Context 1: The oxidation of sulphur and acid formation

Key words:

sulphur oxides, sulphurous acid, sulphuric acid, sources of sulphur compounds

Formation of acids

Sulphur oxides are primarily formed during the combustion of sulphur or the oxidation of sulphur compounds. In the air, they react to particles of sulphuric acid. Acid rain is an environmental problem mainly based on the release of sulphur oxides (sulphur dioxide and sulphur trioxide) as a result of human activity. Nitrogen oxides also play a role in acid rain formation.

Sources of sulphur dioxide

Suphur dioxide is naturally found in volcanic gases and as a product of the oxidation of dimethyl sulphide from oceanic phytoplankton (algeae) or other sulphur compounds formed by micro-organisms. The latter process is described in ACCENT magazine Nr. 5 (oceanic sulphur).
Additionally it is formed in the combustion of coal, heating oil and heavy fuel oil for ship engines, because theses fuels contain some sulphur. These sources are due to human activity.

1. Piece of coal with a sulphur band
Source: www.liathach.supanet.com

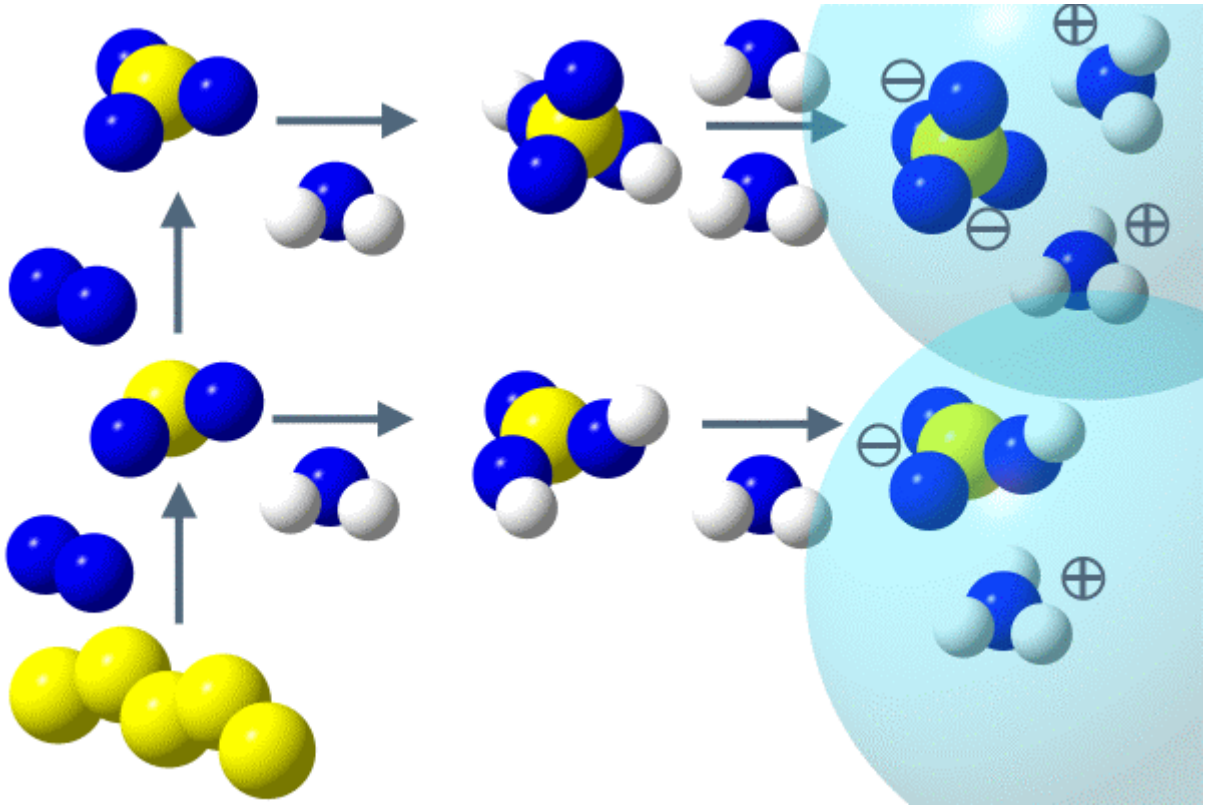
Table: Sulphur emissions in the world

Source	World-wide sulphur emission [Teragramme S per year] average (range)	Contribution to the emissions [%]	Contribution to the sulphur content of the air [%]
Caused by humans	70 (60 - 100)	70	37
volcanic	7 (4 - 16)	7	18
biogenous	22 (15 - 50)	23	42

> 90% of all biogenous emissions are DMS.

Sulphur dioxide can destroy pigments. Therefore, in industry it is used as bleaching agent. The disinfecting effect of sulphur dioxide is often used for the conservation of food (for

example in dried fruit).



2. Sulphur oxidation and reaction with water: Read the text below and explain which compounds are formed during the oxidation / combustion process and in reactions with water. What happens in rain droplets (on the right)? Colour code of the atoms: S = yellow, O = blue, H = white
Scheme: Elmar Uherek

From sulphur dioxide to sulphurous acid

If sulphur dioxide is dissolved in water, it forms a weak acid solution, sulphurous acid.

$$H_2O + SO_2 \rightleftharpoons H_2SO_3$$

In water, sulphurous acid forms hydrated protons H^+ (aq) and two sorts of anions are formed:

$$H_2SO_3 \rightleftharpoons H^+(aq) + HSO_3^-(aq)$$

