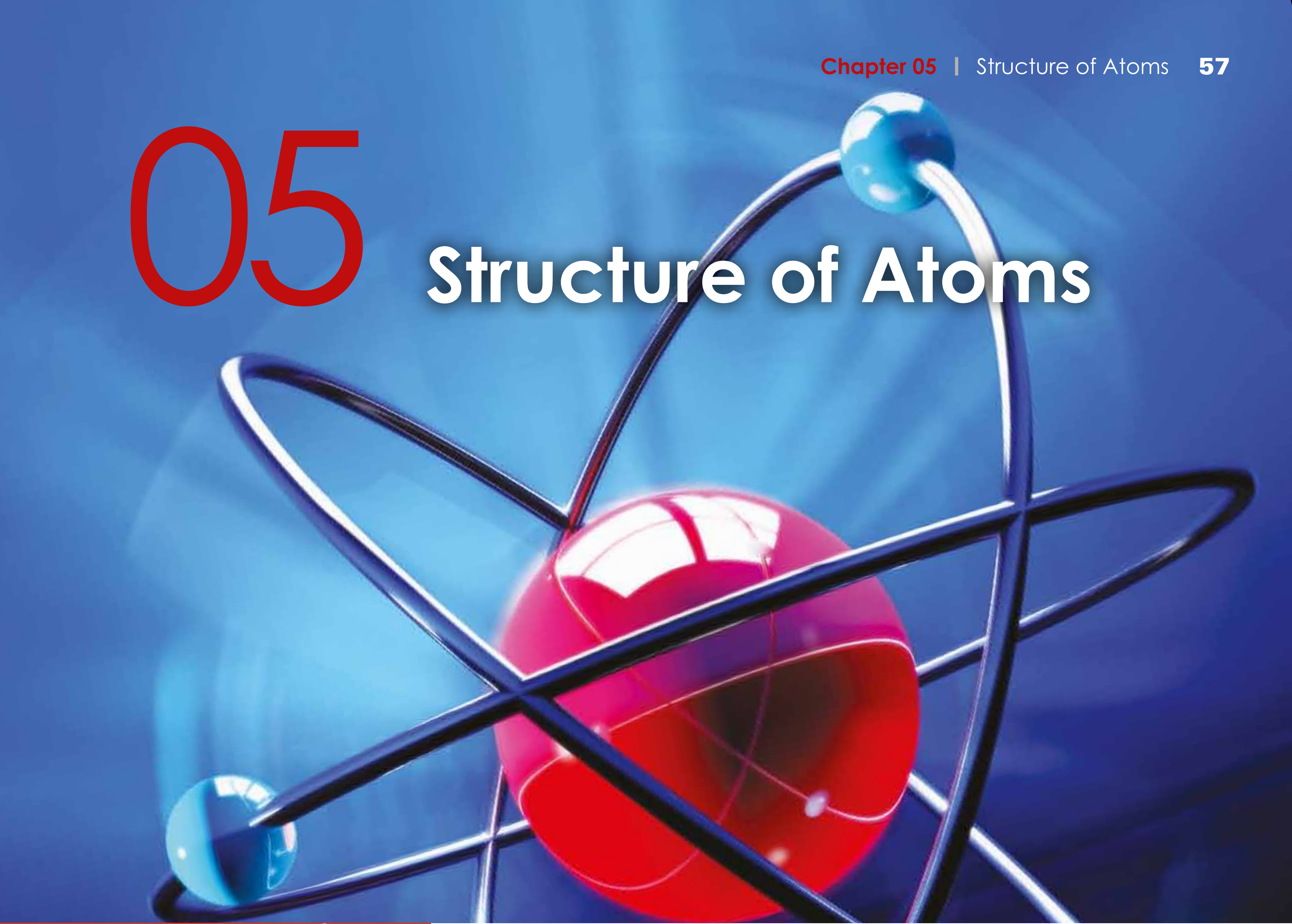
05 Structure of Atoms



Introduction

In the previous chapter, the idea of the atom was introduced. In this chapter, the structure of the atom is investigated. There are two important ideas. They are:

1. As with all ideas in science, the model of the atom is modified in order to account for new experimental observations.
2. Scientific knowledge accumulates over time with later knowledge building on earlier ideas.

Chapter Opener (page 66)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

   What are atoms made of?

   Answer: Students will probably have some general knowledge of subatomic particles.

   How has the model of the atom changed over time?

   Answer: Instead of a solid ball, an atom is now viewed as being largely empty space with a nucleus at its core, surrounded by a cloud of electrons.

   What evidence is there for the belief that an atom contains a nucleus at the centre and that electrons orbit around it?

   Answer: This relates to material that is not in the current textbook but is included in the additional *Chemistry in Society* at the end of this chapter. It deals with the work of J. J. Thomson and Ernest Rutherford.

   What is the relationship between atomic structure and the order of elements in the Periodic Table?

   Answer: Elements are arranged in the Periodic Table in increasing order of proton number. The number of outer shell electrons in an atom corresponds to the group number in the Periodic Table.

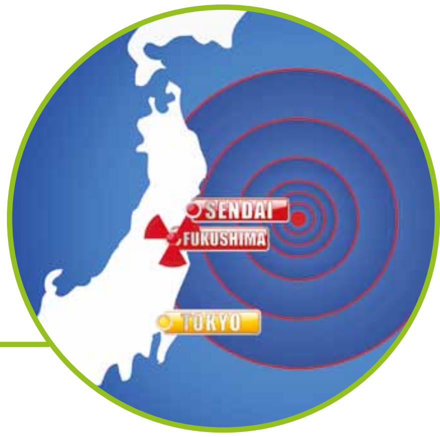
2. Carry out an 'Inquiry Preview.'

