CHAPTER 11

Heat and Matter

11.1 INTRODUCTION

- Why is it that you can smell if a gas tap has been left on when you walk into a laboratory but you cannot smell the water spilt on the front bench?
- Have you ever wondered why you can smell perfume or aftershave lotion?
- Why are many of our anti-pollution laws, especially in very industrialised cities and nations such as some cities in America and Japan, concerned with gases?
- Can hot water freeze more rapidly than cold water?

The answer to each of these questions has something to do with the internal structure of gases, liquids and solids. In this chapter we will look at the theory underlying this structure and hence begin to understand the nature of gases.

11.2 THE KINETIC MODEL OF GASES

In the previous chapter we learnt that gases consist of particles that are relatively free in their ability to move compared with those of liquids and solids. These particles also exert almost no force on each other. Because of this the analysis of gas particles is easier. The understanding of the nature of these particles plays an important part in the understanding of heat, heating, and temperature.

To simplify the understanding of how the motion of the particles of a gas affects the properties of a gas, several assumptions are made about these particles.

Assumption 1 The particles of a gas are in constant random motion. They move at high speeds in straight lines unless they collide with the walls of the container or other particles. These collisions are elastic ('elastic' means they do not lose kinetic energy when they collide).

This helps us to explain why gases mix so readily and why gases fill containers.

Assumption 2 The particles of a gas are separated by large distances compared with the diameter of the particles, which are assumed to be negligible in size.

This explains why gases can be compressed and gas densities, in normal situations, are very small compared with those of solids and liquids.

Assumption 3 The force of attraction between particles is negligible, because they are large distances apart.

Assumption 4 Since heating a substance changes the motion of the particles of the substance, the temperature of a gas is a measure of the average speed or kinetic energy of the particles of the gas.

NOVEL CHALLENGE

Imagine a 1 cm square on your skin. Every second there are 10^{22} blows from air molecules. *Can you detect it? If you can't, give some reasons why you can't feel these blows. If the blows stopped, what would you feel?*

11.3 PRESSURE

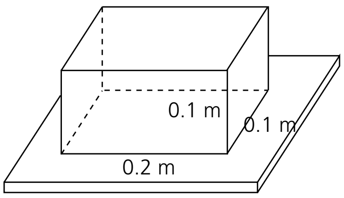
The pressure of gases plays a major part in everyday life: the pressure of gases in the atmosphere affects the weather; the pressure of air in tyres affects the 'ride' of a car. But what is pressure and how do the particles of a gas exert a pressure?

Pressure is the force per unit area ($P = F/A$)

Hence the unit of pressure is a newton per square metre (N m^{-2}) or the modern SI unit of the pascal (Pa), named in honour of the French scientist Blaise Pascal (1623–1666).

The interchanging of the terms 'force' and 'pressure' is common with new physics students but there are major differences that can be illustrated with the following example.

Figure 11.1
Pressure exerted by an object with the 0.2 m × 0.1 m face on the table.



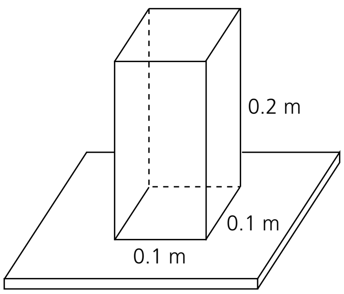
A rectangular solid of 2 kg mass is placed on a table as shown in Figure 11.1. The force this object exerts on the table is 20 N. (This is its weight.) But the pressure it exerts is determined by its area of contact:

$$P = \frac{20\ \text{N}}{0.2\ \text{m} \times 0.1\ \text{m}}$$

$$= \frac{20\ \text{N}}{0.02\ \text{m}^2}$$

$$= 1000\ \text{Pa}$$

Figure 11.2
Pressure exerted by an object with the 0.1 m × 0.1 m face on the table.



But if the object is now placed on its end as shown in Figure 11.2, the force it exerts on the table will remain at 20 N, but the pressure is now:

$$P = \frac{F}{A}$$

$$= \frac{20\ \text{N}}{0.1\ \text{m} \times 0.1\ \text{m}}$$

$$= \frac{20\ \text{N}}{0.01\ \text{m}^2}$$

$$= 2000\ \text{Pa}$$

It can be seen that if the area of contact is small the pressure is very large. Why do women wearing stiletto heels leave impressions on wooden or cork floors? (And it is not because they are heavy.)

- Where else is this effect seen?
- How does this affect our discussion of gases?

When each gas particle collides with the wall of the container it exerts a force on a small area of the wall. This collision produces pressure. Since gases contain many particles it is the constant collisions with the walls of the container that result in the pressure of the gas in the container. This can be seen when you blow up a balloon. When you start, it contains few particles, which make few collisions with the walls, resulting in low pressure. When the balloon contains more particles there are more collisions, exerting greater pressure on the walls, forcing the balloon to expand.

