

ELEMENTS, COMPOUNDS AND MIXTURES

Matter is broadly classified into three, namely: elements, compounds and mixtures.

ELEMENTS

An element is the simplest type of any substance, with unique physical and chemical properties as well as a constant atomic number. The atomic number of one element is different from the atomic number of another element. The atomic number is the number of protons contained in the nucleus of an atom of the element. More than one hundred elements are known. Some examples of the common elements include: hydrogen, carbon, oxygen, sodium, calcium, potassium, etc.

COMPOUNDS

A compound is a substance made up of two or more elements that are chemically combined. This combination is usually in fixed mass ratio. Examples of chemical compounds include: water (H_2O), formed by chemical combination of one molecule of hydrogen (which contains two atoms of hydrogen) and one atom of oxygen; sodium chloride ($NaCl$), formed by chemical combination of one atom of sodium and one atom of chlorine etc.

MIXTURES

A mixture is a substance containing two or more elements/compounds that are not chemically combined. Consequently, mixtures are formed by physical mixing of their components. Some common examples include: sodium chloride solution (obtained by dissolving sodium chloride in water; air (mixture of oxygen, nitrogen, noble gases, carbon (iv) oxide, dust and moisture etc) etc.

Comparison of the characteristics of compounds and mixtures

Mixtures/ Compounds

1. Have variable composition by mass

Have fixed composition by mass

2. Retain most of the properties of their constituents

Properties vary from those of most of their constituents.

3. Constituents can easily be separated by physical means

Constituent can only be separated by chemical means

4. Great heat (energy) changes are not usually involved in their formation

Great heat changes are usually involved in their formation

5. May be homogenous or heterogeneous

Are always homogenous

ATOMS, MOLECULES AND STRUCTURE

Matter is anything that occupies space and has mass. It is made up of atoms, molecules and ions.

ATOM

An atom is known as the smallest part of an element which can take part in a chemical reaction. It comprises of tiny particles called electrons, protons and neutrons. These three particles are present in all atoms except for hydrogen with only one proton and one electron.

MOLECULE

This is known as the smallest particles of a substance, either an element or a compound which is capable of independent existence.

This occurs when two or more atoms join together chemically. Atomicity is known as the number of atoms in a molecules of a given element. Example, the atomicity of O_2 and H_2 is two and is known as diatomic. Others such as phosphorus and sulphur exist as polyatomic molecules.

The molecules of helium and neon are monoatomic because they exist independently as a single atom.

DALTON'S ATOMIC THEORY

The atom is the basic particle which all matter is made. Whether matter is continuous or discontinuous i.e composed of particles, had for many years remained the object of speculative debate until Democritus proposed that all matter is made up of discrete particles which is called atoms. This proposition remained in the realm of philosophy until John Dalton (1803) stated the first theory of the atom from experimental data. The main points of the

Dalton's atomic theory is;

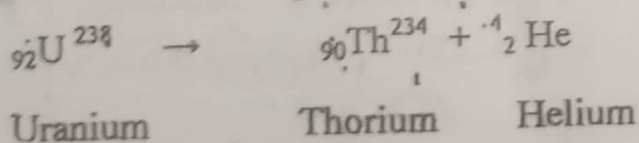
- 1) All matter is composed of tiny particles called atom.
- 2) The atoms of an element are exactly alike, particularly in their masses, atoms of different elements have different masses.
- 3) Chemical reaction occurs by the combination of whole, but not fractional atoms, i.e atoms are indivisible.
- 4) When atoms combine with other atoms, they do so in small whole number ratios.

Towards the end of the nineteenth century, the concept of the indivisibility of atoms began to show sign of weakness.

MODIFICATION OF THE DALTON'S ATOMIC THEORY

- 1) Radioactive substances/atoms undergo spontaneous disintegration or artificial disintegration to produce even smaller particles.

E.g:



2) The discovery of isotopes.

