4 The Structure of the Atom

As you know, everything is ultimately made of atoms, and atoms are made up of subatomic particles—electrons, protons and neutrons. Let us learn a little more about this idea that has brought about a revolution in science.

How the Idea of Atoms Emerged

The Views of Kanad

Way back in the sixth century BC, the Indian philosopher Kanad came forward with the following idea.

Matter is

- not continuous, and
- made up of tiny particles, named *paramanus*.

(In Sanskrit, *param* means final or ultimate, and *anu* means particle.)

Kanad further said that two or more *paramanus* combine to form bigger particles.

The Views of Democritus and Leukiposs

In the fifth century BC, the Greek philosophers Democritus and Leukiposs came up with a similar idea. They thought that on dividing a piece of a substance, one would ultimately get a particle that could not be divided further. They gave the name atomos (in Greek, *atomos* means indivisible) to these ultimate particles.

Dalton's Theory

The theories of Kanad as well as of Democritus and Leukiposs remained forgotten for more than two thousand years. But when experimental chemistry developed, it became necessary to explain the observed facts. In this connection, in 1803, an English chemist, John Dalton, put forward his atomic theory, which can be summarised as follows.

1. Elements are made up of very small particles of matter, called atoms (derived from the Greek word *atomos*).
2. Atoms are indivisible.
3. The atoms of an element have the same weight.
4. The atoms of different elements have different weights.
5. It is the atoms of elements that take part in a chemical reaction.
6. The atoms of an element combine in a simple numerical ratio with those of other element(s) to form a compound.

An atom is defined as the smallest part of an element that takes part in a chemical reaction.

The Subatomic Particles

In the late nineteenth century, however, it was proved that atoms are divisible. And later it was found that atoms are made up of subatomic (or fundamental) particles—electrons, protons and neutrons.

The Electron

Under ordinary conditions, gases are bad conductors of electricity. But a gas becomes a good conductor of electricity if

(i) the pressure of the gas is very low (say, 10 mm of mercury or lower), and

(ii) the voltage applied is very high (say, 10,000 V).

These conditions are achieved in what is called a discharge tube.

Cathode rays

A discharge tube (Figure 4.1) is a long glass tube, at the two ends of which are sealed two metal plates. These plates can be connected to a high-voltage source and are called electrodes. The electrode connected to the negative terminal of the source is called the cathode, and the one connected to the positive terminal is called the anode. There is also a side tube which can be connected to an exhaust pump, used for lowering the pressure of the gas inside the discharge tube.

When a high voltage is applied across the terminals, and the pressure inside the tube is 0.01–0.001 mm of mercury, the end of the tube opposite the cathode starts glowing. This phenomenon is called fluorescence. Investigations have shown that some invisible rays, starting from the cathode, fall on the opposite wall of the tube, causing fluorescence. These rays were named cathode rays.

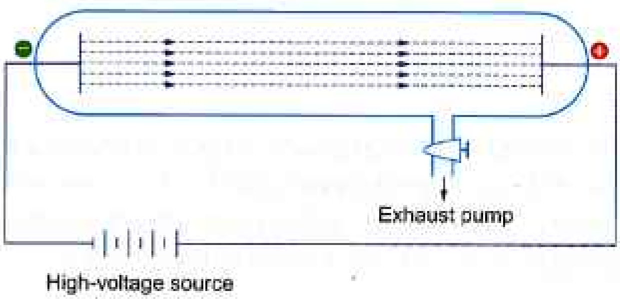

Fig. 4.1 Cathode rays produced in a discharge tube

The characteristics of cathode rays

Sir J J Thomson and others found that cathode rays have the following characteristics.

1. Cathode rays originate at the cathode and travel in straight lines.

   When an object is placed between the

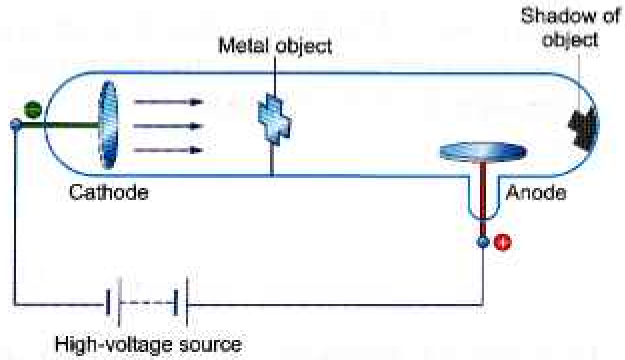

Fig. 4.2 Cathode rays travel in straight lines.

cathode and the anode, a shadow of the object falls on the wall opposite the cathode. A shadow can be formed only when the rays travel in straight lines.

2. Cathode rays are a stream of particles.

   A light paddle wheel, placed in the path of the cathode rays, rotates. This shows that some particles strike the plates of the wheel.

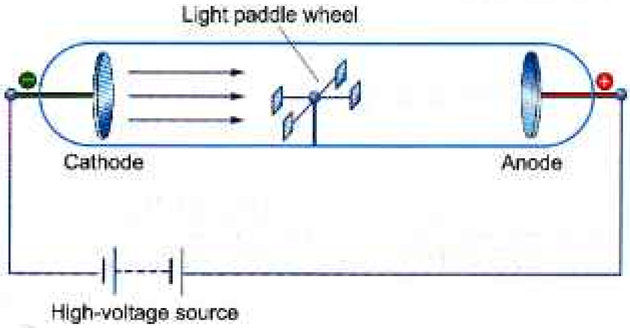

Fig. 4.3 Cathode rays are a stream of particles.

3. The particles constituting cathode rays are negatively charged.

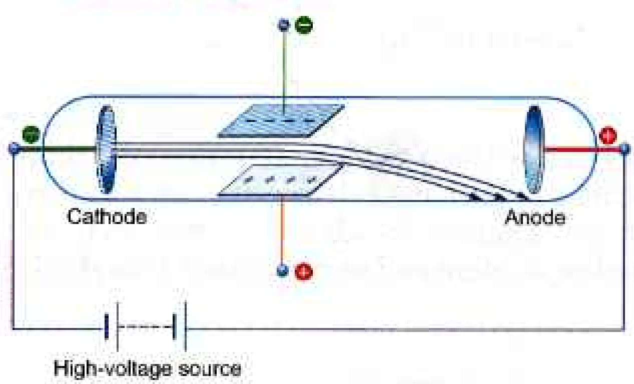

Fig. 4.4 Cathode rays contain negatively charged particles.

This is proved by the fact that the cathode rays bend towards the positive plate in the presence of an electric field.

4. The particles constituting cathode rays have a fixed charge to mass ratio (e/m). This ratio does not change with the gas, the electrodes and the kind of glass used for making the tube.

Thus, Sir J J Thomson concluded that *the particles constituting cathode rays are a universal constituent of all atoms*. He named these particles electrons in 1897.

The charge and mass of an electron

Absolute charge and mass The charge to mass ratio (e/m) of an electron was determined by J J Thomson to be 1.78×10^8 C/g (coulomb per gram). In 1908, R A Millikan determined the charge of an electron to be 1.6×10^{-19}C. Thus, the mass of an electron can be calculated as follows.

$$e = 1.6 \times 10^{-19}\text{C}$$

$$\frac{e}{m} = 1.78 \times 10^8 \text{C/g}$$

$$m = \frac{e}{1.78 \times 10^8 \text{ C/g}} = \frac{1.6 \times 10^{-19}\text{C}}{1.78 \times 10^8 \text{C/g}}$$

$$= 9.1 \times 10^{-28}\text{g}$$

$$= 9.1 \times 10^{-28} \times 10^{-3}\text{kg}$$

$$= 9.1 \times 10^{-31}\text{kg}$$

Relative charge and mass The charge on an electron is taken as the unit of negative charge. So it is said to have a charge of –1 unit. The mass of an electron is about 1/1840 that of a hydrogen atom and so it is treated as negligible.

The Proton

An atom is electrically neutral. But the electrons present in it are negatively charged particles. Hence, the atom must also contain some positively charged particles so that the overall charge on it becomes zero. These particles should be found in the discharge tube itself, when cathode rays are formed.

