 568 |
| H–H | 436 |
| H–I | 298 |
| H–N | 391 |
| H–O | 459 |

# *Exothermic vs. Endothermic Reaction*




*(a) In an endothermic reaction, the energy of the system increases (i.e., moves higher on the vertical scale of energy). (b) In an exothermic reaction, the energy of the system decreases (i.e., moves lower on the vertical scale of energy).*

# Energy in Chemical Reactions

Example: Let's examine the electrolysis of water. The general reaction is

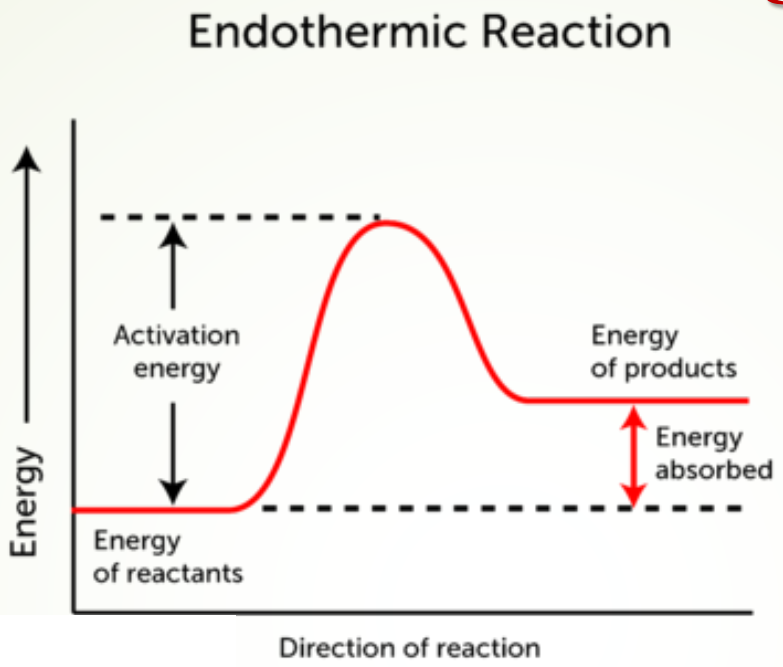
$2H_2O \rightarrow 2H_2 + O_2$ or H–O–H H–O–H → H–H H–H + O=O

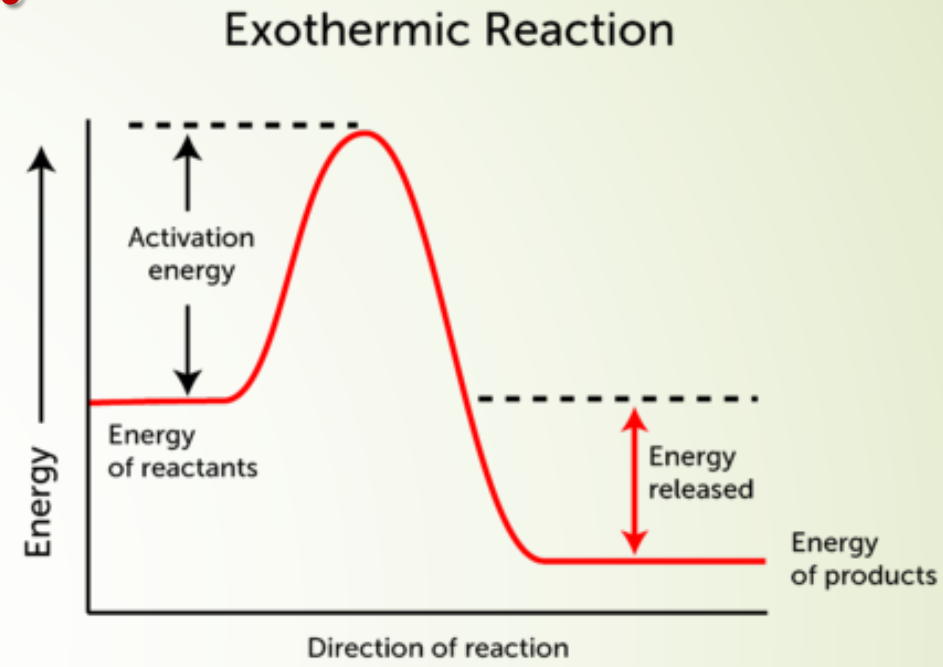
The overall heat of reaction can be calculated as follows:

