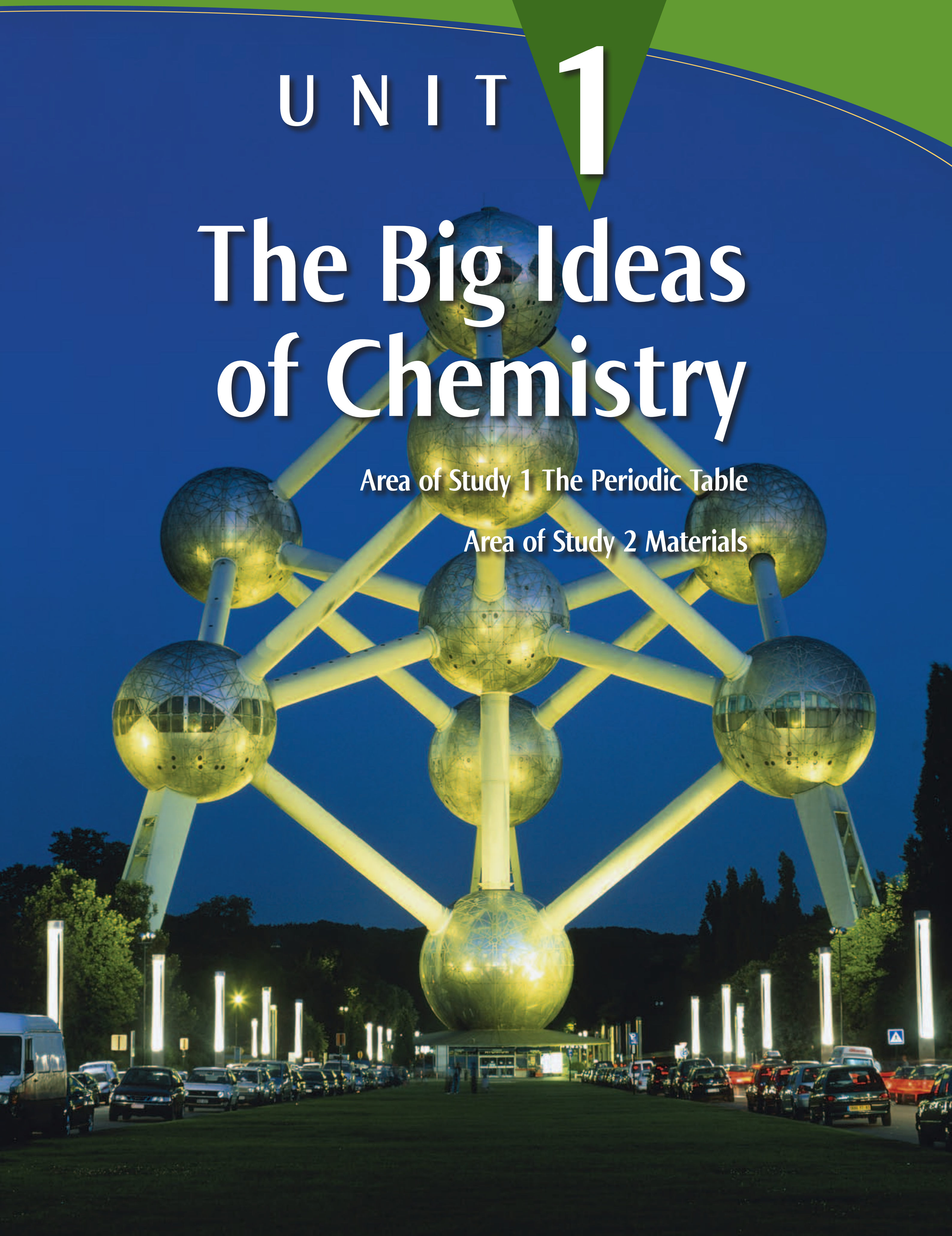
UNIT 1

The Big Ideas of Chemistry

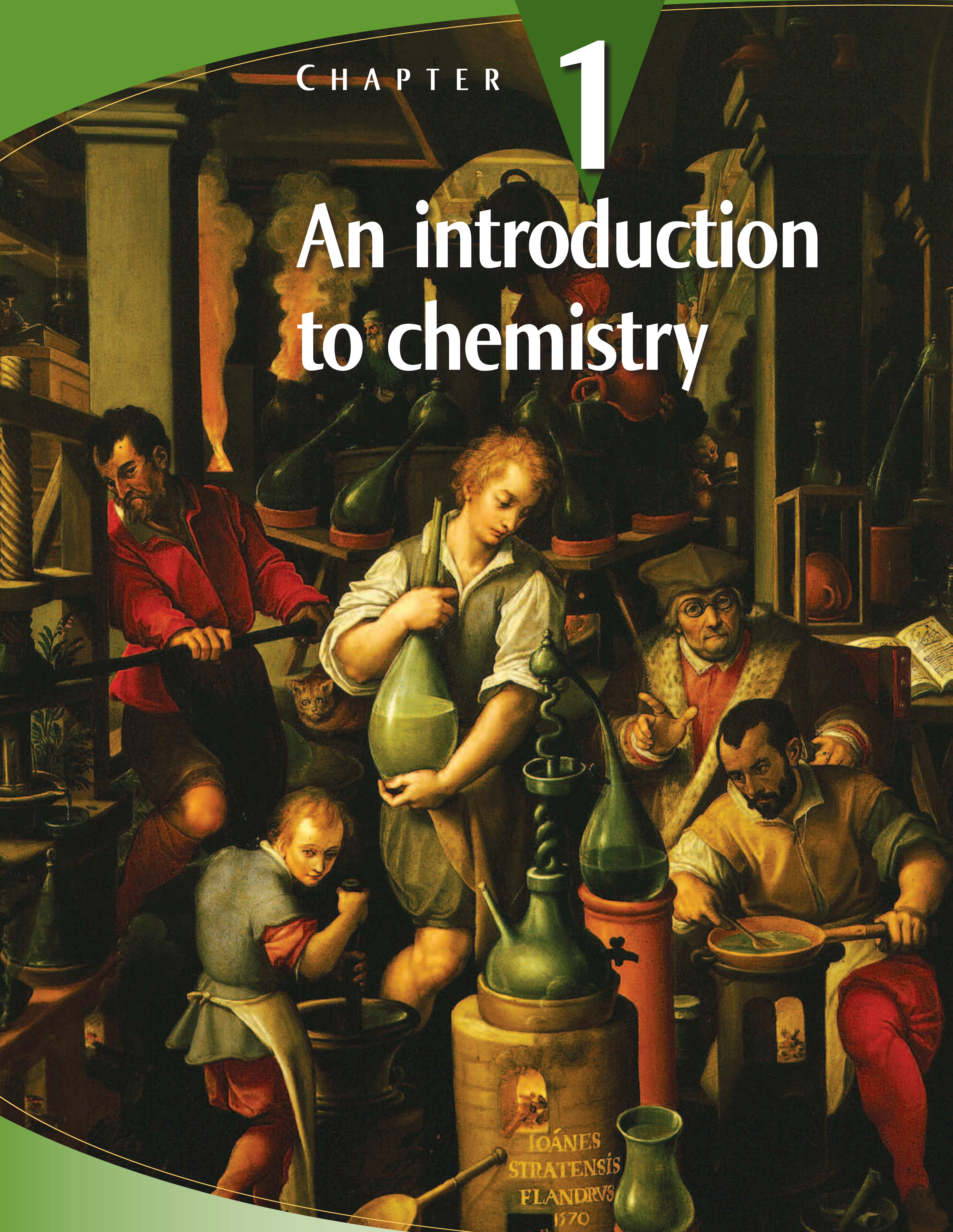
Area of Study 1 The Periodic Table

Area of Study 2 Materials



CHAPTER 1

An introduction to chemistry



Key Knowledge

- Atomic theory—historical development of the model of atomic theory with contributions from Dalton
- Percentage composition (an introduction)

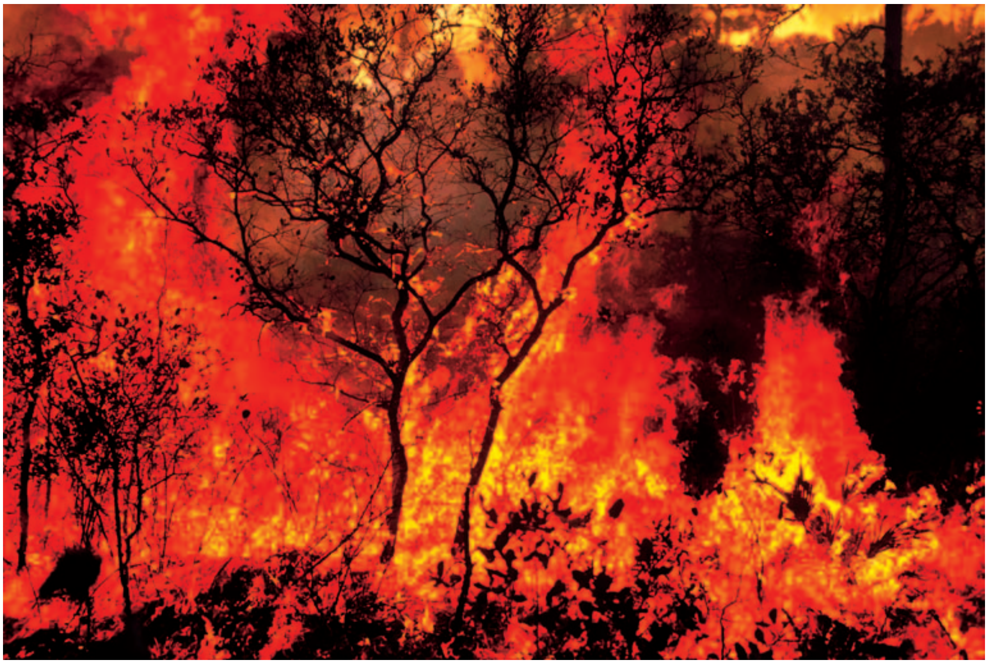


Figure 1.1 Fire is the visible output of a chemical reaction.

Chemistry is everywhere! Fire is the visible output of a chemical reaction. The materials in the buildings and vehicles you have seen today and in the clothes you wear were all produced by chemical reactions. The air you breathe is full of chemicals—including life-giving oxygen. Food is a mixture of chemicals and even pure water is a chemical. And chemical reactions are taking place in every cell of your body—without them you could not exist!

Chemistry is the study of substances and is one of the oldest of the sciences. It began several thousand years ago, when people observed natural processes and experimented with the materials around them to see how they could be used. In this chapter you will learn about some of the early experiments of chemists of some of our great civilisations, of the theories proposed by early philosophers and how all this thinking and experimenting and measuring led to Dalton's model of the atom.

Later in this book you will learn how our understanding and theories of the nature of matter have had to be modified over and over again as new evidence came to light. Knowledge of chemistry grows at an ever-increasing pace, and chemists are developing amazing new materials and substances and gaining a growing understanding of important processes that occur in space, in the environment and in our bodies. They also are modifying manufacturing and laboratory processes according to the principles of green chemistry. This is a time of very exciting research opportunities!

The philosopher's stone

It is likely that **alchemy**, the earliest form of chemistry, began thousands of years ago when it was observed that fire could transform substances into new substances. There is some evidence in ancient Chinese, Egyptian and Tamil records that suggests alchemy may have begun in a great civilisation that was destroyed by massive earthquakes and floods about 10 000 years ago. This could account for the remarkable similarities in the alchemy that was practised in these very different civilisations.