Anode rays

Goldstein repeated the cathode-ray experiment using a perforated cathode (Figure 4.5). He observed that there was a glow on the wall opposite the anode. So, some rays must be travelling in the direction opposite that of the cathode rays, i.e., from the anode towards the cathode. These rays were called anode rays or canal rays (as they moved through the perforations, or canals, in the cathode). It was found that these rays contained positively charged particles, and so J J Thomson called them positive rays.

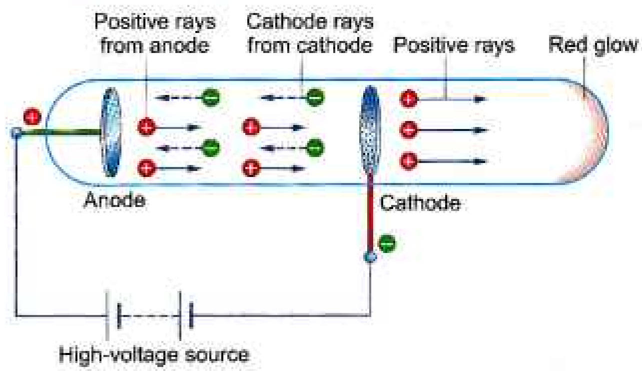

Fig. 4.5 Anode rays

The characteristics of anode rays

The characteristics of anode rays were found by carrying out experiments similar to those with cathode rays. The following characteristics distinguish anode rays from cathode rays.

1. Anode rays are a stream of positively charged particles (because they bend towards the negative plate in an electric field). The charge on a particle which is part of an anode ray is the same (1.6×10^{-19}C) as that on an electron, but opposite in sign.

2. The charge to mass ratio (e/m) of the particles constituting anode rays is not

fixed. Its value depends upon the gas used in the discharge tube, the highest being that for hydrogen.

What constitute the anode rays?

The electrons constituting the cathode rays must come from the atoms of the gas inside the discharge tube. Electrons are negatively charged particles, so the atoms must be left with an equivalent amount of positive charge. It is these positively charged particles that constitute the anode rays.

$$\underset{\text{atom of gas}}{A} \longrightarrow \underset{\text{anode rays}}{\underset{\downarrow}{A^+}} + \underset{\text{cathode rays}}{\underset{\downarrow}{e}}$$

As an electron has a negligible mass, the particle A^+ will have the same mass as A. So, the value of e/m will differ from gas to gas. Or, we can say that the smaller the mass of the gas atom, the higher the value of e/m. Hence, when hydrogen—the lightest element—is taken in the discharge tube, the particles constituting the anode rays have the highest e/m value. The positively charged particles originating from hydrogen atoms are called protons.

$$H \longrightarrow \underset{\text{anode rays}}{\underset{\downarrow}{\underset{\text{proton}}{H^+}}} + \underset{\text{cathode rays}}{\underset{\downarrow}{\underset{\text{electron}}{e}}}$$

The charge and mass of a proton

Charge The charge on a proton is the same (1.6×10^{-19}C) as that on an electron, but with opposite sign. It is taken as a unit of positive charge. So, a proton has a unit positive charge, i.e., +1.

Mass The mass of a proton is the same as that of a hydrogen atom, i.e., 1 amu. A proton is about 1840 times heavier than an electron. Its absolute mass is 1.67×10^{-24} g.

The Neutron

Till now, we have learnt of only one particle that can account for the mass of an atom—the proton. The electron has negligible mass. But, except in the case of hydrogen, it was found that the mass of an atom is greater than that of the protons in it. Further, the unaccounted mass (i.e., the actual mass of the atom minus the mass of the protons) is either equal to or a multiple of the mass of a proton. This suggested that *an atom must contain one more kind of particle which should have*

- *the same mass as a proton, but*
- *no electrical charge on it.*

These particles were named neutrons as they should be electrically neutral.

Experimentally, however, the neutron was observed much later in what is called a nuclear reaction. In 1932, James Chadwick bombarded the element beryllium with α-particles. (α-particles are emitted by radioactive elements and are helium ions with a double positive charge, (He^{2+}) which are described later.) He observed that beryllium changes to carbon, and that neutrons are emitted in the reaction.

$$\underset{\text{beryllium}}{{}^{9}_{4}Be} + \underset{\alpha\text{-particle}}{{}^{4}_{2}He} \longrightarrow \underset{\text{carbon}}{{}^{12}_{6}C} + \underset{\text{neutron}}{{}^{1}_{0}n}$$

Table 4.1 Charge and mass of the subatomic particles

Particle	Charge	Mass
Electron	–1 unit	$\frac{1}{1840}$ of an H-atom (negligible)
Proton	+1 unit	1 amu
Neutron	Zero	1 amu

The Discovery of the Nucleus

The concept of the nucleus was given by Ernest Rutherford in 1911. The idea was based on the results of his famous experiment, known as the α-particle scattering experiment.

Rutherford's α-Particle Scattering Experiment

EXPERIMENT Rutherford bombarded a thin gold foil with α-particles, as described below. α-particles are emitted by radioactive substances like radium and polonium. (We will discuss radioactivity later in the chapter.)

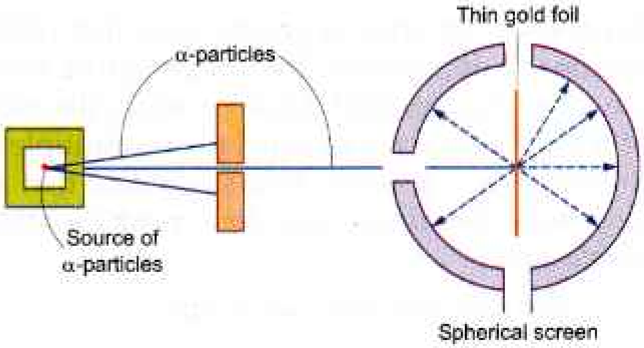

Fig. 4.6 Schematic diagram of Rutherford's α-particle scattering experiment

A beam of α-particles was directed on to a thin gold foil. The foil was surrounded by a spherical screen of zinc sulphide. When an α-particle strikes a zinc sulphide particle, the latter glows. Thus, Rutherford was able to know in which direction an α-particle moved.

Rutherford's observations and conclusions are described below.

1. Most of the α-particles went straight through the foil. This is explained by the fact that they were not attracted to or repelled by any particle. In other words, *the atom is mostly empty*.
2. Some of these particles deviated slightly from their path. They were repelled to a small extent by a positive charge. Very few of the particles, the ones at the centre, almost retraced their path. This meant that they were strongly repelled by a small positively charged body at the centre of the atom. This positively charged body is called the *nucleus*.

   Since the electron has negligible mass, the *mass of the atom is concentrated in the nucleus*.
3. Rutherford also theorised that *electrons revolve round the nucleus at large distances from it*.

Rutherford estimated the diameter of the nucleus to be of the order of 10^{-13} cm and that of the atom to be of the order of 10^{-8} cm. Thus, *the diameter of the nucleus is about* 10^5*(= 1,00,000) times smaller than that of the atom.*

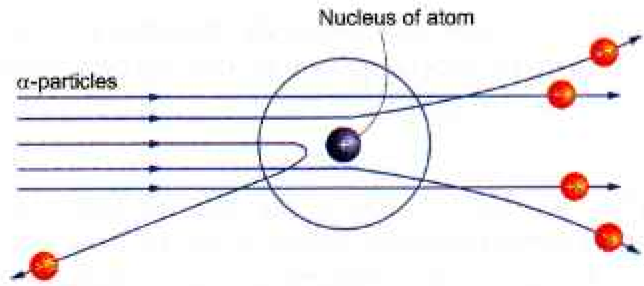

Fig. 4.7 Rutherford's explanation of α-particle scattering on the basis of his nuclear model

How are the Subatomic Particles Placed in the Atom?

As we have just said, the mass of an atom is concentrated in its nucleus. The mass of an electron is negligible, but that of a proton or a neutron is 1 amu. So, protons and neutrons must reside in the nucleus. Remember that the nucleus of a hydrogen atom contains only a proton and no neutrons. The nucleus of an atom is positively charged due to the presence of proton(s) in it.

The electrons revolve round the nucleus in their own orbits, just as planets do in the solar system.

