Experiment 18
Properties of Gases

The Task

In this experiment you will investigate some of the properties of gases, *i.e.* how gases flow, their phase changes and chemical reactivity.

Skills

At the end of the laboratory session you should be able to:

- handle cryogenic liquids and high pressure gas cylinders safely,
- handle syringes safely,
- measure flow times of gases.

Other outcomes

- You will discover how the mass of a gas and its velocity are related.
- You will discover what determines the kinetic energy of a gas.
- You will get some understanding of the concept of errors in measurements.
- You will observe phase changes of gases.
- You will discover the effect of pH on the solubility of carbon dioxide.

The Assessment

You will be assessed on your ability to graph with error bars, to stress the importance of considering the accuracy of experimental data.

Introduction

Gases are all around us. We rely on oxygen in the atmosphere for our survival, while plants rely on the presence of carbon dioxide to enable the production of carbohydrates via photosynthesis. All life is dependent on the conversion of nitrogen in the atmosphere to ammonia, NH_3, by plants and bacteria, because the nitrogen contained in ammonia is essential for the formation of nucleotides and amino acids, the basic building blocks of nucleic acids (RNA and DNA) and proteins, respectively. If not for greenhouse gases in our atmosphere (*e.g.* water vapour and CO_2) the whole surface of the Earth would be permanently covered by snow and ice, but excessive CO_2 emissions now threaten over-heating of the Earth and the melting of the ice caps. However, despite the obvious importance of gases to our lives, we tend to ignore them. Many of them are invisible and have no odour, and therefore, other than on windy days, we often don't notice them at all and we have little direct experience with their behaviour. In this experiment you will gain experience in dealing with gases and discover some of their properties.

Safety

Chemical Hazard Identification

carbon dioxide - non-hazardous. Non-toxic, asphyxiant gas.

nitrogen - non-hazardous. Non-toxic, asphyxiant gas.

argon - non-hazardous. Non-toxic, asphyxiant gas.

4 M HCl - hazardous. Highly corrosive, severe irritant.

4 M NaOH - hazardous. Highly corrosive, severe irritant.

Risk Assessment and Control

Moderate risk.

Needle stick and eye injuries are possible with syringes. If gas is injected into the skin seek medical attention from the Service Room immediately. If walking around the lab holding a syringe, make sure the needle is pointing downwards towards the floor.

Liquid nitrogen can freeze the skin and cause cryogenic (cold) burns.

Waste Disposal

All of the solutions can be disposed of down the sink.

Experimental

This experiment is to be carried out in pairs.

Part A Gas flow velocities and effusion

The principle of the measurements is for you to determine the velocities with which different gases flow from a syringe through a hollow needle into a small space continuously evacuated by a pump. This phenomenon is known as *effusion*. You measure the flow time for all the gas to leave the syringe, t, using a stopwatch, and the total distance that the gas plunger moves, s, with a ruler. You then calculate the gas flow velocity, $v = s/t$.

Effusion requires the gas molecules to pass through the hole in the centre of the needle to escape to the outside. In effect, each molecule must collide with the escape hole. The number of times this happens is directly proportional to the *average speed* of the gas molecules and thus the gas flow velocity. Of course, the gas flow velocity will also depend on the diameter of the hole in the needle and the strength of the vacuum, but in today's experiment both of these are held constant. Hence any differences in flow velocities must be due to the differences in the average speeds of the gas molecules.

Record all flow times for this part of the experiment in your logbook.

(A1) Obtain from your demonstrator one of the special syringe kits containing a stopwatch that can be read to 0.1 s and an ungreased 50 mL syringe fitted with a hollow metal needle.

(A2) The large nitrogen cylinder at the back of the laboratory has a main and a fine control valve. The main control valve will be set by the Service Room staff and you should not alter it. The fine control valve is fitted with a rubber septum. One student should adjust the fine control valve while the other student holds the syringe firmly by the barrel and plunger. To fill the syringe, pierce the rubber septum with the needle of the syringe and turn the fine control valve anticlockwise until the gas pressure is sufficient to push the plunger back smoothly. When about 55 mL of nitrogen gas has entered the syringe, close the valve and withdraw the needle cleanly and deliberately.

(A3) Back at your desk, insert a small rubber cap over one of the glass side arm attachments to the laboratory vacuum line. Turn on the tap to the vacuum line attachment and leave it on while carrying out steps (A4) - (A6). **N.B.** To obtain comparable data for all of the gases you investigate, it is crucial that you:

- don't close the tap to the vacuum line between measurements on different gases,
- use the same syringe for all experiments.

(A4) While one student operates the stopwatch, the other, holding the syringe horizontally, must carefully puncture the rubber cap with the syringe needle. The student with the stopwatch should then measure the time from the instant the plunger passes the 50 mL graduation until the instant that it reaches the zero mark. If the plunger doesn't move smoothly along the syringe barrel, ask your demonstrator to clean the syringe, then repeat the measurement.

(A5) Repeat steps (A2) - (A4) to obtain 3 or 4 measurements of the flow-time for N_2.

(A6) Repeat steps (A2) - (A5) to obtain flow times for the other gases that are available.

For your logbook:

Convert your flow times, t, *into flow velocities,* v.

s = *distance from the 50 mL graduation mark to the 0 mark*

v = s/t.

Draw a graph of average gas flow velocity (y-axis) against molar mass of the gases (x-axis). Include error bars for each point. Error range = highest – lowest value for each calculated value of v.