Learning Outcomes

After completing this chapter, you should be able to:

- appreciate that the model of the structure of the atom has changed over time
- state the relative charges and approximate masses of the subatomic particles
- define proton (atomic) number, nucleon (mass) number and isotope
- describe, with the aid of diagrams, the structure of simple atoms in terms of protons, neutrons (in the nucleus) and electrons (arranged in shells)
- interpret and use symbols such as $^{12}_{6}C$
- deduce the numbers of protons, neutrons and electrons in atoms and ions, given proton and nucleon numbers
- describe the formation of ions by electron loss or gain in order to obtain the electronic configuration of a noble gas

ChemMystery (page 67)



What role did iodine have in the Fukushima nuclear disaster?

Initial Team Investigation

1. To generate electricity, especially as an alternative method in countries that do not have sources of fossil fuels (coal, oil and natural gas).
2. The main danger is due to the radiation given off by the nuclear fuel which is hazardous to human health.
3. Examples: Too expensive, too dangerous to build a plant so close to the population and hence probably resistance, sources of oil and natural gas are readily-available (even though these must be imported).

Teaching pointers

5.1 What Makes Up an Atom? (page 68)

Stimulation

Discuss the idea that models change as more knowledge becomes available and that chemists now believe the atom is not like the old model of a solid ball. Pose the question of how chemists know what the structure of an atom is like when they cannot see it.

Carry out Additional Exercise 1A which can be found at the end of this chapter. It shows how inferences about objects can be made even when we cannot see them.

1. The idea of electrical charge is very abstract, as students have little concrete experience of charges. Thus the discussion of subatomic particles will be somewhat academic and theoretical in nature.
2. As the mass of an electron is very small in comparison with the other subatomic particles, we usually ignore their masses when calculating the mass of an atom.

3. The nuclear model of the atom should be discussed to show how models in Science are modified. Use the information from the additional 'Chemistry in Society: The changing model of an atom' at the end of this chapter to show the kind of experimental observations that could not be explained using the solid ball model of an atom. This material should be photocopied and distributed to the class.
4. If possible, get students to look at an animation of the Rutherford scattering experiment, and to make inferences about the existence of the nucleus at the centre of an atom and the rest of the atom as being mainly empty space.
5. *Analogies in Science*. Analogies were used implicitly in Chapter 4, when comparing elements with Lego blocks and compounds with objects built up of Lego blocks. In this chapter, analogies are made explicit. Spend some time discussing the use of analogies in science and the analogies for the structure of an atom (See 'Notes for Teachers' on the next page). Additional Exercise 1B on the use of analogies in Science and analogies for atomic structure is included at the end of this chapter. It looks at the Solar system as an analogy for the structure of the atom.
6. To understand the size of a nucleus in an atom, the analogy of a grain of rice in a classroom can be used. Place a grain of rice in the centre of the classroom to represent the nucleus. The distribution of the students around the classroom represents the distribution of electrons in an atom.

Chemistry in Society

The Changing model of an atom

Exercise

1. Electron: Thomson, 1897. Proton: Rutherford, 1919. Neutron: Chadwick, 1932.
2. *Dalton*: A solid sphere, no subatomic particles. *Thomson*: Solid positively charged sphere, studded with electrons. *Rutherford*: Mainly empty space with a small positively charged nucleus (*not* protons and neutrons) surrounded by electrons.

Notes for Teachers

Dates for the discovery of subatomic particles

1897: Thomson discovered the electron.

1899: Thomson proposed the 'plum pudding' model of the atom.

1904: The Japanese physicist Hantaro Nagaoka suggested a planetary model of the atom with a nucleus with electrons revolving around the nucleus.

1910: Rutherford discovered the nucleus (but he did not use this term initially).

1911: Rutherford proposed the nuclear model and the existence of a positively charged nucleus. He suggested that protons might exist.

1913: Bohr proposed the idea of electron shells. Thomson showed the existence of isotopes.

1914: Henry Mosely (a student of Rutherford), proposed the atomic number (later renamed as proton number when the existence of the proton was confirmed).

1919: Rutherford discovered/used the term proton.

1920: Rutherford predicted the existence of neutrons in the nucleus.

1932: Chadwick discovered the neutron which led to the nucleon (mass) number.

Using analogies in science

An analogy is a similarity between two different things. Something already understood is used to understand something similar that we do not understand.

To understand the *size* of a nucleus in an atom, the analogy of the football stadium is used. Comparing the sizes of the stadium and a pea helps us to appreciate the sizes of an atom and a nucleus.

An analogy for the *structure* of an atom is the Solar System. The nucleus is at the centre of the atom just as the Sun is at the centre of the Solar System; electrons move around the nucleus as planets move around the Sun; most of the atom is empty space like in the Solar System.

Although analogies are often used in science, they have two limitations:

1. If the source information (such as the Solar System) is not understood, it is difficult to use the analogy.
2. Erroneous comparisons can be made.

Examples of analogies:

- Crude oil is called 'black gold' as it is black in colour and, like gold, is valuable.
- In Physics, for example, a chemical cell is like a water pump.
- In Biology, for example, the heart is like a pump, comparing the organ to a mechanical device.
- In languages (similes, metaphors, idioms), for example, "As pure as snow; I wandered lonely as a cloud, ..." (Poetry), "He gets under my skin!"

IT Link

http://sciencepage.org/analogy.htm
http://sciencepage.org/anlatst.htm#top
http://www.coe.uga.edu/edpsych/faculty/glynn/twa.html

Videos and explanations on Rutherford's scattering experiment:
http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/006_RUTHERFORD.MOV
http://chemmovies.unl.edu/ChemAnime/RUTHERFD/RUTHERFD.html

Teaching pointers

5.2 Atomic Structure (page 69)

1. *Proton number* and *nucleon number* should be the normal terms used. Older, alternative terms such as *atomic number* and *mass number* can be mentioned as they are still used in many books.
2. Students must know the numbers of protons and electrons of the first 20 elements in the Periodic Table, but not the numbers of neutrons. However, they must be able to calculate the number of neutrons given the proton numbers and nucleon numbers.
3. Get students to analyse the numbers of sub-atomic particles, the proton numbers and nucleon numbers for the atoms in Table 5.2.
4. Discuss the idea of the transmutation of elements. See the 'Notes for Teachers' on page 62.
5. For isotopes, stress that the different isotopes have similar chemical properties but different physical properties. For example, pure $^{37}Cl_2$ has a higher mass, density, melting point and boiling point than pure $^{35}Cl_2$.
6. An optional IT exercise on building atoms and isotopes by adding protons and neutrons is included at the end of this chapter. The worksheet can be printed and distributed to the class. (See also the 'Notes for Teachers' on page 62).

