Name _____ Block: _____ Date: _____

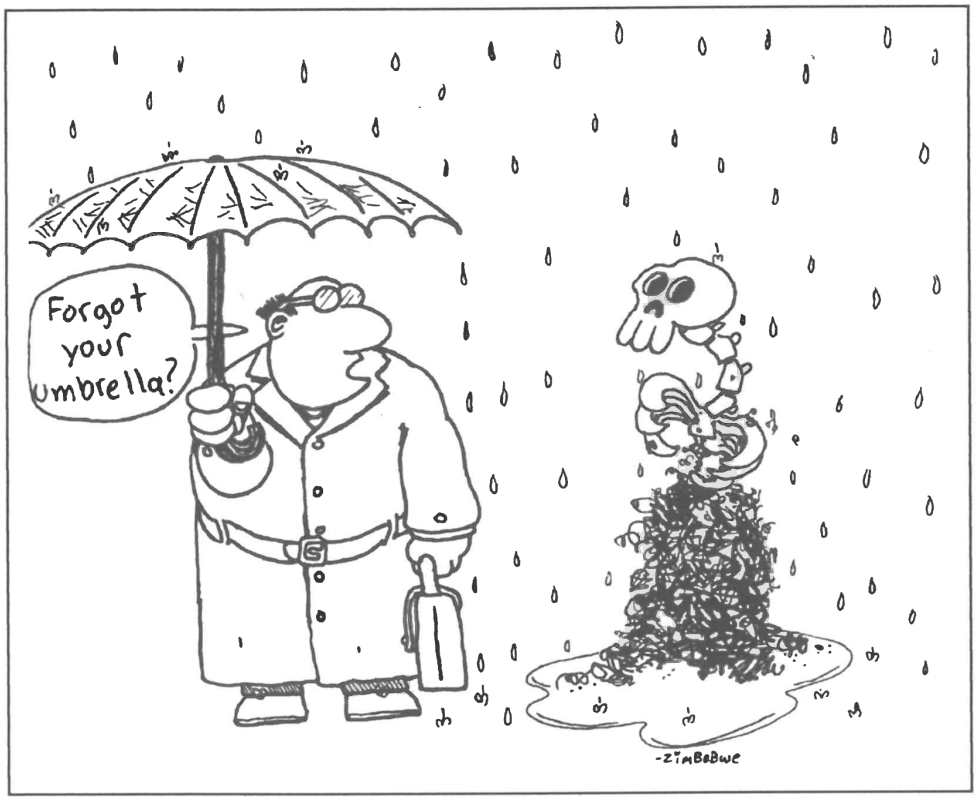
Chemistry 12

ACID RAIN

Because of dissolved CO_2, rain is naturally slightly acidic with a pH of about 5.6.

$$CO_2 + 2\,H_2O \rightleftharpoons H_3O^+ + HCO_3^-\,.$$

Any precipitation with pH < 5.6 is called "acid rain".



Sources of the acidity in acid rain

Most fuels, including coal and oil, are mixtures of many different hydrocarbons, some of which contain sulphur. When fuels containing sulphur are burned, the sulphur present forms sulphur dioxide.

$$S + O_2 \longrightarrow SO_2$$

Subsequent reaction of the SO_2 with air gives

$$2\,SO_2 + O_2 \rightleftharpoons 2\,SO_3$$ (dust and water act as catalysts for this reaction).

When the gases SO_2 and SO_3 join with water vapour, acids are formed.

$$SO_2 + H_2O \longrightarrow H_2SO_3$$ ("sulphurous acid")
$$SO_3 + H_2O \longrightarrow H_2SO_4$$ ("sulphuric acid")

The mixture of SO_2 and SO_3 is often referred to as "SO_X".

Similarly, combustion reactions (such as in an automobile) cause small amounts of N_2 to react with oxygen in the air.

$$N_2 + O_2 \longrightarrow 2\,NO$$
$$N_2 + 2\,O_2 \longrightarrow 2\,NO_2$$

Subsequently, some of the NO reacts with atmospheric O_2.

$$2\,NO + O_2 \rightleftharpoons 2\,NO_2$$

In addition, some of the NO_2 also reacts with water vapour.

$$2\,NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$

Similar to sulphur oxides, mixtures of NO and NO_2 are referred to as "NO_X".