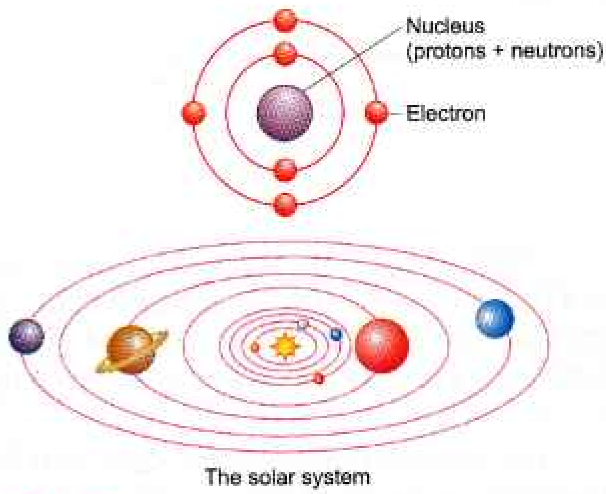

Fig. 4.8 Electrons revolve round the nucleus like planets round the sun.

Numbers of Subatomic Particles in an Atom

Atomic Number and Mass Number

You have learnt in the previous class that, to know the numbers of subatomic particles in an atom, one needs to know the atomic, or proton, number (*Z*) and the mass number (*A*) of the atom.

The atomic number, or the proton number, of an element is the number of protons present in the nucleus of an atom of the element.

The sum of the numbers of protons and neutrons in an atom is known as the mass number of the atom.

You also know that an atom is electrically neutral and so it has the same number of electrons as protons. So, in an atom,

the number of electrons = *Z*,

the number of protons = *Z*, and

the number of neutrons = *A* – *Z*.

The numbers of fundamental particles in atoms with atomic numbers 1 to 20 are given in Table 4.2.

Table 4.2 The numbers of electrons, protons and neutrons in some atoms

Element	Symbol	Atomic number (*Z*)	Mass number (*A*)	Numbers of particles		
				Electrons (*Z*)	Protons (*Z*)	Neutrons (*A* – *Z*)
Hydrogen	H	1	1	1	1	0
Helium	He	2	4	2	2	2
Lithium	Li	3	7	3	3	4
Beryllium	Be	4	9	4	4	5
Boron	B	5	11	5	5	6
Carbon	C	6	12	6	6	6
Nitrogen	N	7	14	7	7	7
Oxygen	O	8	16	8	8	8
Fluorine	F	9	19	9	9	10
Neon	Ne	10	20	10	10	10
Sodium	Na	11	23	11	11	12
Magnesium	Mg	12	24	12	12	12
Aluminium	Al	13	27	13	13	14
Silicon	Si	14	28	14	14	14
Phosphorus	P	15	31	15	15	16
Sulphur	S	16	32	16	16	16
Chlorine	Cl	17	35	17	17	18
Argon	Ar	18	40	18	18	22
Potassium	K	19	39	19	19	20
Calcium	Ca	20	40	20	20	20

Nuclide symbol

The nuclide symbol of an atom is the symbol of the element with its atomic number as the subscript and mass number as the superscript, which are set to the left of the symbol of the element.

The nuclide symbol is expressed as ${}^{A}_{Z}X$. For example, the nuclide symbol ${}^{35}_{17}Cl$ represents a chlorine atom, whose atomic number is 17 and mass number is 35. You can immediately guess that there are 17 electrons, 17 protons and 35 – 17 (= 18) neutrons in the atom.

Isotopes

The atomic number is the characteristic of an element. Every element has its own atomic number which no other element can have. But atoms of the same element can differ in mass number. For example, hydrogen has three types of atoms—${}^{1}_{1}H$, ${}^{2}_{1}H$ and ${}^{3}_{1}H$, and chlorine has two—${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$. Such atoms are called isotopes. The heavier isotopes of hydrogen are called deuterium (${}^{2}_{1}H$ or D) and tritium (${}^{3}_{1}H$ or T). In fact, most elements have isotopes.

Atoms of an element with different mass numbers are called isotopes.

As the isotopes of an element have the same *Z*, they have the same number of electrons and the same number of protons. But, as the mass number (*A*) differs, the value of (*A* – *Z*), i.e., the number of neutrons in the atoms differs (Table 4.3). For example, ${}^{35}_{17}Cl$ has 17 electrons, 17 protons and 35 – 17 = 18 neutrons, whereas ${}^{37}_{17}Cl$ has 17 electrons, 17 protons and 37 – 17 = 20 neutrons. Thus, isotopes can also be defined as follows.

The atoms of an element which differ in the number of neutrons are called isotopes.

As the atomic number of an element is fixed, its isotopes are often represented or named without the atomic number, e.g., ^{35}Cl or chlorine-35, and ^{37}Cl or chlorine-37.

Table 4.3 **Numbers of subatomic particles in the isotopes of some elements**

Isotope	Numbers of subatomic particles		
	Electrons (= Z)	Protons (= Z)	Neutrons (= A − Z)
$^{1}_{1}H$	1	1	1 − 1 = 0
$^{2}_{1}H$	1	1	2 − 1 = 1
$^{3}_{1}H$	1	1	3 − 1 = 2
$^{12}_{6}C$	6	6	12 − 6 = 6
$^{13}_{6}C$	6	6	13 − 6 = 7
$^{14}_{6}C$	6	6	14 − 6 = 8
$^{16}_{8}O$	8	8	16 − 8 = 8
$^{17}_{8}O$	8	8	17 − 8 = 9
$^{18}_{8}O$	8	8	18 − 8 = 10
$^{35}_{17}Cl$	17	17	35 − 17 = 18
$^{37}_{17}Cl$	17	17	37 − 17 = 20

Atomic Mass

The atomic mass of an element is the number of times an atom of the element is heavier than a hydrogen atom.

Here, the mass of a hydrogen atom is taken as the unit of mass, i.e., 1 atomic mass unit (amu).

Can the atomic mass of an element be fractional?

As you know, it is the protons and neutrons that make up the mass of an atom and they have a mass of 1 amu each. So, the atomic masses of elements should have been in whole numbers. But it has been found that *elements have fractional atomic mass*, e.g., chlorine has an atomic mass of 35.5. This is because isotopes of these elements are present in any natural sample.

Let us see why the atomic mass of chlorine is a fractional number—35.5. In fact, any natural sample of chlorine contains 75% atoms of mass number 35, and 25% atoms of mass number 37. Thus, the atomic mass that we find is actually the average atomic mass of the two isotopes.

The average atomic mass of chlorine

$$= \frac{75 \times 35 + 25 \times 37}{100}$$

$$= \frac{25(3 \times 35 + 37)}{100}$$

$$= 35.5 \text{ amu.}$$

The atomic mass of an element is relative to the mass of a hydrogen atom. So it is also called the relative atomic mass of an element. The unit amu is not used for relative atomic mass.

The Bohr Model of the Atom

In 1913, Niels Bohr presented a model of the atom, called the Bohr model. This model was the first in the series of modern concepts, which explained many properties of the atom. It is based on certain assumptions (usually called postulates), which we will now discuss.

The Postulates of the Bohr Model

The Bohr model is based on the following postulates.

1. Electrons revolve round the nucleus only in certain permissible circular orbits, also called shells.

   The orbit nearest the nucleus is counted as the first ($n = 1$), and is called the K shell. The subsequent orbits, i.e., the second, third, fourth, fifth, etc., orbits are called the L, M, N, O, etc., shells respectively.

2. Each orbit (shell) has a definite energy.

   The energy of a shell in a given atom can be theoretically calculated.

3. The energy of an electron remains constant so long as it revolves in a given orbit.

   So, these orbits (or shells) are also called energy levels.

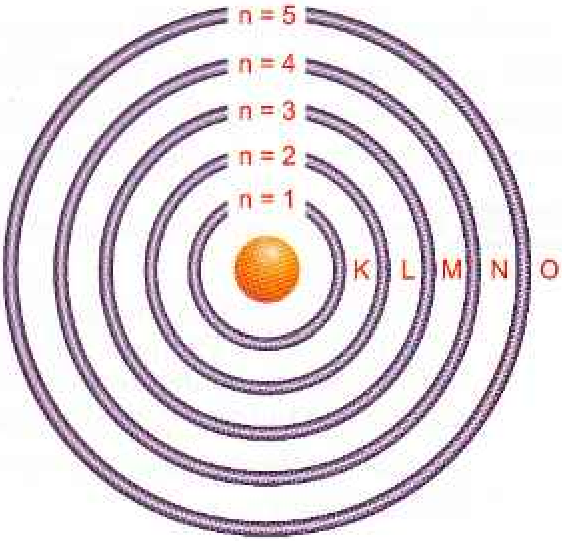

Fig. 4.9 The electron shells in an atom

4. An electron absorbs energy while jumping from a low-energy level to a high-energy level.

   Suppose the energy of the K shell of an atom is 4 units and that of the L shell is 7 units. Then an electron in the K shell will have to be given 3 units of energy for jumping to the L shell.