(page 72)

Mystery Clue

U-235: no of protons = 92.
Number of neutrons = 143.
U-238: no of protons = 92.
Number of neutrons = 146.

Chemistry Inquiry (page 70)

Subatomic Particles in an Atom

Group Discussion

1. Iron (Fe)
2. ${}^{56}_{26}Fe$
3. Similarities: Number of protons equals the number of electrons. Protons and neutrons have same size/mass.

   Differences: Number of neutrons differs. Charges differ — protons positive, electrons negative, neutrons none. Electrons have smaller size/mass.

Skills Practice (page 72)

1. Number of protons = number of electrons = 9. Number of neutrons = 10.
2.

Atom	Proton number	Nucleon number	Number of protons	Number of neutrons	Number of electrons
helium	2	4	2	2	2
oxygen	8	16	8	8	8
potassium	19	39	19	20	19
iodine	53	127	53	74	53

Table 5.4

3. (a) **D** (It has the greatest number of protons and neutrons.)
   (b) **A** and **C** (They have the same number of protons but different numbers of neutrons.)

Chemistry in Society (page 72)

Carbon Dating

Exercise

1. Carbon dating can be used to determine the age of objects used in Singapore in the past. This helps us to deduce several aspects of Singapore's history, such as how everyday living was like in the past.
2. Accuracy is important as inaccuracies can result in faulty predictions which lead to incorrect theories being formed.

   Inaccuracies in carbon dating can cause errors in predicting the times when some plant or animal species lived in the past.

(page 73)

Mystery Clue

- The emission of particles or rays when the nucleus in an atom spontaneous disintegrates. The uranium atoms break up/decay into smaller atoms.

  (Note: Students are only expected to have a very basic idea of radioactive decay; no details of the fissile products or how they form is expected.)
- The nucleus in I-131 has four more neutrons than the nucleus in I-127.

Notes for Teachers

Additional Exercise 2: Building atoms and isotopes
The instructions in the activity worksheet at the end of this chapter apply to CD-ROMs that are used to build atoms. An example of such a CD-ROM is *Science and Nature: Elements*.

In Part A, students should find that:

- Each element has a unique proton number (number of protons).
- For the first 20 elements, the number of protons is approximately equal to the number of neutrons.
- For elements with more than 20 protons, the number of neutrons becomes increasingly greater than the number of protons.
- The number of electrons equals the number of protons.

In Part B, students should find that:

- For isotopes of hydrogen, the number of protons remains unchanged as neutrons are added and that ^{1}H and ^{2}H exist in nature, ^{3}H is man-made and ^{4}H does not exist at all.
- ^{35}Cl and ^{37}Cl are natural isotopes of chlorine while ^{40}Cl is man-made and ^{42}Cl does not exist.
- Boron consists of ^{10}B and ^{11}B (80.1%).

Answers for Additional activity

A. Building atoms

2. (a) Hydrogen
   (b) $^{1}_{1}H$
3. Carbon $^{12}_{6}C$, calcium $^{40}_{20}Ca$, bromine $^{80}_{35}Br$
4. (a) One
   (b) The number of protons is equal to the number of electrons.
   (c) No
   (d) (i) The number of neutrons is similar to the number of protons (except for hydrogen which has no neutrons).
   (ii) The number of neutrons increases more than the number of protons.

B. Isotopes

1. (a) Three (b) $^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$ (c) Zero, one and two respectively
2. These isotopes are unstable and decompose into more stable isotopes.
3. Possible answers: helium, He; fluorine, F; sodium, Na; aluminium; A*l*

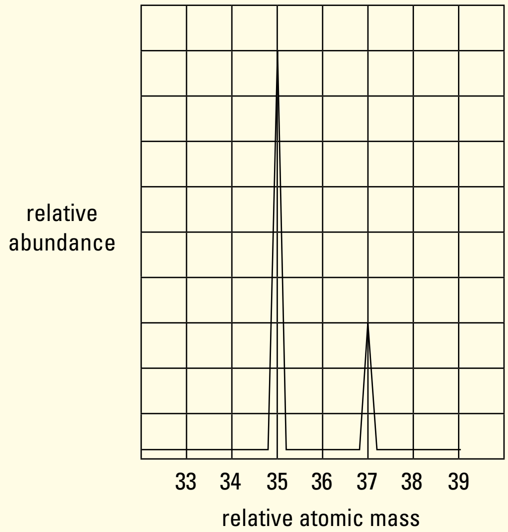
The transmutation of elements
In 1915, Ernest Rutherford fired alpha particles (which contain protons) at some nitrogen gas (proton number 7). Protons entered the nuclei of the nitrogen atoms and changed them into oxygen atoms (proton number 8). This experiment provided strong evidence that atoms consist of protons as distinct particles and that the number of protons identifies the atom.

Similar methods have been used by other scientists to make the non-naturally occurring elements that follow uranium (element number 92) in the Periodic Table. In the nuclear reactions that take place in nuclear power stations and in atomic bombs, the nuclei of atoms of uranium or plutonium 'split' to form elements with a lower proton number.

For centuries, alchemists had searched for something that would turn less valuable metals into gold. They called this the "philosopher's stone". Rutherford finally discovered how to transmute the elements.

