Chemical Principles

1. Fundamentals

VC210 CHEMISTRY

Prof. Huai Sun, Chemistry Building A, Room 521 Email: huaisun@sjtu.edu.cn

Prof. Shou-Hang Bo, JI Building, Room 534 Email: shouhang.bo@sjtu.edu.cn

Office hours: Wed. 15:00PM - 17:00PM.

Teaching Assistants

TA Name Pinyin	TA name Chinese	Student ID	TA's email	Recitation Sched.	Office Hour
Wang Yisen	王屹森	517370910202	stevewang1022@sjtu.edu.cn	Tue. 18:20~20:20	Tue. 20:20~21:20
Huang Ziyuan	黄梓渊	517370910250	huangziyuan2017@sjtu.edu.cn	Mon. 18:20~20:20	Mon. 20:20~21:20
Zhao Yiqing	赵漪青	517370910190	cissy1999@sjtu.edu.cn	Thu. 18:20~20:20	Thu. 20:20~21:20
Han Xu	韩旭	517021911111	HanXu2017@sjtu.edu.cn	Wed. 18:20~20:20	Wed. 20:20~21:20

Homework (online)	**20%**
Quizzes (two)	**30%**
Final Exam	**50%**
Total Maximum	**100%**

Scores are recorded relatively, will be curved.

What is Chemical Principles

Qualitative Physical Chemistry, understand macroscopic phenomenon from microscopic level of understanding

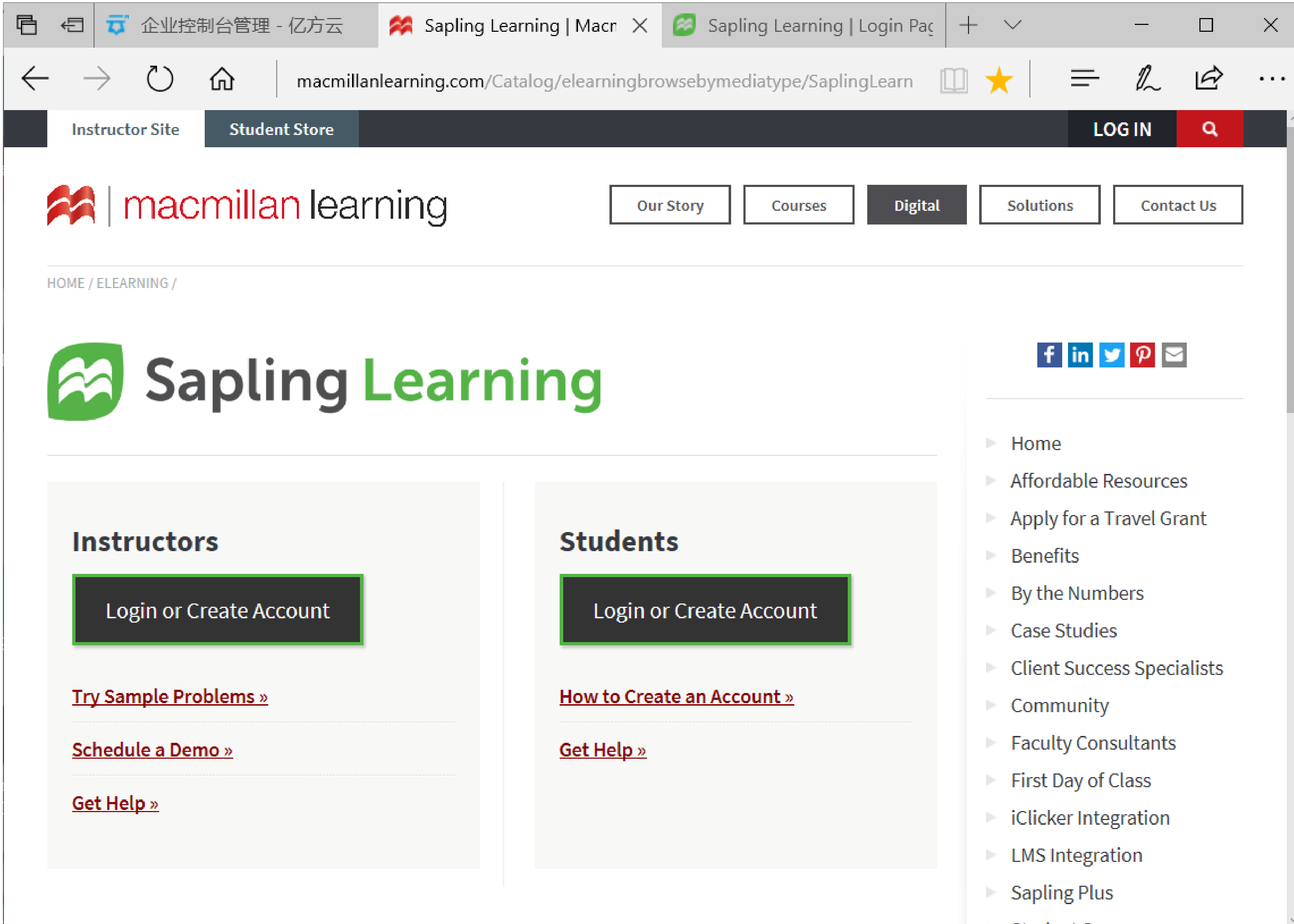
- Quantum theory, electrons, chemical bonds, and theories for molecular structures
- Condensed matters, states, state functions, phase changes, theories and thermodynamics first and second laws
- Equilibria - Physical and Chemical, direction of the process
- Kinetics – how fast is the process.

How to Study Chemical Principles

- Read smartly. Read topic sentence and closing statement, read the summery and key points. Improve your reading skill gradually.

- Do not be disguised by the simplicity. Always go further, try to answer why, not just what.

- Do the homework on Sapling Learning, pay attention to the deadline, it will not be grated after the deadline!


企业控制台管理 - 亿方云
Sapling Learning | Macr
Sapling Learning | Login Pac
macmillanlearning.com/Catalog/elearningbrowsebymediatype/SaplingLearn
Instructor Site
Student Store
LOG IN
macmillan learning
Our Story
Courses
Digital
Solutions
Contact Us
HOME / ELEARNING /
Sapling Learning
Instructors
Login or Create Account
Try Sample Problems »
Schedule a Demo »
Get Help »
Students
Login or Create Account
How to Create an Account »
Get Help »
Home
Affordable Resources
Apply for a Travel Grant
Benefits
By the Numbers
Case Studies
Client Success Specialists
Community
Faculty Consultants
First Day of Class
iClicker Integration
LMS Integration
Sapling Plus

Branches of Chemistry

- **Organic**: carbon compounds
- **Inorganic**: everything but carbon compounds
- **Physical**: theory and principles
- Newer
  - **Biochemistry**
  - **Analytical**: techniques, devices
  - **Computational**
  - **Medical**
  - **Chemical Engineering**: production

Measurements

Common Unit

Quant.	Unit	Abbre.	SI equiv.
Mass	Pound	lb	0.453 kg
	Tonne	T	10^3 kg
Length	Inch	in.	2.54 cm
Volume	Quart	qt	0.946 L
Time	Minute	min	60 s
Temperature Kelvin K or Celsius °C			

Since Kelvin is the absolute scale it has no “°” symbol.

Common SI prefixes

SI System, you'll find them in the back binder

	For Example	
Mega	M = 10^{6}	1 **Mega**watt (wind turbine)
kilo	k = 10^{3}	**kilo**meter (distance)
deci	d = 10^{-1}	
centi	c = 10^{-2}	
milli	m = 10^{-3}	**milli**liter, syringes
micro	μ = 10^{-6}	**micro**meter, cell diameter
nano	n = 10^{-9}	**nano**meter, Chemical bond
pico	p = 10^{-12}	**pico**meter, atom diameter

What are **Important Figures**

Science is collecting data and reporting our results.

We have to **justify** our data by reporting the **correct number of digits from our measurements**.

We only write the **correct number** of digits in our reports, these are called **significant figures**.

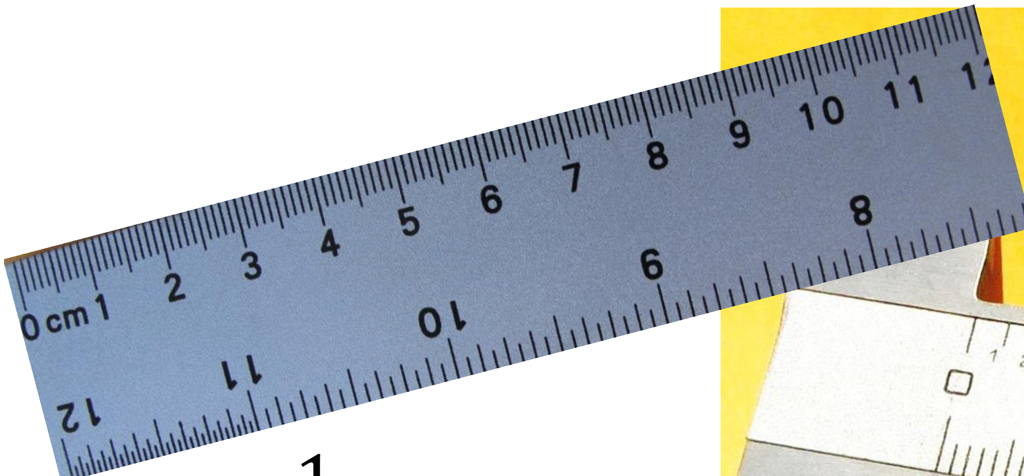
The number of significant figures in our calculations **cannot exceed** our data measurements.

You can't generate data from a calculator!