3) Many molecules most especially the organic compounds are now known to be compounds which consist of very large number of atoms joined together especially in the formation of polymers.

$K_2Cr_2O_7$. . . Ans.

- oxidation number of K = +1
- Let the oxidation number of Cr = x
- oxidation number of Oxygen = -2

$$\therefore K_2Cr_2O_7 = 0$$

$$(2 \times +1) + 2x + (7 \times -2) = 0$$

$$2 + 2x - 14 = 0$$

$$2x - 12 = 0$$

$$x = \frac{+12}{2} \quad 2x = +12$$

$$x = \frac{+12}{2} = \underline{+6}$$

The compound is heptaoxidochromate (VI).

4. Calculate the oxidation state of sulphur in SO_4^{2-}

$$SO_4^{2-} = -2$$

$$S + (4 \times -2) = -2$$

$$S - 8 = -2$$

$$S = +6 - 2$$

$$S = \underline{+4}$$

The compound is tetraoxosulphate (VI) ion.

Balancing redox equations

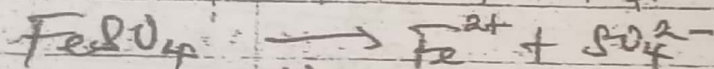
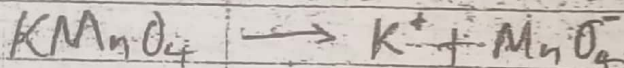
Balancing chemical equations for many reactions can be obtained by considering two equations involved in the reactions.

The oxidation half-equations shows the production of electrons in the reactions while the reduction half-equations shows the transfer of these electrons to the substance being reduced.

Steps in balancing redox reaction
- Ion-electron method.

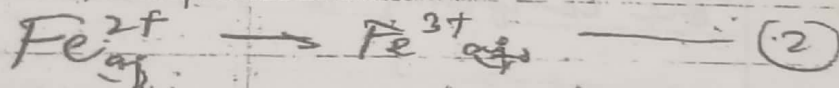
Example: Write a balanced ionic equation for redox reaction between acidified potassium ~~oxo~~^{manganate} (VII) and Iron (II) tetraoxosulphate (5 marks).

Step I:



- MnO_4^- is the oxidizing agent hence MnO_4^- is reduced to Mn^{2+} i.e. $\text{MnO}_4^- \rightarrow \text{Mn}^{2+}$ — (1)

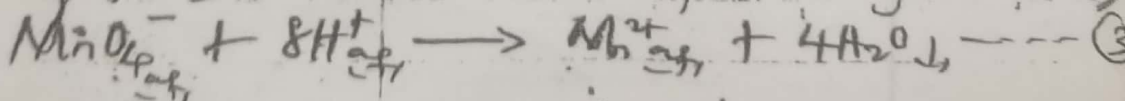
- Fe^{2+} is the reducing agent, hence it is oxidized to Fe^{3+}



Step II:

i. Reduction half-equation

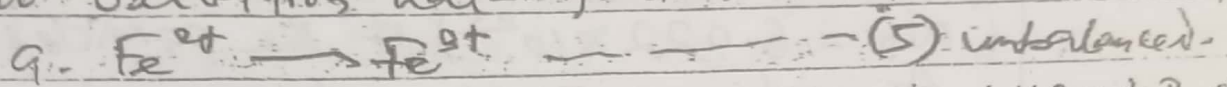
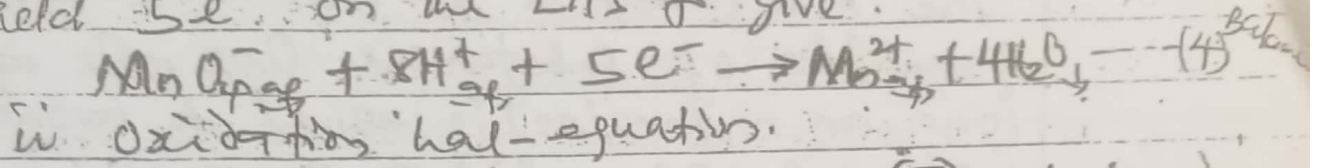
a. Balance The number of atoms first adding the correct number of H^+ and H_2O . The appropriate species (In neutral or acid solution H_2O and H^+ may be added for balancing oxygen and hydrogen. In alkaline solution, OH^- may be used)