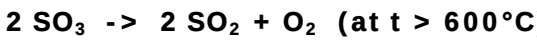
Sulphurous acid forms a proton and a hydrogen sulphite anion

$$HSO_3^-(aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq)$$

Hydrogen sulphite gives a proton and a sulphite anion.
From each molecule of sulphurous acid two protons can be released. Therefore sulphurous acid is called a bi-protonous acid.
However, sulphurous acid is an unstable acid. Already, at normal room temperature, it decomposes into sulphur dioxide and water.

Sulphuric acid

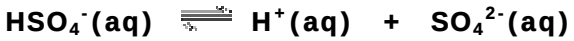
With the combustion of sulphur and during oxidative reactions in the air not only sulphur dioxide is formed but also sulphur trioxide. The amount formed of each of these gases depends strongly on the temperature, since sulphur trioxide decomposes into sulphur dioxide and oxygen at temperatures above 600°C:



If sulphur trioxide dissolves in water, sulphuric acid is formed:

Sulphuric acid is also a bi-protonous acid which decomposes in water to yield two protons and an anion.

In the first step sulphuric acid forms a proton and hydrogen sulphate anion.



Hydrogen sulphate decomposes to give another proton and a sulphate anion.

Acid rain

The solution of sulphuric acid in the water of rain drops increases the concentration of protons, i.e. the pH value decreases. The rain becomes more acidic. Acid rain does not only dissolve some rocks (carbonate rock), but also attacks metal surfaces and mobilises certain ions in the soil, which are toxic for plants. The consequences are damage to buildings, metal tools, the acidification of lakes and damage to forests.

You will find more detailed information on acid rain by choosing the links in the link list.

3. a) A limestone sculpture of one of the twelve apostles at the front of the St. Peter and St. Paul church in the old town of Krakow, Poland. Acid rain has caused incredible damage and copies of this and the other eleven apostles have been made to replace the originals. Photo: Sebastian Wypych.

3. b) The copy made to replace the damaged original apostle sculpture. Photo: Sebastian Wypych.

Authors:
Andrea Heiseler - Chemistry teacher, Cologne/Bonn (Germany)
Elmar Uherek - Max Planck Institute for Chemistry, Mainz
English check: Mark Jacob, TU Freiberg