Figure 1.2 Only the great leaders of the early civilisations were permitted to possess gold, the perfect material.

Chinese writings refer to 'Sons of Reflected Light', people who visited them from this lost civilisation and taught them many skills; Egyptian writings call them 'Lords of Light'. There has been speculation that this was the lost city of Atlantis, and according to Tamil records Sri Lanka is the only surviving land mass from this lost civilisation.

True alchemists did not want to conquer nature or merely to observe it, they wanted to work in partnership with nature to help it improve. They felt they could achieve this by manipulating time—by speeding up the transformations of minerals and metals that occurred very slowly in nature and by slowing down the ageing process. Some called the magical substance that could achieve this the **philosopher's stone**.

The alchemists believed that the perfect material was gold, because it shone like the Sun—the giver of life. One of their aims, therefore, was to transform other materials into gold; the other was to discover the secret of immortality. But they also held 'mother earth' sacred, for they saw it as the source of life. So they believed that they should only perform their experiments with a 'pure' heart. Thus they must transform not only natural objects around them towards greater perfection, but also their 'inner selves'.

Figure 1.3 Alchemists are often portrayed as secretive frauds. Most gave mystical explanations for their observations, but their researches led to our modern science of chemistry.

To do this they restricted their work to sacred places, followed strict taboos, made sacrifices and underwent cleansing rituals before performing their experiments. Many retreated to mountains and lived ascetic lives. Their records used many secret symbols and were full of metaphors, as they did not want their knowledge to fall into the wrong hands and be abused.

Gold has always been a very valuable metal. Over the history of alchemy, there have been those who proclaimed themselves as alchemists but who were in fact greedy, and cheated people. Unfortunately, and ironically when you consider that true alchemists believed their experiments would not succeed unless they were morally worthy, many have judged all alchemists by these unscrupulous people. The truth is that much of the valuable chemical and medical knowledge we have now and many of our widely used laboratory techniques, such as distillations, were developed by alchemists. Many later famous and highly respected scientists, such as Sir Isaac Newton, were practising alchemists.

The alchemists of China

Historical writings held in China today at their Academy of Sciences in Beijing show that Chinese alchemy began about 3000 years ago. The alchemists sought minerals, stones and plants that would enable them to live longer and searched for the 'pill of immortality', an elixir made from gold that would enable them to leave their corpses and fly off to join the immortals in the heavens. As is the case for the Taoist monks who still practise alchemy today, however, their greatest goal was not to produce gold from other substances but rather to refine and perfect themselves. Although they did not find the pill of immortality, most of the alchemists were doctors and as a result of their experiments they developed drugs to treat many diseases.

Figure 1.4 Many patients find Chinese herbal medicines beneficial. Some Australian doctors have also gone on to study Chinese medicine, so they can give their patients the benefit of its approach to healing.

The early Chinese alchemists also developed special gentle exercises for regulating vital energy (which they called *chi*) to improve wellbeing and enable people to live longer. These exercises, known as *qigong*, are still practised by many people today, who find them very beneficial. Alchemy is still a living tradition for Taoist monks.

The great forensic mystery

In 1972 an amazing discovery was made on the outskirts of Changsa, Hunan Province, China. Changsa is a city that is about 3000 years old. A coffin was found buried in a big chamber 16 metres below ground. Inside the coffin were three smaller coffins. Inside the innermost coffin was the body of Lady Tai, wrapped in many layers of silk. In her death she was accompanied by beautiful objects, pouches of medicinal and aromatic plants and many statues.

Forensic scientists from London who examined Lady Tai's body were astonished to find it was in a state that would suggest she had only been dead for a couple of days. Yet she had been buried there since around 186 BCE!

In the coffin there was some brown liquid that contained a compound of mercury and sulfur, and the body had been completely sealed in the coffin with methane under pressure and stored deep underground, but despite extensive forensic testing, the scientists could not work out how she could have been so perfectly preserved. The body had not been embalmed or frozen. Clearly the alchemists of that time had worked out how to preserve bodies. This was important to them, as it was in other great civilisations, as it was believed a person could only reach immortality if their physical body was preserved.

How this body was preserved is still one of the greatest scientific mysteries of today! The ability of the alchemists to isolate methane gas and pump it into the coffin under pressure was in itself remarkable.

The alchemists of India and Tibet

In India and Tibet alchemy evolved mostly to support medicine. Ayurvedic medicine is one of the oldest systems of medicine that is still practised today. This system of medicine aims to achieve longevity and is based on a holistic approach. It places great value on the mind, on morality and on compassion. The alchemists prepared medicinal elixirs from oils and herbs, minerals and metals. The therapeutic use of gold was recognised.

As in China, the alchemists of India always combined taking their elixirs with meditation, breath control and exercises to prolong their lives and transform themselves. And, like their Chinese counterparts, they guarded their teachings carefully and largely passed them on orally. Their writings were full of symbols and metaphors. There is evidence that contacts occurred between members of the Indian and Chinese civilisations around the 5th century BCE, which could account for these similarities. There was also early contact with the great civilisation of Afghanistan, from which much was learned.

Figure 1.5 Mercury can even dissolve gold and silver and has been used since ancient times to extract gold and silver from rocks.

There is also evidence that at least 3000 years ago the very advanced civilisation of India was interested in finding an elixir of immortality—the philosopher's stone—which they called the 'jewel of the wise'. To prepare this elixir, the early alchemists sought to reduce substances to their 'primary form'—the original matter from which the universe was made. To accomplish this, they burned solids to ash and boiled liquids to obtain their sediments. The ash was dissolved in mercury, which was called quicksilver in those times, and the mixture was then specially treated.