5. An electron gives out energy while jumping from a high-energy level to a low-energy level.

   Thus, for the atom mentioned above, an electron in the L shell will give out 3 units of energy while jumping to the K shell.

Electron Transition

The jumping of an electron from one level to the other is called electron transition. The energy change in an electronic transition can be easily understood by performing the following activity.

Activity Throw a few crystals of table salt into the blue flame of your kitchen stove. The flame will become golden yellow.

An electron in the sodium atom absorbs energy from the flame and jumps to the higher level. While coming back to the original, i.e.,

Fig. 4.10 Crystals of table salt impart a golden yellow colour to a blue flame due to electron transition in sodium.

Fig. 4.11 A sodium-vapour lamp gives a golden yellow light due to electron transition in sodium.

lower level, it gives out energy in the form of a golden yellow light.

Sodium-vapour lamps (generally used in street and car lights) work on the same principle. The light emitted by these lamps is golden yellow as they contain sodium vapour.

The Arrangement of Electrons in Atoms

The arrangement of electrons in the different shells of an atom is called electronic configuration.

The electron shells of an atom are not filled arbitrarily. The number of electrons in a shell follows a set of rules, called the Bohr–Bury rules.

Bohr–Bury Rules

Of the various Bohr–Bury rules, we need to know the following two in order to write the electronic configuration of elements up to calcium (Z = 20).

1. The maximum number of electrons that can be accommodated in a shell is given by $2n^2$, where n is the number of the shell. For example, $n = 1$ denotes the first (K) shell, and so on.

   You can easily calculate that the K, L, M, N,… shells can accommodate a maximum of 2, 8, 18, 32,… electrons, respectively.

Shell	n	Maximum number of electrons
K	1	$2 \times 1^2 = 2$
L	2	$2 \times 2^2 = 8$
M	3	$2 \times 3^2 = 18$
N	4	$2 \times 4^2 = 32$

and so on.

2. The outermost shell of an atom cannot contain more than 8 electrons in any case.

   You will learn how to apply Rule 2 when we discuss the electronic configurations of argon and potassium.

Applying Bohr–Bury rules

By now, it should be clear to you that the only electron in a hydrogen atom ($_1H$) occupies the K shell, and so do the two electrons in a helium atom ($_2He$). As the K shell cannot have more than two electrons (Rule 1), the third electron of the lithium atom ($_3Li$) must go to the next shell, i.e., the L shell. So, the arrangement of electrons in a lithium atom can be shown as $K_2 L_1$. However, there is a convention that the names of the shells are not mentioned in electronic configuration. The order in which the numbers of electrons are mentioned indicate the order of the shell, i.e., K, L, M, N,… respectively. Thus, the electronic configuration of hydrogen is written as 1, that of helium as 2, and that of lithium as 2, 1. The electronic configurations of elements up to calcium are given in Table 4.4.

EXAMPLE 1 *What is the electronic configuration of oxygen (Z = 8)?*

Solution The total number of electrons in an oxygen atom is 8. Of these, 2 electrons will be accommodated in the K shell and the remaining 6 in the L shell.

So, the electronic configuration of oxygen is 2, 6.

EXAMPLE 2 *What is the electronic configuration of argon (Z = 18)?*

Solution The total number of electrons in an argon atom = 18. Of these,

2 electrons will go to the K shell,
8 " " " " L shell, and
8 " " " " M shell.

So, the electronic configuration of argon is 2, 8, 8.

EXAMPLE 3 *Can the electronic configuration of $_{19}K$ be 2, 8, 9? If not, give the correct configuration of the atom.*

Solution According to the Bohr–Bury rules, there cannot be more than 8 electrons in the outermost shell of an atom. So, the configuration 2, 8, 9 is not possible.

The correct configuration is 2, 8, 8, 1.

Table 4.4 The electronic configurations of some common elements

Element	Symbol	Atomic number	Electronic configuration			
			K	L	M	N
Hydrogen	H	1	1			
Helium	He	2	2			
Lithium	Li	3	2	1		
Beryllium	Be	4	2	2		
Boron	B	5	2	3		
Carbon	C	6	2	4		

Element	Symbol	Atomic number	Electronic configuration			
			K	L	M	N
Nitrogen	N	7	2	5		
Oxygen	O	8	2	6		
Fluorine	F	9	2	7		
Neon	Ne	10	2	8		
Sodium	Na	11	2	8	1	
Magnesium	Mg	12	2	8	2	
Aluminium	Al	13	2	8	3	
Silicon	Si	14	2	8	4	
Phosphorus	P	15	2	8	5	
Sulphur	S	16	2	8	6	
Chlorine	Cl	17	2	8	7	
Argon	Ar	18	2	8	8	
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2

Valency

Atoms of different elements combine to form compounds.

The force that holds two or more atoms together to form a new entity is called a chemical bond.

Atoms may combine in various ways. One is by the transfer of an electron from one atom (usually a metal atom) to another (usually a nonmetal atom). The bond formed by the transfer of electron(s) is called an ionic or electrovalent bond. The compounds thus formed are called ionic or electrovalent compounds.

Examples of Ionic Bond

Let us see how an ionic bond is formed.

1. Sodium chloride (NaCl)

Consider the formation of sodium chloride from sodium and chlorine. A sodium atom (2, 8, 1) transfers an electron to a chlorine atom (2, 8, 7).

By losing an electron, the sodium atom acquires a positive charge, and forms the

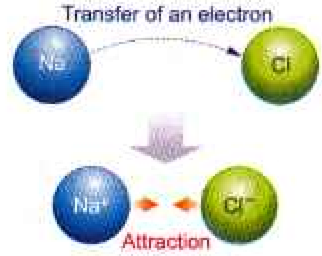

Fig. 4.12 The formation of NaCl

positive ion, or *cation*, Na^+. This is because the protons are in excess of the electrons (11 protons against 10 electrons) in a sodium ion.

$$\underset{(2,8,1)}{Na} - e \longrightarrow \underset{(2,8)}{Na^+}$$

At the same time, the chlorine atom that gains an electron, acquires a negative charge and forms the negative ion, or *anion*, Cl^-. This is because the electrons are in excess of the protons (18 electrons against 17 protons) in a chlorine ion.

$$\underset{(2,8,7)}{Cl} + e \longrightarrow \underset{(2,8,8)}{Cl^-}$$

The two oppositely charged ions, Na^+ and Cl^-, are held strongly by an electrostatic force of attraction. And a new substance, sodium chloride (NaCl), is formed.

2. Magnesium oxide (MgO)

A magnesium atom loses two electrons, which an oxygen atom gains. As a result, two oppositely charged ions, Mg^{2+} and O^{2-}, are formed. These ions are held together by electrostatic forces of attraction, and magnesium oxide (MgO) is formed. The charges on the two ions are balanced.

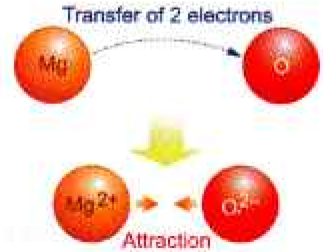

Fig. 4.13 The formation of MgO

$$\underset{(2,\,8,\,2)}{\mathrm{Mg}} - 2e \longrightarrow \underset{(2,\,8)}{\mathrm{Mg}^{2+}}$$

$$\underset{(2,\,6)}{\mathrm{O}} + 2e \longrightarrow \underset{(2,\,8)}{\mathrm{O}^{2-}}$$

3. Magnesium chloride ($MgCl_2$)

You have seen that a magnesium atom loses two electrons, but a chlorine atom can take up only one. So two chlorine atoms come up to form two Cl^- ions in order to balance the charge on one Mg^{2+} ion. Thus is magnesium chloride ($MgCl_2$) formed.