*Describe the experimental behaviour you observed (*i.e.*, does the flow velocity increase, decrease or remain the same with increasing molar mass; if there is a change, is it linear or not.)*

According to classical mechanics, the kinetic energy, E_K*, of a particle is given by* $E_K = ½mv^2$. *As discussed earlier, your flow velocities are directly proportional to the average molecular speed of each gas. Therefore, based on the equation for kinetic energy, calculate a quantity (let's call it* E_{exp}*) that is directly proportional to the average kinetic energy per mole of each gas from your flow velocities and their molar masses.*

Calculate a value of E_{exp} *for each flow time measurement you made and, from these, an average* E_{exp} *for each gas. Then draw a graph of average* E_{exp} *(y-axis) against molar mass of the gases (x-axis).*

Based on the variation in flow times you measured for each gas, estimate errors in each value of average E_{exp} *and record them on your graph as error bars.*

*Describe the behaviour you observed (*i.e.*, does the kinetic energy increase, decrease or remain the same with increasing molar mass).*

Note: It is to be expected that there will be some non-systemic variation in any set of measurements. Therefore the error bars on the E_{exp} values are essential in order for you to judge whether or not the variation you observe is significant.

Part B Phase changes

At normal atmospheric pressure, gases only undergo physical changes at low temperatures. Test tubes attached to balloons filled with the gases you will investigate, argon and carbon dioxide, are available at the front of the laboratory. You will obtain the low temperatures required by using liquid nitrogen.

(B1) Collect some liquid nitrogen in a doubly insulated foam cup from a demonstrator. Place the foam cup in a 250 mL beaker for improved stability.

(B2) Collect a balloon filled with argon, return to your bench and carefully place the test tube into the liquid nitrogen. **Record your observations in your logbook.**

(B3) Lift the test tube out of the liquid nitrogen. Immediately inspect the contents of the test tube. **Record your observations in your logbook.**

(B4) Allow the test tube to warm to room temperature and **record what happens to the contents of the test tube and the balloon in your logbook.**

(B5) Collect a balloon filled with carbon dioxide and repeat steps (B2) - (B4).

For your logbook:

How did the behaviour of carbon dioxide differ from that of argon?

From your observations, can you suggest, for a fixed volume of gas, what determines its pressure (and kinetic energy)?

Part C Solubility of carbon dioxide in water

The solubility of carbon dioxide has important environmental consequences, which you will discuss later. In this part of the experiment you will investigate the solubility of carbon dioxide in acidic, neutral and basic water solutions.

(C1) **Copy the following table into your logbook and record all your observations into it.**

	Volume (mL)			pH from colour of universal indicator.
	Initial	Final V_{final}	Dissolved V_{sol}	
H_2O (5.0 mL)	45			
H_2O (5.0 mL) + 4 M NaOH (1.0 mL)	46			
H_2O (5.0 mL) + 4 M NaOH (1.0 mL) + 4 M HCl (1.0 mL)	47			

(C2) Collect freshly boiled deionised water (about 10 mL) to which universal indicator has already been added.

(C3) Take the three syringes from the gas-syringe kit provided. Check that they are clean, and that the plungers move freely. Fit the rubber cap to the 50 mL syringe, making sure it seals tightly. Fit the 5 mL and 1 mL syringes each with a hollow plastic needle.

(C4) Use the dispensing syringe provided with the large cylinder of CO_2 (at the front of the laboratory) to inject 40 mL of CO_2 into your 50 mL syringe through the cap.

(C5) Draw 5.0 mL of the freshly boiled deionised water into the 5 mL syringe and inject the contents through the cap of the 50 mL syringe. **Shake until the volume is constant, then record it in the first line of your table in your logbook. Determine the pH of the solution using the comparison cards on the side wall and record it also in the table in your logbook.** Retain the syringe and its contents for the remainder of this part of the experiment.

(C6) Using the 1 mL syringe, inject 1.0 mL of 4 M NaOH into the 50 mL syringe. Shake to equilibrate. **Record the final volume and the pH in the second line of the table in your logbook.**

(C7) Empty the 1 mL syringe, and rinse thoroughly to remove all traces of NaOH. Then rinse twice with a little 4 M HCl, and use the syringe to inject 1.0 mL of 4 M HCl into the 50 mL syringe. Shake until the system has returned to room temperature, the heat of the reaction no longer being detectable. **Record the final volume and pH of the solution in the last line of the table in your logbook.**

(C8) Clean and dry the syringes. Store the syringe barrel and piston separately in the box provided.

For your logbook:

What effect did the dissolution of carbon dioxide have on the pH of water, i.e. *does it become acidic or basic?*

Try to write chemical equations to explain the effect of carbon dioxide on the pH of water.

Was carbon dioxide more soluble in basic solution or acidic solution?

Try to write chemical equations to explain the dependence of carbon dioxide solubility on pH.

Group Discussion

From your experiment today, can you explain the effect that increased carbon dioxide levels in the atmosphere would have on the pH of the seas?

There exists an equation, known as the ideal gas equation, which relates the pressure, P, of a gas to its temperature, T and its concentration, c. ($c = n/V$, where n is the number of moles of gas and V is its volume.) The equation can be expressed in the following form:

$$P = constant \times cT$$

where the constant has the same value for all gases. From the results of your experiment today, can you explain why this equation applies to all gases at normal temperatures and pressures?