The discovery of isotopes
In 1913, J. J. Thomson discovered that some elements could have atoms of different masses. Thomson's apparatus was later developed into a **mass spectrometer** which could be used to compare the masses of atoms and the proportion of each isotope in the element. The reason elements had atoms of different masses was only explained after the discovery of the neutron.

The diagram below shows the mass spectrum for the element, chlorine. This shows that chlorine consists of two isotopes, with isotopic masses of 35 and 37 respectively. The heights of the peak indicate that the abundance of the isotopes in chlorine is 75% of ^{35}Cl and 25% of ^{37}Cl.



Teaching pointers

5.3 How are Electrons Arranged in an Atom? (page 74)

1. How are the electrons arranged in an atom? The nuclear model cannot answer this question. The idea of electron shells came to Bohr while he was attending a horse-racing meeting. The movement of the horses in different 'orbits' around the track made him think of a similar movement of electrons around the nucleus. (See also 'Notes for Teachers' on creativity.)
2. Experimental evidence for shells and electronic structure comes from ionisation energies from emission spectra, though this knowledge is beyond the 'O' Level course.
3. A magnetic board can be very useful for showing electronic structure. Coloured magnetic buttons can represent electrons. With a white magnetic board, the shells may be drawn using a felt pen.
4. Electrons can be represented as dots, circles or crosses. However, it is important that they are drawn clearly. In the electron diagrams, electrons are drawn in pairs. The reasons for such pairing are also beyond the 'O' Level course.
5. Students must know the electronic configurations of the first 20 elements and be able to draw their electronic structures. A useful exercise is to get students to draw the electronic structure of each of these elements.
6. The IT link on page 75 of the textbook gives a website for the animation of electronic structures. It shows the movement of electrons in shells around the nuclei of atoms. Another link, shown below, also shows animations with single electrons in shells:
http://web.visionlearning.com/custom/chemistry/animations/CHE1.3-an-atoms.shtml

Teaching pointers

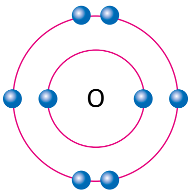
Electronic Structure and the Periodic Table (page 75)

1. Probably the most convincing evidence for the model of the electronic structure is the way it can account for the order of the elements in the Periodic Table and the properties of the elements in the groups.
2. This is only intended to be a brief introduction to the Periodic Table. The Periodic Table is used as a convenient way of presenting all the elements. The three points to make at this stage are:
   - The elements are arranged in order of proton number.
   - Elements in the same Group have the same number of outer shell electrons.
   - The number of outer shell electrons increases one-by-one across a period.
3. Table 5.11 on page 75 brings together many ideas from previous section.
4. A detailed study of the Periodic Table and the properties of the elements can be left until Section 4.

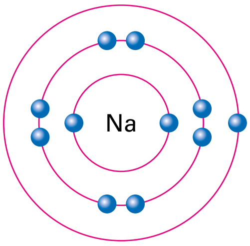
Skills Practice (page 76)

1. An atom of silicon has three shells with 2, 8 and 4 electrons respectively.
2. Electronic structures of:

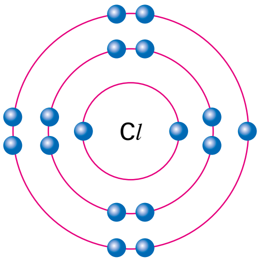
oxygen, O



sodium, Na

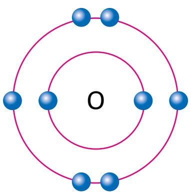


chlorine, C*l*

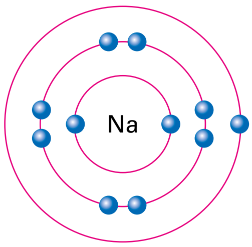


3. The atom has two shells with 2 and 8 electrons respectively. The atom is neon, Ne.
4. Outer electronic structures of:

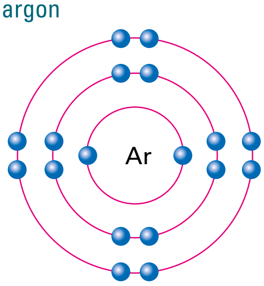
(a) oxygen



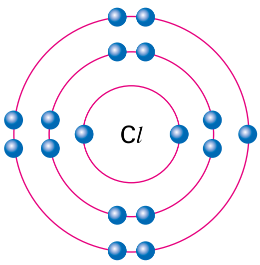
(b) sodium



(c) argon



(d) chlorine



5. **(a)** Radium – Ra. Polonium – Po. Antimony – Sb.
   (b) Radium – Group II, Polonium – Group VI. Antimony – Group V.
   (c) Radium and polonium are metals. Antimony is a metalloid.
   (d) Radium – 2. Polonium – 6. Antimony – 5.

Notes for Teachers

Developing creativity

Creativity involves the ability to generate and extend ideas, to suggest hypotheses, to apply imagination, and to look for alternative innovative outcomes. The idea of the electronic structure that Bohr suggested, illustrates several of the criteria necessary for the development of creative ideas. These are:

- Linking of ideas that do not seem to have a natural connection, especially from widely different areas of knowledge and experience, as in the case of horse racing and electron movement. People with wide interests or those who consciously look for knowledge outside their own speciality, are more likely to make such connections.
- The greater the depth of understanding in a subject, the more likely connections within the content of that subject will be made.
- It helps to take a break from trying to solve a problem or coming up with an explanation. The brain needs time to make connections.

Teaching pointers

5.4 How are Ions Formed from Atoms? (page 76)

1. Link the discussion of ions here with the earlier work in Chapter 4. Point out that historically, the concept and the label 'ion' were used *before* electrons were discovered, so how the charge on an ion arose was not understood at that time.
2. Point out to students that the word *stable* means *not likely* to change.
3. Students should be able to write the formulae and draw the electronic structures for all of the first 20 elements that form ions.

