Chapter 1 - Matter and Structure of Atoms

> “
> Key point of the chapter:
>
> - Classification of Matter(states, particles)
> - *Change of State
> - Structure of Atoms(History, Electronic *Structure)
> - *Chemical Formulae
> - Oxidation Numbers
> - Physical and Chemical Properties
> - Separation of Mixtures

Classification of Matter

States of Matter

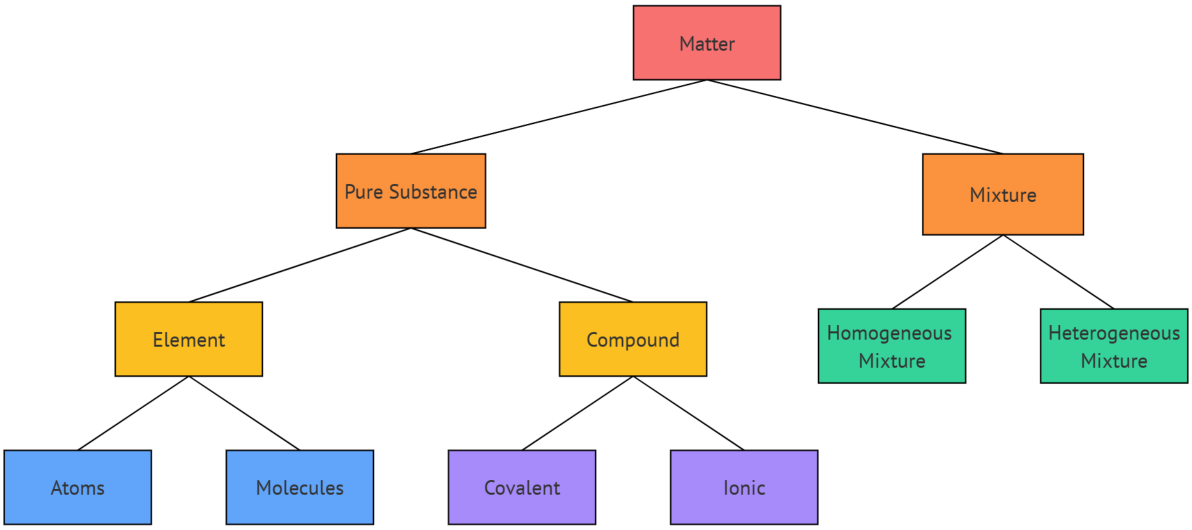
- Matters have **volume** & **mass**
- Matter can exist in three different **physical states**: **solid**, **liquid**, **gas**
- The states of matter can be changed by changing the **temperature** and/or **pressure**
  - Changes in pressure of temperature have greater impact on **gas**

Physical State	solid	liquid	gas
Volume	fixed volume	fixed volume	no fixed volume
Density	high	moderate to high	low
Shape	fixed shape	no fixed shape	no fixed shape
Fluidity	does not flow	generally flows	flows easily
Movement	vibrate in a fixed position	free to move	move freely
Particles	closely packed	slightly further apart	far apart from one another
Attraction Force & Kinetic Energy	$E_k < F$	$E_k \approx F$	$E_k > F$

- Attraction forces (F) between the particles won't change, but the kinetic energy (E_k) of particles will be affected by heat.