b. to balance the number of charges

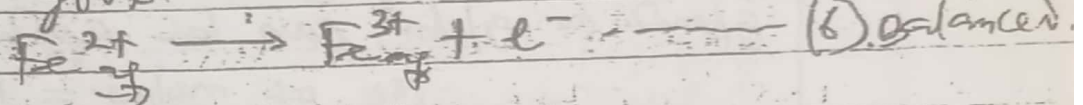
$$-1 + 8 = (-1) + (x) = +7$$

The difference in number of charges is $5e^-$, we add $5e^-$ on the LHS to give:



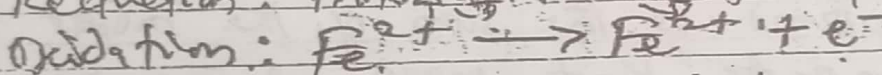
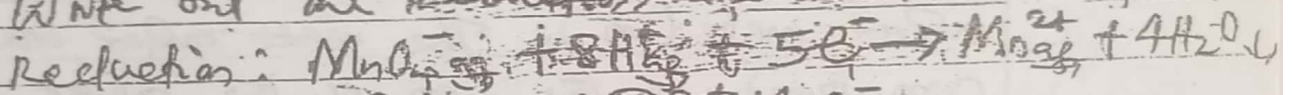
To balance the number of charges, LHS = +2 and RHS = +3.

Therefore, we add one (1) electron (e^-) to the RHS to give

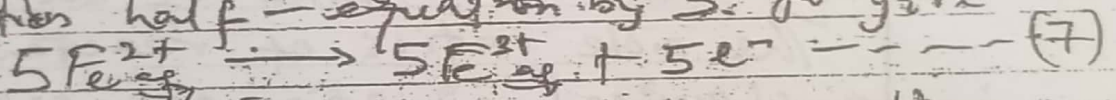


STEP III

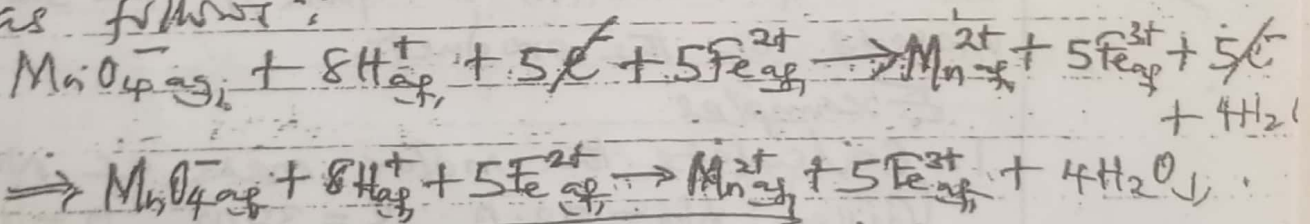
Write out the reduction and oxidation half-equations



However, the number of electrons on the two half equations are not the same. Hence, multiply the oxidation half-equation by 5 to give



Now, combining the two half equations i.e. equations (4) and (7) to eliminate the electrons we will give the overall ionic equation as follows:



The mole (mol) is the base S.I unit for quantities of substances. One mole of particles (ions or molecules) is equal to Avogadro's number ($N_A = 6.022 \times 10^{23}$) of the particles.

A mole of oxygen atom contains 6.022×10^{23} atoms of oxygen. It has a mass of 16g.

In calculating moles, the ratio of mass of substance in gram (g) to the molar mass in g/mol or g/dm³ can be applied.

$$\text{No. of moles} = \frac{\text{mass of substance (g)}}{\text{molar mass (g/mol or g/dm}^3\text{)}}$$

The mass of 1 mole of a substance is called its molar mass (M). The molar mass (M) of a compound is the sum of the molar masses of elements that make up the compound, each multiplied by the number of moles of that element in 1 mole of the compound.