   Na^+, Mg^{2+}, Cl^- and O^{2-} are discussed in the Textbook, while Li^+, F^- and S^{2-} are in Question 1 of the Skills Practice on page 79. The others are H^+, Be^{2+}, N^{3-}, Al^{3+}, P^{3-}, K^+ and Ca^{2+}.
4. Ensure that students can read and pronounce the names of the ions correctly, For example, Mg^{2+} is 'M-g-two-plus' or 'magnesium two plus,' while Cl^- is 'C-*l*-minus.'
5. The knowledge obtained in this section will be used when ionic bonding is discussed in the next chapter.

Skills Practice (page 79)

1. Lithium Li^+. (The atom loses one electron to give an electron arrangement 2 like helium.)

   Fluorine F^-. (The atom gains one electron to give an electron arrangement 2.8 like neon.)

   Sulfur S^{2-}. (The atom gains two electrons to give an electron arrangement 2.8.8 like argon.)
2. (a) The sodium ion has a single, positive change; it has 11 protons and 12 neutrons. The oxide ion has a double, negative charge; the nucleus has 8 protons and 8 neutrons.

   (b) Both ions have three shells, 10 electrons and the same electronic structure of 2.8.
3. The atom is nitrogen N. The ion is the nitride ion N^{3-}. Nitrogen atoms have 7 electrons; the nitride ion has 10 electrons as in Figure 5.18.

05 Chapter Review

Self-Management

Misconception Analysis (page 80)

1. **False** The number of protons (which have a positive charge) equals the number of electrons (which have a negative charge).

2. **True** The number of protons identifies an atom. For example, atoms of carbon have 6 protons. Adding one more proton to a carbon atom changes it into a nitrogen atom. Although the number of neutrons does not change, these do not affect the *kind* of atom.

3. **False** All atoms, *except* hydrogen, have both protons and neutrons. Hydrogen has a single proton.

4. **False** Isotopes are atoms of the *same* element; the number of protons is the same while the number of neutrons is different.

5. **False** The subscript/lower numbers are proton numbers (number of protons). As these differ, X and Y are different elements. The upper numbers are nucleon numbers. Atoms of X have 6 protons and 8 neutrons; atoms of Y have 7 protons and 7 neutrons.

6. **False** Only the second shell holds a maximum of 8 electrons. The third shell holds a maximum of 18 electrons.

7. **False** Atoms of elements in the same *group* have the same number of outer shell electrons. For example, all Group I elements have 1 outer shell electron. Atoms of elements in the same *period* have the same number of shells.

8. **True** This is because they have stable noble gas electronic configurations.

Practice

Structured Questions (page 80 – 81)

1.

Element	Symbol	Number of protons	Number of electrons	Formula of ion
sodium	Na	11	10	Na^{+}
calcium	Ca	20	18	Ca^{2+}
bromine	Br	35	36	Br^{-}
potassium	K	19	18	K^{+}
aluminium	Al	13	10	Al^{3+}

Table 5.10

2. (a)

Particle	Charge (+/–/0)	Found in nucleus (Yes/No)
proton	+	yes
electron	–	no
neutron	0	yes

Table 5.11

(b) proton, electron, neutron

3.

Element	Proton number	Nucleon number	Number of protons	Number of neutrons	Number of electrons
fluorine	9	19	9	10	9
iron	26	56	26	30	26
gold	79	197	79	118	79
copper	29	64	29	35	29
titanium	22	48	22	26	22

Table 5.12

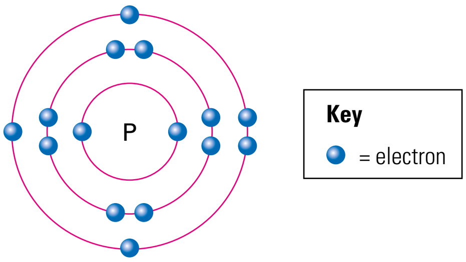
4. (a)

Element	Proton number	Nucleon number	Electronic configuration
A	3	7	2.1
B	18	40	2.8.8
C	16	32	2.8.6
D	12	24	2.8.2
E	19	39	2.8.8.1

Table 5.14

(b) B
(c) A and E. Both are in Group I as atoms of both elements have one outer shell electron.
(d) B. Its three shells are full of electrons.

5. (a) It corresponds to the proton number which is the number of protons in the nucleus.
(b) It corresponds to the nucleon number which is the number of protons and neutrons.
(c) Electronic structure of a phosphorus atom:



(d) (i) Group V
(ii) Both have 5 outer shell electrons.

6. (a) Beryllium, Be
(b) $^{9}_{4}Be$
(c) $^{10}_{4}Be$. It has one more neutron but the same number of protons and electrons.

7. (a) $^{28}_{14}Si$ has 14 neutrons. $^{30}_{14}Si$ has 16 neutrons.
(b) (i) 28 and 30 respectively
(ii) Isotopes
(c) (i) Three
(ii) Both have the electronic configuration of 2.8.4.

8. (a) In the nucleus
(b) 2.8
(c) Charge = –2 (number of protons – number of electrons = 8 – 10 = –2)
(d) O^{2-}

9. (a)

	Fluoride ion	Neon atom	Sodium ion
Number of protons	9	10	11
Number of electrons	10	10	10
Overall charge	–1	0	1

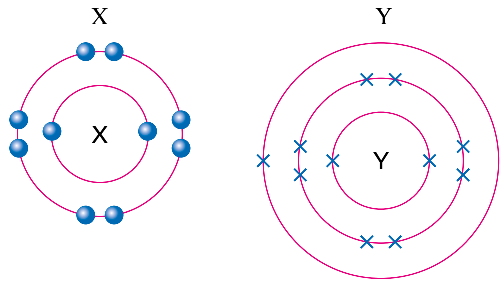
Table 5.13

(b) They have 10 electrons, two shells and the same electronic configuration of 2.8.
(c) Different numbers of protons and different overall charges
(d) Neon has a stable electronic structure.