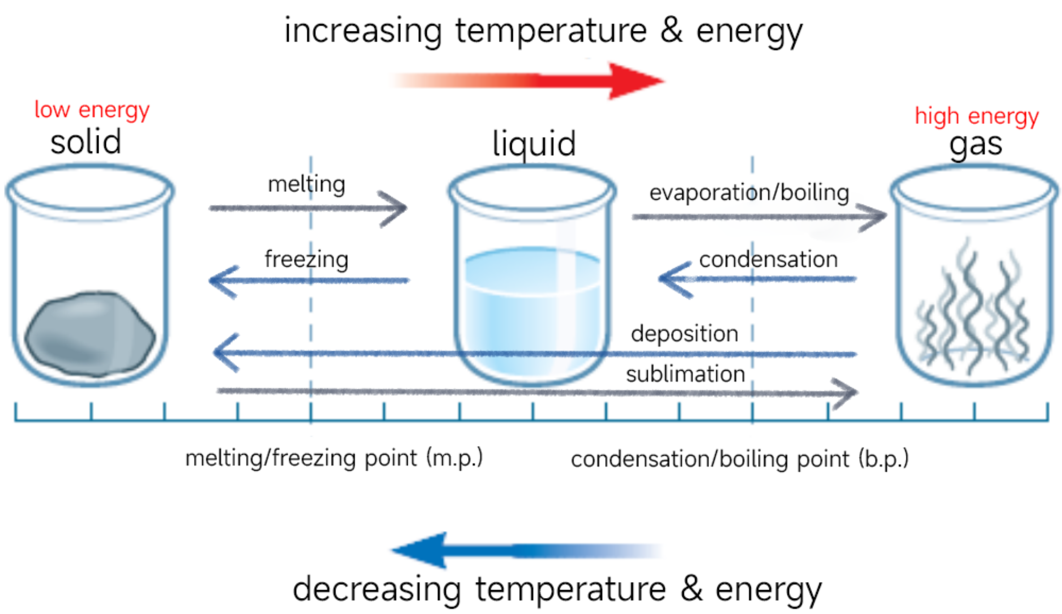
Particles

- There're three types of particles that made up matters: **atoms**, **molecules**, **ions**



The Change of State of Matter

- All states of matter show an increase in volume (**expansion**) when the **temperature** is **increased** and a decrease in volume (**contraction**) when the **temperature** is **lowered**
- Large **increases/decreases** in **temperature** and **pressure** can cause a substance to **change** its **physical state**



Boiling & Evaporation

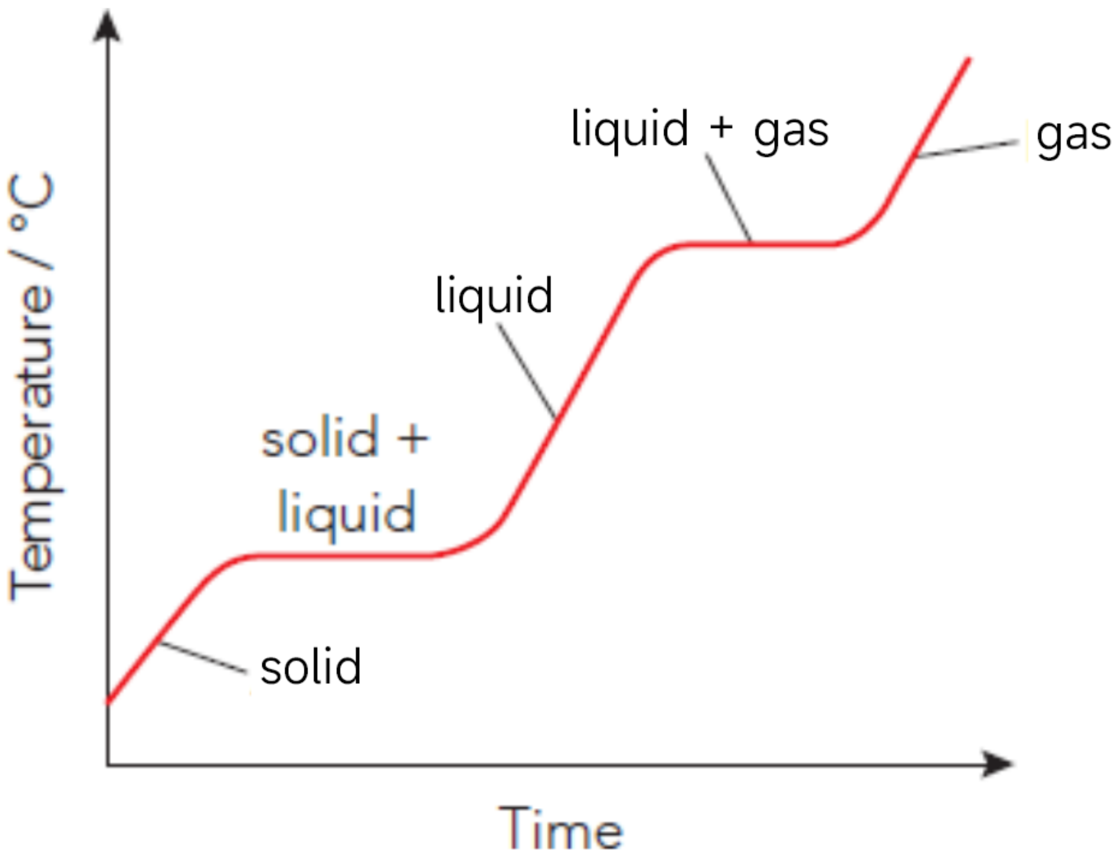
- **Evaporation** take place over a range of temperatures, only take place from the surface of the liquid
  - the rate of evaporation may be affected by the temperature and surface area
  - *volatile* : term that describes a liquid that evaporates easily
    - usually a liquid with low boiling point because there're weal intermolecular forces between the molecules in the liquid
- **Boiling** takes place at a **specific temperature**