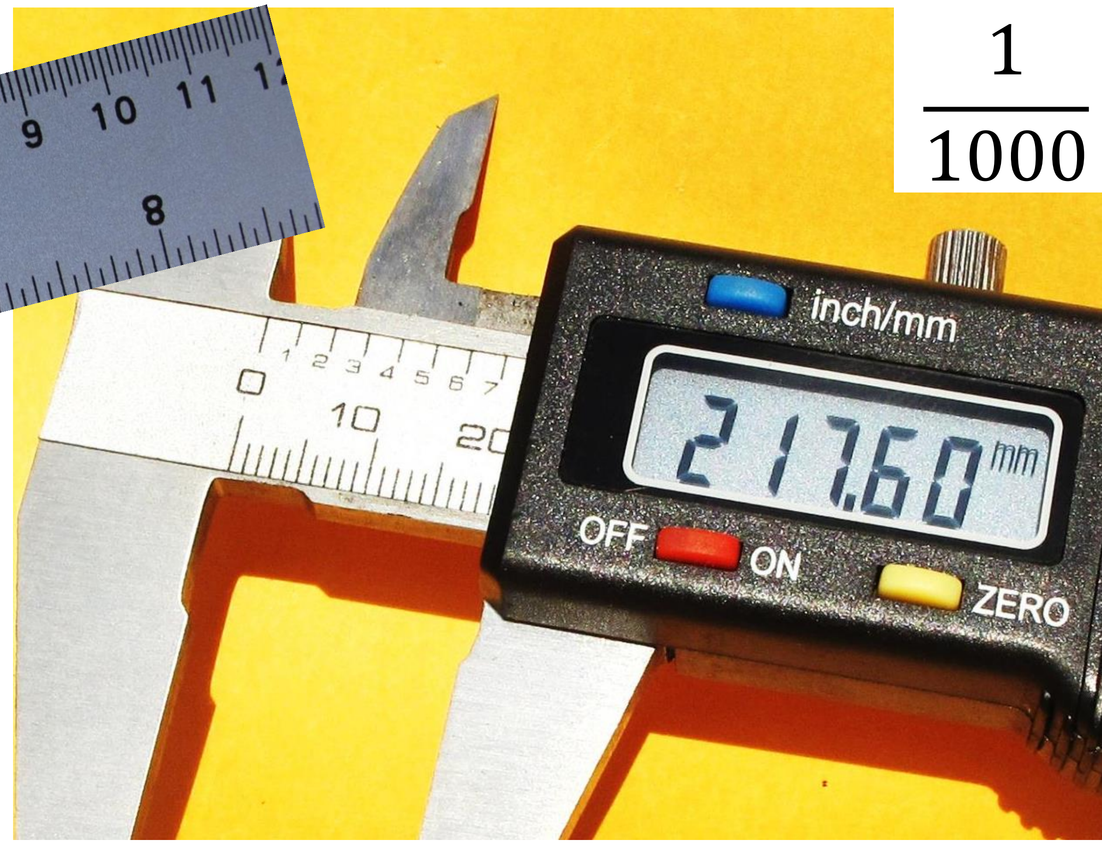
Measurements: **Measured**

Measured number come from measuring tools.

The problem is **measuring tools** are **not exact** ; accuracy is determined by the manufacture.



$$\frac{1}{100}$$



$$\frac{1}{1000}$$

Recording Measurements

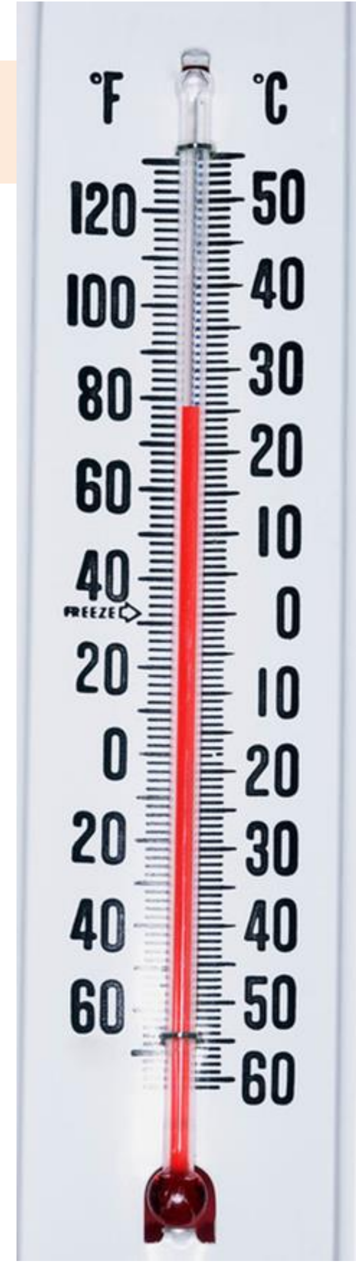
When using a measuring tool

1. Write all the digits you see
2. Make one guess
3. Add units

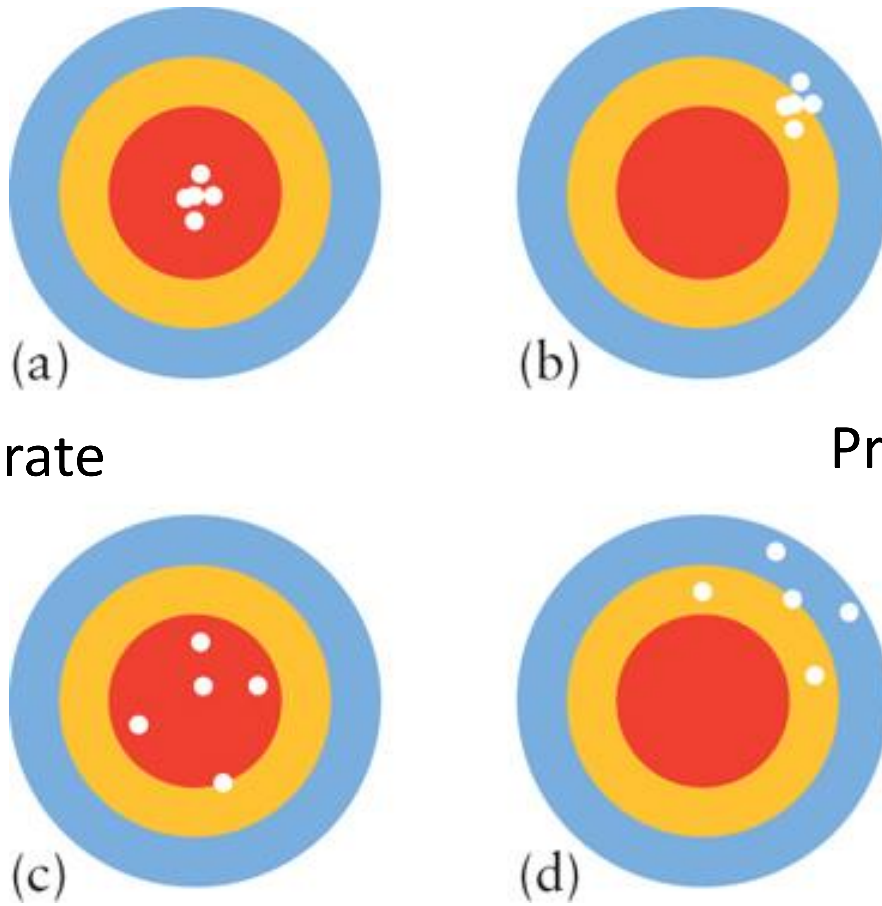
25

25.7

25.7 ℃



Precision and Accuracy



Precise & Accurate

Precise not accurate

Accurate

Neither precise nor accurate

Two Notations

Numbers in our data are written in either

1. Ordinary notation
2. Scientific notation

A big advantage of **scientific notation** is it's easier to write both **big** and **small** numbers.

Ordinary notation	Scientific notation
36,000,000	3.6×10^7

Significant Figure (SF)

The number of digits are called significant figures (SF).

9547 cm (4 SF)

4.29 g (3 SF)

Different kinds of Zero's

Captive: 807 (3 SF) all the zero's count

Trailing: 600. (3 SF) decimals make zero's SF

600 (1 SF) without decimals zero's are not SF

Decimal Point:

Trailing zeros: 12.000 (5 SF) because it is measured.

Leading: 0.00010 (2 SF) leading zero's are not SF.

Significant Figure (SF)

How many SF in the following

725	3 SF
6001	4 SF
9010	3 SF no decimal
9010.	4 SF decimal
0.00680	3 SF leading no, trailing yes
1 ft = 12 in	∞, it's a definition

Significant Figure (SF)

Addition or subtraction, keep the smallest last decimal place:

725.001+ 10.23 = 735.23

Multiplication or division, keep the smallest SF

8.89 / 3.0 = 3.3 (not 3.2966666)

Matter and Energy

All objects **move**, except at the hypothetical temperature zero Kelvin.

A common **energy** formula: $E_k = \frac{mv^2}{2}$ shows the relationship between **energy**, **mass** and **speed**.

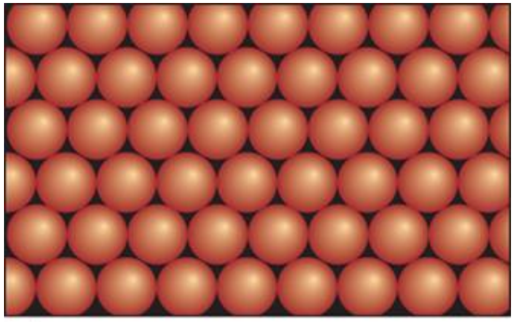
We see in many energy equations the **mass** and **motion** relationship.

Matter and Energy

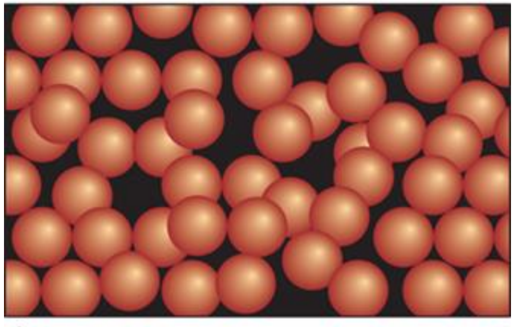
Matter has mass and volume.

3-states of matter

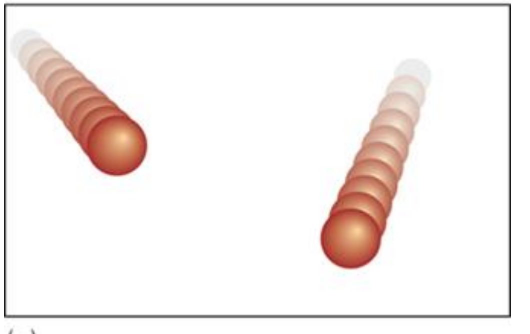
a) **Solids**
b) **Liquids**
c) **Gases**



(a)



(b)



(c)

Atoms begin to oscillate faster as temperature is increased.

