Diffusion of Ammonia in the Atmosphere

Ammonia (NH_3) is the most abundant alkaline gas in the Earth's atmosphere. Its emission into the atmosphere surged in the 1910s following its commercial production as an agricultural fertilizer. The use of NH_3 as a fertilizer has allowed humankind to produce larger crop yields and a greater abundance of livestock than would have been possible otherwise. Despite these benefits for food security, the increased production of NH_3 has perturbed the natural nitrogen cycle and particularly has influenced the chemistry that occurs in our atmosphere.

Figure 1: NH_3 fertilizer application to a cropland
(Source: https://wattsupwiththat.com)

When NH_3 is applied to an agricultural field, it can enter the gas phase and diffuse through the atmosphere. As NH_3 has a lifetime of approximately 70 days in the troposphere, it can be transported to other areas and promote chemical reactions along its journey. NH_3 preferentially reacts with acidic gases in the atmosphere, such as sulphuric acid (H_2SO_4) or hydrogen chloride (HCl), as shown below:

$$NH_{3(g)} + HCl_{(g)} \leftrightarrow NH_4Cl_{(white\ solid)}$$

Figure 2: Emissions from a coal power plant
(Source: https://inhabitat.com)

Acidic gases like HCl can be emitted into the atmosphere from a variety of sources, however the dominant source in many areas worldwide is from the burning of coal for electricity production. Its reaction with NH_3 shown above is a reversible reaction, therefore it can be considered only a temporary reservoir of NH_3 rather than a permanent sink. Even even after its reaction with HCl, NH_3 can continue to travel throughout the atmosphere and influence chemical reactions.

The presence of both NH_3 and HCl in the atmosphere can have toxic effects for plants and lichens, even in low concentrations. More predominantly, the formation of aerosol particles in the upper atmosphere by reaction of NH_3 with acidic gases can nucleate cloud formation, which impacts everything from the Earth's radiation balance to the occurrence of severe weather events. Because of the influence that both NH_3 and HCl have on atmospheric chemical reactions measurements of their rates of diffusion is of interest for many environmental chemists. However, current analyses rely on complex methods for measurements of diffusion, such as the use of elaborate gas flow chambers coupled to mass spectrometry (MS) instrumentation. Therefore, what is required is a low cost, experimentally simple method for the determination of the diffusion rates of these gases.

Instructions to Students

Your task is to design a laboratory experiment that can quantify the rate of diffusion (defined as distance travelled per unit time) for each of NH_3 and HCl in the atmosphere. Your experiment should use only items that can be found in a common chemistry laboratory (i.e. glassware, rubber stoppers, relevant chemicals, etc.). Hint: Keep in mind the physical states of the reactants and products when designing your experiment. You should include all necessary steps and equipment that would be required to perform the experiment.

Questions

How would you theoretically calculate a ratio of the rates of diffusion of two different gases? Compare this theoretical calculation for the ratio of diffusion rates between HCl and NH_3 to your estimated values from your experiment.

Would you expect there to be differences from your results and rates of diffusion in the open atmosphere? Why?