The mole ratios of reactant and products in a chemical equation are called stoichiometry.

The law of conservation of mass states that the sum of the masses of the reactants of a chemical reaction is equal to the sum of the masses of the products.

Examples

1. Calculate the molar mass of Na_2SO_4 .
(Given: $\text{Na} = 23.0$, $\text{S} = 32.0$, $\text{O} = 16.0$)

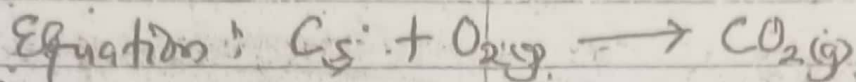
Solution.

1 mole of Na_2SO_4 (Sodium tetraoxosulphate VI) contains
2 mole^{atoms} of $\text{Na} = (2 \times 23.0)\text{g} = 46.0\text{g}$
1 mole atom of $\text{S} = (1 \times 32.0)\text{g} = 32.0\text{g}$
4 mole atoms of $\text{O} = (4 \times 16.0)\text{g} = 64.0\text{g}$
 \therefore molar mass of $\text{Na}_2\text{SO}_4 = 142.0\text{g/mol}$.

(1)

of carbon (IV) oxide (CO_2)?

Answer



From the equation, 1 mole molecule of CO_2 contains 2 mole
1 mole molecule of CO_2 contains 2 mole atoms of O
 \therefore 0.1 mole molecule of CO_2 contains $\frac{2}{1} \times 0.1$ mole
 $= 0.2$ mole.

3. How many moles of Na_2CO_3 are there in 14.0g of the compound? ($\text{Na} = 23.0$, $\text{O} = 16.0$, $\text{C} = 12.0$)

Ans.

1 mole molecule of Na_2CO_3 contains:

2 mole atoms of $\text{Na} = (2 \times 23.0g) = 46.0g$

3 mole atoms of $\text{O} = (3 \times 16.0)g = 48.0g$

1 mole atom of $\text{C} = (1 \times 12.0)g = 12.0g$

Molar mass of $\text{Na}_2\text{CO}_3 = 106g(\text{mol})$.

But 106g is the mass of 1 mole Na_2CO_3 .

\therefore 14g of Na_2CO_3 contains $\frac{14g}{106g} \times 1 = 0.132$ mole.

4. How many moles are represented by
a. 6.35g of CO_2 , b. 9.11g of SO_2 , c. 15.02g of $\text{Ca}(\text{NO}_3)_2$?

Ans.

a. molar mass of $\text{CO}_2 = (12 \times 1) + (16 \times 2)$
 $= 12 + 32$
 $= 44g(\text{mol})$.

But 44g of CO_2 contains 1 mole of CO_2 .

\therefore 6.35g of CO_2 contains $6.35g \times \left(\frac{1 \text{ mole}}{44g}\right) = 0.144$ mole

5. How many atoms are present in 1.16g of Na

Ans.

1 mole of Na atom = 23.0g

1)

∴ 1.16g of Na atom will contain $\frac{1.16g \times 6.022 \times 10^{23}}{23.0g} = 3.0 \times 10^{22}$

Assignment

6. From the equation: $2KClO_3 \rightarrow 2KCl + 3O_2$
How many moles of O_2 will be formed from 1.65 moles $KClO_3$.

Ans.

From the equation: 2 moles of $KClO_3$ produced 3 moles of O_2
∴ 1.65 moles of $KClO_3$ produced $\frac{1.65 \text{ moles} \times 3 \text{ moles}}{2 \text{ moles}}$
 $= 2.48 \text{ moles } O_2$
 $\approx 2.5 \text{ moles } O_2$

PERCENTAGE COMPOSITION OF COMPOUND.