What's the difference between these three states**?**

Energy

Kinetic is the energy that a body possesses due to motion.

$$E_K = \frac{1}{2}mv^2$$

Potential is the energy that a body possesses due to its position in a field of force. $E_P = mgh$

Electromagnetic is the energy due to attractions and repulsions between electric charges.

$$E_P = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

m = mass
v = velocity
g = gravitational force
h = height
q = charge

Energy

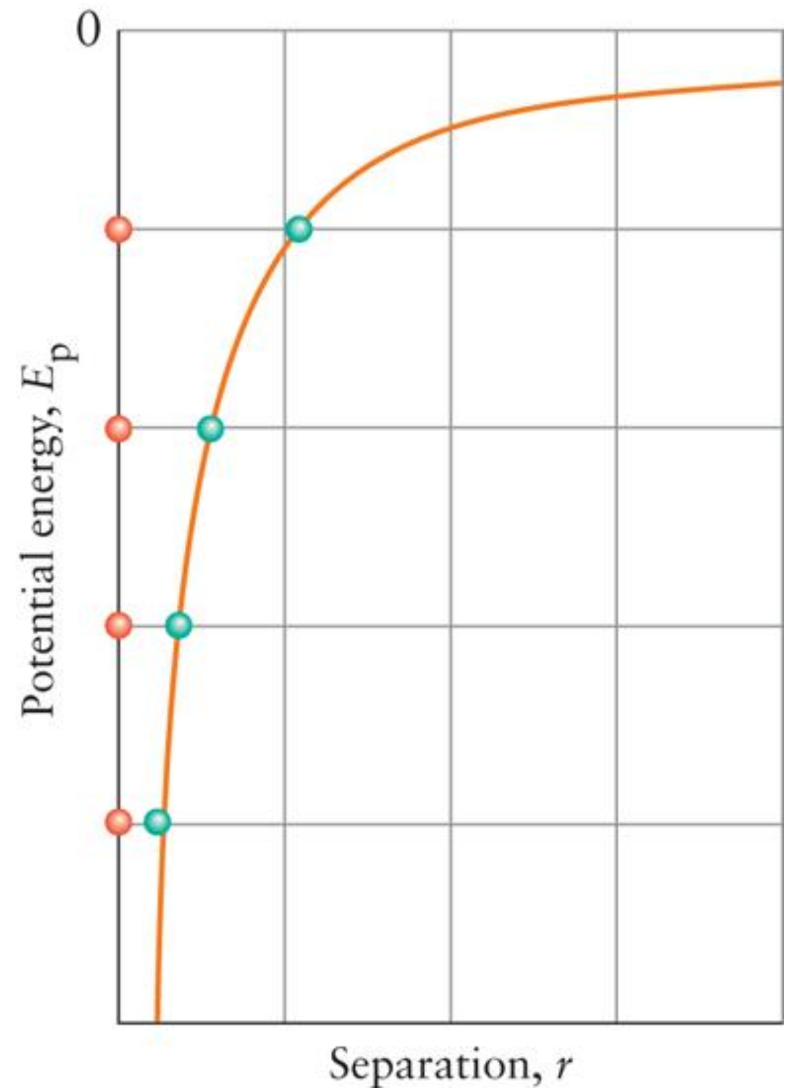
Electromagnetic is the attractive and repulsive energy between electric charges

The **energy of electric charges**

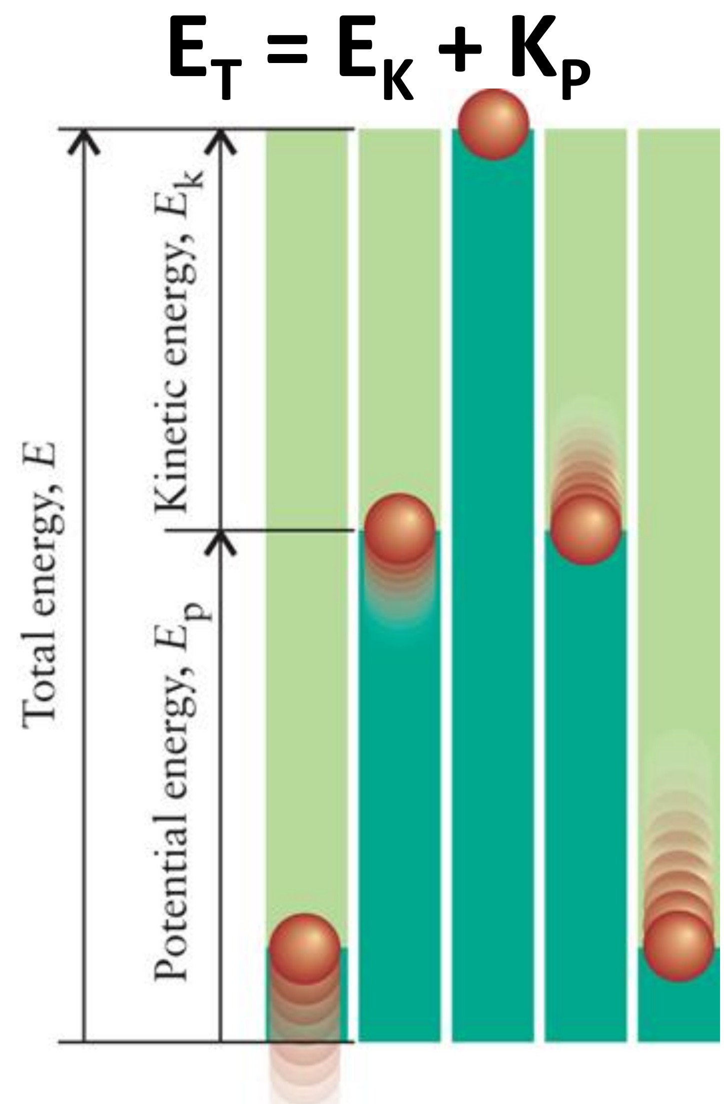
nuclei and electrons are charged.

Coulomb potential energy of two opposite charges (one red the other green)

$$E_P = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$



Total Energy = $E_K + E_P$

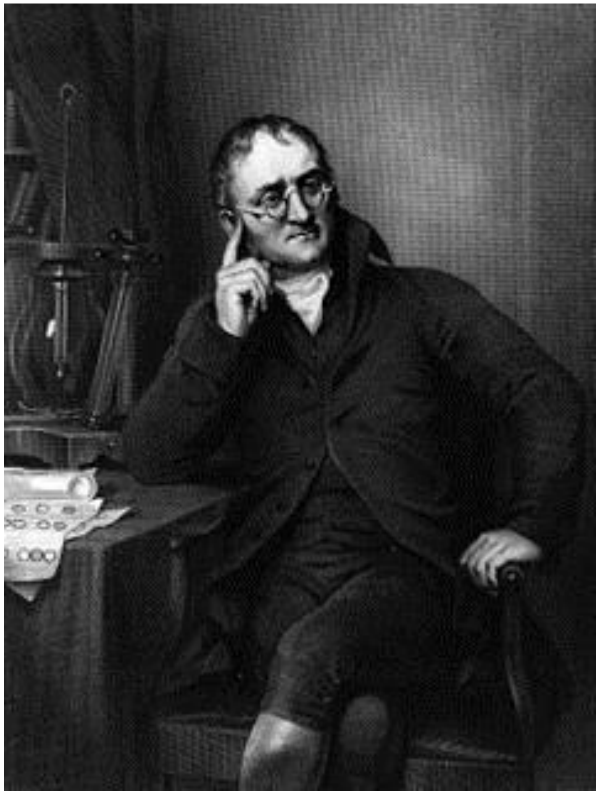


A ball thrown up has high KE and **zero** PE. At the top of its flight, it has **zero** KE and high PE. On the return, its KE rises and its PE approaches **zero** again.

On impact its energy is dissipated as **thermal** motion, the chaotic, random motion of atoms and molecules.

Totaling KE and PE of Earth and the ball are the same; **Law of conservation of energy**, is energy can be neither created nor destroyed.

Elements and Atoms



Dalton

1. Atoms of the same element are identical.
2. Compounds are combinations of atoms.
3. In chemical reactions, atoms are neither created nor destroyed.
4. Chemical reactions exchange atom partners.

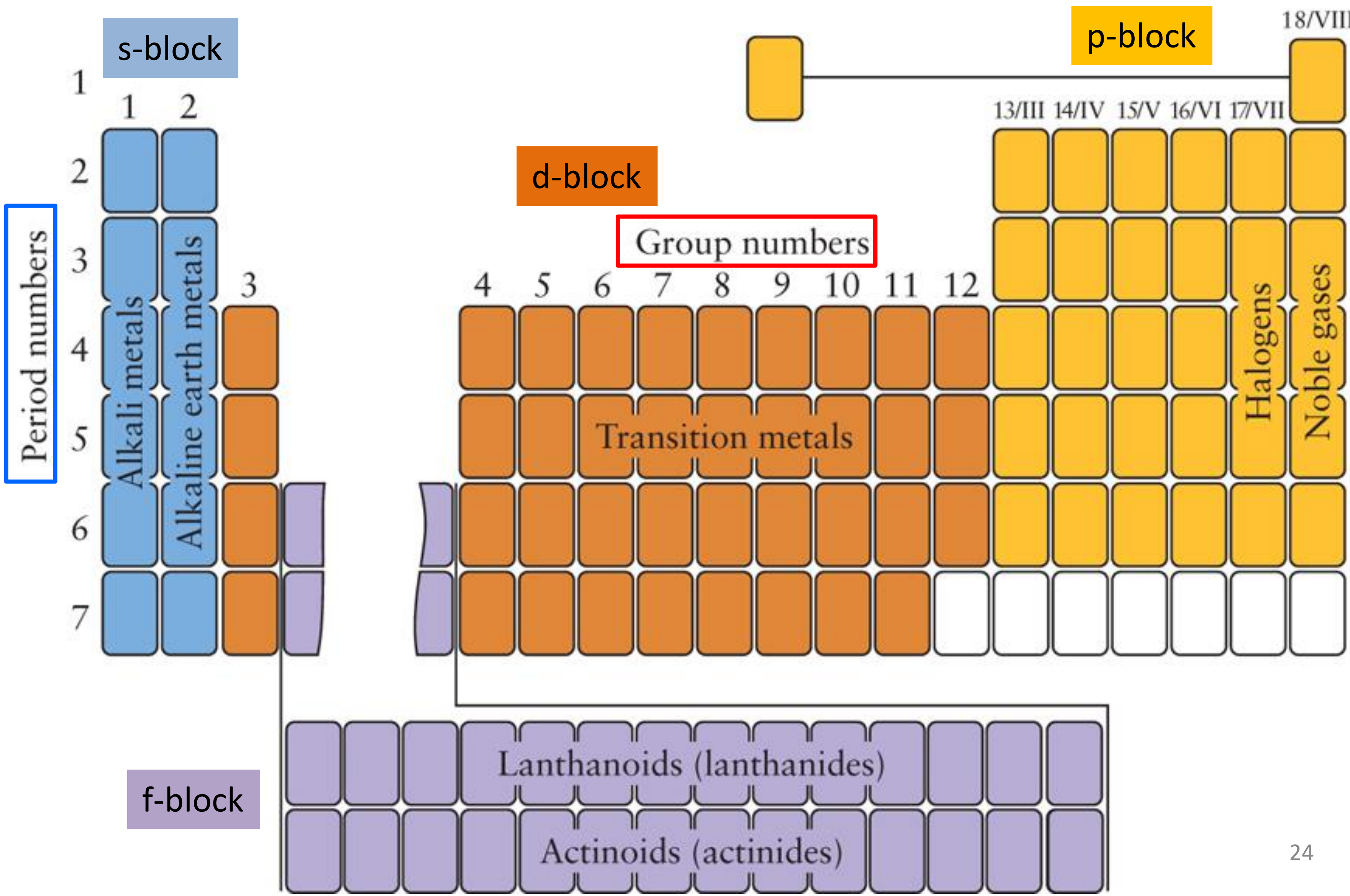
Nuclear Model: Isotopes

Isotopes of an element have the **same atomic number** but **different mass numbers**. Their nuclei have the same number of protons but different numbers of neutrons.

