Kinetic Theory and Boyle`s Law

# Aims

* ***recall and solve problems using the equation of state for an ideal gas expressed as pV = nRT (n = number of moles).***
* ***infer from a Brownian motion experiment the evidence for the movement of molecules.***
* ***state the basic assumptions of the kinetic theory of gases.***

# Brownian motion in a smoke cell

This is a ‘classic’ experiment that gives strong circumstantial evidence for the particulate nature of air.

You will need:

* Smoke cell, incorporating a light source and lens (Whitley Bay pattern)
* Microscope, low power (e.g. x10 objective, x 10 eyepieces) and large aperture
* Power supply, 0 to 12 V dc
* Microscope cover-slip
* Smoke source (e.g. paper drinking straw)

Set up



The smoke can come from a piece of burning cord using a dropping pipette or a burning straw (preferably paper). The straw should burn at the top and then be extinguished. The bottom end of the straw should poke into the plastic smoke container.

The cell may need to be cleaned if a waxy or plastic straw is used.

Remove the glass cell from the assembly to clean it. Afterward, push it fully back into the assembly. It may help to wet the outside of the glass tube. You will find it helpful to clean the glass cell after every five to ten fillings to obtain the best results; otherwise the light intensity is reduced.

The cell is illuminated from one side to make the smoke particles visible under the microscope. This is called dark ground illumination. A small piece of black card prevents stray light from the lamp reaching the eye. The lamp is placed below the level of the glass rod in order to minimise convection.

What to do



1. Fill the cell with smoke using a dropping pipette and cover it with a glass cover-slip. This will reduce the rate of loss of smoke from the cell
2. Place the cell on the microscope stage, fit the mask and connect to a 12 V power supply.
3. Start with the objective lens of the microscope near the cover-slip. While looking through the microscope, slowly adjust the focus, moving the objective lens away from the cover-slip, until you see tiny dots of light.
4. Watch the particles carefully. Note what you see.

# Brownian motion: facts and myths

Robert Brown is correctly referred to as having observed the jittering motion of small particles, but

1. he wasn't the first to record the observation,

and

1. he did NOT observe the motion of actual pollen grains.

How many text books etc continue to hand on these mistakes?

The title of Browns paper was "A Brief Account of Microscopical Observations ... on the Particles CONTAINED in the Pollen of Plants". Pollen itself is too large (and hence has too much mass) to be small enough to be buffeted significantly by water molecules etc. [The most recent reference pointing this out: *Nature*, 10 March 2005 p 137]

The first recorded observation of what we now call Brownian motion was made in 1785 by Jan Ingenhauz using charcoal dust. [Ref: *Nature,* 7 June 2001 p 641]

Having used particles derived from living matter, Brown had to try several other inanimate substances to convince himself that the motion he observed was not something to do with a 'life force', but a property of all microscopic matter. This 'systematic investigation' is what won for Brown the accolade of having the jittering motion named after him, work that Ingenhauz didn't need to do.

Today's research into nano technology now routinely fabricates nanoparticles. Controlling them suspended in liquids is quite a task. One method is to use a direct current controlled by a feedback system to cancel out the Brownian Motion. The position of the 20 nm polystyrene spheres is monitored by a fluorescence microscope and the voltage across the solution altered accordingly. So far nano-particles have been confined to within 1 micron. Alternatively, the path of the particle can be manipulated by suitable changes of the applied voltage. [Ref: *Nature*, 10 March 2005 p 156.]

Even before the recent advent of nano-technology, Einstein's 1905 paper on Brownian Motion is his most cited paper (i.e. more than for Special Relativity or his work on photons). It is used by scientists working on such varied topics as aerosol particles ("pollution"), the properties of milk, paints, granular media (powders) and semiconductors. [Ref *Nature,* 20 January 2005 p 216]

External references

This activity is taken from <http://www.practicalphysics.org>

‘Brownian motion: facts and myths’ is taken from CAPT (Connecting Advancing Physics Teachers) e-mail support by Rick Marshall.

# The density of air

Background

The density of air is so small compared with solids or liquids that we may sometimes consider it insignificant. Yet when a stiff wind blows, we know that air has mass. And there is a lot of it, for example in a room or in a hot-air balloon. This simple experiment allows you to find its density.

You will need

* large polythene container with tap (e.g. collapsible water container for camping)
* foot-pump
* bucket or trough
* water
* rubber connecting tube
* measuring cylinder 100 cm3
* mass balance, electronic 0 – 1 kg ± 1 g

What to do

* 1. Using the foot-pump, fill the polythene container with air until it is hard.



* 1. Using a balance, find the mass of the container plus air.



* 1. Fill the measuring cylinder with water and invert it over a bucket of water, so that the cylinder remains full of water.
	2. Release excess air from the container until it is again at atmospheric pressure, finding the volume released. This can be done by bubbling the air through the connecting tube and into the measuring cylinder. If the cylinder becomes completely filled, use repeat fills to find the total volume of air released.



* 1. Find the mass of the container plus remaining air. The difference between this mass and the mass found earlier is of course the mass of the released air.
	2. Use the mass and volume of air released to calculate its density.
	3. Explain why it was necessary to release the air into the measuring cylinder, rather than simply finding the volume of the plastic container.

You have shown

1. That the density of air is about 1.2 kg m–3 or 0.012 g cm–3.

# Changes in volume, changes in pressure

Common behaviour

Gases are remarkable because they are all so similar. Solids vary considerably because their particles are tightly bound together, and the details of the bonding affect the properties of the material. Gas particles are not tightly bound and spend most of their time not interacting with other particles, so are much simpler. Once you know the mass and speed of the particles that make up the gas, you know enough to be able to predict some macroscopic properties of the gas.

Here you look at how packing more and more gas into a given volume affects the pressure. Precisely because all gases behave in very similar ways, you do not need to worry about which gas you use.

You will need

* Boyle’s law apparatus

Thinking about the measurements



You need to measure how the volume of a fixed number of particles affects the pressure. Squeezing these particles into a smaller and smaller volume results in more and more collisions with the walls, giving a higher pressure. However, you will only get a true relationship between pressure and volume if the number of particles stays the same: you need to make sure that no molecules escape. Rough and ready results can be obtained by using syringes, but these leak, so more precise ways have evolved – sealing off a volume of gas behind a liquid makes for a good seal. It is the measurement of volume that turns out to be the difficult one to get right. You may be able to set up a slicker arrangement using automated data capture, but you will need to take great care to measure the volume, ensuring the equivalent of a leak-proof syringe, where you can measure the position of the plunger or piston.

Compressing a gas will warm it up and vice versa, so after changing the volume leave sufficient time for the temperature to return to its original value.

A traditional solution



1. Take readings of pressure and volume for a suitable range of volumes, determined after a pre-test. Plot a graph as you go.
2. Look for a pattern in the results and then plot a presentation graph, showing the pattern clearly.
3. Are there any regions of the graph that do not fit your pattern as well? Can you account for these deviations in ways that relate back to the state of the gas at that point – or other likely weaknesses in the experimental arrangement?

You have

1. Measured how the volume of a gas changes with its pressure.
2. Thought carefully about why the experiment is set up in a particular way.
3. Produced a set of presentation-quality graphs describing the relationships you found.

TAP 601-7: Boyle’s law, density and number of molecules





This diagram shows how pressure and number of molecules are connected, providing a basis for understanding where Boyle’s law comes from.