10. (a) They have the same number of electrons, the same arrangement of electrons, the same nucleon number, the same total number of electrons, protons and neutrons and they are both ions (list any three).
(b) They have different proton numbers and different numbers of neutrons. Ion A has a single positive charge, A^+ (as it has 11 protons and 10 electrons) while ion B has a single negative charge, B^- (as it has 9 protons and 10 electrons).
(c) By transferring a proton from A to B and a neutron from B to A.

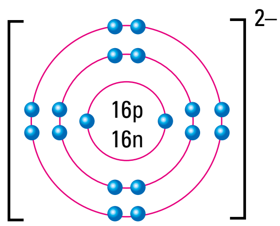
Free Response Questions (page 82)

1. (a) Electronic structures of:



(b) The electronic structure of X is 2.7. With 7 outer shell electrons, it is in Group VII of the Periodic Table and is a non-metal. The electronic configuration of Y is 2.8.1 which means it has one outer shell electron. Y is in Group I of the Periodic Table and is a metal.
(c) X gains one electron to obtain the stable electronic configuration of neon which is 2.8. With 10 electrons but only 9 protons, the ion has an overall charge of –1. The ion is written as X^-. Y loses its one outer shell electron to obtain the electronic configuration of 2.8 which is also the same as that of neon. The ion has 10 electrons but 11 protons, giving the ion an overall charge of +1. The ion is written as Y^+.

2. (a) The proton number is 16 so there are 16 protons in the nucleus and 16 electrons. The nucleon number is 32 so there are 16 neutrons in the nucleus. Thus, in this atom, the numbers of protons, neutrons and electrons are identical. With 16 electrons, the electronic structure is 2.8.6 indicating that there are 3 shells and it is in Period 3. Because there are 6 electrons in the outer shell, the element is in Group VI of the Periodic Table. With 6 outer electrons, the atom can gain 2 more electrons to form the ion X^{2-} with an overall charge of –2.
(b)



3. Different responses are possible. Here are examples of what could be included:
    - Dalton's model of an atom as a solid ball was accepted during the 19th Century.
    - Discovery of the electrons.
    - Discovery of the first subatomic particle at the end of the 19th Century, resulting in the first modification to Dalton's model of the atom.
    - Further changes were made with the discovery of the nucleus and the atom as consisting mainly of empty space.
    - Discovery of shells led to the electronic structure.
    - Discovery of proton and neutron led to the atomic number and mass number.
    - This led to the model we use today (at 'O' Level).

Extension (page 82)

1. (a) Ratio of diameter of atom to that of the nucleus = 10 000 to 1. Therefore, the diameter of the atom is 10 000 times more than that of the nucleus.
   (b) Diameter of the pea ~ 1 cm (0.01 m). Diameter of stadium ~ 150 m. Ratio of diameter of stadium to pea = 15 000. Therefore, this is a fair comparison.

2. In Rutherford's experiment, alpha particles were fired at a thin sheet of gold atoms. In the analogy, an alpha particle is like the 15-inch shell and the thin sheet of gold is like the tissue paper. Rutherford expected most of the alpha particles to pass straight through the gold just as he would expect a large shell fired at a piece of tissue paper to pass straight through. Most alpha particles did pass straight through, but some bounced straight back. Rutherford was surprised at this result just as he would have been surprised if a large shell fired at a piece of tissue paper bounced back and hit him.

Additional

Chemistry in Society

The Changing Model of the Atom

The work of scientists in the late 19th Century and early 20th Century resulted in new models for the structure of the atom. Here are two of these models and some of the evidence for them.

Figure 5.4 J. J. Thomson (1856–1940)

The Thomson model

In 1897, J. J. Thomson (Figure 5.4), an English physicist, did experiments that led to the discovery of the electron. Thomson also showed that

(1) an electron carries a negative charge, and

(2) atoms contain electrons.

In 1903, Thomson proposed a new model of the atom. He described the atom as a positively charged sphere with electrons pushed into it. It was something like a cake studded with raisins; the raisins were the electrons (Figure 5.5).

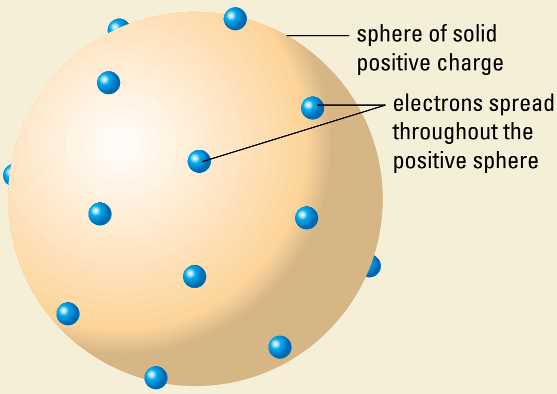


Figure 5.5 Thomson's model of an atom

Note: The positive sphere in Thomson's model is not a proton; the proton was discovered later. Although Thomson suggested that the atom is a positively charged sphere, he did not have any experimental evidence to support this hypothesis.

The Rutherford model

Thomson's model of the atom was soon to be modified. This was due to the work of Ernest Rutherford (Figure 5.6), a New Zealand physicist working in England. In 1910, he carried out a simple but clever experiment, from which he showed that an atom has a nucleus (Figure 5.7).

In this experiment, Rutherford used small positively charged particles (called alpha particles) to bombard a very thin sheet of gold foil. When an alpha particle hit the fluorescent screen, a small flash of light was produced. This light could be seen through a microscope.

