Oxides

Oxides are chemical compounds with one or more oxygen atoms combined with another element (e.g. Li_2O).

Introduction

Some oxides can react directly with water to form an acidic, basic, or amphoteric solution. An **amphoteric** solution is a substance that can chemically react as either acid or base. However, it is also possible for an oxide to be neither acidic nor basic. There are different properties which help distinguish between the three types of oxides. The term **anhydride** ("without water") refers to compounds that assimilate H_2O to form either an acid or a base upon the addition of water.

Oxides are binary compounds of oxygen with another element, e.g., CO_2, SO_2, CaO, CO, ZnO, BaO_2, H_2O, etc. These are termed as oxides because here, oxygen is in combination with only one element. Based on their acid-base characteristics oxides are classified as acidic or basic. An oxide that combines with water to give an acid is termed as an acidic oxide. The oxide that gives a base in water is known as a basic oxide.

Acidic Oxides

Acidic oxides are the oxides of non-metals (groups 14-17). These **acid anhydrides** or acidic oxides form acids with water:

- Sulfurous Acid

$$SO_2+H_2O \rightarrow H_2SO_3$$

- Carbonic Acid

$$\mathbf{CO_2+H_2O \rightarrow H_2CO_3}$$

- Sulfuric Acid

$$\mathbf{SO_3+H_2O \rightarrow H_2SO_4}$$

Acidic oxides are, therefore, known as acid anhydrides, e.g., sulfur dioxide is sulfurous anhydride; sulfur trioxide is sulfuric anhydride. When these oxides combine with bases, they produce salts, e.g.,

$$SO_2+2NaOH \rightarrow H_2SO_3+H2O$$

Basic Oxides

Generally Group 1 and Group 2 elements form bases called base anhydrides or basic oxides e.g.,

$$K_2O(s)+H_2O(l) \rightarrow 2KOH(aq)$$

Basic oxides are the oxides of metals. If soluble in water they react with water to produce hydroxides (alkalies) e.g.,

$$\mathbf{CaO+H_2O \rightarrow Ca)OH)_2}$$

$$MgO + H_2O \rightarrow Mg(OH)_2$$

$$Na_2O + H_2O \rightarrow 2NaOH$$

These metallic oxides are therefore, known as basic anhydrides. They react with acids to produce salts, e.g.,

$$MgO + 2HCl \rightarrow MgCl_2 + H_2O$$

$$Na_2O + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$$

Amphoteric oxides

An amphoteric solution is a substance that can chemically react as either acid or base. For example, when HSO_4^- reacts with water it can make hydroxide or hydronium ions.

$$HSO_4^- + H_2O \rightarrow SO_4^{2-} + H_3O^+$$

$$HSO_4^- + H_2O \rightarrow H_2SO_4 + OH^-$$

Amphoteric oxides are metallic oxides, which show both basic as well as acidic properties. When they react with an acid, they produce salt and water, showing basic properties. While reacting with alkalies they form salt and water showing acidic properties, e.g.,

$$ZnO + 2HCl \longrightarrow \underset{\text{zinc chloride}}{ZnCl_2} + H_2O \text{ (basic nature)}$$

$$ZnO + 2NaOH \longrightarrow \underset{\text{sodium zincate}}{Na_2ZnO_2} + H_2O \text{ (acidic nature)}$$

$$Al_2O_3 + 3H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3H_2O \text{ (basic nature)}$$

$$Al_2O_3 + 2NaOH \longrightarrow 2NaAlO_2 + H_2O \text{ (acidic nature)}$$

Amphoteric oxides have both acidic and basic properties. A common example of an amphoteric oxide is aluminum oxide. In general, amphoteric oxides form with metalloids. (see chart below for more detail). Example with acidic properties:

$$Al_2O_3 + H_2O \rightarrow 2Al(OH) + 2H^+$$

Example with basic properties:

$$Al_2O_3 + H_2O \rightarrow 2Al^{3+} + 3OH^-$$

Neutral Oxides

These are the oxides, which show neither basic nor acidic properties, that is, they do not form salts when reacted with acids or bases, e.g., carbon monoxide (CO); nitrous oxide (N_2O); nitric oxide (NO), etc., are neutral oxides.

Peroxides and Dioxides

Oxides: Group 1 metals react rapidly with oxygen to produce several different ionic oxides, usually in the form of M_2O. With the oyxgen exhibiting an oxidation number of -2.

$$4Li + O_2 \rightarrow 2Li_2O$$

Peroxides: Often Lithium and Sodium reacts with **excess** oxygen to produce the peroxide, M_2O_2. with the oxidation number of the oxygen equal to -1.

$$H_2 + O_2 \rightarrow H_2O_2$$

Superoxides: Often Potassium, Rubidium, and Cesium react with excess oxygen to produce the superoxide, MO_2. with the oxidation number of the oxygen equal to -1/2.

$$Cs + O_2 \rightarrow CsO_2$$

A peroxide is a metallic oxide which gives hydrogen peroxide by the action of dilute acids. They contain more oxygen than the corresponding basic oxide, e.g., sodium, calcium and barium peroxides.

$$BaO_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O_2$$

$$Na_2O_2 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O_2$$

Dioxides like PbO_2 and MnO_2 also contain higher percentage of oxygen like peroxides and have similar molecular formulae. These oxides, however, do not give hydrogen peroxide by action with dilute acids. Dioxides on reaction with concentrated HCl yield Cl_2 and on reacting with concentrated H_2SO_4yield O_2.

$$PbO_2 + 4HCl \rightarrow PbCl_2 + Cl_2 + 2H_2O$$

$$2PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O + O_2$$

Compound oxides

Compound oxides are metallic oxides that behave as if they are made up of two oxides, one that has a lower oxidation and one with a higher oxidation of the same metal, e.g.,

Red lead: $Pb_3O_4 = PbO_2 + 2PbO$

Ferro-ferric oxide: $Fe_3O_4 = Fe_2O_3 + FeO$

On treatment with an acid, compound oxides give a mixture of salts.

$$Fe_3O_4 + 8HCl \longrightarrow 2FeCl_3 + FeCl_2 + 4H_2O$$

$$\text{Ferro - ferric oxide} \longrightarrow \text{ferric chloride + ferrous chloride}$$

Preparation of Oxides

Oxides can be generated via multiple reactions. Below are a few.