Mercury was used because it was thought to be endowed with the properties of all metals. However, even in those times, it was recognised that while mercury can be used to dissolve many things, it is highly toxic.

The alchemists of Tibet also prepared an elixir of life, which they called the 'supreme nectar', although they believed that the elixir was not needed by people who followed a spiritual pathway. The elixir contained eight metals, especially mercury, lead, silver and gold. To prepare this elixir, they used a similar but even lengthier and more painstaking process than that used in India, so that its mercury content was in a form and concentration that would not be harmful. (Lead also is toxic, but it is not clear whether this was known at the time.)

A 13th century treatise records that the alchemists of India used a number of the laboratory techniques we use today, such as distillation, sublimation, powdering and melting, to prepare their elixirs.

The alchemists of Egypt

The word alchemy comes from the ancient Arabic word *Al-kemia,* which meant 'the black land'. This may have been from the colour of their elixir of life.

The earliest alchemists of Egypt experimented to create fine perfumes, ointments, medicines, cosmetics, dyes and even imitation jewellery. They used mercury to separate gold and silver from their ores. In addition, like the alchemists of China, they believed that the physical body must be preserved if the person was to achieve immortality and they too applied their practical skills to the preservation of bodies. However, unlike the Chinese, they used a process of mummification, which was a lengthy and involved procedure in which a number of chemicals were used.

In about 332 BCE, the Greek warrior Alexander the Great conquered Egypt. Although we may question this act of war, one truly great thing he did accomplish, was to establish a spectacular new marble city on the Nile River. Unsurprisingly, he named this new Greek city after himself: Alexandria. Before long, Alexandria had become the intellectual capital of Greece and a truly multicultural society. Many great scholars moved there from all over the known world, for it had a great library, botanical gardens, dissecting rooms and even an observatory.

Figure 1.6 A modern bain-marie is used to heat solutions in a controlled way.

The word 'philosopher' comes from the Greek word *philosophos,* which means 'lover of wisdom'.

With the introduction of Greek philosophy to their society, the alchemists of Alexandria became possibly the first scientists to combine theory and experiment. The experimental methods they used were mainly distillation and sublimation. As they tried to improve their experimental processes, some alchemists invented equipment that is still used today. For example, in about the 1st century CE, an alchemist known as 'Maria the Jewess' invented water baths and sophisticated distillation apparatus that is very like the apparatus we use today. One of her inventions still in use today is known as a bain-marie, a French term that literally means 'Maria's bath'.

Tragically, two centuries later, the Alexandrian alchemists were persecuted by the Roman Emperor Diocletian. He burned the books that contained all the knowledge they had built up, along with the thousands of books that contained all the knowledge the doctors, astronomers, mathematicians, and so on, had built up over the centuries. The greatest library of the ancient world was destroyed.

Alchemy and Western science

As a result of the tragic loss of precious records in Alexandria, alchemy became a more mystical and less scientific pursuit that spread across many parts of the world. It first moved to Greece and Rome. When the Roman Empire collapsed, it moved to the Middle East to the Islamic world, where it continued to be influenced by Greek philosophy but was far better documented. Here many important new laboratory techniques and chemical discoveries were made, including 'aqua regia', a mixture of hydrochloric and nitric acids that can dissolve gold.

Probably the greatest alchemist of the Islamic world was Jabir ibn Hayyan, also called Al-Sufi and later known to the west as Geber, who was born in about 722 CE. He studied mathematics and science and later began to practise alchemy. Strongly influenced by Aristotle, he believed that all metals are made up of all four elements—earth, air, fire and water. By finding out the exact numerical proportion of each element in a metal, he could determine how to alter the balance and hence form a different metal. Jabir established a number system to measure these proportions, emphasised the importance of experiments and carefully weighed and measured substances. This more scientific approach was to influence later European alchemy. However, it is difficult to judge whether he repeated his experiments under controlled conditions, a procedure that is used to assess the validity of experimental findings today.

It was through the Islamic world that alchemy moved to Spain and eventually across Europe. Alchemy was readily accepted by the Christian Church because of its strong connections to Greek and Roman culture. Gerbet of Aurillac, who later was to become Pope Silvester II, was among the first to bring alchemy from Spain to Europe. But Western alchemy developed its own philosophical system that was only superficially connected to the major Western religions. However, in other civilisations

Different names of element				Symbols over time					
Latin	French	German	English	1500s	1600s	1700s	1783	1808	1814
Aurum	Or	Gold	Gold						Au
Hydrargyrum	Mercure	Quecksilber	Mercury						Hg
Plumbum	Plomb	Blei	Lead						Pb

Figure 1.7 Some early alchemical symbols

alchemy remained closely tied to their spiritual beliefs. Chinese alchemy, for example, remained closely connected to Taoism.

While some alchemists focused their endeavours on preparing useful products such as cosmetics, perfumes or medicines, most still searched for the philosopher's stone. Secret signs and symbols were used to record discoveries and observations. This added to a commonly held perception that alchemists were secretive frauds. Unfortunately, there were to be no further significant advances in experimental science for more than a thousand years!

Nevertheless, a few alchemists did carefully record their observations, and chemical knowledge accumulated little by little over that time. But it was not until the 1600s that another truly scientific alchemist emerged.

In 1666 Marie Meurdrac, a French alchemist, wrote her first treatise (report) on her discoveries. Her treatise included explanations of laboratory apparatus that she had invented and techniques she had developed. It displayed tables of the weights of various substances and the results of her experiments on metals. In addition it described how to prepare a number of medicines and cosmetics.

Nicholas Flamel

Click on the link to **Nicholas Flamel** and find out about this famous French alchemist. What is he supposed to have achieved and what is the story behind this? What did he do with the money he earned? In what well-known recent novels is Nicholas Flamel mentioned?

QUESTIONS 1.1

1 List at least four kinds of substances that were commonly prepared by the alchemists in the different early great civilisations.