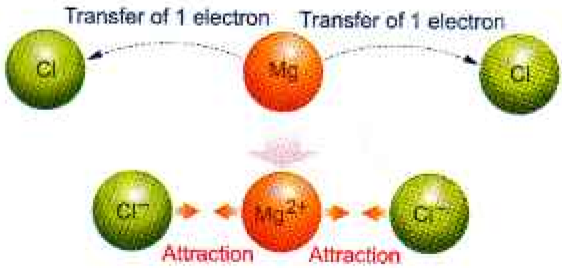

Fig. 4.14 The formation of $MgCl_2$

4. Sodium oxide (Na_2O)

A sodium atom loses one electron to form an Na^+ ion, but an oxygen atom requires two electrons to form an O^{2-} ion. So, two sodium atoms lose one electron each, forming two Na^+ ions, in order to balance the charge on the O^{2-} ion. Thus is sodium oxide (Na_2O) formed.

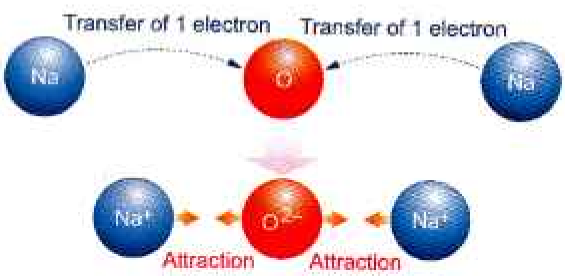

Fig. 4.15 The formation of Na_2O

Changes in Electronic Configuration

Let us look at the electronic configurations of the atoms and the ions they form on losing or gaining electrons.

$$\underset{(2,\,8,\,1)}{\mathrm{Na}} - e \longrightarrow \underset{(2,\,8)}{\mathrm{Na}^{+}}$$

$$\underset{(2,\,8,\,2)}{\mathrm{Mg}} - 2e \longrightarrow \underset{(2,\,8)}{\mathrm{Mg}^{2+}}$$

$$\underset{(2,\,8,\,3)}{\mathrm{Al}} - 3e \longrightarrow \underset{(2,\,8)}{\mathrm{Al}^{3+}}$$

$$\underset{(2,\,8,\,7)}{\mathrm{Cl}} + e \longrightarrow \underset{(2,\,8,\,8)}{\mathrm{Cl}^{-}}$$

$$\underset{(2,\,6)}{\mathrm{O}} + 2e \longrightarrow \underset{(2,\,8)}{\mathrm{O}^{2-}}$$

$$\underset{(2,\,5)}{\mathrm{N}} + 3e \longrightarrow \underset{(2,\,8)}{\mathrm{N}^{3-}}$$

We find that each ion formed has *eight electrons in the outermost shell.*

> When an atom attains eight electrons in its outermost shell, the atom is said to have achieved an octet.

Thus, it appears that an atom loses or gains electrons in order to attain an octet. By attaining an octet, an atom becomes stable. The noble-gas atoms, except helium (2), have an octet e.g. Ne (2, 8) and Ar (2, 8, 8). They are stable, and reluctant to combine with other atoms. Based on this fact came the octet rule, which is stated as follows.

> During a chemical reaction, changes occur in such a way that each combining atom, except hydrogen and lithium, attains an octet.

A hydrogen or lithium atom becomes stable by attaining a duplet, i.e., the configuration of helium.

The octet can also be attained by an atom in ways other than the transfer of electron(s). This gives rise to other kinds of bonding.

You will learn more about these in higher classes.

The numerical value of valency

The numerical value of the valency of an element taking part in the formation of an ionic bond equals the number of electrons an atom of the element loses or gains in the process.

Thus, the valencies of sodium, magnesium and aluminium are 1, 2 and 3 respectively. Similarly, the valencies of chlorine, oxygen and nitrogen are also 1, 2 and 3 respectively.

Radioactivity

Our knowledge of the atomic structure owes a great deal to the phenomenon of radioactivity. You have seen how, using α-rays, Rutherford discovered the nucleus and Chadwick discovered the neutron. Radioactivity has been used in various other fields too.

Discovery of Radioactivity

Light affects a photographic plate, but it cannot pass through a black paper. So, we protect a photographic plate from light by covering it with a black paper. Sometime in 1896, the scientist Henri Becquerel kept a photographic plate covered with black paper in his drawer. He had also kept a uranium sample in the same drawer. To his surprise, he found that the photographic plate was clouded.

Further experiments led Becquerel to conclude that uranium gives out some kind of invisible rays that

- pass through black paper, and
- affect a photographic plate.

These rays were named radioactive rays. A substance emitting such rays is called a radioactive substance, and the phenomenon itself is known as radioactivity.

A phenomenon in which there is a spontaneous emission of radiation from a substance is known as radioactivity.

A substance that spontaneously emits radiation is said to be radioactive.

Later, some other elements, like radium, polonium and thorium, too, were found to be radioactive.

Radioactive Rays

Radioactive rays are of three kinds—alpha (α), beta (β) and gamma (γ) rays.

How are they separated?

When the rays emerging from a radioactive substance pass through an electric field, they separate into three parts (Figure 4.16). The separation is recorded on a photographic plate kept in their path.

1. α-rays Some rays *bend towards the negative plate*, and are called α-rays. They are made of α-particles, which are bipositive helium ions (He^{2+}). We use the nuclide symbol ${}^{4}_{2}He$ to denote an α-particle.

2. β-rays Some rays *bend towards the positive plate*, and are called β-rays. They are a stream of β-particles, which are nothing but electrons. We use the symbol ${}^{0}_{-1}\beta$ for a β-particle.

3. γ-rays Some rays *pass straight through*, and are called γ-rays. γ-rays do not contain any kind of particles—charged or uncharged. They are a kind of radiation, known as electromagnetic radiation, like light, but more energetic than light rays or even X-rays.

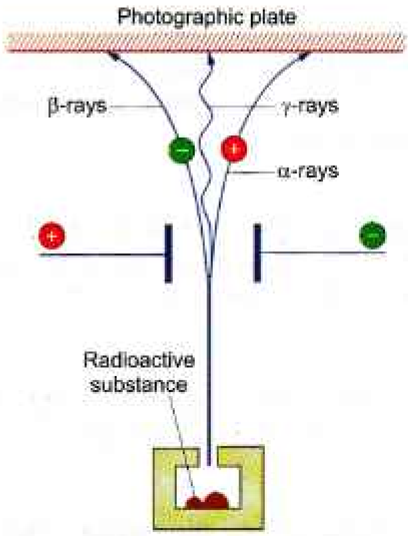

Fig. 4.16 α-, β-, and γ-rays from a radioactive substance

Radioactivity is a Nuclear Phenomenon

Radioactive rays are emitted by atoms due to changes in their nuclei. So, we say that radioactivity is a nuclear phenomenon.

What happens if an α-particle is emitted?

An α-particle ($^{4}_{2}He$) contains 2 protons and 2 neutrons. So, if an atom loses an α-particle, the proton number of the atom decreases by 2, and the mass number decreases by 4 (2 protons + 2 neutrons). Due to a change in the proton number, the atom now becomes that of a *new element*. Thus, uranium-238 ($^{238}_{92}U$), on emitting an α-particle, gives an atom of the element whose proton number (*Z*) is 90 and mass number (*A*) is 234. Such an element is thorium (Th).

$$\underset{\text{uranium-238}}{^{238}_{92}U} \longrightarrow \underset{\text{thorium-238}}{^{234}_{90}Th} + \underset{\alpha\text{-particle}}{^{4}_{2}He}\text{ , or}$$

$$^{238}_{92}U \xrightarrow{-\alpha} {^{234}_{90}Th}$$

Dalton would not have believed that an atom of an element could be changed to that of another.

What happens if a β-particle is emitted?