By direct heating of an element with oxygen

Many metals and non-metals burn rapidly when heated in oxygen or air, producing their oxides, e.g.,

$$2Mg + O_2 \xrightarrow{\text{Heat}} 2MgO$$

$$2Ca + O_2 \xrightarrow{\text{Heat}} 2CaO$$

$$S + O_2 \xrightarrow{\text{Heat}} SO_2$$

$$P_4 + 5O_2 \xrightarrow{\text{Heat}} 2P_2O_5$$

By reaction of oxygen with compounds at higher temperatures

At higher temperatures, oxygen also reacts with many compounds forming oxides, e.g.,

- Sulphides are usually oxidized when heated with oxygen.

$$2PbS + 3O_2 \xrightarrow{\Delta} 2PbO + 2SO_2$$

$$2ZnS + 3O_2 \xrightarrow{\Delta} 2ZnO + 2SO_2$$

- When heated with oxygen, compounds containing carbon and hydrogen are oxidized.

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$$

- By thermal decomposition of certain compounds like hydroxides, carbonates, and nitrates

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

$$2Cu(NO_3)_2 \xrightarrow{\Delta} 2CuO + 4NO_2 + O_2$$

$$Cu(OH)_2 \xrightarrow{\Delta} CuO + H_2O$$

By oxidation of some metals with nitric acid

$$2Cu + 8HNO_3 \xrightarrow{Heat} 2CuO + 8NO_2 + 4H_2O + O_2$$

$$Sn + 4HNO_3 \xrightarrow{Heat} SnO_2 + 4NO_2 + 2H_2O$$

By oxidation of some non-metals with nitric acid

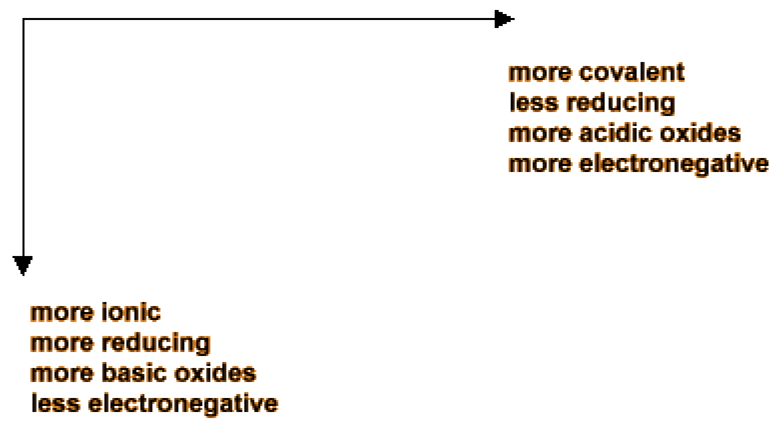
$$C + 4HNO_3 \longrightarrow CO_2 + 4NO_2 + 2H_2O$$

Trends in Acid-Base Behavior

The oxides of elements in a period become progressively more acidic as one goes from left to right in a period of the periodic table. For example, in third period, the behavior of oxides changes as follows:

Na_2O, MgO	Al_2O_3, SiO_2	P_4O_{10}, SO_3, Cl_2O_7
Basic	Amphoteric	Acidic

If we take a closer look at a specific period, we may better understand the acid-base properties of oxides. It may also help to examine thephysical properties of oxides, but it is not necessary. Metal oxides on the left side of the periodic table produce basic solutions in water (e.g. Na_2O and MgO). Non-metal oxides on the right side of the periodic table produce acidic solutions (e.g. Cl_2O, SO_2, P_4O_{10}). There is a trend within acid-base behavior: basic oxides are present on the left side of the period and acidic oxides are found on the right side. However, this trend yields the question of where and when does the shift occur? The figure below shows how, as we move from left to right, the oxides are more acidic and as we move from top to bottom, the oxides are more basic.



Aluminum oxide shows acid and basic properties of an oxide, it is amphoteric. Thus Al_2O_3 entails the marking point at which a change over from a basic oxide to acidic oxide occurs. It is important to remember that the trend only applies for oxides in their highest oxidation states. The individual element must be in its highest possible oxidation state because the trend does not follow if all oxidation states are included. Notice how the amphoteric oxides (shown in blue) of each period signify the change from basic to acidic oxides.

Groups: 1 2 3 14 15
16 17

Li	Be	B	C	N	O	F
Na	Mg	Al	Si	P	S	Cl
K	Ca	Ga	Ge	As	Se	Br
Rb	Sr	In	Sn	Sb	Te	I
Cs	Ba	Tl	Pb	Bi	Po	At

The figure above show oxides of the *s*- and *p-block* elements.

purple: basic oxides blue: amphoteric oxides pink: acidic oxides

Source: http://chemwiki.ucdavis.edu/Inorganic_Chemistry/Descriptive_Chemistry/Compounds/Oxides