To calculate this:

- Write the formula of the compound
- Calculate its molar mass
- Divide the total mass of the atom in question by the molar mass of the compound and multiply by 100

Example:

Calculate the percentage composition of Sodium tetroxosulphate (VI) [Na = 23, S = 32, O = 16g]

Ans.

The molar mass of Na_2SO_4 : $(23 \times 2) + (32 \times 1) + (16 \times 4)$
 $= 46 + 32 + 64$
 $= 142 \text{ g/mol}$

∴ % Composition of Sulphur = $\frac{\text{mass of Sulphur}}{\text{Molar mass of } Na_2SO_4} \times 100$
 $= \frac{32g}{142g} \times 100 = 22.50\%$

% Composition by mass Oxygen = $\frac{64g}{142g} \times 100 = 45.10\%$

% Composition by mass of Sodium = $\frac{46}{142} \times 100 = 32.40\%$

This formula shows the simplest ratio of the number of atoms present in a compound.

MOLECULAR FORMULA:

This shows the actual number of atoms of the different elements present in one molecule of a compound.

Example 1.

The analysis of a certain organic compound shows that it contains 39.3% Carbon, 6.9% Hydrogen and 53.2% Oxygen.

a. Calculate the empirical formula

b. If the relative molecular mass is 60. What is the molecular formula of the compound

[C = 12, H = 1, O = 16]

Soln

Element Present	C	H	O
% Composition by mass	39.3	6.9	53.2
Number of mole Present:	$\frac{12}{39.3}$	$\frac{1}{6.9}$	$\frac{16}{53.2}$
	3.33	6.9	3.33
Divide by the smallest number:	$\frac{3.33}{3.33}$	$\frac{6.9}{3.33}$	$\frac{3.33}{3.33}$
Ratio	1	2	1

Empirical formula = CH_2O

But molecular formula = $(\text{CH}_2\text{O})_n$

$$(\text{CH}_2\text{O})_n = 60$$

$$30n = 60$$

$$n = 60/30 = 2$$

Hence, molecular formula = $(\text{CH}_2\text{O})_2 = \text{C}_2\text{H}_4\text{O}_2$

LIMITING REACTANT

The limiting reactant in a reaction mixture is the reactant in shortest supply that limits how much product can be made.

Sometimes the quantity of product is less than which should have been made given the quantities of reactants available. The ratio of the actual to the theoretical yield is usually expressed as percentage, called the percent yield.

NB: In all reactions, there will be one reactant that will "limit" the yield of the product.

However, the limiting reactant is not always the one present in the smallest quantity or amount.

Using mole ratio: $aA \rightarrow bB$

Grams A	1 mol A	b mol B	Molar Mass = $M_{grs, B}$
$M_{grs, A}$	g mol A	1 mol B	

Examples 1.

Consider the reaction: $2Al + 3S \rightarrow Al_2S_3$

- What mass of Aluminium Sulphide can be produced from 9.00g of Al reacting with 8.00g of Sulphur?
- What is the limiting reactant [Al=26, S=32, S₀]

9g Al	1 mol Al	1 mol Al_2S_3	150g Al_2S_3 = 25g Al
26g Al	2 mol Al	1 mol Al_2S_3	

8g S	1 mol S	1 mol Al_2S_3	150g Al_2S_3 = 12.5g Al
32g S	3 mol S	1 mol Al_2S_3	

There will be 12.5g of Al_2S_3 produced and S is the limiting reactant.

Assignment.

What mass of aluminium sulphate can be produced from the reaction of 20.0g of sulphuric acid with 25.0g aluminium hydroxide. What is the limiting reactant.

(3)

Example - Limestone

Calcium carbonate decomposes into CaO and CO_2 .
Analogous process is called CaCO_3 and CO_2 .
It is covered from CaCO_3 or CaO .

When a chemical reaction takes place between two or more substances, new substances are formed. The substances that are undergoing the reaction are called reactants (shown at the left hand side) and the products (shown at the right hand side).