Sublimation

- Example of substances that sublimes:
  - iodine, dry ice (solid CO_2), mothballs, ammonium chloride (NH_4Cl)
- Ammonium chloride doesn't REALLY sublime, at a certain temperature, it decomposes to ammonia and hydrogen chloride (both gases), which appears to be sublimation but is not.

- Iodine can exist in liquid state. The iodine seems to miss out the liquid stage if heated strongly because the temperature rises very quickly, the m.p. and b.p. are close together, the liquid stage is not seen as it boils quickly
    - To make iodine melt to form a liquid at atmospheric pressure:
        - heat the solid slowly
        - use some tools(electrical heater, oil bath) to control the rise of temperature carefully

Heating and Cooling Curves



- The **temperature stays constant** during the state changes.
- During heating, all the energy absorbed at m.p. and b.p. goes into weakening the attraction forces between particles without temperature rise.
- During colling, all the heat energy released at condensation point and freezing point is given out into increasing of the intermolecular forces without temperature falls.
- *exothermic changes* : freezing, condensing
- *endothermic changes* : melting, boiling, evaporation

- ### Effect of impurities

- **A pure substance melts and boils at definite temperature**.
- The presence of any **impurity** will **lower the freezing/melting point** of the solid
    - It makes it harder for the particles to arranged closely in fixed positions which is necessary if a substance is changed into a solid
    - It disrupts the formation of the lattice of the solid, less energy is required to break the lattice, this leads to a lower melting point
    - *lattice* : a regular 3D arrangement of particles in a crystalline solid
- The presence of any **impurity** will **increase the condensing/boiling point** of the liquid
    - It makes it harder for the particles to gain high kinetic energy which is necessary if a substance is changed into a gas/vapour(mixture of two states)
    - the molecules need more energy(heat) than normal in order to escape from the liquid and become vapour.
- Thus, **purity of substance** is checked by **determining the m.p. and b.p.**
- These values can also be used to **identify an unknown substance**.