2 Explain why the alchemists believed that:
  - **a** humans should strive for immortality
  - **b** they should find methods to turn other metals (known as base metals) into gold
  - **c** on death, bodies should be completely preserved

3 **a** What was the philosopher's stone supposed to do?
  - **b** State the names given to the philosopher's stone in China, India and Tibet.

4 What evidence is there to suggest that alchemy may have begun in an ancient civilisation and was spread to different lands by some of the members of that society before it was destroyed?

5 Why did alchemists use secret signs and symbols and metaphors in their writing?

6 Many people condemn alchemy as 'quackery' and alchemists as secretive frauds. After reading about them, would you agree with this view? State your reasoning.

7 The alchemists of many civilisations were meant to approach their work with a 'pure heart', to transform their 'inner selves' and not just the materials in their laboratories. Western science and the Greek philosophy that underpinned it, on the other hand, were always more concerned with unravelling the secrets of nature and explaining why substances behave as they do. Do you think that Western society would benefit from expecting its scientists to be 'morally worthy'? Would this solve problems that are encountered sometimes, when a scientist is discovered to have cheated or when scientific discoveries have been used to harm people or harm the environment? Discuss.

The elements

The philosophers of ancient Greece saw the Earth produce new growth every spring, and dead plants decay back into the Earth. They felt the breeze on their faces and felt the force of the wind. They saw rain, rivers and seas, and the fires on their hearths. In about 450 BCE, these observations led the Greek philosopher Empedocles to deduce that all matter was made from just four 'ingredients'—earth, air, water and fire—which he called **elements**.

This theory was reasonable when you consider the observations they would have made. A burning sapling produced fire. Sap oozing from the wood was evidence of the element water. The smoke and steam produced gave the element air, and the ash gave earth. Interestingly, carbon, sulfur, iron, copper, silver, tin, gold, mercury and lead, which we now call elements, were all known at that time, but these were thought to be different combinations of earth, air, water and fire.

The ancient Egyptians thought all matter was made up of space, air, water and earth, while the Indian and Tibetan philosophers proposed five elements: those of Empedocles (earth, air, water and fire) and 'ether' (space). Empedocles may, in fact, have derived his idea from them. The ancient Chinese philosophers, using similar reasoning, also proposed five elements: wood, metal, air, water and fire.

At the time of publishing this book, there are 111 known elements, although some of these have only been produced synthetically. These are listed in the Periodic Table on the inside front cover of this book and will be studied later.

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Ancient names

Interestingly, some of the symbols used for the elements derive from their ancient names or from the names of the compounds in which they were first discovered. For example, Islamic alchemists discovered 'soda' and 'potash', which were compounds of sodium and potassium respectively. The Arabic names for these chemicals were *al-natrum* and *al-qaliy*, which were Latinised to *natrium* and *kalium*, explaining the symbols Na and K for these two elements.

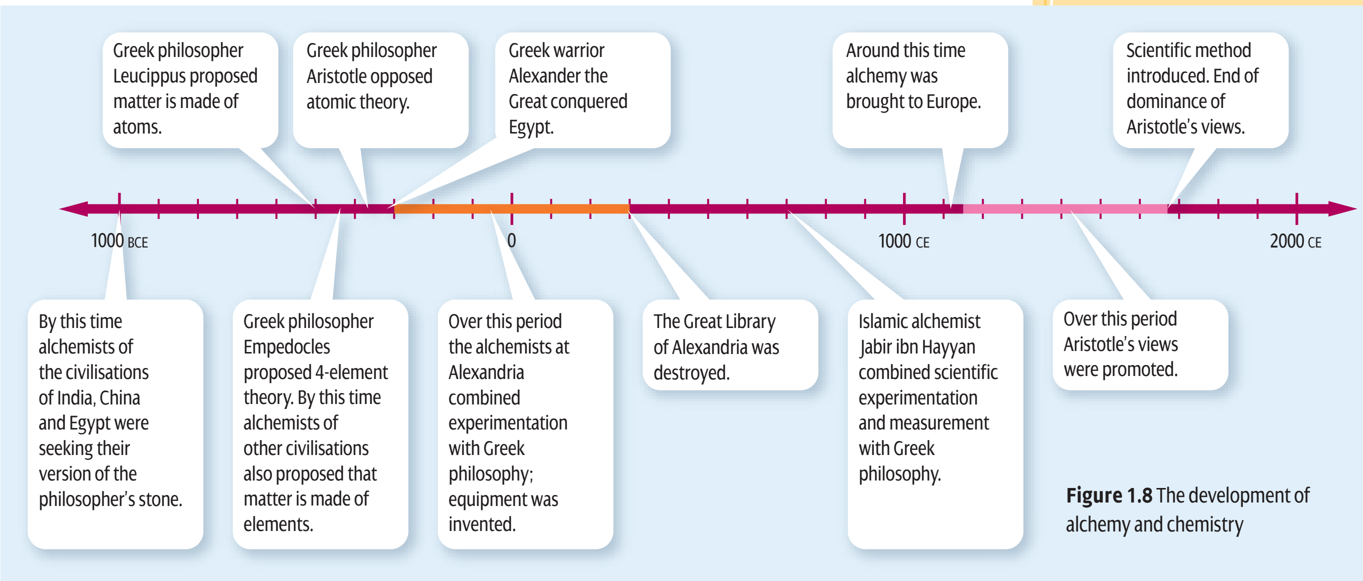


Figure 1.8 The development of alchemy and chemistry

The origins of atomic theory

About 50 years before Empedocles, another Greek philosopher, Leucippus, suggested that matter was made up of small particles. This was an attempt to explain the complexity of natural bodies and phenomena in terms of the arrangement and rearrangement of tiny indivisible particles. His student Democritus expanded on this theory, using the Greek word *atomos,* meaning 'that which cannot be cut', to describe these particles. We now call them **atoms**. Democritus stated that atoms move about in a void and are infinite in number, unchangeable and indestructible. There are different atoms that have different sizes, shapes and motion. They can combine in clusters by means of tiny hooks or barbs on their surface. All changes we see in visible objects are brought about by relocations of atoms.