The combined "soup" of H_2SO_3, H_2SO_4, HNO_2 and HNO_3 constitutes "acid rain".

It should be noted that nature also contributes to the acid rain problem with volcanic eruptions, gases given off by rotting vegetation, etc. For example, nitric oxide, NO, is produced in relatively large quantities by lightning and sulphur dioxide is spewed out in massive amounts by some volcanic eruptions.

Natural Protection Against Acid Rain

Most lakes have a moderate CO_2 / HCO_3^- buffering capacity, but once a lake receives large amounts of acid rain, the buffering capacity is exceeded and the lake ecosystems begin to be harmed. However, if the acid rain is halted, the absorption of CO_2 from the atmosphere eventually reverses most, if not all, of the effects of acid rain.

In addition, some lakes are in limestone–rich areas. The limestone ($CaCO_3$) can neutralize the acidity of acid rain. For example:

$$H_2SO_4(aq) + CaCO_3(s) \longrightarrow CaSO_4(s) + CO_2(aq) + H_2O(l).$$

Eventually, however, even the available limestone may be used up. In some cases, lakes may have powdered limestone dumped into them from airplanes to reverse some of the effects of acid rain.

Some Environmental Problems Associated with Acid Rain

1. Fish and plant growth is seriously affected in acidified water and soil. Many lakes are now "fishless" and contain little or no algae. Forests begin to die whenever their soil is sufficiently acidified. The devastation of the sugar maples in Quebec, the Black Forest in Germany and much of the forests of Scandinavia is evidence of the killing effects of acid rain. The question then becomes: how much is the heritage of a people worth?

2. Acid rain leaches minerals out of rocks and soils. For example, poisonous substances such as aluminum ions are leached out of rocks, while beneficial nutrients are leached out of the topsoil and down to the subsoils where these nutrients are generally unavailable for plant growth.

3. Metal and stone structures, especially buildings made of limestone (which has been much favoured as a building material in the past), are damaged by acid rain. The facings of many ancient buildings are now completely destroyed and many statues are unrecognizable.

Other Problems Related to Acid Rain

1. Acid rain often falls to earth far from the region in which it was created. Until international agreements were reached, nations often didn't bother to clean up their pollution because they didn't suffer directly from the effects of the acid rain they create. The cost of cleaning up industrial processes, using different fuels or alternate engines in cars is ENORMOUS and may require industries to be closed down if they can't afford to comply with strict pollution regulations. It is often considered to be political suicide to spend vast sums of money when the average person sees no immediate benefit. Who should pay for the cleanup?
2. People's health suffers directly and indirectly from water contaminated by acid rain, and water contaminated by chemicals leached from rocks.
3. Food crops such as radishes, tomatoes and apples are easily destroyed by acid rain.

Glimmers of Hope

An upsurge in public awareness on many environmental issues, including acid rain, has started a wave of well–publicized international conferences and agreements concerned with overcoming such problems and halting pollution. Abandoning our technology is not the answer, for then nothing could reverse some of the problems which have been set in motion. However, new technologies offer a way to bring many of the problems to a halt.

- Alternate nonpolluting energy sources are increasingly being used.
- Industrial processes are being modernized to cut down on pollution and to recycle harmful waste products.
- International cooperation on pollution problems is proceeding at an accelerating rate; people are making their governments listen to their concerns.

EXERCISES:

146. Some of the most acidic rain ever observed had a pH of 2.2. If 2.5 cm of such rain fell into a small lake having a surface area of 25 hectares ($2.5 \times 10^5\ m^2$) over a 24 hr period, how many kilograms of limestone ($CaCO_3$) would be required to neutralize the effects of this single rainfall? ($10^3\ L = 1\ m^3$) The neutralization equation is

$$CaCO_3 + 2\,H_3O^+ \longrightarrow Ca^{2+} + CO_2 + 3\,H_2O\,.$$

147. The aluminum ions leached out of rocks by acid rain will be in the form: $Al(H_2O)_6^{3+}$. Why will these ions add to the problem of groundwater acidity?