Structure of Atoms

- ### The Historical Development of Atomic Model

1. John Dalton
    - atomic model: all matter was made up of atoms
2. J.J. Thomson
    - plum pudding model: discovered electron(negatively charged particles)
3. Ernest Rutherford
    - Rutherford model: discovered protons(positively charged particles) and nucleus
4. Niels Bohr
    - Bohr model / planetary model: electrons move in specific energy levels or "shells" around the nucleus of an atom
5. James Chadwick

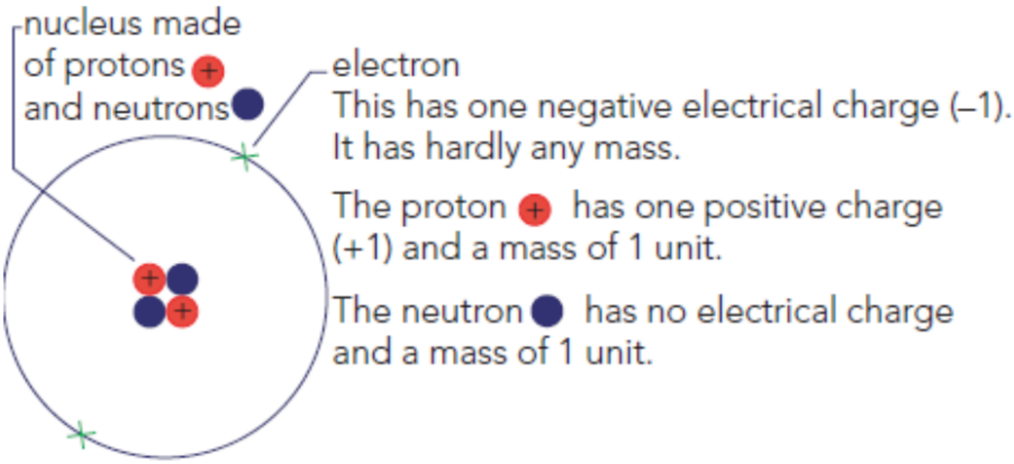
- discovered the neutron(electrically neutral / no electrical charge)
- completing the picture of the three main *subatomic particles* that make up atoms

Characteristics of Protons, Neutrons and Electrons

Subatomic Particle	proton(p)	neutron(n)	electron(e)
Relative Mass	1	1	1 / 1840 (negligible)
Relative Charge	+1	0	-1
Location in Atom	in nucleus	in nucleus	surrounding/outside nucleus

- **Atoms are electrically neutral**, so every atoms have an **equal number of protons and electrons** to cancel out the charges
- The **number of neutrons** required to hold the nucleus together **increases** as the **atomic size (atomic number) increases**
  - **Hydrogen** atom is the only atom that has **no neutron**
  - Neutrons are important in making the nucleus of an atom stable
    - Protons are positively charged and would therefore repel each other.
    - The presence of the neutrons counteracts this repulsion and means that the nucleus can hold together.

Example: Helium



A helium atom has these charged particles in it:

2 protons	charge +2	these charges cancel out
2 electrons	charge –2	

We say the charges balance.
The atom has no overall electrical charge.

A helium atom has:

2 protons	mass 2 units
2 neutrons	mass 2 units
2 electrons	with hardly any mass

So a helium atom has a total mass of:
2 + 2 = 4 units

Atomic Number and Mass Number

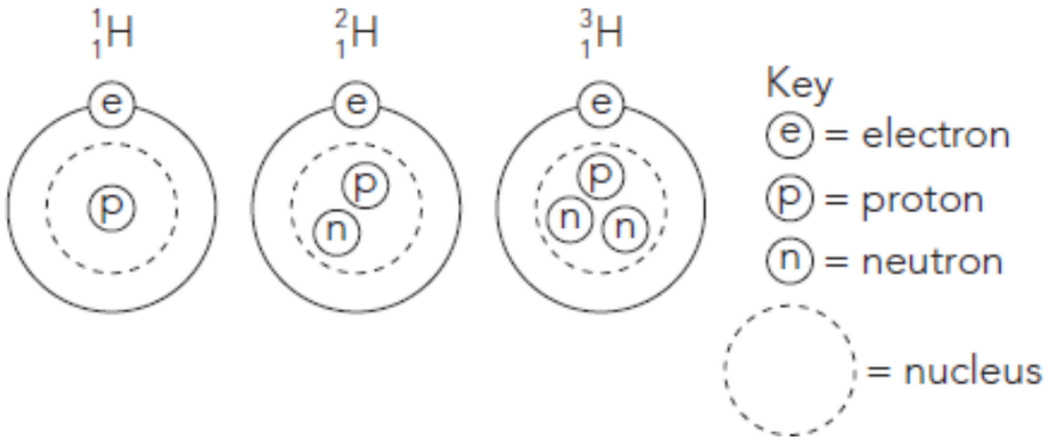
- We can represent a particular atom of an element by combining the chemical symbol of the element with the nucleon(A) and atomic(Z) numbers of the atom.

