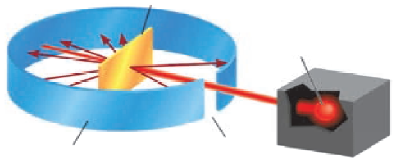
Chapter 3

# Atomic Structure



When we look around us we can see objects of different shapes, sizes, colours and textures. All these objects are made of different substances and all substances are made up of very tiny particles. Now, the question is: How small are these particles?

When we add a few drops of Dettol to a glass of water, all of it smells of Dettol. The smell can be detected even when we keep on adding more and more water. Why is it so?

Let us do an activity to understand:

**Activity–1**

- Dissolve two-three crystals of potassium permanganate in 100 mL water (Fig. 1). Carefully note the colour of the solution.
- Take 10 mL of this solution and add it to 90 mL water.
- Now take out 10 of the second solution and add it to 90 mL water.
- Keep diluting the solution for 5-8 times.
- Is the final solution still coloured?

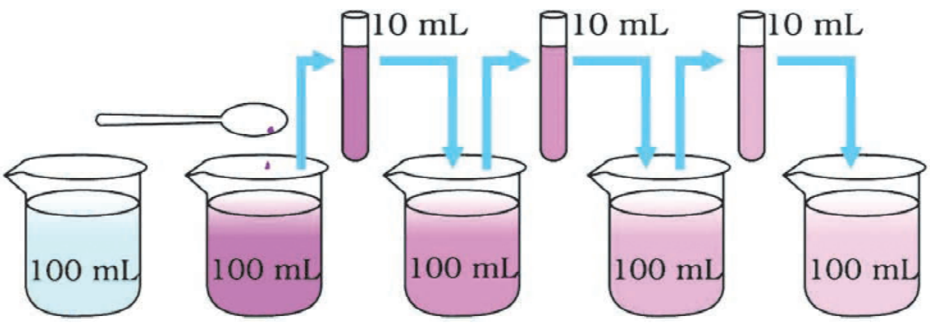



**Fig. 1 : How small are the particles in matter**

To detect the colour of the diluted solutions, place a piece of white paper behind the beaker and compare with a beaker of plain water.

Through this activity, we see that a few crystals of potassium permanganate are sufficient to colour a large volume of water. Just think, how many particles are there in one crystal of potassium permanganate and how small they must be.

Actually, the particles are so minute that the substance cannot have any smaller particles. These particles are of two types – atoms and molecules. Atom is a fundamental particle. Atoms join together to form molecules. People have been trying to understand the atom for several centuries. How did we reach our present understanding of the atom? Let us read more about it.

## 3.1 The story of the atom

The story of the attempts to understand the atom is very fascinating and begins as early as 500 BC. The Indian philosopher *Maharishi Kanad* postulated that if we go on dividing matter (*dravya*), we shall get smaller and smaller particles.Ultimately, a time will come when further division will not be possible and we will get the smallest particles which would be indivisible. An ancient Greek philosopher Leucippus and his student Democritus also thought of what would happen if we go on dividing matter and believed that a stage would come when particles obtained could not be divided further. Democritus called these indivisible particles *atoms* meaning those that cannot be split. He also said that the entire universe is made of atoms.

But we know that science is more than thinking and philosophizing. It needs different experiments, analysis, logic and theories to test ideas. Since Democritus did not have any basis for his ideas therefore his atomic theory did not become very popular. In 306 BC, an Athenian, Epicurus wrote in his book that all things around us are made of atoms. Lucretius also mentioned atoms in his poem, 'Nature of Things'. Ultimately, these opinions gained experimental validity when new techniques were developed in chemistry in the eighteenth century.

You have already read that the mass of matter remains conserved during a chemical reaction. In 1799, the French chemist Proust postulated the law of constant proportions according to which all chemical compounds are made of elements and "in a chemical compound the elements are always present in definite proportions by mass". This law was experimentally verified by many scientists and it explained the formation of many compounds. The various efforts to describe the two laws also helped in building an understanding of the atom.