However, the well-known Greek philosopher, scientific observer and physician Aristotle argued that matter was continuous and not made of small separate particles. He also strongly supported the four-element theory.

Although Aristotle's work on logic survived and was known much earlier, his views on the nature of matter were not known to Christian Europe until the arrival of Arab scholars in about the 12th and 13th centuries. But then his views came to be regarded by the Churches of the time as possessing an almost divine authority. This cannot be blamed on Aristotle, who did not believe in blind obedience to authority, and in fact promoted the idea that we can only gain knowledge through experience and observation, not just by thinking.

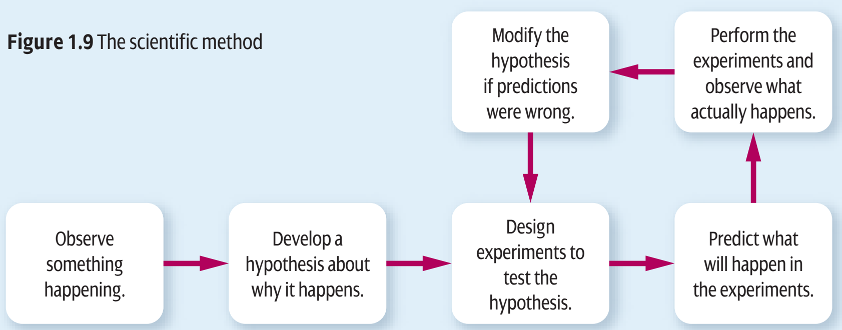
Interestingly, Alexander the Great (page 6) was a student of Aristotle.

The preoccupation with Aristotle's ideas and beliefs, especially during the Middle Ages, is now regarded as a sign of the Dark Ages for Western science. European societies persecuted those who questioned his ideas. Even as late as 1624 the Parliament of Paris passed a law compelling all chemists to teach Aristotle's four-element theory on pain of death or confiscation of goods! It was not until the end of the Dark Ages that these ideas were put to the test by using the approach of the scientific method, which is considered next.

The age of enlightenment

The 17th century in Europe witnessed an increased questioning of the assumptions of religion, government and society, and science. The **scientific method**, the approach we use today to test and revise our ideas by experimentation, evolved from this willingness to question assumptions and from the realisation that assertions must be backed by experimental evidence.

Figure 1.9 The scientific method



The 17th century became a very important period of rapid development in scientific knowledge. New instruments were invented to increase the range and sensitivity of observations. These included weighing scales, thermometers and the microscope. The scales, like the other inventions, made a huge difference, as you will soon learn.

Sceptical chemists

In 1661 the Irish scientist Robert Boyle vainly attempted to isolate Aristotle's four elements. In his book *The Sceptical Chymist,* he questioned the validity of the four-element theory, since he could not extract earth, fire, air or water from materials such as gold and copper. He also emphasised the importance of accurate experimentation as the only way to test and support or disprove hypotheses, and realised that chemistry should be studied in its own right, not just to support other fields of endeavour such as medicine.

The idea that matter was continuous was also being discarded. In 1730, Sir Isaac Newton declared his support for the atomic theory first suggested by Leucippus (page 9) and proposed that atoms were held together by mutual attraction.

Then oxygen was discovered in 1774 by Joseph Priestley, and hydrogen was discovered seven years later by Henry Cavendish; both were English chemists. It was observed by chemists that hydrogen would burn in air to produce water. This gave the French chemist Antoine Lavoisier the means to discredit the four-element theory at last, since he found that the mass of the water formed equalled the combined mass of the oxygen and hydrogen from which it was produced. Lavoisier was also the first person to clearly explain the process of combustion.

Both Boyle and Lavoisier proposed a new definition of an element. Boyle defined an element as 'a simple unmingled body'. After conducting some brilliantly designed experiments, Lavoisier wrote the first 'modern' Chemistry textbook, entitled *Elements of Chemistry,* which was published in 1789. In his book Lavoisier proposed that an element should be defined as a substance that cannot be decomposed (broken up) by any method. He said an element was 'the final point capable of being reached by analysis'. The 23 elements known at the time were listed in his book.

The Lavoisiers

Figure 1.10 Marie and Antoine Lavoisier

Antoine Lavoisier did not achieve all of his discoveries on his own. His young wife Marie, who married him when she was just 14, soon became his laboratory partner as well. Lavoisier, who at 28 was already an established chemist when their arranged marriage took place, realised that his bride was highly gifted. With his encouragement, she quickly proved to be a very talented scientist, linguist and artist, and soon played an integral part in all his work. Marie learnt English and Latin so that she could translate important documents from other scientists into French for Antoine. Soon she was annotating her translations with her own comments. She collaborated with him in designing and performing their experiments and recording their findings. She also illustrated many of their publications with great accuracy and skill, including diagrams of the apparatus they used. Marie played such an active role in all of her husband's discoveries that their work cannot be separated.

Marie turned their home into a popular scientific meeting place, taking an active part in all of the discussions and debates and impressing their learned visitors. After both her husband and father were killed in the French Revolution, Marie became a fugitive and was briefly imprisoned. All of their estates, including their laboratory, were confiscated. It is hard to imagine how much was lost to the scientific world as a result.

Nevertheless, Marie completed the publication of her husband's work. However, although she was a successful businesswoman, she found it increasingly difficult to be accepted as a scientist in her own right, and she died frustrated, angry and embittered.

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Off with his head!