$$^{A}_{Z}\mathrm{X}$$

- Example: representing the structure of iodine atoms, using the above format
    - $$^{127}_{53}\mathrm{I}$$ $$Iodine - 127$$
- Atomic number / proton number (Z) = number of protons in the nucleus of an atom
- Nucleon number / mass number (A) = number of protons + number of neutrons
- number of electrons = number of protons = atomic number
- number of neutrons = mass number - atomic number (A-Z)

• Isotopes

- *Isotopes* are atoms of the same element that have the **same proton number** but a **different nucleon number**. Many Isotopes are **radioactive** because their nuclei are unstable (radioisotopes).
- Many elements have naturally occurring isotope.
- Hydrogen, the simplest element, has two naturally occurring isotopes: hydrogen and deuterium. A third Isotope, tritium, can be made artificially.



- The isotopes of an element have the **same chemical properties**.
  - Isotopes have the **same electronic configuration**. It determine the way it forms bonds and react with other atoms.
- The isotopes **differ in some of their physical properties** (such as density, rate of diffusion)
  - Examples
    - difference in density between ordinary ice and heavy-water ice(deuterium oxide, D_2O)
    - radioactivity of tritium and carbon-14 (radioisotopes)

- Relative Atomic Mass (A_r)

- A single atom cannot be weighed on a balance.
- Masses of all atoms are compared to the mass of a **carbon-12 atom**.
- One atom of carbon-12 is given the mass of 12 precisely.
- $$1 \text{ atomic mass unit (a.m.u)} = \frac{1}{12} \times \text{mass of one atom of carbon-12}$$

- Examples of value obtained for other element
Element	Atomic Symbol	Relative Atomic Mass (A_r)
carbon	C	12
hydrogen	H	1
copper	Cu	64
- **Most elements exist naturally as a mixture of isotopes**, therefore, the value we use for the **atomic mass** of an element is an **average mass**.

  $$A_r(X) = (\text{isotope}_1 \text{ abundace} \times \text{mass of isotope}_1) + (\text{isotope}_2 \text{ abundace} \times \text{mass of isotope}_2)$$

- Examples
    - Iridium has two isotopes. These isotopes are iridium-191 and iridium-193. A natural sample of iridium consists of 37.3% of iridium-191.
    - $$\begin{aligned} A_r(Ir) &= (191 \times 37.3\%) + (193 \times (100 - 37.3)\%) \\ &= (191 \times 37.3\%) + (193 \times 62.7\%) \\ &= 192.254 \end{aligned}$$

