CHAPTER 27

Atomic Structure

27.1 INTRODUCTION

The existence of the atom is widely accepted but its incredibly small size is hard to comprehend. Only recently have scientists been able to see and photograph individual atoms. Every breath you take contains about 10^{24} atoms. The full stop at the end of this sentence is a million atoms wide.

People get very confused about atoms. They ask questions like these:

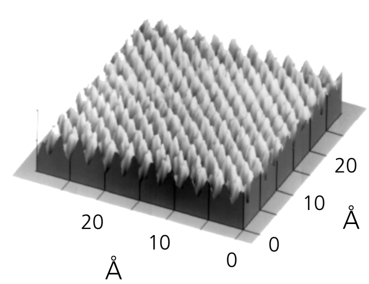
- If atoms are mostly empty space, how come a brick feels so hard?
- What colour is an atom?
- If the electron is negative why doesn't it get sucked into the positive nucleus?
- How many atoms are there in the universe? It must be a mind-bogglingly big number!
- If the nucleus is made up of positive particles, why don't they fly apart?
- How do we know atoms really exist if you can't see them?

Scientists have answered the last question but the rest need careful explanation. That's what this chapter is about.

27.2 FOUNDATIONS OF ATOMIC THEORY

The word *atom* comes from the Greek words *a* meaning 'not' and *tom* meaning 'to cut'; hence, not cuttable, or indivisible. This arose from the ideas of the Greek philosophers Democritus and Leucippus 2500 years ago.

Photo 27.1
Photo of surface of graphite in air taken by Dr K. Finlayson (Murdoch University, WA) using a scanning force microscope (SFM). Individual carbon atoms can clearly be seen at this magnification of 1.5 million times. The unit 'angstrom' (Å) is a non-SI unit equal to 10^{-10} m.



Democritus

The word 'philosopher' was used differently from the way it is now. Until the word 'scientist' was coined in 1830, natural philosophers were people who loved learning about the world (it comes from the Greek *philos* = 'love', *sophia* = 'wisdom'). One of the first philosophers to suggest the idea of atoms was Leucippus; however, not much is known about his work. The earliest writing about atoms was that of **Democritus of Abdera** (460–371 BC). He argued that you could not keep cutting up something into smaller and smaller pieces forever; eventually you would end up with a piece that could not be cut any further — the 'atom' (Figure 27.1). Democritus also argued that atoms were in constant motion and that all atoms were composed of the same substance but differed in size and shape. His model accounted for many observable properties of matter but as he believed that the atom was the fundamental indivisible particle, he did not try to explain its structure.

Greek philosophers did not test their theories by experiments as scientists would today. This wasn't because they did not have the equipment to do so; Greeks had no inclination to conduct experiments because the philosophers came from élite (rich and powerful) families

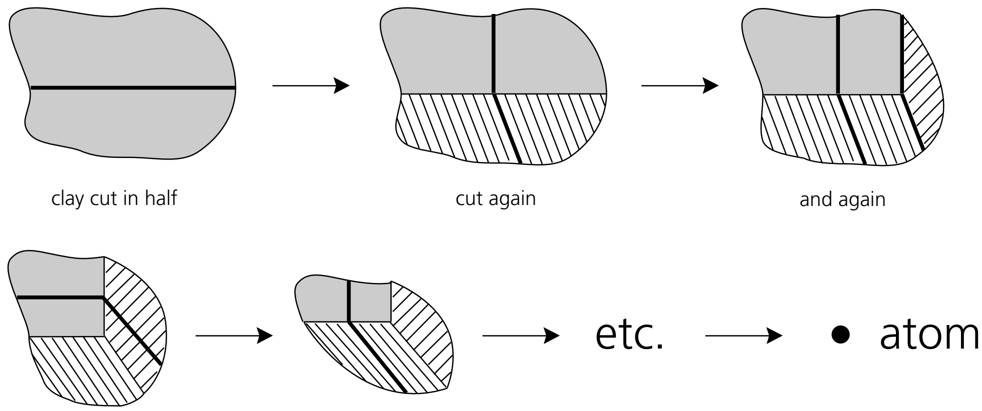


Figure 27.1
Democritus's concept of the atom.

PHYSICS FACT

The word 'scientist' was coined by the distinguished Oxford professor William Whewell in 1834. Up until then they were called 'natural philosophers' (= lovers of learning about nature).

and thought manual work (such as experimenting) was only for slaves. They developed their ideas by reasoning and discussion. Their method of reasoning was to state some important principle or law, often based on observations of the heavens, then draw conclusions based on it. Experimentation generally did not occur — that was a seventeenth-century development.

Aristotle

One of the most famous natural philosophers was **Aristotle**, born in 384 BC. His father was doctor to the king of Macedonia and Aristotle received a good education in Athens under the teaching of another famous Greek philosopher, Plato. His writings were vast and many of his theories went unnoticed until the thirteenth century, when Christian theologians began to endorse his work as being truth. Aristotle argued that matter could be divided an infinite number of times until there was a void, that is, nothing. He taught that matter was made up of four elements — earth, air, fire and water — and that different combinations produced different substances (Figure 27.2). This was at odds with the atomic theory but religious leaders could understand Aristotle's view of matter. They did not like the idea of atoms that moved around seemingly without the control of the gods. So from 300 AD to 1600 AD, the atomic theories lay dormant while Aristotle's ideas flourished.