Element	Symbol	Atomic number, Z	Mass number, A	Abundance, %
hydrogen	^{1}H	1	1	99.985
deuterium	^{2}H or D	1	2	0.015
tritium	^{3}H or T	1	3	—*
carbon-12	^{12}C	6	12	98.90
carbon-13	^{13}C	6	13	1.10
oxygen-16	^{16}O	8	16	99.76

- Every element has an isotope. There are close to 2000 known isotopes of all 118 elements.
- The **chemical properties** of all the atom's isotopes are the same.

Groups are the vertical columns, numbered 1 through 18.
Periods are the horizontal rows, numbered 1 through 7.



Compounds

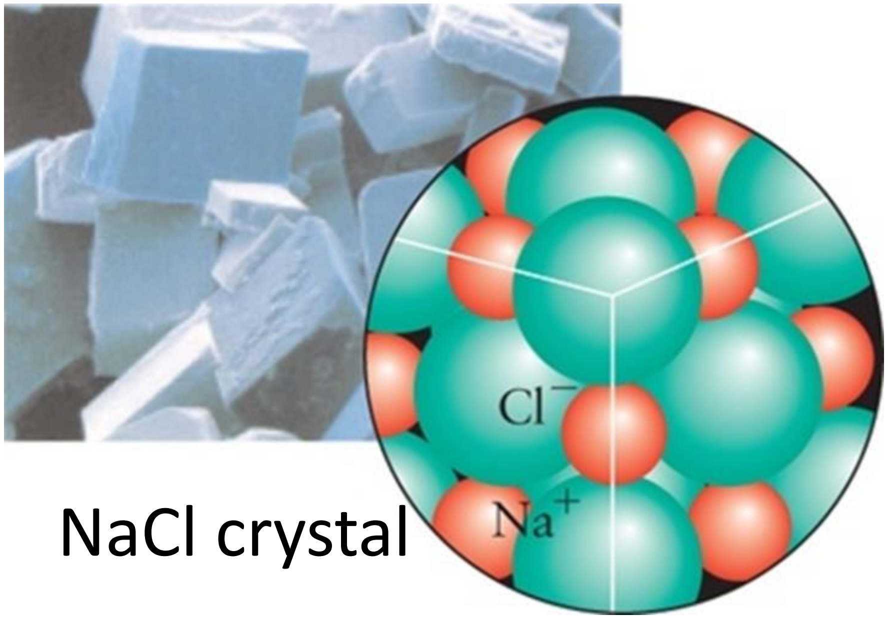
Compound are **electrically neutral** consisting of two or more different elements.

Compounds are classified as either ***organic*** or ***inorganic***.

Organic compounds contain **carbon** and usually hydrogen. There are millions of organic compounds, including fuels, sugars, and most medicines.

Inorganic compounds are <u>all the other compounds</u>; they include water, calcium, ammonia, silica, hydrochloric acid, and many more.

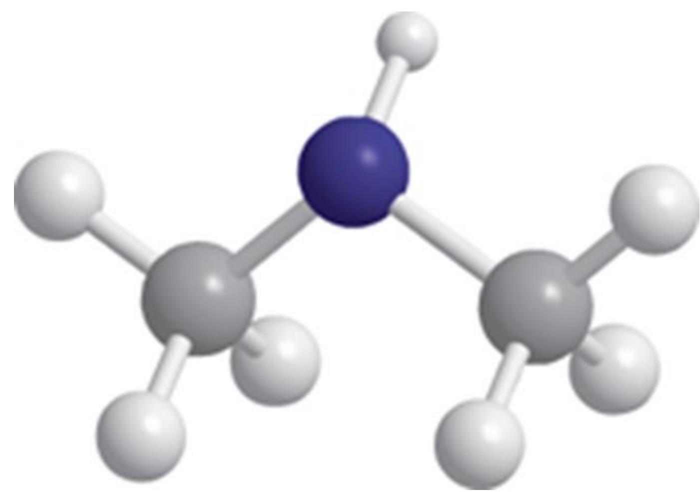
The forces holding ions or molecules.



NaCl crystal

Ions are positively and negatively charged atoms. These are ***not*** discrete ions, instead a vast sea of charges holds the ions together in a crystal.

Dimethylamine



Molecules are discrete groups of atoms bond by strong forces, pairs of electrons, making neutral bonds.

Positively charged ions are called **cations**, and a negatively charged ions are called **anions**.

cation

Na^{+} sodium cation

Ca^{2+} calcium cation

An example of a "polyatomic" (many-atom) cation is the *ammonium ion*, NH_4^+

anion

A negatively charged chlorine atom is an anion and is denoted **Cl^{-}**. An example of a polyatomic anion is the *carbonate ion*, CO_3^{2-}

Classifying compounds by the kind of element

Two **nonmetals** are **molecular**: Water (H_2O) is an example of a binary molecular compound

nonmetal-nonmetal

A **metal** and a **nonmetal** are **ionic**: sodium chloride (NaCl) is an example of an ionic compound.

cation	**anion**

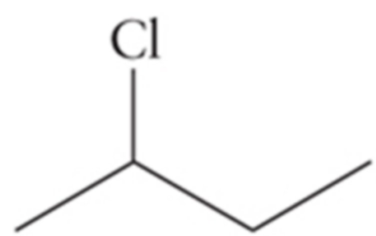
Organic chemists draw complex structures in a simple way.

Carbon typically forms four bonds, so there is no need to show the C-H explicitly; shown is 2-chlorobutane.

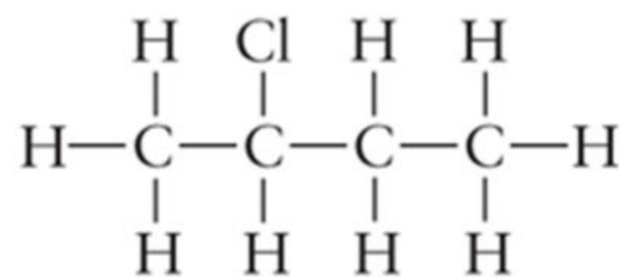
A **line structure** represents a chain of carbon atoms. Atoms other than C and H are shown by their symbols.

$CH_3CHClCH_2CH_3$

condensed formula



line structure

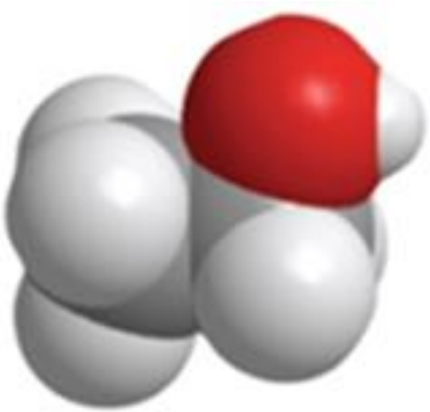


structural formula

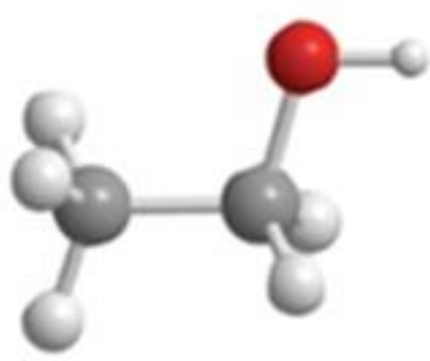
Ways a chemist can represent <u>ethanol</u>, C_2H_6O

CH_3CH_2OH

A **space-filling** model



A **ball-and-stick**

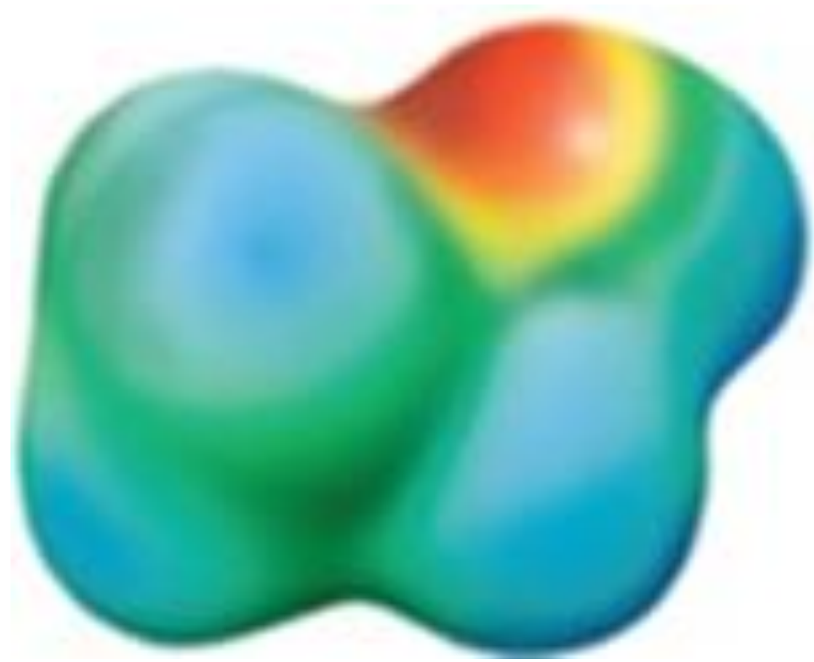


A **tube** structure

Electrostatic potential surface (elpot) show electric charge distribution.

A **red tint** indicates a negative potential due to the negatively charged electrons.

