

A demonstration of acid rain

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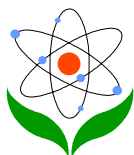
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Abstract

A demonstration showing acid rain formation is described. Oxides of sulfur and nitrogen that result from the burning of fossil fuels are the major pollutants of acid rain. In this demonstration, SO_2 gas is produced by the burning of matches. An acid-base indicator will show that the dissolved gas turns an aqueous solution acidic.

What acid rain is

As atmospheric CO_2 dissolves in water to form carbonic acid, rain is naturally acidic. Normal rain has a pH of about 5.6. It has been generally considered that rain whose



pH is lower than 5.6 to be acid rain because this is the pH value of carbon dioxide in equilibrium with distilled water.

The main cause of acid rain is the presence of strong mineral acids, mainly sulfuric (H_2SO_4) and nitric (HNO_3) acids, derived from the atmospheric oxidation of sulfur dioxide (SO_2) and nitrogen oxides (NO_x). These gases are emitted from both natural and anthropogenic sources.

Volcanic eruptions release gaseous SO_2 and H_2S that are eventually converted to sulfuric acid. Thus rain that falls far from inhabited or industrialized areas, through supposedly unpolluted air, has a pH lower than 5.6 - generally about 5.0.

The burning of fossil fuels is the most important anthropogenic source. Sulfur as pyrite is present as impurities in coal, gasoline and petroleum products and is oxidized to SO_2 when these fuels are burned. Nitrogen oxides released from the burning of fossil fuels in automobiles and power plants come from the air itself rather than from impurities in fuels. Nitrogen and oxygen of the air can be converted to NO at high temperatures. The temperatures of combustion chambers of the internal combustion engine are effective in this conversion. NO reacts with oxygen to form NO_2 which dissolves in water to form nitric acid.

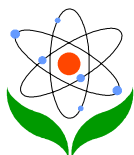
The effects of acid rain

Acid rain has a variety of ecologically damaging consequences, including the following:

- Direct toxic effects to plants from excessive acid concentrations
- Indirect toxic effects to plants, such as Al^{3+} liberated from soil
- Acidification of lake water with toxic effects to living organisms
- Corrosion of metal and building materials
- Respiratory effects on humans and other animals

Old demonstration on acid rain

Acid rain is a familiar environmental problem that is discussed in chemistry or environmental lectures in universities as well as in secondary schools. Several demonstrations related to acid rain have been published (Goss, 2003; Solomon, Oliver-Hoyo & Hur, 1998; Driscoll, 1997). These involve the generation of either SO_2



or NO_2 . Then the gas is dissolved in water and turns the color of an acid-base indicator to show the solution is acidic. Both of these gases are toxic that will cause concern for safety. In these demonstrations, as a considerable amount of these toxic gases are produced, they have to be carried out in a fume cabinet.

New demonstration on acid rain

In this demonstration, SO_2 is produced simply by the burning of matches. No special apparatus or chemicals apart from an indicator are required. No special safety precautions have to be taken as well.

Procedure

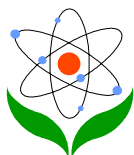
Experimental set-up

1. Prepare an indicator solution by dissolving 0.01g methyl orange in 100 ml distilled water.
2. Dilute the indicator solution from 10 ml to 50 ml. Add 10 ml of the resulting indicator solution to each of the 2 glasses.
3. Stick a wooden splint to the inner side of the glass containing 10 ml indicator solution by a blue tack (Fig. 1a).
4. Stick 2 matches to the inner side of another glass containing 10 ml indicator solution by a blue tack (Fig.1b).