Electronic Configuration of Elements

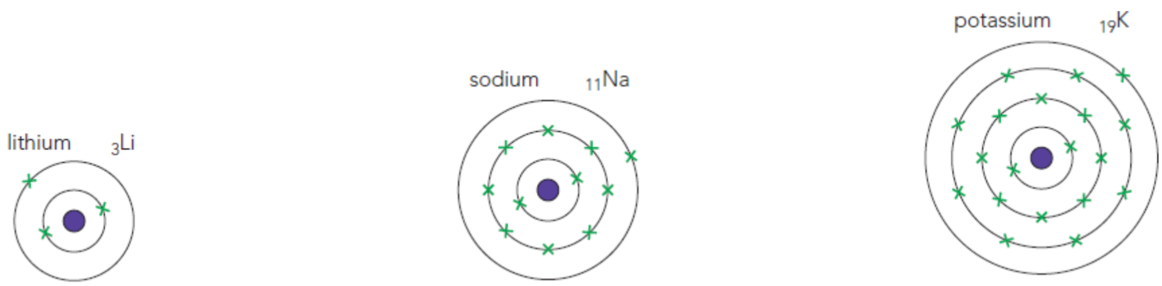
Bohr's atomic theory

- electrons are in **orbit** around the central nucleus of an atom
- the electron orbits are called **electron shells / energy levels** and have different energy
- **shells that are further from the nucleus have higher energies**
- the shells are filled starting with the one with lowest energy (closest to the nucleus)
- the first shell can hold only two electrons
- the outermost shells can hold eight electrons to give a stable arrangement of electrons
- If the number of electrons of an atom is more than 20, the third shell will hold 18 electrons. If the numbers of electrons is 20 or less, the third shell will hold 8 electrons
- **electron arrangement / configuration**: the way in which the electrons are distributed in the shells of an atom

Example of Electron Configurations of The First 20 Elements

Element	Symbol	Atomic Number (Z)	Electron configuration
hydrogen	H	1	1
boron	B	5	2.3
oxygen	O	8	2.6
neon	Ne	10	2.8
magnesium	Mg	12	2.8.2
phosphorus	P	15	2.8.5
potassium	K	19	2.8.8.1

Another way of showing electron structure



Periodic Table

- The electron configuration of an element determines the group number and period number of that element in the periodic table

Chemical Formulae

• Nomenclature of Inorganic Compounds

- Binary Covalent Compounds

- Covalent / molecular compounds are form when nonmetal elements bond to each other
- The first element in the formula is simply listed using the name of the element.
- The second element is named by taking the stem of the element name and adding the suffix -ide.
- A system of numerical prefixes is used to specify the number of atoms in a molecule.

Atoms in Compound	Prefix on the Name of the Element
1	mono-*(not used for the first element's name)
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Examples

Chemical Formula	IUPAC name
NO	nitrogen monoxide
SF_6	sulfur hexoxide
ClO_2	chlorine dioxide
NCl_3	nitrogen trifluoride
I_2O_5	diiodine pentoxide

Exceptions

- Compounds that are always called by the common names

chemical formula	common name
H_2O	water
NH_3	ammonia
CH_4	methane
PH_3	phosphine

- Common name that getting used more frequently than systematic name

chemical formula	systematic name	common name
NO	nitrogen monoxide	nitric oxide
N_2O	dinitrogen monoxide	nitrous oxide
NaCl	sodium chloride	table salt
$NaHCO_3$	sodium hydrogencarbonate/bicarbonate	baking soda
$MgSO_4$	magnesium sulfate	Epsom salt

- Ionic Compounds

- Ionic compounds are formed when metal atoms lose one or more of their electrons to nonmetal atoms.
- Ionic compounds are made up of ions.
- Some elements can form two different ions, we can use two ways too distinct them:
    - **Stock System** (Modern approach)
    - Common System

Ion	stem	charge	modern name	common name
Iron	ferr-	2+	iron(II) ion	ferrous ion
		3+	iron(III) ion	ferric ion
copper	cupr-	1+	copper(I) ion	cuprous ion
		2+	copper(II) ion	cupric ion

Common Cations

Cations with 1+	
Li^{+}	lithium ion
Na^{+}	sodium ion
K^{+}	potassium ion
Cu^{+}	copper(I) ion
Ag^{+}	silver ion
H^{+}	hydrogen ion