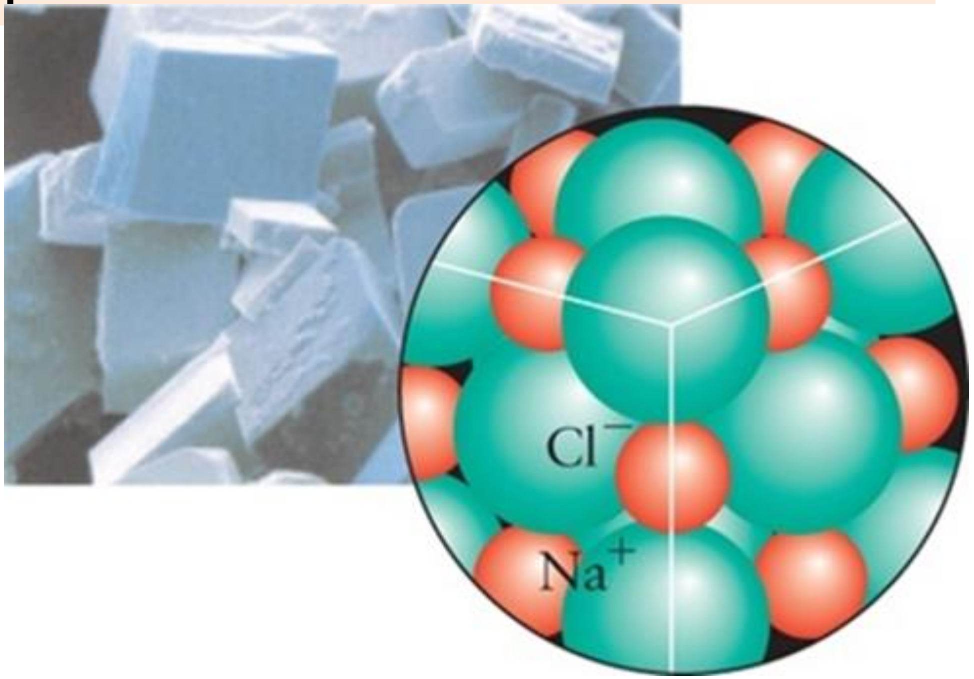
CH_3CH_2OH



A **blue tint** indicates a positive potential due to a positively charged nuclei .

Formulas for **ionic** compounds have a ***different meaning*** from those of **molecular** compounds.

Ionic compounds form into crystals due to the vast sea of charges between anions and cations.



Formal units are discrete, electrically neutral, units in a crystal. NaCl is the formula for the crystal containing one Na^+ ion for each Cl^- ion.

The crystal for the binary compound, $CaCl_2$, is formed from Ca^{2+} and Cl^- ions in the ratio 1:2.

Nomenclature of Compounds

Many compounds have **informal** or common names before their compositions were known, including water, salt, sugar, ammonia, and quartz.

A **systematic** name reveals each element present and, often the arrangement of atoms.

The systemic naming of compounds, which is called chemical nomenclature, follows the simple rules described in this section.

Names of Cations

Na^+ is a monatomic cation so it's name is "sodium ion."

However, copper exists as Cu^+ and Cu^{2+} having more than one oxidation number. The charge is written as a **roman numeral** in parentheses.

Cu^+ is a copper (I) ion
Cu^{2+} is a copper(II) ion
Fe^{2+} is an iron(II) ion
Fe^{3+} is an iron (III) ion.

Names of Anions

Monatomic anions, such as the Cl^- ions in sodium chloride and the O^{2-} ions are named by adding the suffix "-ide".

C carbon → C^{4-} carbide

Br bromine → Br^- bromide

Anions with oxygen

If only ***single* oxoanion** exists for an element the suffix **-ate** is added to the stem: carbon**ate** ion, CO_3^{2-}.

Ions (cation or anion) with a **larger** number of oxygen atoms gets **-ate**, and the **smaller** is given **-ite**.

NO_2^-	and	NO_3^-
nitrite		nitrate

AsO_3^{3-}	and	AsO_4^{3-}
arsenite		arsenate

Anions with oxygen and halogens

Some elements, particularly the halogens, form **more than two** kinds of oxoanions, then use prefix:

The **greatest** number of oxygen atoms has a **per-** prefix and **-ate** ending

The **least** number of oxygen atoms has a **hypo-** prefix and **-ite** ending

perchlorate ion	ClO_4^-	perfluorate ion	FO_4^-
chlorate ion	ClO_3^-	chlorate ion	ClO_3^-
chlorite ion	ClO_2^-	bromite ion	BrO_2^-
hypochlorite ion	ClO^-	hypoiodite ion	IO^-

Anions with hydrogen

HS^- and HCO_3^- are anions beginning with "hydrogen“, add hydrogen:

HS^- is hydrogen sulfide ion

HCO_3^- is the hydrogen carbonate ion

If two hydrogen atoms are present in an anion, use the di- prefix

$H_2PO_4^-$ is dihydrogen phosphate

$H_2PO_3^-$ is dihydrogen phosphite.

An older system of nomenclature used the prefix bi-, as in bicarbonate ion for HCO_3^- *.*

Ionic compounds start with a metal.

Metals have varying oxidation states (OS). Metals in main groups (1, 2, 13-17) except Sn and Pb have a single OS. Metals in groups 3-12 (transition, except Zn and Ag) have multiple OS.

Metals with multiple OS are given a roman numeral in parenthesis to identify the oxidation number of the metal.

Cu^{+} is a copper (I) ion and
Cu^{2+} is a copper (II) ion and
Fe^{2+} is an iron (II) ion and
Fe^{3+} is an iron (III) ion.

Non-acid molecular compounds,

"#"nonmetal + "#"nonmetal (-ide)

Use the Greek numbering system (do not use mono in the first name)

- 1 – mono
- 2 – di
- 3 – tri
- 4 – tetra
- 5 – penta
- 6 – hexa
- 7 – hepta
- 8 – octa
- 9 – nona
- 10 – deca

BF_3	boron trifluoride
SO_3	sulfur trioxide
CO	carbon monoxide
P_2O_5	diphosphorous pentaoxide
P_4O_{10}	tetraphosphorous decaoxide
CO_2	carbon dioxide

Aqueous Acid with hydrogen

Symbols: aqueous = (aq), gas = (g), solid = (s)

-ide goes to "hydro_-ic" acid

-ate goes to "ic" acid

-ite goes to "ous" acid

Name the following:

HCl (aq)	(aq) means acid, and Cl^- is chloride,	hydrochloric acid
HCl (g)	(g) means gas, and Cl^- is	hydrogen chloride
$HClO_4$	ClO_4^- perchlorate, ate → ic ,	perchloric acid
$HBrO_3$	BrO_3^- is bromate, ate → ic ,	bromic acid
HIO_2	IO_2^- is iodite,	iodous acid
HClO	ClO^- is hypochlorite,	hypochlorous acid
H_2SO_3	SO_3^{2-} , sulfite	sulfurous acid
H_3PO_3	PO_3^{2-}, phosphite	phosphorous acid

Hydrates: with water

Greek prefix “ “hydrate

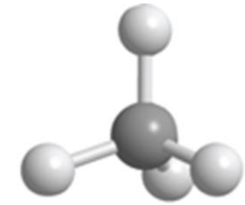
1-mono
2-di
3-tri $Ba_3(PO_3)_2 \cdot 6\ H_2O$
4-tetra Barium phosphite hexahydrate
5-penta
6-hexa $CaSO_4 \cdot 3H_2O$
7-hepta calcium sulfate trihydrate
8-octa
9-nona
10-deca

Names of Some Common Organic Compounds

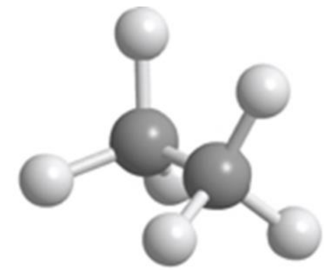
Compounds of hydrogen and carbon are called hydrocarbons. They include methane, CH_4; ethane, C_2H_6 ; and benzene, C_6H_6.

Hydrocarbons that have no carbon-carbon multiple bonds are called alkanes. Thus, methane and ethane are both alkanes.

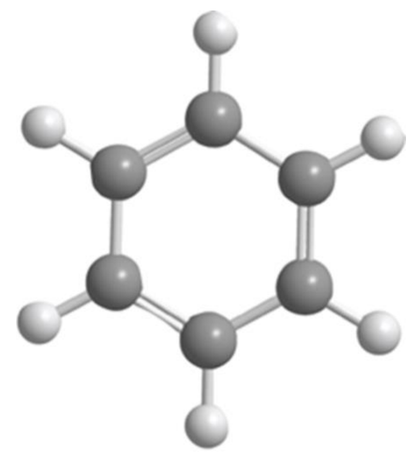
Hydrocarbons with double bonds are called alkenes. Ethene, $CH_2{=}CH_2$ is the simplest example of an alkene.



Methane, CH_4



Ethane, C_2H_6



Benzene, C_6H_6

Unbranched alkanes with up to 12 carbon atoms

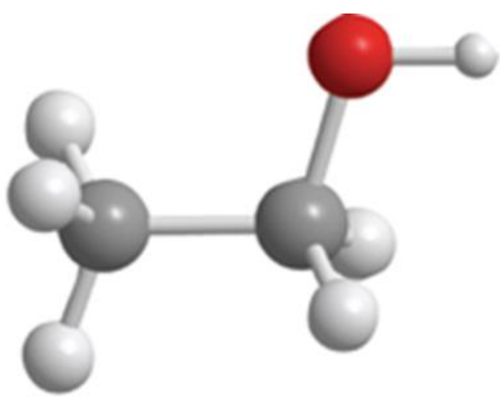
Number of carbon atoms	Formula	Name of alkane
1	CH_4	methane
2	CH_3CH_3	ethane
3	$CH_3CH_2CH_3$	propane
4	$CH_3(CH_2)_2CH_3$	butane
5	$CH_3(CH_2)_3CH_3$	pentane
6	$CH_3(CH_2)_4CH_3$	hexane
7	$CH_3(CH_2)_5CH_3$	heptane
8	$CH_3(CH_2)_6CH_3$	octane
9	$CH_3(CH_2)_7CH_3$	nonane
10	$CH_3(CH_2)_8CH_3$	decane
11	$CH_3(CH_2)_9CH_3$	undecane
12	$CH_3(CH_2)_{10}CH_3$	dodecane

Alcohols

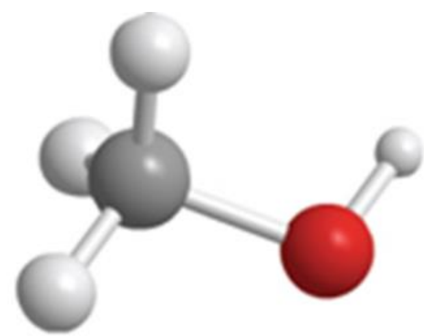
An alcohol is a type of organic compound that contains an -OH group.

Ethanol, CH_3CH_2OH, the "alcohol" of beer and wine, is an ethane molecule in which one H atom has been replaced by an -OH group.