A β-particle is an electron, but not one from those revolving round the nucleus. A β-particle is formed when a neutron gets converted into a proton inside the nucleus.

$$\underset{\text{neutron}}{^{1}_{0}n} \longrightarrow \underset{\text{proton}}{^{1}_{1}p} + \underset{\beta\text{-particle}}{^{0}_{-1}\beta}$$

So, the proton number (*Z*) of the atom increases by 1, but the mass number (*A*) remains the same. A new element is formed. For example, on emitting a β-particle, sodium-24 ($^{24}_{11}Na$), a radioactive isotope of sodium, gives magnesium-24 ($^{24}_{12}Mg$).

$$\underset{\substack{\text{sodium-24}\\\text{(radioactive)}}}{^{24}_{11}Na} \longrightarrow \underset{\substack{\text{magnesium-24}\\\text{(stable)}}}{^{24}_{12}Mg} + \underset{\beta\text{-particle}}{^{0}_{-1}\beta}$$

Artificial, or Induced, Radioactivity

It is possible to turn certain nonradioactive atoms into radioactive atoms by bombarding them with a high-speed particle. For example, aluminium-27, on being bombarded with a neutron, emits an α-particle and changes to sodium-24.

$$\underset{\text{aluminium-27}}{^{27}_{13}Al} + \underset{\text{neutron}}{^{1}_{0}n} \longrightarrow \underset{\text{sodium-24}}{^{24}_{11}Na} + \underset{\alpha\text{-particle}}{^{4}_{2}He}$$

In the next step, sodium-24 emits a β-particle and changes to magnesium-24.

$$^{24}_{11}Na \longrightarrow {^{24}_{12}Mg} + {^{0}_{-1}\beta}$$

Such a phenomenon is called artificial or induced radioactivity.

> When a nonradioactive atom is transformed into a radioactive atom on being bombarded with a high-speed particle, the phenomenon is called artificial or induced radioactivity.

Nuclear Fission

When certain heavy nuclei are struck by a neutron, they are split into two lighter nuclei. Such a nuclear reaction is called nuclear or atomic fission. *A large amount of energy is released in nuclear fission.*

Where does this energy come from? You may have heard of Einstein's famous mass-energy equation, $E = mc^2$. Here, E =

energy, m = mass and c = velocity of light. Detailed calculations have shown that the actual mass of whatever we get as a result of fission is less than what we started with. How do we account for this loss of mass? It is converted into energy ($E = mc^2$). Remember that here m is the loss of mass, i.e., the mass that has been converted into energy.

All heavy nuclei do not undergo fission. For example, uranium-235 is fissionable (or fissile), but uranium-238 is not. Uranium-235 splits in several ways, one of which is shown below.

$$\underset{\text{uranium}}{{}^{235}_{92}\text{U}} + \underset{\text{neutron}}{{}^{1}_{0}\text{n}} \longrightarrow \underset{\text{barium}}{{}^{143}_{56}\text{Ba}} + \underset{\text{krypton}}{{}^{90}_{36}\text{Kr}} + \underset{\text{neutron}}{3\,{}^{1}_{0}\text{n}} + \text{energy}$$

The three neutrons released in this reaction will hit three more uranium nuclei, each releasing three neutrons, and so on. Thus, a chain reaction will set in.

If the chain reaction is left uncontrolled, it can cause great damage. Atomic bombs, based on the fission of uranium and plutonium, were dropped over Hiroshima and Nagasaki in Japan in August 1945, during World War II. Thousands of people died in the holocaust. This is the dark side of nuclear fission.

Fig. 4.17 An atomic explosion

However, there is a bright side of nuclear fission too. If the chain reaction is controlled, nuclear fission becomes a great source of energy. The calorific value of ^{235}U-fission is about 2.5 million times greater than that of coal.

Nuclear Fusion

It has been found that, at extremely high temperatures (millions of degrees Celsius), certain lighter nuclei combine (or fuse) to form heavier nuclei. For example, two deuterium nuclei combine to give a tritium and a hydrogen nucleus.

$$\underset{\text{deuterium}}{{}^{2}_{1}\text{H}} + \underset{\text{deuterium}}{{}^{2}_{1}\text{H}} \longrightarrow \underset{\text{tritium}}{{}^{3}_{1}\text{H}} + \underset{\text{hydrogen}}{{}^{1}_{1}\text{H}} + \text{energy}$$

Such a nuclear reaction is called nuclear fusion. A large amount of energy is released in a fusion reaction (for similar reasons as in fission.)

The hydrogen bomb is based on nuclear fusion. Several tests for such bombs have been made. One of them is based on the following scheme.

$$\underset{\text{deuterium}}{{}^{2}_{1}\text{H}} + \underset{\text{hydrogen}}{{}^{1}_{1}\text{H}} \longrightarrow \underset{\text{helium}}{{}^{3}_{2}\text{H}} + \text{energy}$$

The hydrogen bomb is many times more powerful than even the atom bomb.

The sun is our main source of energy. Several fusion reactions, like the following, are going on in the sun.

$${}^{2}_{1}\text{H} + {}^{1}_{1}\text{H} \longrightarrow {}^{3}_{2}\text{He} + \text{energy}$$

$${}^{3}_{2}\text{He} + {}^{2}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + {}^{1}_{1}\text{H} + \text{energy}$$

Using Nuclear Energy

You have learnt that both fission and fusion can be used as a source of energy. But fusion requires very high temperatures, which poses its own problems. So fission is mainly used.

Nuclear power plants

Nuclear power plants are set up to generate electricity. There are now more than 525 nuclear power plants in the world, including 10 in India. France generates a large part of its electricity from nuclear plants.

A nuclear plant consists mainly of a nuclear reactor, in which fission is carried out. As you know, the fission of uranium-235, if uncontrolled, can cause great damage. Therefore, in a nuclear reactor, we need to control this reaction, so that an explosion does not occur. Thus, rods made of a substance that can absorb neutrons are used to slow down the reaction in a nuclear reactor. These rods, called control rods, are interspersed with the rods of the fuel (uranium).

As a large amount of heat is released during fission, a coolant is also required. Water is often used as a coolant.

The heat generated in a reactor is used to convert water into steam.The steam is used to drive turbines and generate electricity (Figure 4.18).

You will be surprised to learn that by the fission of 1 g of ^{235}U, 20,000 kWh (kilowatt hour—a unit of energy) of electricity can be generated. This is sufficient for a month for 100 families, each consuming 200 units a month.

Safety requirements As we will soon learn, exposure to radioactivity is harmful. Hence, the following safety measures are taken in a nuclear power plant.

1. There should be *no leakage* in the plant. If a radioactive material leaks out, it can cause great harm to the people around.
2. The reactor must be surrounded by thick *concrete* so that radioactive rays do not come out.
3. A *fire* should never break out in a nuclear plant. The radioactive isotopes coming out with the smoke can travel long distances with the wind. If this happens, the radioactive substance will settle down on the earth as dust or come down with rain.
4. All operations must be *remote-controlled*.
5. Great care must be taken in the *disposal of nuclear wastes*. If this is not done, radioactive dust may settle down over large areas, and large water bodies may become radioactive. If this happens, many people will fall ill and many will die.
6. The *level of radiation* in the body of any worker in a nuclear power plant must not rise above a prescribed maximum. So, everybody working in a nuclear plant must undergo regular medical check-ups.

Harmful Effects of Radiation

By about 1920, people realised that radiation from radioactive materials was harmful to living organisms. A large number of women who were employed for painting dials of instruments with luminiscent paints containing

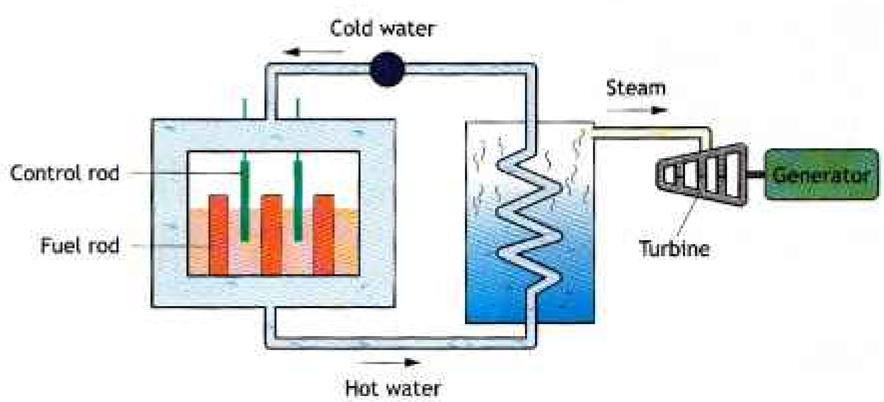

Fig. 4.18 How nuclear power plants generate electricity

radium died of bone cancer. They did not know that they were introducing a harmful substance, radium, into their body, while tipping the brush with their tongue. The maximum amount of radium that our body can tolerate is only one-millionth of a gram.