In chemical reaction, which are labelled (g), (l), (aq), (s), (p), (c), (d), (e), (f), (h), (i), (j), (k), (l), (m), (n), (o), (p), (q), (r), (s), (t), (u), (v), (w), (x), (y), (z), (aa), (ab), (ac), (ad), (ae), (af), (ag), (ah), (ai), (aj), (ak), (al), (am), (an), (ao), (ap), (aq), (ar), (as), (at), (au), (av), (aw), (ax), (ay), (az), (ba), (bb), (bc), (bd), (be), (bf), (bg), (bh), (bi), (bj), (bk), (bl), (bm), (bn), (bo), (bp), (bq), (br), (bs), (bt), (bu), (bv), (bw), (bx), (by), (bz), (ca), (cb), (cc), (cd), (ce), (cf), (cg), (ch), (ci), (cj), (ck), (cl), (cm), (cn), (co), (cp), (cq), (cr), (cs), (ct), (cu), (cv), (cw), (cx), (cy), (cz), (da), (db), (dc), (dd), (de), (df), (dg), (dh), (di), (dj), (dk), (dl), (dm), (dn), (do), (dp), (dq), (dr), (ds), (dt), (du), (dv), (dw), (dx), (dy), (dz), (ea), (eb), (ec), (ed), (ee), (ef), (eg), (eh), (ei), (ej), (ek), (el), (em), (en), (eo), (ep), (eq), (er), (es), (et), (eu), (ev), (ew), (ex), (ey), (ez), (fa), (fb), (fc), (fd), (fe), (ff), (fg), (fh), (fi), (fj), (fk), (fl), (fm), (fn), (fo), (fp), (fq), (fr), (fs), (ft), (fu), (fv), (fw), (fx), (fy), (fz), (ga), (gb), (gc), (gd), (ge), (gf), (gg), (gh), (gi), (gj), (gk), (gl), (gm), (gn), (go), (gp), (gq), (gr), (gs), (gt), (gu), (gv), (gw), (gx), (gy), (gz), (ha), (hb), (hc), (hd), (he), (hf), (hg), (hh), (hi), (hj), (hk), (hl), (hm), (hn), (ho), (hp), (hq), (hr), (hs), (ht), (hu), (hv), (hw), (hx), (hy), (hz), (ia), (ib), (ic), (id), (ie), (if), (ig), (ih), (ii), (ij), (ik), (il), (im), (in), (io), (ip), (iq), (ir), (is), (it), (iu), (iv), (iw), (ix), (iy), (iz), (ja), (jb), (jc), (jd), (je), (jf), (jg), (jh), (ji), (jj), (jk), (jl), (jm), (jn), (jo), (jp), (jq), (jr), (js), (jt), (ju), (jv), (jw), (jx), (jy), (jz), (ka), (kb), (kc), (kd), (ke), (kf), (kg), (kh), (ki), (kj), (kk), (kl), (km), (kn), (ko), (kp), (kq), (kr), (ks), (kt), (ku), (kv), (kw), (kx), (ky), (kz), (la), (lb), (lc), (ld), (le), (lf), (lg), (lh), (li), (lj), (lk), (ll), (lm), (ln), (lo), (lp), (lq), (lr), (ls), (lt), (lu), (lv), (lw), (lx), (ly), (lz), (ma), (mb), (mc), (md), (me), (mf), (mg), (mh), (mi), (mj), (mk), (ml), (mm), (mn), (mo), (mp), (mq), (mr), (ms), (mt), (mu), (mv), (mw), (mx), (my), (mz), (na), (nb), (nc), (nd), (ne), (nf), (ng), (nh), (ni), (nj), (nk), (nl), (nm), (nn), (no), (np), (nq), (nr), (ns), (nt), (nu), (nv), (nw), (nx), (ny), (nz), (oa), (ob), (oc), (od), (oe), (of), (og), (oh), (oi), (oj), (ok), (ol), (om), (on), (oo), (op), (oq), (or), (os), (ot), (ou), (ov), (ow), (ox), (oy), (oz), (pa), (pb), (pc), (pd), (pe), (pf), (pg), (ph), (pi), (pj), (pk), (pl), (pm), (pn), (po), (pp), (pq), (pr), (ps), (pt), (pu), (pv), (pw), (px), (py), (pz), (qa), (qb), (qc), (qd), (qe), (qf), (qg), (qh), (qi), (qj), (qk), (ql), (qm), (qn), (qo), (qp), (qq), (qr), (qs), (qt), (qu), (qv), (qw), (qx), (qy), (qz), (ra), (rb), (rc), (rd), (re), (rf), (rg), (rh), (ri), (rj), (rk), (rl), (rm), (rn), (ro), (rp), (rq), (rr), (rs), (rt), (ru), (rv), (rw), (rx), (ry), (rz), (sa), (sb), (sc), (sd), (se), (sf), (sg), (sh), (si), (sj), (sk), (sl), (sm), (sn), (so), (sp), (sq), (sr), (ss), (st), (su), (sv), (sw), (sx), (sy), (sz), (ta), (tb), (tc), (td), (te), (tf), (tg), (th), (ti), (tj), (tk), (tl), (tm), (tn), (to), (tp), (tq), (tr), (ts), (tt), (tu), (tv), (tw), (tx), (ty), (tz), (ua), (ub), (uc), (ud), (ue), (uf), (ug), (uh), (ui), (uj), (uk), (ul), (um), (un), (uo), (up), (uq), (ur), (us), (ut), (uu), (uv), (uw), (ux), (uy), (uz), (va), (vb), (vc), (vd), (ve), (vf), (vg), (vh), (vi), (vj), (vk), (vl), (vm), (vn), (vo), (vp), (vq), (vr), (vs), (vt), (vu), (vv), (vw), (vx), (vy), (vz), (wa), (wb), (wc), (wd), (we), (wf), (wg), (wh), (wi), (wj), (wk), (wl), (wm), (wn), (wo), (wp), (wq), (wr), (ws), (wt), (wu), (wv), (ww), (wx), (wy), (wz), (xa), (xb), (xc), (xd), (xe), (xf), (xg), (xh), (xi), (xj), (xk), (xl), (xm), (xn), (xo), (xp), (xq), (xr), (xs), (xt), (xu), (xv), (xw), (xx), (xy), (xz), (ya), (yb), (yc), (yd), (ye), (yf), (yg), (yh), (yi), (yj), (yk), (yl), (ym), (yn), (yo), (yp), (yq), (yr), (ys), (yt), (yu), (yv), (yw), (yx), (yy), (yz), (za), (zb), (zc), (zd), (ze), (zf), (zg), (zh), (zi), (zj), (zk), (zl), (zm), (zn), (zo), (zp), (zq), (zr), (zs), (zt), (zu), (zv), (zw), (zx), (zy), (zz).

Generally, the chemical formula of reactant appears first, followed by a reaction arrow and the chemical formula of the products. The proportions of the reactant and products are expressed by coefficients placed before their formulae and symbols. In parentheses are used to indicate their physical states: (g) for gas, (l) for liquid and (s) for solids. Also, the subscript (aq) denotes aqueous. Examples are:
1. $\text{NaOH}_{(aq)} + \text{HCl}_{(aq)} \longrightarrow \text{NaCl}_{(aq)} + \text{H}_2\text{O}_{(l)}$
2. $\text{H}_2\text{g} + \text{Cl}_{2(g)} \longrightarrow 2\text{HCl}_{(g)} + 2\text{e}$

Balancing chemical equations

When a chemical equation is written, it must be balanced. This follows the:

1. Law of Conservation of mass
2. Law of Conservation of electrical charge must be considered.
3. Writing number (of moles) or coefficient before the chemical compound, if its more than one (1).
4. Stating the physical state of the reactants and products.