NOVEL CHALLENGE

A matchstick is placed in a test-tube of water. When you place your thumb over the top and press down, the match sinks. Propose a reason for this and test to see if we're lying!

THE GAS LAWS 11.4

The properties of a gas are easy to explain because the particles act independently without exerting any significant forces on each other. This is true except in the extremes, when the temperature is very low or when the pressure is high. In these circumstances the particles are maintained in close proximity to each other. The properties of gases that play a part in understanding the behaviour of gases are volume, pressure, temperature and the number of particles in the sample.

The relationships between these variables have been investigated for centuries and affect how we handle gases today.

Boyle's law

One of the earliest scientists to investigate the relationships between the above variables was the British chemist and physicist **Robert Boyle** (1637–91). By experimenting with gases he established that the volume of a gas decreased as the pressure of the gas increased. If the temperature of a confined gas sample was kept constant and the pressure on the gas increased by placing more mass on a piston, as shown in Figure 11.3, the volume of the gas changed, as shown in Figure 11.4. This suggested that pressure was inversely proportional to volume.

When the pressure was plotted against the inverse of volume, Boyle obtained a straight line, as shown in Figure 11.5. This indicated that pressure is directly proportional to the inverse of volume ($P \propto 1/V$),

or $$PV = \text{constant}$$

This relationship is known as **Boyle's law**, which states: For a fixed mass of gas at constant temperature the pressure of the gas varies inversely as the volume. This means for a particular sample of gas at constant temperature an increase in pressure from P_1 to P_2 causes a corresponding decrease in volume from V_1 to V_2.

$$P_1V_1 = \text{a constant} = P_2V_2$$

or $$P_1V_1 = P_2V_2$$

This is normally how Boyle's law is expressed when solving problems.

Example

A scuba diver releases a 1.0 cm^3 bubble of gas at a depth where the pressure is 4 atmospheres. What will be the volume of that gas at the surface where the pressure is 1 atmosphere (assuming the temperatures are the same)?

Solution

$$P_1V_1 = P_2V_2$$
$$4\text{ atm} \times 1\text{ cm}^3 = 1\text{ atm} \times V_2$$
$$V_2 = 4\text{ cm}^3$$

Note: the units of pressure and volume are not that important as long as they are consistent. That is, P_1 and P_2 have to have the same units and V_1 and V_2 as well. Some common units of pressure are pascals (Pa), mm of mercury (mmHg) and atmospheres (atm).

Figure 11.3
A device used to show the relationship between pressure and volume.

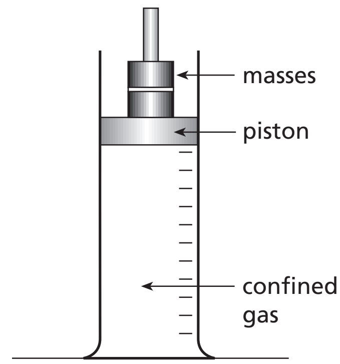


Figure 11.4
Pressure–volume relationship of a confined gas.

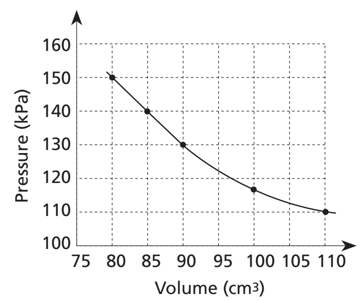
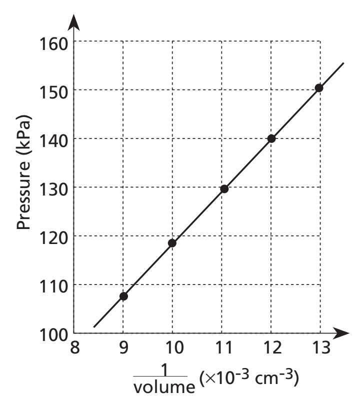


Figure 11.5
Pressure vs 1/volume graph to establish Boyle's law.



Questions

1. A balloon of volume 2.0 L contains air at 230 kPa. What would be the pressure of the gas when its volume is reduced to 0.50 L?
2. A hot-air balloon has a volume of 10 m^3 at sea-level. The balloon then rises to a height in the atmosphere where the pressure is 0.20 atmospheres. What would be the resulting volume of the balloon? (Assume constant temperature.)
3. A diver dives to a depth of 40 m in fresh water where he releases a toy balloon of volume 10 cm^3. What will be the size of the balloon when it reaches the surface? (The pressure increases at a rate of 1 atmosphere for every 10 m descent in fresh water.)
4. A student testing Boyle's law places masses on the top of a syringe as shown in Figure 11.6. With 500 g on the top of the syringe the volume is 50 mL. What mass will need to be placed on the piston for the volume to be 12.5 mL?