Cations with 2+	
Mg^{2+}	magnesium ion
Ca^{2+}	calcium ion
Ba^{2+}	barium ion
Mn^{2+}	manganese (II) ion
Fe^{2+}	iron (II) ion
Co^{2+}	cobalt (II) ion
Ni^{2+}	nickel (II) ion
Cu^{2+}	copper (II) ion
Zn^{2+}	zinc ion
Sn^{2+}	tin (II) ion
Pb^{2+}	lead (II) ion

Cations with 3+	
Al^{3+}	aluminium ion
Cr^{3+}	chromium(III) ion
Fe^{3+}	iron(III) ion

Cations with 4+	
Pb^{4+}	lead(IV) ion
Si^{4+}	silicon(IV) ion
Sn^{4+}	tin (IV) ion

Common Anions

Anions with 1-	
F^{-}	fluoride ion
Cl^{-}	chloride ion
Br^{-}	bromide ion
I^{-}	iodide ion
*H^{-}	hydride ion

Anions with 2-	
O^{2-}	oxide ion
S^{2-}	sulphide ion
*O_2^{2-}	peroxide ion

Anions with 3-	
N^{3-}	nitride ion
P^{3-}	phospide ion

Anions with 4-	
C^{4-}	carbide ion

Examples

Compounds	Name
NaCl	sodium chloride
$CaBr_2$	calcium bromide
Mg_3N_2	magnesium nitride

Nomenclature of Acids

Acids that doesn't Contain Oxoanion

- Naming as Ionic compounds
  - first write the cation(usually hydrogen), then write the anion
  - Ionic name is preferred when the compound is not acting as an acid
    - i.e. pure HCl in gas phase
- Naming as Acids
  - Add prefix hydro- to the name of anion, then replace the last syllable from –ide to –ic acid.
  - Acid name is preferred when the compound acts as an acid
    - particularly when it is in solution form in water
- Examples

Compounds	name(aqueous)	name(gas)
HCl	hydrochloric acid	hydrogen chloride
HBr	hydrobromic acid	hydrogen bromide
H_2S	hydrosulfuric acid	hydrogen sulfide
HF	hydrofluoric acid	hydrogen fluoride
HI	hydroiodic acid	hydrogen iodine
*HCN	hydrocyanic acid	hydrogen cyanide

- all above the above are binary acids, except HCN

Acids that Contains Oxoanion & Others

chemical formula	name	ion	name of ion
HNO_2	nitrous acid	NO_2^-	nitrite ion nitrate(III) ion
HNO_3	nitric acid	NO_3^-	nitrate ion nitrate(V) ion
H_2CO_3	carbonic acid	HCO_3^-	hydrogencarbonate ion bicarbonate ion
		CO_3^{2-}	carbonate(IV) ion
CH_3COOH	ethanoic acid acetic acid	CH_3COO^-	ethanoate ion acetate ion
$HMnO_4$	permaganic acid	MnO_4^-	maganate(VII) ion permaganate ion
H_2SO_3	sulfurous acid	SO_3^{2-}	sulphite ion sulphate(IV) ion
H_2SO_4	sulfuric acid	SO_4^{2-}	sulphate(VI) ion
H_2CrO_4	chromic acid	CrO_4^{2-}	chromate(VI) ion
$H_2Cr_2O_7$	dichromic acid	$Cr_2O_7^{2-}$	dichromate(VI) ion
H_3PO_4	phosphoric acid	PO_4^{3-}	phospate(V) ion
$HClO$	hydrochlorous acid chloric(I) acid	ClO^-	hydrochlorite ion chlorate(I) ion
$HClO_2$	chlorous acid chloric(III) acid	ClO_2^-	chlorite ion chlorate(III) ion
$HClO_3$	chloric acid chloric(V) acid	ClO_3^-	chlorate ion chlorate(V) ion
$HClO_4$	perchloric acid chloric(VII) acid	ClO_4^-	perchlorate ion chlorate(VII) ion
H_2O	water	OH^-	hydroxide ion
*NH_3	ammonia	NH_4^+	ammonium ion