CH_3OH is the toxic alcohol called **methanol**, or wood alcohol



Ethanol, CH_3CH_2OH

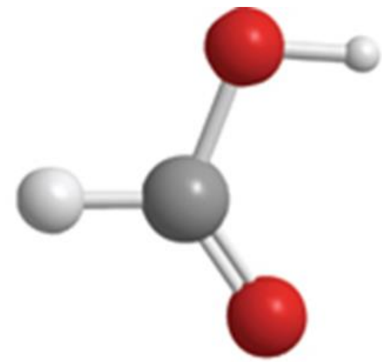


Methanol, CH_3OH

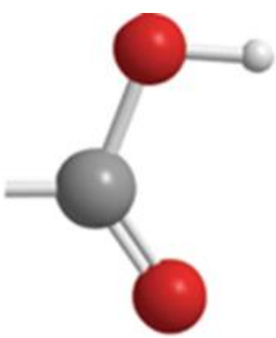
Carboxylic acid

A carboxylic acid contains the carboxyl group, -COOH. The most common example is **acetic acid**, CH_3COOH.

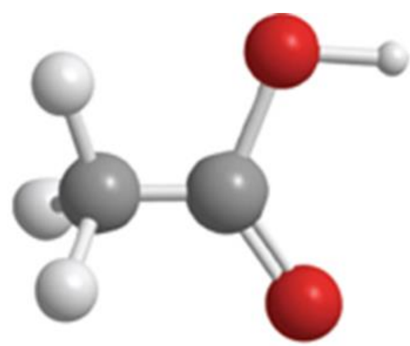
Formic acid, HCOOH, is the acid of ant venom.



Formic acid, HCOOH



Carboxyl group, —COOH

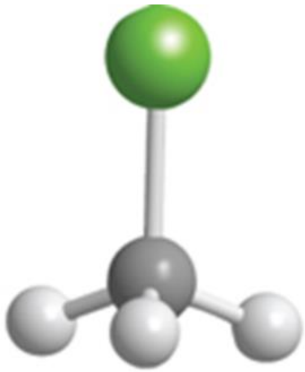


Acetic acid, CH_3COOH

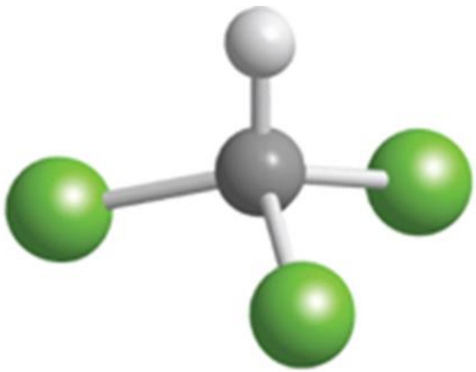
Ethanoic acid

Haloalkane

A haloalkane is an alkane in which one or more H atoms have been replaced by **halogen** atoms.



Chloromethane, CH_3Cl



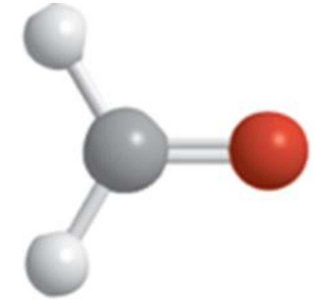
Trichloromethane, $CHCl_3$

Chemical Formulas

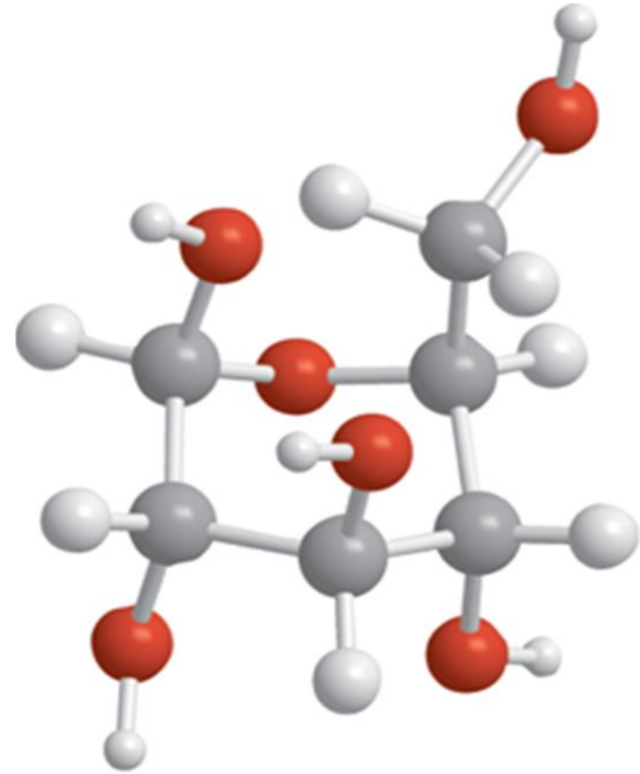
Empirical formulas tell us the ***ratio*** of atoms, for glucose, the carbon, hydrogen, and oxygen ratio is 1:2:1.

Molecular formulas are the **actual number of atoms**, for a glucose molecule it is $C_6H_{12}O_6$.

Other molecules with a 1:2:1 ratio are: formaldehyde, CH_2O (a preservative);
acetic acid, $C_2H_4O_2$ (vinegar);
lactic acid, $C_3H_6O_3$ (sour milk).

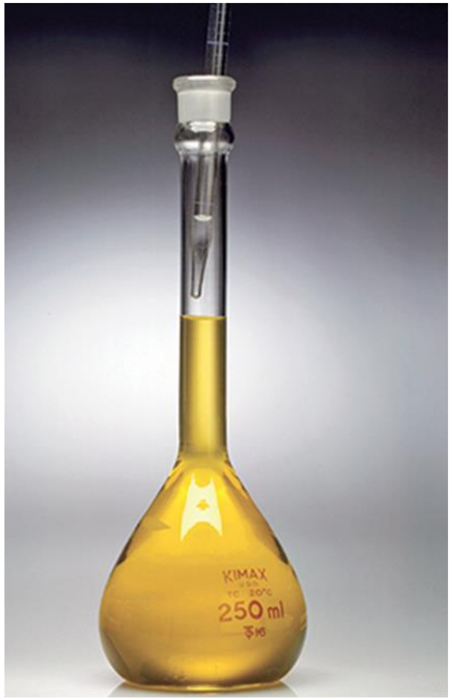


Formaldehyde, CH_2O



α-D-Glucose, $C_6H_{12}O_6$

Mixtures are made of: Solute, Solvent, & Solution



Solute: is always the **least amount**.

Solvent: is the **greater amount**.

Solution: a **combination** of solute and solvent.

This definition applies to any mixture in any physical state.

Mixtures are either heterogeneous or homogeneous.

Homogeneous: well mixed into a single phase; a microscope can not distinguish the particles:

- Syrup
- Sugar water
- Bleach
- Window cleaner
- Gasoline
- Turpentine
- Alloys

Moles and Molar Masses

How do we measure the quantity in chemistry? How many molecules, how many atoms? – the quantity is Mole.

1 mole of objects = 6.0221×10^{23} of those objects .

6.0221×10^{23} mol^{-1}, the Avogadro's constant, N_A,

Molar Mass

Molar mass of an object is the mass of one mole such object, in grams per mole ($g \cdot mol^{-1}$).

Since the number of 1 mole is fixed, then Molar Mass has the same value of Molecular Mass (in atomic unit).

- The *molar mass* of Cr is 51.9961 $g \cdot mol^{-1}$, C is 12 $g \cdot mol^{-1}$.
- The *molar mass* of a molecular compound is the mass per mole of the molecules;

  molar mass of water H_2O is 18.00 $g \cdot mol^{-1}$

  molar mass of NaCl is 58.5 $g \cdot mol^{-1}$

Molarity

The molar concentration, c, is the amount of solute in moles divided by the volume of the solution (in liters):

$$\text{Molarity} = \frac{\text{amount of solute}}{\text{volume of solution}}$$

$$c = \frac{\text{mol of solute}}{\text{Liters of solution}}$$

Often denoted as M: $1\ \text{M} = 1\ \text{mol}\cdot\text{L}^{-1}$

The symbol M is read as "molar" and is not an SI unit. Chemists work in millimolar ($\text{mmol}\cdot\text{L}^{-1}$ or mM) or in even micromolar ($\mu\text{mol}\cdot\text{L}^{-1}$ or µM).

Nuclear Model: Isotopic Mass

$$\text{Atomic Mass} = \sum \left(\text{fractional abundance of isotope}\right)_n \times \left(\text{mass of isotope}\right)_n$$

Data for different isotopes of Oxygen

^{16}O 99.759 %, 15.99491 amu

^{17}O .0370%, 16.99913 amu

^{18}O .204%, 17.99916 amu

Make sure that fractional abundance is in decimal form

(.99759)(15.99491) = 15.956 amu

(.000370)(16.99913) = .00629 amu

(.00204)(17.99916) = .0367 amu

= 15.99899 amu

= 15.999 amu

See E.13

Chemical Equations

stoichiometric coefficient

$$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$$

A subscript gives the number of each type of atom.

Stoichiometric coefficient show the same numbers of atoms of each element on both sides of the arrow.

Since it is balanced it adheres to the law of conservation of mass.

A complete chemical equations

Chemical equation typically show the physical state of each reactant and product by using a state symbol:

(**s**): solid, (**l**): liquid, (**g**): gas, (**aq**): aqueous solution

The complete, balanced chemical equation is:

$$2\ Na(\mathbf{s}) + 2\ H_2O(\mathbf{l}) \rightarrow 2\ NaOH(\mathbf{aq}) + H_2(\mathbf{g})$$

Interpreting chemical equations

$$2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$$

When any 2 **atoms** of sodium react with 2 **molecules** of water, they produce 2 **formula units** of NaOH and one **molecule** of hydrogen.

Using Avogadro's principle we conclude: 2 moles of Na atoms react with 2 moles of H_2O molecules, producing 2 moles of NaOH formula units and 1 mole of H_2 molecules.

The **stoichiometric coefficients** tell us the ***relative number*** of moles of each substance, reacts or products, in the reaction.

Symbols in a chemical equations

The Greek letter Δ (delta) over the arrow indicates heat.

Converting limestone into quicklime requires 800°C:

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

A catalyst is a substance that increases the rate of a reaction but is not itself consumed in the reaction.

Here vanadium(V) oxide is a catalyst during the production of sulfuric acid.

$$2\ SO_2(g) + O_2(g) \xrightarrow{V_2O_5} 2\ SO_3(g)$$

When in water some ionic and or molecular compounds conducted electricity; some strongly and some not at all.