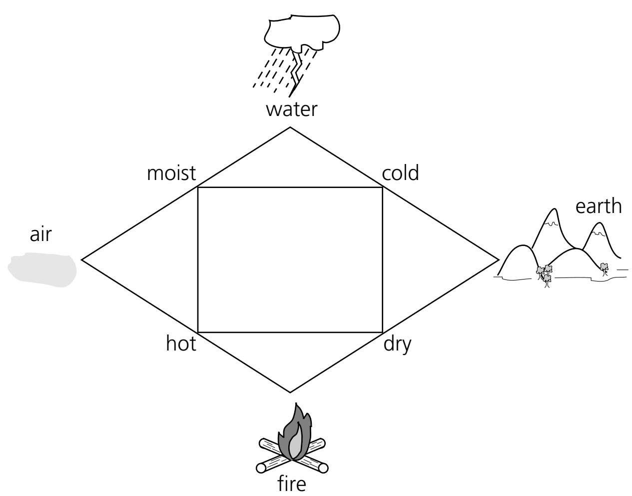
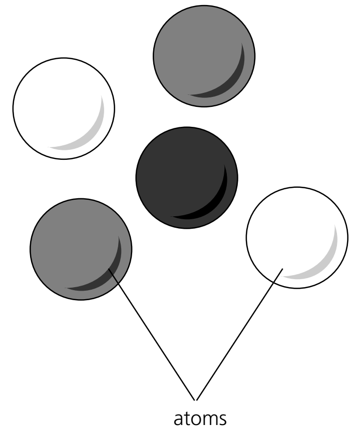


Figure 27.2
Aristotle's concept of the four elements.

THE WORK OF JOHN DALTON 27.3

A long time passed before the idea of atoms was revived. In the seventeenth century, an Englishman by the name of Francis Bacon (1561–1626) introduced the idea of experimentation as a way of understanding nature. He reasoned that direct observation of nature rather than a study of Aristotle or theology (religious writings) gave a better idea of how the world worked. He is often thought of as the father of modern science. Later, people like Galileo and Descartes supported his idea of the experimental method. This inspired a lot of experimental work through England and Europe. Robert Boyle (1627–91) investigated the gas laws; Joseph Priestley (1733–1804) experimented with the extraction of gases; Antoine Lavoisier (1743–94) discovered the composition of air; and Henry Cavendish (1731–1810) discovered hydrogen. These experiments paved the way for a breakthrough in our understanding of matter. Near the beginning of the nineteenth century, the English scientist **John Dalton** (1766–1844) conducted a series of experiments, and published his atomic theory proposing the existence of individual particles called atoms in all matter (Figure 27.3), with a list of atomic masses. Dalton believed that all atoms of the same element were identical and that compounds were formed by the combination of atoms in small whole-number ratios. Other scientists went on to add to his theories and then in 1897, **J. J. (Joseph) Thomson** discovered the electron. This discovery led to the modern-day theory of atomic structure.

Figure 27.3
Dalton's model.



27.4 DISCOVERY OF THE ELECTRON

The big leap in our understanding of atomic structure came with the use of electricity in the laboratory. In the mid-nineteenth century, the effects of sparks, arcs and electrical discharges through gases were most interesting but of little importance. But after Heinrich Gessler invented the vacuum pump in 1855, electrical discharges through gases at low pressures produced brilliant results. Suddenly, the possibility of using vacuum tubes for electrical lighting (and making a fortune) was investigated and knowledge about the discharge increased dramatically. **Sir William Crookes** (1832–1919) in 1876 designed a number of tubes to study these charges. A variety of discharge tubes based on Crookes' designs are commonly available in physics classrooms today (Figure 27.4).

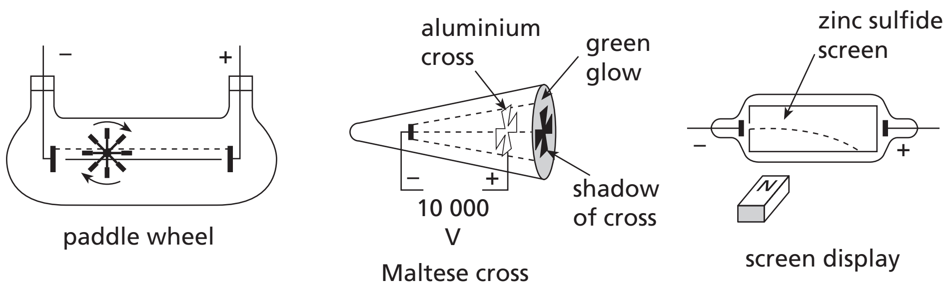
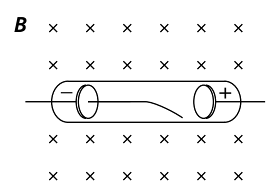


Figure 27.4
Discharge tubes commonly used in school laboratories.

These tubes contained various gases at low pressure and when a high voltage (about 20 000 V) was applied across the terminal at the ends, a purple light was seen; but as the pressure was reduced, the purple faded and the glass glowed with a green light near the positive end. There was dispute about what caused this glow but the invisible rays involved became known as 'cathode rays' as they emanated from the negative (cathode) terminal. The green light was an example of fluorescence (Latin *fluere* = 'to flow' and *esse* = 'to exist') — light given off by a substance (the glass) when being illuminated by energy from an external source (the discharge).

Crookes suggested that cathode rays would be deflected by magnetic fields (Figure 27.5) and by a series of experiments, Thomson was able to show this magnetic field deflection and so proved Crookes' hypothesis to be correct.

Figure 27.5
A magnetic field (into the page) deflects cathode rays downward.



Thomson devised a technique for passing cathode rays through an electric and a magnetic field that were orientated so as to exert opposing forces on the negatively charged rays. By this method, Thompson was able to measure the charge-to-mass ratio of the cathode ray particles, which he named electrons. The rays were deflected by the fields and struck the