Tragically, despite being one of the greatest scientists of his century, Lavoisier was guillotined during the French revolution. His 'crime' was that he obtained the money to fund all of his research by becoming a 'tax farmer'. In France tax farmers collected taxes for the King and were much despised because they only collected from the poor, not the rich, and made huge profits from it.

The discovery of chemical laws

Shortly before Antoine was executed, the Lavoisiers conducted an experiment in which some tin was sealed in a flask containing air. It was then heated and changed to tin oxide. They found that during this chemical reaction the total mass did not change. (Mass will be considered in more detail in Chapter 3.)

They formally announced their discovery in 1785, calling this the **Law of Conservation of Mass**. In simple terms this states:

In a chemical reaction, the total mass of the products equals the total mass of the reactants.

They next formulated the **Law of Constant Proportions**, one statement of which is as follows:

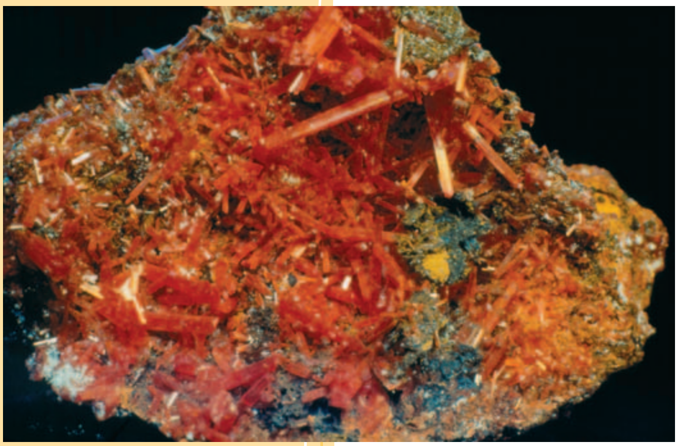
The same compound, however formed, contains the same elements chemically combined, in constant proportions by weight.

A number of chemists have since tested this law with far more accurate, more sensitive equipment than the Lavoisiers had at their disposal. They too have not been able to detect any changes in mass after a chemical reaction, provided the reaction takes place in a totally sealed vessel.

The difference between a compound and a mixture

From these two laws, we know that a **compound** is formed when two or more different elements join together chemically, in a set proportion, to form a new substance. This is similar to a chess set in which there is always one king and one queen, two bishops, two knights, two rooks and eight pawns of each colour. This proportion never changes.

Figure 1.11 Crocoite, a lead chromate mineral



An example of this is the compound lead chromate, found in nature as a rare mineral known as crocoite. Tasmania is one of the few places in the world where crocoite has been discovered. In this compound, the elements lead, chromium and oxygen are always present in the proportions, by mass, of 64% lead, 16% chromium and 20% oxygen, no matter how this compound is made or where it is found.

The distinction between compounds and mixtures was a crucial advance in understanding. In a **mixture**, the proportion of the elements may vary. For example, the composition of the air breathed in by a cyclist riding in peak hour traffic in the centre of Melbourne will differ from the composition of the air breathed in by a skier on the slopes of Mount Buffalo. But it is still air, irrespective of the proportion of each element. Air is a mixture. (In fact, air is a mixture of pure elements *and* compounds.)

EXPERIMENT 1.1

John Dalton's model of the atom

Other important mathematical relationships were soon discovered by the English chemist John Dalton, who used his own experimental results as well as analysing the results of other chemists. These findings made him very curious. Why would elements only combine in such particular, exact proportions?

Dalton realised that the only logical explanation was that not only is matter composed of atoms, but also each element has its own unique set of atoms. In chemical reactions, these atoms simply rearrange, combining with one another in simple proportions.

In 1805, Dalton published his conclusions in the form of the following proposals:

1 All matter is composed of extremely small particles, called atoms, which are held together by forces of attraction.
2 Atoms are indivisible and cannot be created or destroyed.
3 All atoms of the same element are identical in all respects and have the same mass.
4 Atoms of different elements are totally different and have different masses.
5 Atoms of different elements can combine with one another in simple whole-number ratios to form compounds.

Dalton believed that the atom is a solid sphere, unable to be divided any further (Figure 1.13). The **Dalton model of the atom** was the first model of the atom.

When Dalton proposed his very simple model of the atom, it fitted in with the evidence known at the time. But as the theories have been tested by experiment according to the scientific method (page 10), our understanding of the structure of the atom has had to be changed again and again as new evidence has come to light. John Dalton was not completely right! You will learn about these changing theories and the experiments that led to the successive models of the atom in later chapters.

Figure 1.12 John Dalton is often described as an English schoolteacher. What is not so well known is that he was the headmaster of a school at age 12.