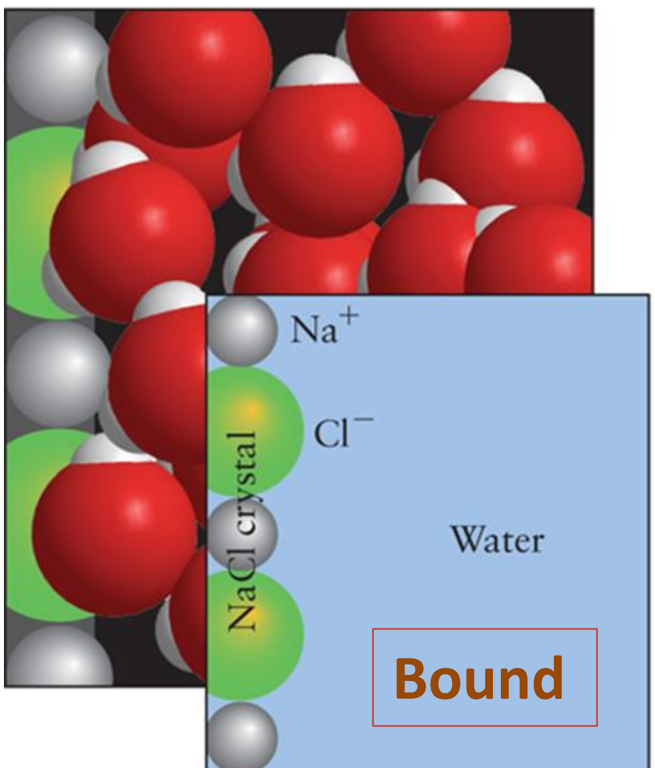
nonelectrolyte | weak electrolyte | strong electrolyte

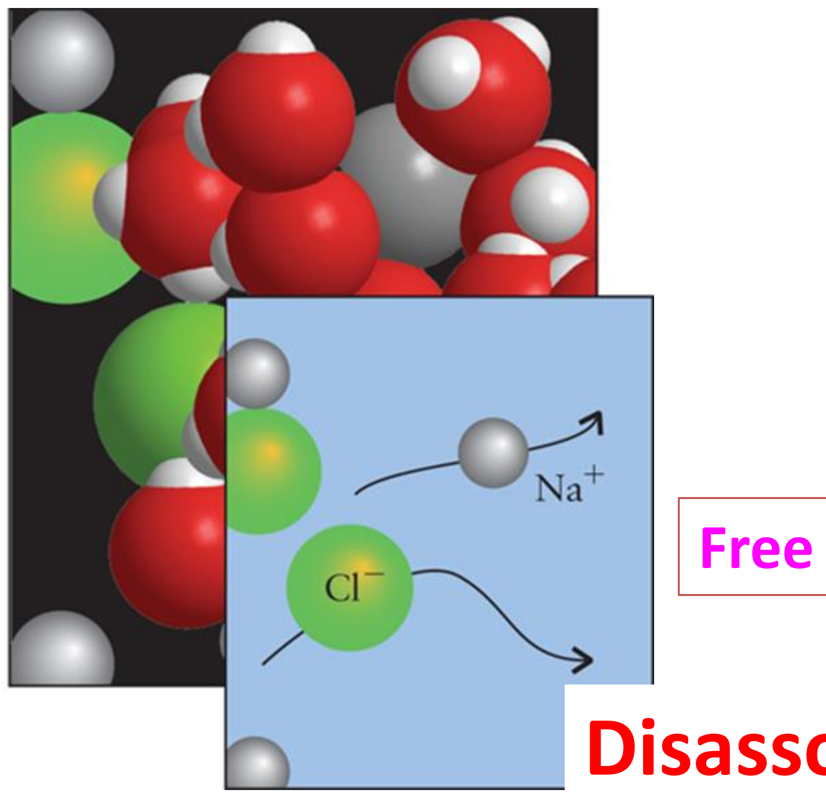
Distinguishing between electrolytes is how ***well*** they conduct electricity, hence strong, weak and non.

Strong electrolytes

Only solutions with ions can conduct electrical current since ions have charge (so become charge carriers). Therefore ionic solutions are referred to as electrolytes.

Notice, ions become **free** to move when the solid dissolves.





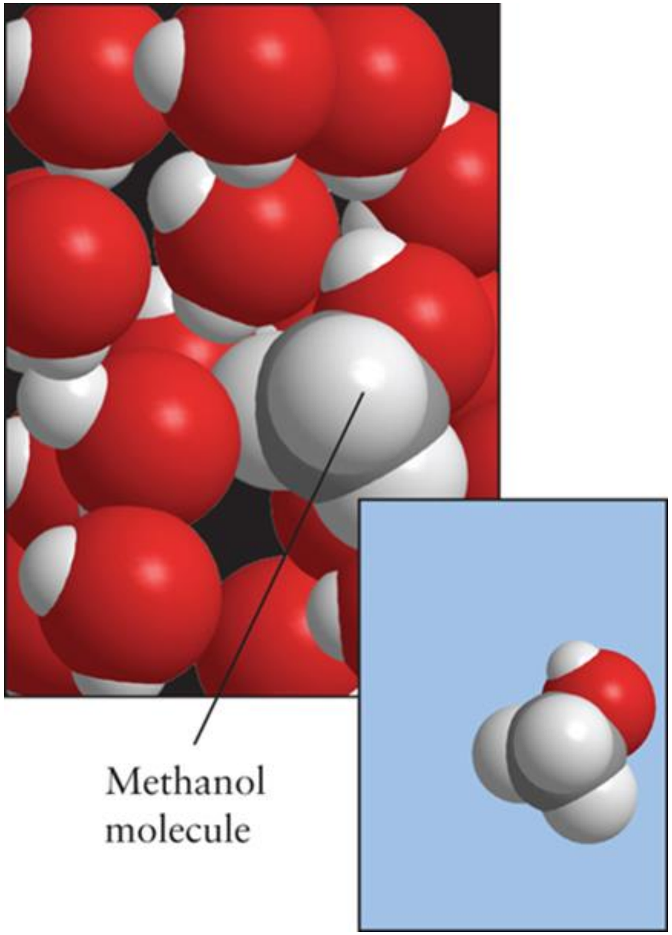
Disassociation

Nonelectrolyte

A nonelectrolyte **does not** form ions in solution.

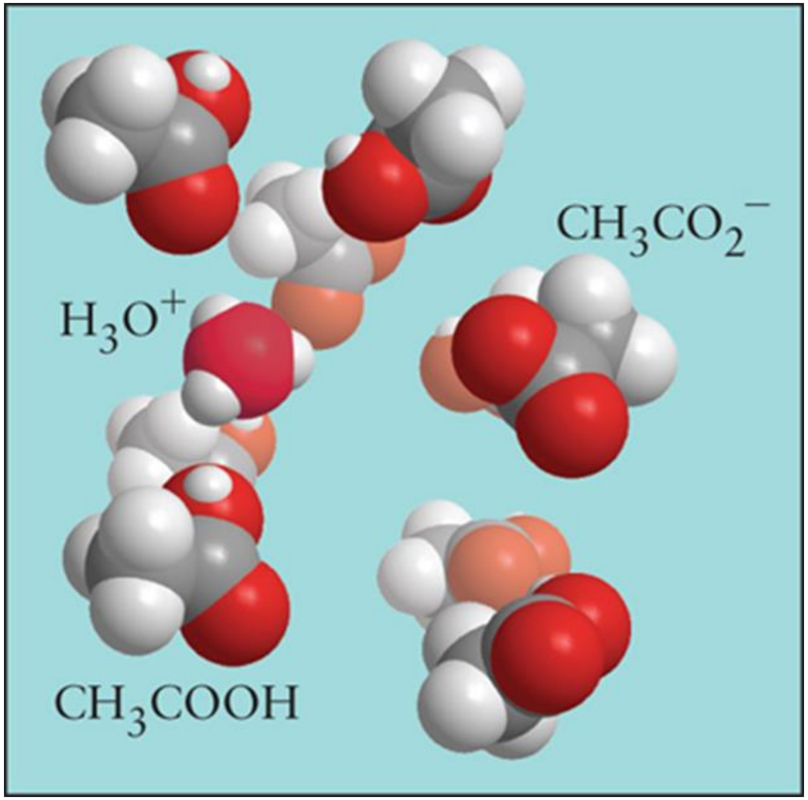
They can be solids or dissolve yet no ions are present.

In a nonelectrolyte solution, molecules do not disassociate, they remain **intact**.



Non-disassociation

Weak electrolyte



Slight-disassociation

Weak electrolytes barely ionizes in solution; they mostly remain intact.

Acetic acid is a weak electrolyte.

Only a small fraction (1%) of CH_3COOH molecules separate (slightly or disassociates negligibly) into hydrogen ions, H^+, and acetate ions, $CH_3CO_2^-$.

Soluble verses insoluble

In a **precipitation reaction**, (aq) indicates a substances dissolved in water and (s) indicates a solid that has precipitated:

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

Soluble: are all in the same phase i.e. solid table salt dissolves in water.

Insoluble: a different phases i.e. solid in a liquid.

Soluble compounds can be strong, weak and nonelectrolytes; **these may or may not disassociate**.

Insoluble compounds are nonelectrolytes, and do not disassociate.

Acid and base definitions

The Swedish chemist Svante Arrhenius, in 1884:

An **acid** is a compound that contains hydrogen and reacts with water to form hydrogen (H^+) ions.

$$HCl(aq) \rightarrow Cl^-(aq) + H^+(aq)$$

Hydrochloric acid, HCl, is an **acid** because it produces hydrogen ion H^+

A **base** is a compound that produces hydroxide ions (OH^-) in water.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Ammonia, NH_3, is the **base** because it produces hydroxide OH^-.

Acid and base definitions: Brømnsted-Lowry

In 1923, Thomas Lowry in England and Johannes Brønsted in Denmark, came up with a proton (H^+) transfer idea.

An acid is a proton donor and a base is a proton acceptor.

H_2O proton acceptor.

$$HCl(aq) + H_2O(l) \rightarrow Cl^- (aq) + H_3O^+ (aq)$$

HCl proton donor.

HCI releases a hydrogen ion, H^+, to water, producing **hydronium ions** (**H_3O^+**)and chloride ions.

H_2O accepts the hydrogen ion to form H_3O^+, water is acting as a Brønsted base in this reaction.

Classifying acids and bases

Brømnsted-Lowry acids and bases are further categorized based on their deprotonation gain or loss strength:

A **strong** acid is completely deprotonated in solution.
A **weak** acid is incompletely deprotonated in solution.
A **strong** base is completely protonated in solution.
A **weak** base is incompletely protonated in solution.