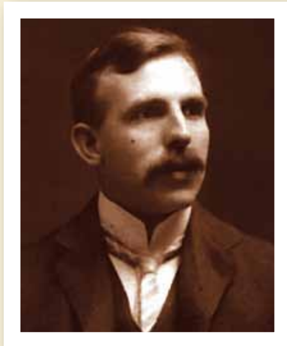


Figure 5.6 Ernest Rutherford (1871–1937)

Rutherford found that most of the alpha particles went straight through the gold foil (position **A** in Figure 5.7). Some of the alpha particles were deflected slightly by the foil (to position **B**). However, a few alpha particles bounced straight back (to position **C**) as if they had hit something very small and dense in the gold atoms.

Thomson's model could not explain these observations. In Thomson's model, electrons are spread all through the atom. Therefore, all the alpha particles should be deflected in a similar way. But this did not happen. Thus, Thomson's model had to be modified. To explain why most alpha particles passed straight through the gold, Rutherford suggested that the atom must be mostly empty space. He also suggested that there is a small, dense object at the centre of the atom. This would explain why some of the alpha particles bounced straight back (Figure 5.8).

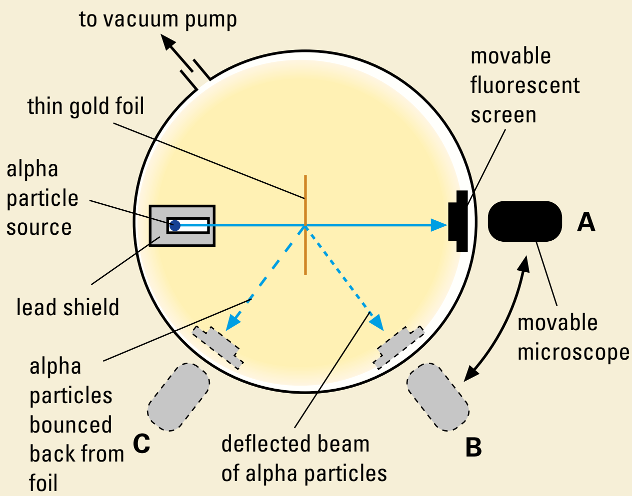


Figure 5.7 The apparatus used for Rutherford's alpha particle scattering experiment

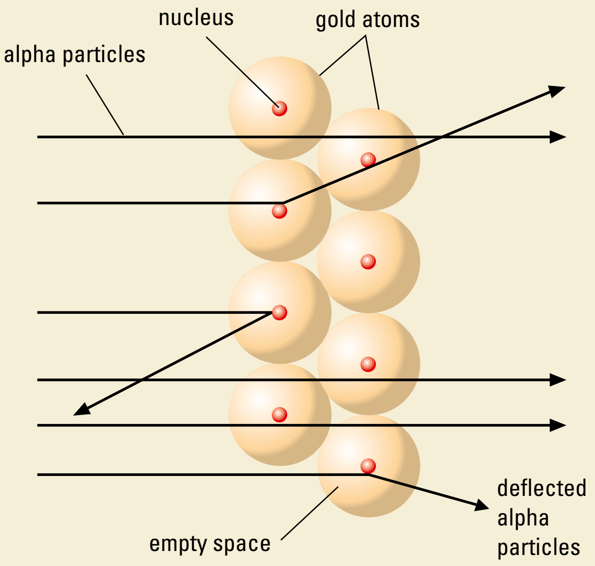


Figure 5.8 Explaining the results of Rutherford's experiments

By doing mathematical calculations, Rutherford showed that the centre of the atom was positively charged. He named this small centre of the atom the nucleus. Then, in 1911, he proposed the existence of the proton as a subatomic particle with a positive charge.

Rutherford did not discover the neutron. However, he suggested that it might exist. It was one of his students, James Chadwick (1891-1974), who in 1932 discovered the neutron.

IT Link

Simulation of the Rutherford scattering experiment

http://micro.magnet.fsu.edu/electromag/java/rutherford/
http://phet.colorado.edu/en/simulation/rutherford-scattering

Very instructive videos and explanations on Rutherford's scattering experiment

http://cwx.prenhall.com/petrucci/medialib/media_portfolio/text_images/006_RUTHERFORD.MOV

http://chemmovies.unl.edu/ChemAnime/RUTHERFD/RUTHERFD.html

Exercise

1. Which scientist discovered, and in which year, the following: the electron, the proton, the neutron and the nucleus? [*elaborating*]
2. Compare Dalton's, Thomson's, and Rutherford's models of the atom with the nuclear atom in Figure 5.2. [*comparing*]

Additional Teaching Material

Additional Exercise 1: Investigating Objects We Cannot See

Objectives
- To make inferences about an object without seeing it
- To appreciate that there can be limitations in the gathering of scientific evidence
- To appreciate the usefulness of analogies in understanding scientific ideas

Strategy
- Using analogies

Key Competency
CIT: sound reasoning (*using analogies*)

A. Making inferences about objects we cannot see

Your teacher will give you a lump of plasticine. Inside each lump is a letter from a toy set. You are provided with a long needle. Without taking the lump apart, try to find out which letter is inside the lump (Figure 1).

Figure 1

1. Briefly describe what you do, what you observe and your inferences. While you are doing the experiment, try to visualise (to see in your mind) the letter inside the lump.

2. Which letter do you think the lump contains?

Questions

1. There are limitations in what you can discover because you cannot see the letter. Give one example of what you cannot discover about the letter.

____

2. This experiment is similar to the Rutherford scattering experiment (Figure 2).

   Give one example of how the procedure Rutherford used is similar to the procedure in your experiment.

   ____

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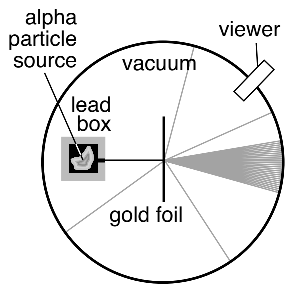

Figure 2

B. An analogy for the structure of the atom

To help understand the structure of an atom, we can use the analogy of the Solar System (Figure 3).