Marie Curie, who (with her husband, Pierre Curie) discovered radium, also died of the effects of radiation.

The following harmful effects of radiation are prominent.

1. Loss of hair
2. Cataract
3. Mouth ulcer
4. Damage to thyroid glands
5. Breast cancer
6. Ulcers in the stomach and intestines
7. Burns in the skin
8. Leukaemia (blood cancer)
9. Bone cancer
10. Internal bleeding

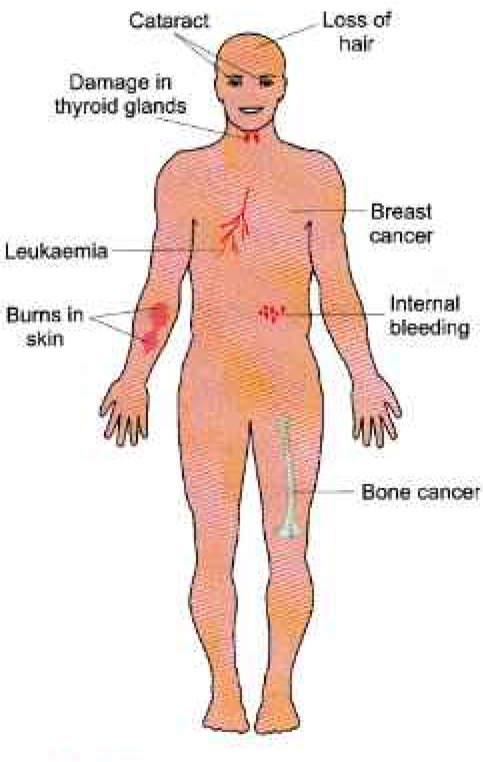

Fig. 4.19 Harmful effects of radiation

Uses of Radioactive Materials

Radioactive materials find application in many fields. Let us look at a few examples.

1. Nuclear power Controlled nuclear fission is used for generating electricity. Nuclear power is also used for the propulsion of submarines, ships and spacecraft.

2. Nuclear weapons Radioactive substances are used to make atomic (based on nuclear fission) and hydrogen bombs (based on nuclear fusion). In a nuclear war, all life on earth could be wiped out.

3. Tracer technique A radioactive isotope shows its presence by emitting radiation. Thus, the movement of a substance containing a radioactive isotope in a living organism can be easily traced. The technique of tracing the movement of such a substance is called the tracer technique. This technique has enabled us to understand many complicated processes like photosynthesis. The tracer technique is also used to find out how a chemical reaction takes place.

4. Radiocarbon dating Carbon-14, a radioactive isotope, is formed in the earth's atmosphere when cosmic rays (neutrons) strike nitrogen atoms.

$$^{14}_{7}\mathrm{N} + ^{1}_{0}\mathrm{n} \longrightarrow ^{14}_{6}\mathrm{C} + ^{1}_{1}\mathrm{H}$$

Carbon-14 emits β-rays to decay into nitrogen.

$$^{14}_{6}\mathrm{C} \longrightarrow ^{14}_{7}\mathrm{N} + ^{0}_{-1}\beta$$

Cosmic rays enter our atmosphere continuously, which means that the rate of formation of carbon-14 and that of its decay are in proportion. As you know, living organisms use carbon dioxide. A small part of this has carbon-14. The proportion of carbon-14 is constant in living organisms. However, when the organism dies, the proportion of carbon-14 decreases continuously due to the emission of β-particles. (A dead organism stops exchanging carbon with the

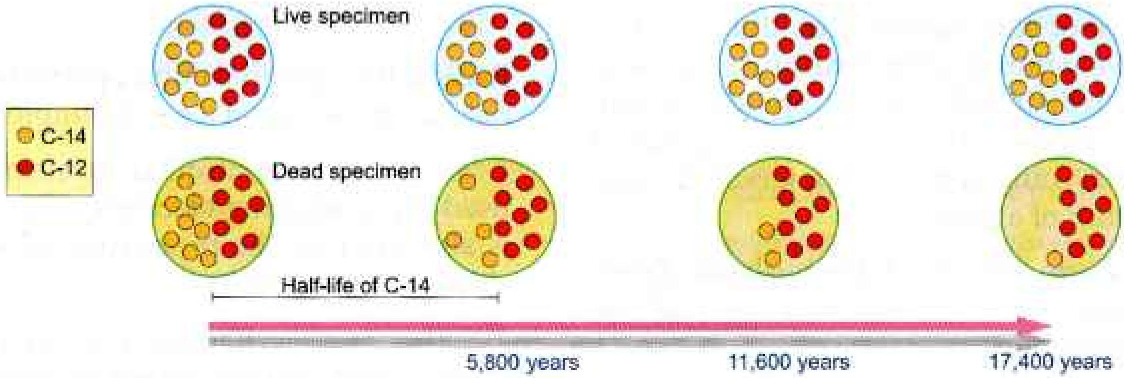

Fig. 4.20 Representation of the rate of decay of a plant sample in terms of half-life of C-14

atmosphere, so there is no carbon-14 to replenish that loss through the emission.)

The rate of decay is found in terms of half-life. The half-life of carbon-14 is 5,800 years. This means that the carbon-14 count in a sample will become 50% in 5800 years and $(50 \times \frac{1}{2})\%$ = 25% in (5800 + 5800) years = 11,600 years (see Figure 4.20). We can work out when a plant died by comparing the ratio of carbon-12 and carbon-14 in a living plant to that in a dead plant. This method is used to identify the age of dead plants and fossils, and is called radiocarbon dating.

5. In medicine Radioactive isotopes have been used in medicine too. Iodine-131 is used for the treatment of thyroid diseases. Radiation from cobalt-60 is used for killing cancerous cells.

Points to Remember

- An atom is made up of subatomic particles, called *electrons*, *protons* and *neutrons*.
- *Electrons*—the negatively charged particles—were discovered from the cathode rays in the discharge tube by Sir J J Thomson.
- *Protons*—the positively charged particles—were discovered from the anode rays in the discharge tube containing hydrogen.
- *Neutrons*—the electrically neutral particles—were discovered by the action of α-particles on beryllium by James Chadwick.
- Rutherford's α-particle experiment showed that an atom is mostly empty and that there is a positively charged body called the *nucleus* at the centre of it.
- The nucleus of an atom consists of protons and neutrons (except that of a hydrogen atom which consists of a proton only and no neutrons).
- The electrons revolve round the nucleus in their own orbits.
- The *atomic number*, or the *proton number* (Z), of an element is the number of protons present in the nucleus of an atom of the element.
- The sum of the numbers of protons and neutrons in an atom is known as the *mass number* (*A*) of the atom.
- In an atom,

  the number of electrons = the number of protons = Z, and the number of neutrons = $A - Z$.
- Atoms of an element with different mass numbers are called *isotopes*.
- Isotopes of an element differ in the number of neutrons in them.
- The *atomic mass* of an element is the number of times an atom of the element is heavier than a hydrogen atom.

- Most elements have isotopes. The atomic mass of such an element is the average of the masses of the different isotopes present in a natural sample of the element. So these elements have a fractional atomic mass.
- According to the Bohr model, electrons revolve round the nucleus in certain permissible circular orbits, called *shells*. The energy associated with each shell is fixed.
- The arrangement of electrons in different shells of an atom is called *electronic configuration*. The electrons are filled in the shells according to the Bohr–Bury rules.
- *Ionic*, or *electrovalent*, bonds are formed between atoms by the transfer of electrons from one to another.
- During a chemical combination, changes occur in such a way that each combining atom, except those of hydrogen and lithium, attains its octet. This is called the *octet theory*.
- A phenomenon in which there is a spontaneous emission of radiation from a substance is known as *radioactivity*.
- A substance that spontaneously emits radiation is said to be *radioactive*.
- Radioactive rays are of three kinds—α-, β-, and γ-rays.
- *α-rays* consist of α-particles, which are doubly charged helium ions (He^{2+}). *β-rays* consist of electrons. γ-rays consist of high-energy electromagnetic radiation.
- In *nuclear*, or *atomic, fission*, a heavy nucleus splits into two lighter nuclei when struck by a neutron. A large amount of energy is released in the process.
- In *nuclear fusion*, lighter nuclei combine (or fuse) to form a heavier nucleus. A large amount of energy is released in fusion too.
- *Nuclear power plants* are based on the fission of isotopes like uranium-235 and plutonium-239.
- There are many harmful effects of radiation.
- Radioactive materials find application in many fields.