Examples of strong and weak acids.

$$HCl(aq) + H_2O(l) \rightarrow Cl^-(aq) + H_3O^+(aq)$$

strong

100% ionization

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

weak

About 1% ionization

Neutralization reactions

An acid base reaction is called a neutralization reaction.

Neutralization reactions take place between a strong acid and metal hydroxide:

$$\text{Acid} + \text{metal hydroxide} \rightarrow \text{salt} + \text{water}$$

“Salt” is taken from ordinary table salt, sodium chloride.

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Neutralization reactions

Another acid and base reaction producing a salt and water.

$$2\ HNO_3(aq)\ +\ Ba(OH)_2(aq)\ \rightarrow\ Ba\ (NO_3)_2(aq)\ +\ 2\ H_2O(l)$$

The complete ionic equation (section I):

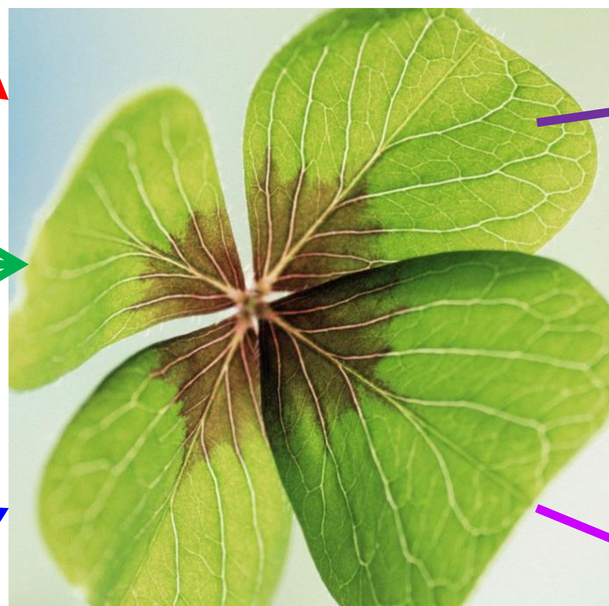
$$2\ H^+\ (aq) + 2NO_3^-\ (aq)\ +\ Ba^{2+}\ (aq) + 2OH^-\ (aq)\ \rightarrow$$
$$Ba^{2+}\ (aq)\ + 2NO_3^-\ (aq)\ +\ 2\ H_2O(l)$$

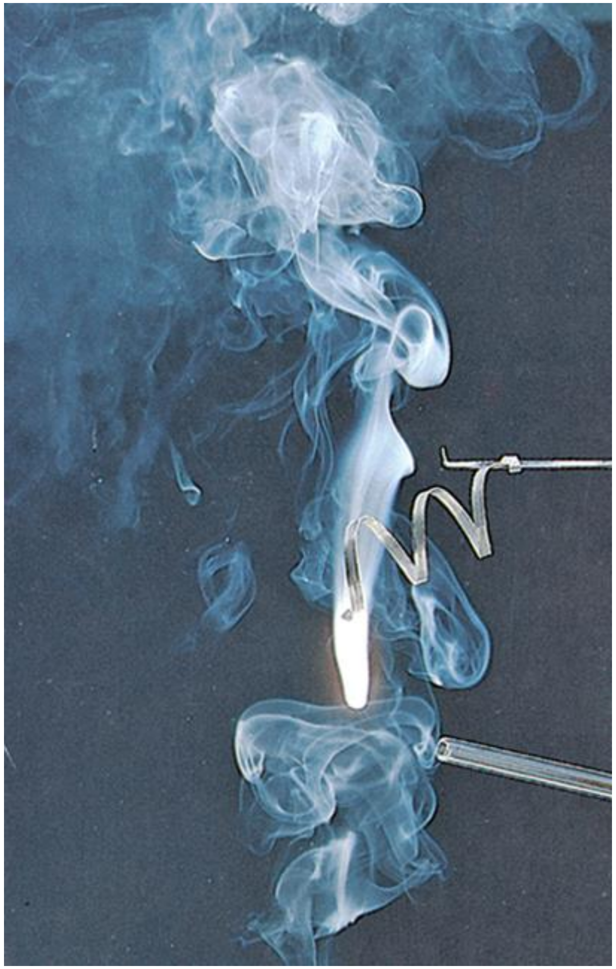
And finally simplified into a net ionic equation.

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

The net of any strong acid base neutralization reaction is the formation of water.

Reduction Oxidation reactions range from ***common*** **combustion**, **corrosion**, to elaborate **photosynthesis**, **metabolism** and **metals extraction** reactions.





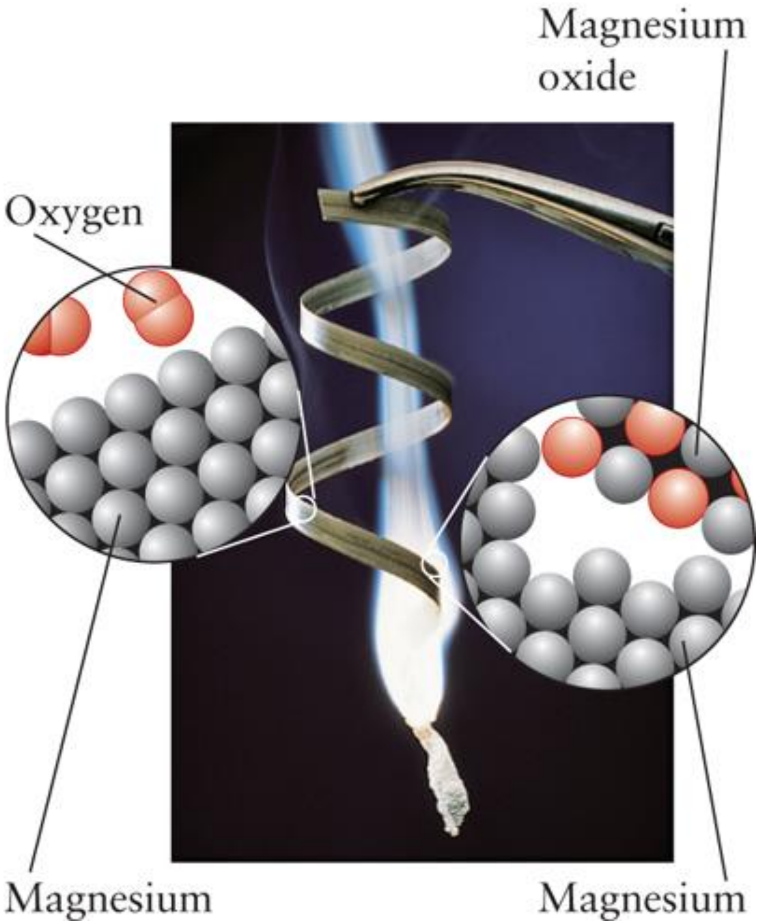
Oxidation is the **loss** of electrons.

In the **classic sense**, oxidation means “a reaction with oxygen."

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

Mg atoms lose electrons to form Mg^{2+} ions, and the oxygen, O_2, gain electrons to form O^{2-} ions.

$$2Mg + O_2 \rightarrow 2Mg^{2+}O^{2-}$$



A similar reaction takes place.

$2\mathbf{Mg}(s) + Cl_2(g) \rightarrow 2MgCl_2(s)$

The pattern of reaction is the same, the ***magnesium*** **looses electrons** in an "**oxidation** reaction" even though no oxygen takes part.

$\mathbf{Mg}^0(s) + Cl_2 \rightarrow Mg^{2+}\,Cl^-$

Steel production

A **reduction** is the **gain** of electrons

One example **reduction**, a **gain of electrons**, is with **iron(III)** oxide and carbon monoxide:

$$\mathbf{Fe}_2O_3(s) + 3CO(g) \xrightarrow{\Delta} 2Fe(l) + 3CO_2(g)$$

This is the reverse of oxidation.

Here $\mathbf{Fe^{3+}}$ is reduced to Fe^0 metal, a gain of electrons in this example.

Electron gain and electron loss occur together

Oxidation or reduction occur in conjunction with the other.

Here chlorine and bromide transfer electrons between each other to produced chloride and bromine.

$$\underset{\text{charge}}{\overset{-1}{}}\qquad \underset{\text{charge}}{\overset{0}{}}\qquad\qquad \underset{\text{charge}}{\overset{-1}{}}\qquad \underset{\text{charge}}{\overset{0}{}}$$

$$2Na\underline{Br}\ (s) + \underline{Cl}_2\ (g) \rightarrow 2\ Na\underline{Cl}\ (s) + \underline{Br}_2\ (l)$$

Half reactions:

Same electron

$$2\ Br^- \rightarrow Br_2 + 2\ e^-$$

$$2\ e^- + Cl_2 \rightarrow 2\ Cl^-$$

The electron lost by the Br^- goes to the Cl_2.

How much product can we expect in a reaction?

How much reactant do we need. This is referred to as **reaction stoichiometry**.

The **key** to reaction stoichiometry are balanced chemical equations.

Stoichiometric coefficient tells us relative amounts (number of moles) of reactants that produce products.

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

Reaction stoichiometry

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

$$1 \text{ mole } N_2(g) + 3 \text{ moles } H_2(g) \rightarrow 2 \text{ moles } NH_3(g)$$

If 1 mol N_2 reacts, then 3 mol H_2 will be consumed and 2 mol NH_3 will be produced.

$1 \text{ mol } N_2 \ \hat{=}\ 3 \text{ mol } H_2$ $\qquad$ $1 \text{ mol } N_2 \ \hat{=}\ 2 \text{ mol } NH_3$

The sign $\hat{=}$ is read "*is chemically equivalent to,*" and these expressions are called stoichiometric relations.

Reaction Yield

Actual yields are the isolated quantity a chemist gathers after a reaction.

A **theoretical yield** is the ***maximum*** quantity (amount, mass, or volume) of product possible in a reaction; it must be calculated.

A **percentage yield** is the fraction of the theoretical yield actually produced, expressed as a percentage:

$$\text{Percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

The Limits of Reaction

When deciding which reactant is limiting, calculate which reactant produces the least amount of product.

$$1\ N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

For example, suppose we have *10 mol* N_2 and *20 mol* H_2, how much NH_3 can each make?

Using stoichiometry mole ratios:

$$1 \text{ mol } N_2 \triangleq 2 \text{ mol } NH_3$$
$$3 \text{ mol } H_2 \triangleq 2 \text{ mol } NH_3$$

Hydrogen is the **limiting reactant** because it produces the least.

$$\frac{2 \text{ mol } NH_3}{3 \text{ mol } H_2} \times \frac{\mathit{20\ mol\ H_2}}{1} = 13 \text{ mole } NH_3$$