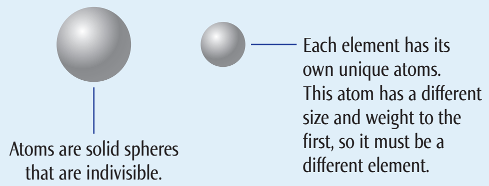
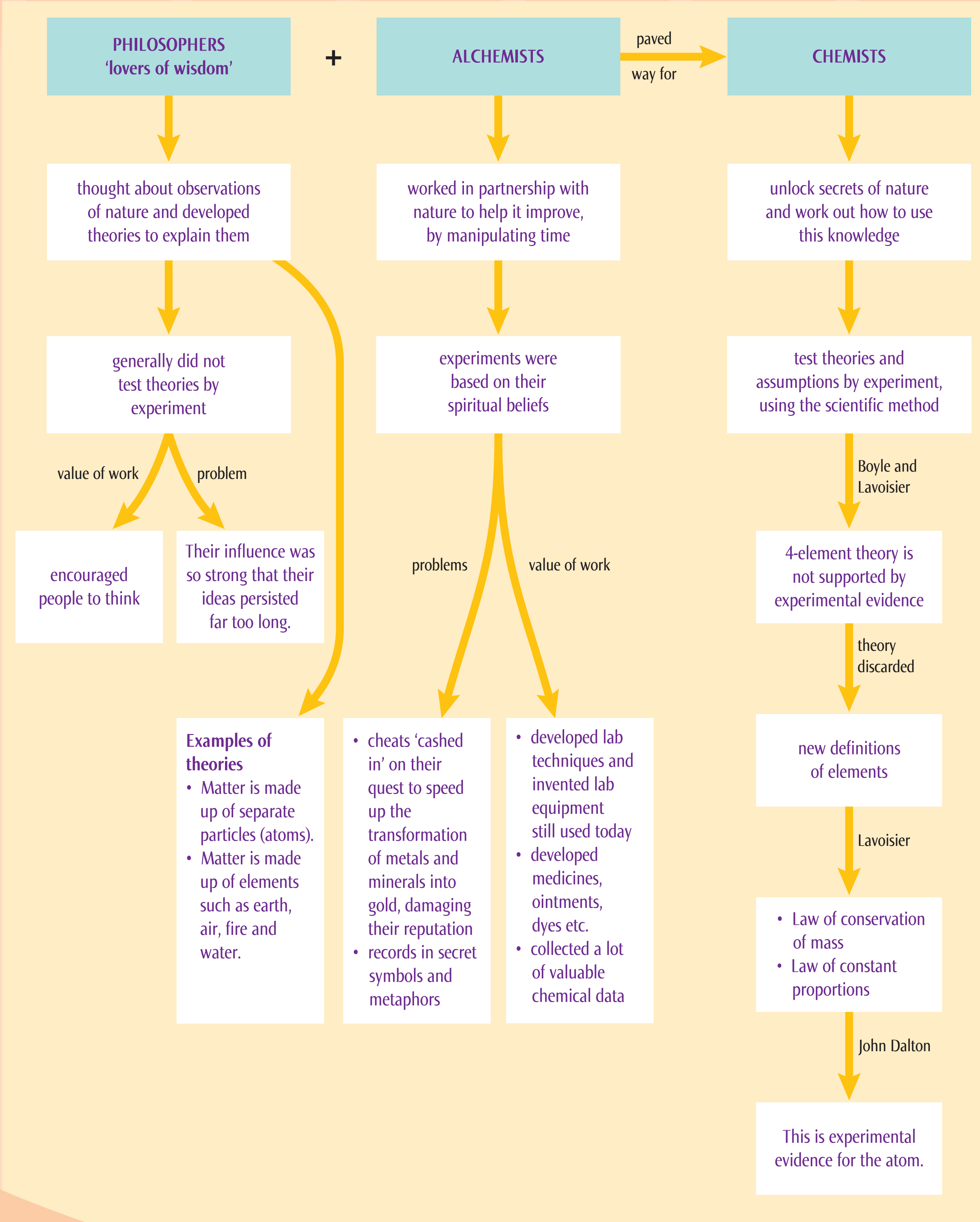


Figure 1.13 The Dalton model of the atom

QUESTIONS 1.2

1 a Compare the definitions of an element given by the Greek philosophers, Robert Boyle and Antoine Lavoisier.
  b Compare the different early theories about what the elements were. For example, which theories believed that fire is an element?
2 a State the Law of Conservation of Mass.
  b Name the chemists who deduced this law.
  c Suggest why this law only applies if the chemical reaction is performed in a sealed container.
3 It has been found that the compound we call water always consists of 88.9% oxygen and 11.1% hydrogen, by mass, no matter how or where it forms.
  a What law does this data illustrate?
  b State the definition of a compound that arose from this law.
  c What is the key difference between a compound and a mixture?
4 a Who first proposed that matter was made of atoms?
  b Why was this proposal rejected for a very long time?
  c Name one invention that helped reinstate this theory.
  d What scientific evidence led to the early atomic theory being accepted at last?
5 Draw and annotate a simple illustration of the Dalton model of atoms of, for example, gold and mercury. Show clearly how they are similar and how they differ, according to his theory.
6 Identify the key differences between the approach of alchemy and the approach of the scientific method to scientific experimentation.

Visual summary



Key terms

alchemy	elements	mixture
atoms	Law of Conservation of Mass	philosopher's stone
compound	Law of Constant Proportions	scientific method
Dalton model of the atom		

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Review questions

1 Copy and complete Table 1.1.

Table 1.1 A comparison of the alchemy of different early civilisations and societies

Feature	China	India and Tibet	Early Egypt	Egypt and Greece (the alchemists of Alexandria)
In what ways were the practical skills of the alchemists applied?				
What beliefs did these alchemists hold in common?				
What did these alchemists call the material that was supposed to transform substances and give immortality?				
From what elements did they believe matter was made?				
In what key ways did their approach to experimentation differ from that of modern chemists?				

2 Robert Boyle is often referred to as the founder of modern chemistry. Describe the contribution he made to our understanding of what elements are and to our approach to scientific experimentation.

3 The Greek philosopher Aristotle had enormous influence on the thinking of alchemists. What were his main beliefs?

4 Explain why science is described as having gone through Dark Ages for hundreds of years.

5 Antoine Lavoisier and John Dalton played key roles in the growing knowledge of chemistry which took scientists out of the Dark Ages and set the foundation for modern chemistry.

   a Outline the major proposals of each of these famous chemists, which arose from their own experimentation and from the knowledge of the findings of other chemists.

   b What kinds of experiments did they conduct that provided such conclusive evidence for their proposals?

6 In many societies, women were not encouraged to have an education and the contributions they made to science and medicine were often not recorded. Summarise the contributions made by each of these women to chemistry and state the period and region in which their contributions were made.

   a Maria the Jewess   b Marie Meurdrac   c Marie Lavoisier

Figure 1.14 Robert Boyle