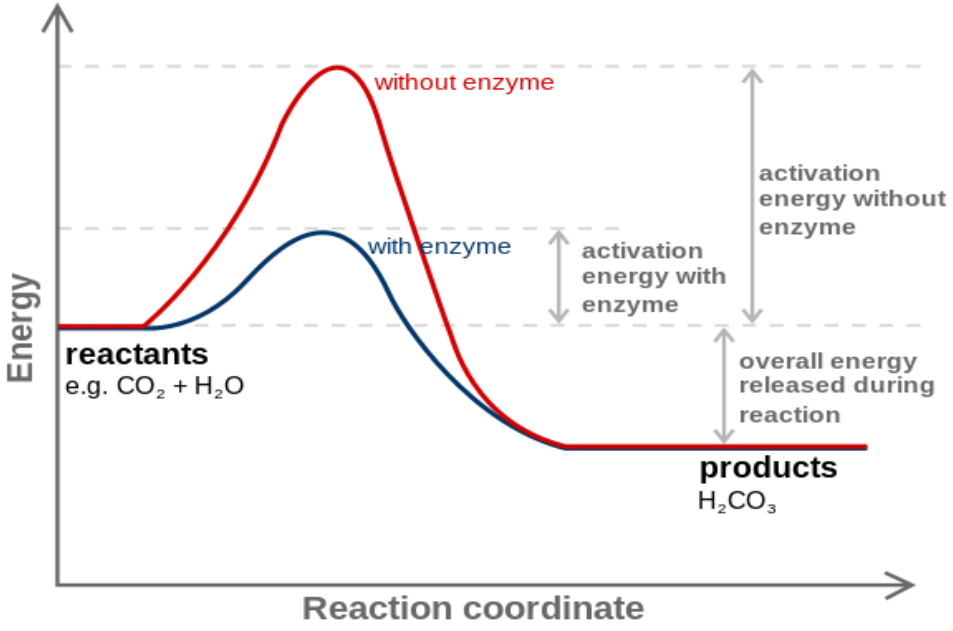
| Bond | Bond energy (kJ/mol) | Number of bonds broken | Energy required (kJ) | Number of bonds formed | Energy Released (kJ) |
|---|---|---|---|---|---|
| H–O | 459 | 4 | 1836 | | |
| H–H | 436 | | | 2 | 872 |
| O=O | 498 | | | 1 | 498 |
| | | Sum | 1836 | | 1370 |
| | | Result | 466 | | |

Thus, this is an ***Endothermic*** reaction (energy required) that absorbs 466 kJ.
The thermochemical equation is $2H_2O + 466kJ \rightarrow 2H_2 + O_2$

# Activation Energy




- Energy Needed for Reactants to React is termed the ***Activation Energy.***
- Catalysts Speed Up Reaction By Reducing Activation Energy.
- If the activation energy is lower, reaction can occur at lower temperature.

Examples of catalysts:

- ❑ Catalytic converter – car
- ❑ Enzymes in body
- ❑ Ozone breakdown by CFC's in freon.

# Acids and Bases

**Acids** are proton ($H^+$) donors and **bases** are proton acceptors.

**Example:**

$$\mathbf{HCN} + \mathbf{H_2O} \Leftrightarrow \mathbf{H_3O^+} + \mathbf{CN^-}$$

acid base $\rightarrow$

$\leftarrow$ (acid) (base)

We say that **HCN** is an acid because **an $H^+$ ion leaves it** to join **$H_2O$** to make **$H_3O^+$**.

# Acids and Bases

**Acids** are proton ($H^+$) donors and **bases** are proton acceptors.

**Example:**

$$\mathbf{HCO_3^-} + \mathbf{H_2O} \Leftrightarrow \mathbf{H_2CO_3} + \mathbf{OH^-}$$

base acid → (acid) (base)

←

Here **the proton left $H_2O$** to form $H_2CO_3$ , so water acts like an acid. Interesting!

***Water can be either an acid or a base depending on its function in the reaction!!*

# Acids and Bases

**Acids** are proton ($H^+$) donors and **bases** are proton acceptors.

**Practice:** (Identify the acids and bases)

a) $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+$

b) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

# Acids and Bases

**Acids** are proton ($H^+$) donors and **bases** are proton acceptors.

**Practice:** (Identify the acids and bases)

a) $H_3PO_4$ + $H_2O$ $\Leftrightarrow$ $H_2PO_4^-$ + $H_3O^+$

acid base $\rightarrow$

$\leftarrow$ (base) (acid)

b) $NH_3$ + $H_2O$ $\Leftrightarrow$ $NH_4^+$ + $OH^-$

base acid $\rightarrow$

$\leftarrow$ (acid) (base)

# Acids and Bases

**Did you notice a pattern?**

- Acids release $H^+$ ions in aqueous solution.
- **H is written first** in formula. (Example: HCl)

- Bases release $OH^-$ ions in aqueous solution.
- **OH is written last**, following metal ion. (NaOH)

***Which are acids and which bases?***

$H_2SO_4$ LiOH KOH $HCHO_2$

# Acids and Bases

## Neutralization Reactions

When acids and bases react and water is formed plus a salt.

($H^+ + OH^- \rightarrow H_2O$)

**Example:**

$$HCl + NaOH \rightarrow H_2O + NaCl$$

**acid** + **base** → water + **salt**

***Complete this reaction*:**

$$HBr + KOH \rightarrow$$

# pH Scale

pH Scale: This scale is used to compare how strong an acid or base is.