Exercise

Short-Answer Questions

1. What name was given by Kanad to the tiny particles that matter is made up of?
2. Answer the following on the basis of Dalton's atomic theory.
   (a) Are atoms divisible?
   (b) Do atoms of the same element have the same weight?
   (c) Do atoms of different elements have the same weight?
   (d) What are the particles that take part in a chemical reaction?
3. Name the particles that constitute the cathode rays and also the β-rays.
4. What are the anode rays made of?
5. Give the equation that led to the discovery of neutrons.
6. Is the energy associated with an electron shell fixed?
7. What is the maximum number of electrons that can be accommodated by the N shell?
8. Can the outermost electron shell of an atom contain more than eight electrons?
9. What is radioactivity?
10. Give the nuclide symbols of α- and β-particles.
11. What is nuclear fission? Give an example of a fissionable isotope.
12. What is nuclear fusion?
13. How does the sun give us so much energy?
14. What is that set-up of a nuclear power plant called in which nuclear fission is carried out?

15. Name the following.
    (a) The technique in which a radioisotope is used to know how a complicated chemical reaction takes place
    (b) A technique which tells us the age of an antique
    (c) The isotope that is used for treating thyroid disorders
    (d) An isotope whose radiation is used for killing cancerous cells
16. Name any five harmful effects of radiation.

Long-Answer Questions

1. Describe the cathode-ray experiment of Sir J J Thomson that led him to conclude that cathode rays are made of negatively charged particles.
2. Explain how the cathode rays and the anode rays are produced in a discharge tube.
3. Discuss the electronic configuration of argon ($Z = 18$) and potassium ($Z = 19$).
4. Describe how electricity is produced in a nuclear power plant, giving a diagram.

Objective Questions

Choose the correct option.

1. Which of the following is an electrically neutral particle?
   (a) The electron (b) The proton (c) The neutron (d) The α-particle
2. The electrical charge on an electron is
   (a) 1.6×10^{-19}C (b) 1.78×10^{8}C (c) 1×10^{-19}C (d) none of these
3. Which of the following rays will pass undeviated through an electric field?
   (a) α-rays (b) β-rays (c) γ-rays (d) Cathode rays
4. Which of the following atoms has eight electrons in its outermost shell?
   (a) ${}_{8}O$ (b) ${}_{10}Ne$ (c) ${}_{11}Na$ (d) ${}_{12}Mg$
5. Which of the following ions has/have attained the octet?
   (a) Na^{+} (b) O^{2-} (c) Cl^{-} (d) All of these
6. Which of the following atoms is an isotope of ${}^{23}_{11}Na$? (The symbols are fictitious.)
   (a) ${}^{24}_{12}X$ (b) ${}^{24}_{11}A$ (c) ${}^{23}_{13}E$ (d) ${}^{28}_{14}G$

Fill in the blanks.

1. The e/m value of the cathode-ray particles is ______ . (fixed/variable)
2. The e/m value of the anode-ray particles is ______ . (fixed/variable)
3. The mass of atoms, except that of hydrogen, ______ be explained without considering neutrons. (can/cannot)
4. The isotopes of an element differ in the number of ______ in the atoms. (electrons/protons/neutrons)
5. For jumping from the M shell to the N shell, an electron will ______ energy. (absorb/radiate)
6. Complete the following table.

Element	Z	A	Number of subatomic particles		
			Electrons	Protons	Neutrons
Na		23	11		
Al	13				14
Si		28		14	
S	16				16
Ar		40			22

7. Complete the following table.

		Electronic configuration			
Element	Z	K	L	M	N
B	5				
F	9				
Al	13				
P	15				
S	16				
Cl	17				

8. Hydrogen attains a/an _______ during a chemical combination. (duplet/octet)
9. The concept of the atomic bomb is based on nuclear _______ . (fission/fusion)
10. The concept of the hydrogen bomb is based on nuclear _______ . (fission/fusion)
11. _______ fission is carried out in a nuclear reactor. (Controlled/Uncontrolled)

Indicate which of the following statements are true and which are false.

1. An atom must contain the same number of protons as neutrons.
2. An electron can be found in any of the shells.
3. A sodium-vapour lamp gives out yellow light.
4. Generally, a metal loses electrons and a nonmetal gains them.
5. Radioactivity is a nuclear phenomenon.

About Those Who Showed Us the Atom

John Dalton (1766–1844)

John Dalton was born in England on 6 September 1766. Right at the age of twelve, he started his teaching career—first in schools and then in a college in Manchester. He studied mathematics, meteorology (the science dealing with weather) and chemistry, and became the president of the Philosophical Society in 1817 and held that office until his death. He was a Fellow of the Royal Society (FRS) too.

John Dalton laid the foundation of modern science by advancing his atomic theory in 1803. He investigated the behaviour of gases too. He published a large number of observations on weather and some natural phenomena occurring in the sky. Surprisingly enough, he also gave a theory on colour-blindness, from which he and his brother suffered.

Dalton died on 27 July 1844. More than 40,000 people came to Manchester to pay their last respects to the departed genius.

J J Thomson was born in Manchester on 18 December 1856. Appointed a lecturer in 1883, he later became Cavendish Professor of Experimental Physics, Cambridge, and Royal Institution, London, in 1884. He held this position till 1918. Elected an FRS in 1884, he was the president of the Royal Society during 1916–20. He was awarded honorary doctorates by 21 universities.

Joseph John Thomson (1856–1940)

J J Thomson announced the discovery of electrons in the evening lecture at the Royal Institution on Friday, 30 April 1897. This opened the doors of the atom for scientists. He had, in fact, cut the uncuttable (the atom).

He was awarded the Nobel Prize in 1906 for his researches on the passage of electricity through gases. (His son, George P Thomson, also received the Nobel Prize in 1937.) He was knighted in 1908.

Sir J J Thomson died on 30 August 1940.

Ernest Rutherford (1871–1937)

Ernest Rutherford was born on 30 August 1871 in New Zealand. After graduating from the University of New Zealand, he joined as a research student under J J Thomson in the Cavendish Laboratory in 1894. In 1898, he left for Canada to join McGill University, Montreal, as Macdonald Professor of Physics. Otto Hahn, who discovered nuclear fission later, worked with him at Montreal in 1905–06.

Rutherford returned to England in 1907 to join the University of Manchester as Longworthy Professor of Physics. In 1919, he succeeded Sir J J Thomson as Cavendish Professor of Physics at Cambridge.

While at Manchester, he discovered the nucleus and gave the concept of the nuclear atom in 1911.

Elected FRS in 1903, he was the president of the Royal Society from 1925 to 1930.

Rutherford was awarded the Nobel Prize in 1908 for his research on the disintegration of elements and the chemistry of radioactive substances.

He was knighted in 1914 and appointed to the Order of Merit in 1925.

He directly inspired at least four scientists, including Chadwick, who worked with him in his laboratory, to win the Nobel Prize. Four other winners—G P Thomson, Appleton, Powell and Aston—also worked in his laboratory for some time.

Lord Rutherford died on 19 October 1937.

Niels Bohr (1885–1962)

Niels Bohr was born in Copenhagen, Denmark, on 7 October 1885. Graduating in 1909, he obtained his doctorate degree in 1911 from Copenhagen University.

In 1912, he worked for some time in Rutherford's laboratory at Manchester, where he got interested in the structure of the atom. In 1913, he presented his atomic model, for which he was awarded the Nobel Prize in 1922.

In 1916, Bohr was appointed Professor of Theoretical Physics, Copenhagen University. In 1920, the Institute of Theoretical Physics was opened for him in Copenhagen University, which he headed until his death. He received honorary doctorates from 34 universities, including those of Bombay and Calcutta.

After World War II, he became a great advocate of peace. Niels Bohr died on 18 November 1962.