Fig. 1a

Fig. 1b



Production of acidic gases

5. Ignite the wooden splint (Fig. 2a) and the matches (Fig. 2b) by a glowing splint.



Fig. 2a

Fig. 2b

Collection of acidic gases

6. Cover the glasses with watch glasses.

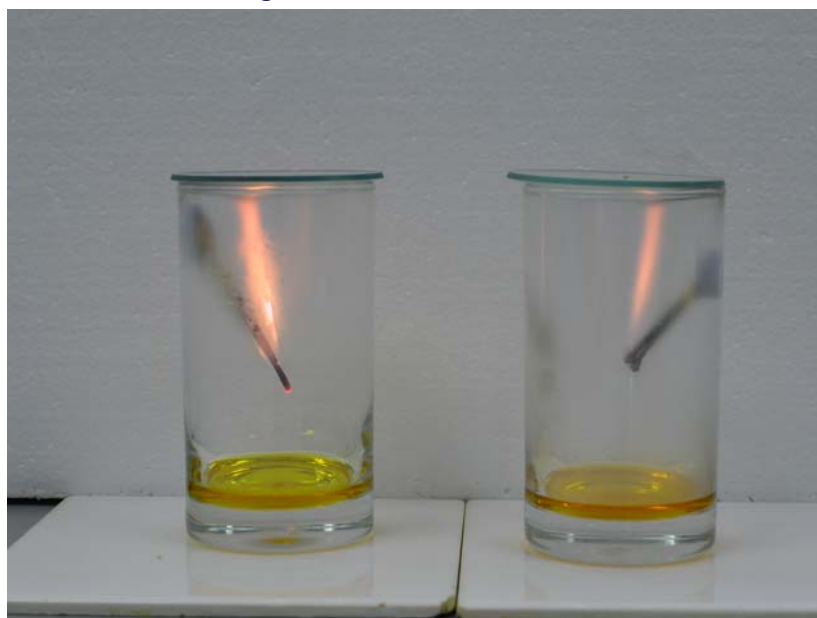


Fig. 3a

Fig. 3b

Indication of the formation of acid rain

7. Swirl the indicator solutions gently and observe their color.

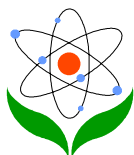


Fig. 4a

Fig. 4b

Discussion

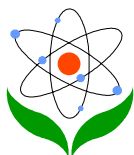
The pH range over which the indicator changes from the acid color to the basic color for methyl orange is 3.2-4.4 (Lide, 2002). At $\text{pH} > 4.4$, the yellow basic form predominates. On the other hand, if methyl orange is in a solution of $\text{pH} < 3.2$, the red acidic form predominates.

The burning matches have produced a color change of the indicator from yellow (Fig. 1b) to red (Fig. 4b). It indicates that something acidic dissolved in the indicator solution. We can ask two questions?

1. What acid caused the color change?
2. Where did this acid come from?

We may consider carbonic acid as the source of the acid as it is a product of the combustion of wood. However, the burning of the wooden splint (Fig. 4a) did not cause a color change of the indicator. We have to conclude that the ignited match introduced something much more acidic than CO_2 . The acid must have come from something in the flammable head of the match.

The head of a match contains sulfur and potassium chlorate(V). The match can be ignited when the head comes in contact with phosphorus, generally coated on the side



of the box. The chemical reaction when we strike a match is the oxidation of a 'fuel' by potassium chlorate(V). Sulfur in the match head acts as the fuel, while phosphorus only initiates the reaction (Emsley, 2001). SO₂ is produced as a result of the oxidation of sulfur. The reaction of the burning of a safety match goes as follows:



SO₂ is significantly more soluble in water than CO₂, as indicated by its Henry's law constant of 1.2 molL⁻¹atm⁻¹ compared to 3.38 x 10⁻² molL⁻¹atm⁻¹ for CO₂ (Lide, 2002). The value of the acid dissociation constant of 1.7 x 10⁻² for SO₂ is more than four orders of magnitude higher than the value of 4.45 x 10⁻⁷ for CO₂ (Lide, 2002). Thus, a small amount of dissolved SO₂ is able to lower the pH of a solution considerably resulting in the observed color change of the indicator. Dissolved CO₂ can also lower the pH of a solution, but to a much lesser extent that it is unable to cause a color change of the indicator.

References

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