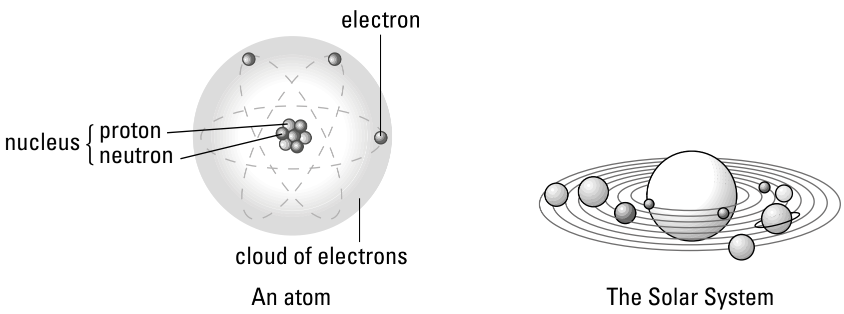

Figure 3 Comparing the structure of an atom and the Solar System

1. In the table, show some ways in which the atom and the Solar System are similar.

Atom	Solar system

2. With analogies, there are always comparisons we cannot make. List two such comparisons of the atom and the Solar System that we cannot make.

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Additional Teaching Material

Additional Exercise 2: Building Atoms and Isotopes

Objectives

- To use a modelling programme to build atoms and isotopes

Key Competency

ICS: management of information (*use of models*)

A. Building atoms

1. Open a suitable atom modelling program on your computer. (A suitable programme for this exercise is the CD-ROM: *Science and Nature: Elements*.)

2. Start with one proton on the screen. See how many neutrons and electrons go with this atom.

(a) What is the name of the element?

(b) Show the structure of this atom in symbol form, i.e. symbol with proton number and nucleon number.

3. Now add protons, one at a time, to make models of other atoms. Name some of these atoms and show their structures in symbol form.

4. Find the answers to the following questions:

(a) How many proton numbers can a particular element have?

(b) What is the relationship between the numbers of protons and the numbers of electrons in an atom?

(c) Is the number of neutrons in an atom equal to the number of protons?

(d) What patterns do you notice for the numbers of neutrons and protons when atoms have

(i) from 1 to 20 protons, and

(ii) more than 20 protons?

B. Isotopes

1. Start with an atom of hydrogen, ${}^{1}_{1}H$. Then add neutrons to make the other two isotopes of hydrogen.

(a) How many isotopes does hydrogen have?

____

(b) Write the symbols for these isotopes.

____

(c) How many neutrons do the isotopes have?

____

2. Now look at the two isotopes of chlorine, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ on the screen. See if you can make other isotopes of chlorine by changing the number of neutrons. What do you notice about an isotope such as ${}^{40}_{17}Cl$?

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3. Name some elements that seem to have just one isotope.

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Additional Teaching Material

Additional Exercise 3: Comparing ions

Objectives

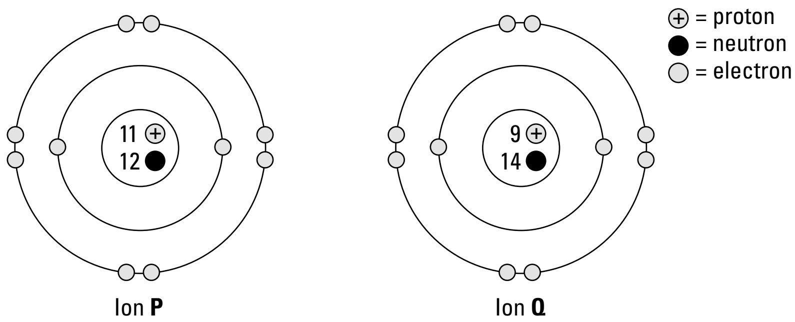
- To decide which features of two ions are the same and which are different

Competencies

CIT: sound reasoning (*comparing*)

A. Building atoms

1. The structures of two ions, **P** and **Q**, are shown in the diagram below.



In chemistry, it is usually only possible to move electrons from one atom to the other. Imagine that you have the power to move any particle between atoms, not just the electrons, but also the neutrons and protons.

Ions **P** and **Q** can be made the same by moving one particle from ion **P** to ion **Q** and one particle from ion **Q** to ion **P**.

Look carefully at the two ions. Then decide which features of the two ions are the same and which features are different. Do this by considering the electrons, protons, nucleus and the electric charges on the two nuclei and on the two ions.

Then work out how to move the particles to make both ions the same.

Use the graphic organiser on the next page to help you.

Comparing

What is the purpose of this comparison? →

Factors	How are they different?

Factors	How are they different?

Conclusion →

From ion P to ion Q:
From ion Q to ion P:

Answers

Additional Exercise 1:

A. Questions

1. E.g. I can infer the shape of the letter but not its colour/kind of material.

2. E.g. The nucleus in an atom is like the letter in the plasticine. In both experiments, observations and inferences were made without seeing objects directly.

B. 1.

Atom	Solar system
The nucleus is at the centre of the atom.	The Sun is at the centre of the Solar System.
Electrons orbit the nucleus.	Planets orbit the Sun.
Most of the atom is empty space.	Most of the Solar System is empty space.

2. E.g. Planets are different; electrons are identical. The electrons are charged particles but not the planets. The Sun is hot but not the nucleus.

Additional Exercise 3:

Comparing

What is the purpose of this comparison? → To work out what particles must be moved to make both ions the same

Factors	How are they different?
Electrons	They have the same number and the same arrangement.
Nucleus	They have the same nucleon number.

Factors	How are they different?
Number of protons	**P** has two more protons.
Number of neutrons	**Q** has two more neutrons.
Charge on nucleus	**P** has a nuclear charge of 11+ and Q has a nuclear charge of 9+.
Electric charge of ion	**P** has a charge of +1 and Q has a charge of –1.

Conclusion →

From ion P to ion Q: Move one proton.

From ion Q to ion P: Move one neutron.

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