John Dalton was a school teacher and scientist in Britain who explained why the different laws were true and he gave us the atomic theory. Dalton's efforts were published in the form of a book in 1808. Dalton's theory can be described as follows:

1. All matter is made of atoms.
2. Atoms are indivisible, infinitely small particles, which cannot be created or destroyed in a chemical reaction.
3. Atoms of a given element are identical in mass and chemical properties.
4. Atoms of different elements have different masses and chemical properties.

5. Atoms of different elements combine in the ratio of small whole numbers to form compounds.
6. The relative number and kinds of atoms are constant in a given compound.

**Dalton's law of multiple proportions**

**John Dalton**

Dalton saw that 3 g of carbon reacts with 4 g of oxygen to form carbon monoxide and 3 g of carbon reacts with 8 g of oxygen to form carbon dioxide. We can see that 8 g oxygen is double of 4 g oxygen. When Dalton took more such examples of elements combining in different ratios, he found that their proportions were always in simple whole number multiples which means that each time the atom is indivisible. He later published this result as law of multiple proportions. So we can say that when two elements combine to form more than one compound then the ratios of the masses of one element combining with a fixed mass of the second element are simple whole numbers. In the example given above we see 4 and 8 g oxygen combining with 3 g of carbon to give carbon monoxide and carbon dioxide respectively. So the ratio of mass of oxygen combining is 4:8 or 1:2 which is a simple, whole number ratio.

## 3.2 Is atom indivisible?

With the idea of an indivisible atom, chemists were able to explain chemical reactions as well as describe different laws and rules. But the concept of an indivisible atom did not last long as many experiments were conducted to understand the nature of matter which took the atomic theory into an entirely new direction.

On the one hand, the nature of the atom was being discussed and at the same time experiments were also being conducted to understand reactivity of gases. The contributions of the British physicist J.J. Thomson (1856-1940) and the German scientist Goldstein (1850-1930) in the study of gases needs to be appreciated. For example, Goldstein observed that when a sufficiently high voltage is applied across the electrodes of a glass tube filled with gas at low pressure, current flows and a stream of shiny rays are emitted from the cathode. Goldstein called these rays as cathode rays (Fig.2).

This experiment was repeated later under many different conditions. The scientist Schuster placed metallic plates on both sides of the path of cathode rays. When voltage was applied across the plates, one acted as cathode and the other as anode. He observed that when cathode rays pass through these plates, they bend (deflect) towards the positively charged plate that is, anode (Fig.3). In this way, it was confirmed that the cathode rays are made up of negatively charged particles.

Later, Thomson calculated the mass and charge on these negatively charged particles and found that the nature of the cathode ray particles was always identical and it was independent of the cathode material. He named these negatively charged particles electrons. Electron is a subatomic particle of all atoms. Thus, Thomson challenged the long-held belief that atom is indivisible. J.J. Thomson received the Nobel Prize for physics in 1906 for his discovery of electron.

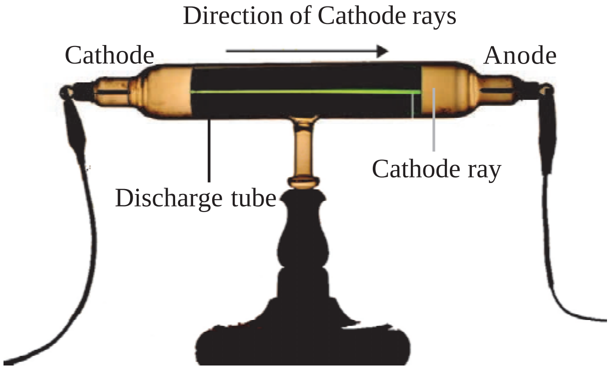



**Fig. 2 : Cathode ray**

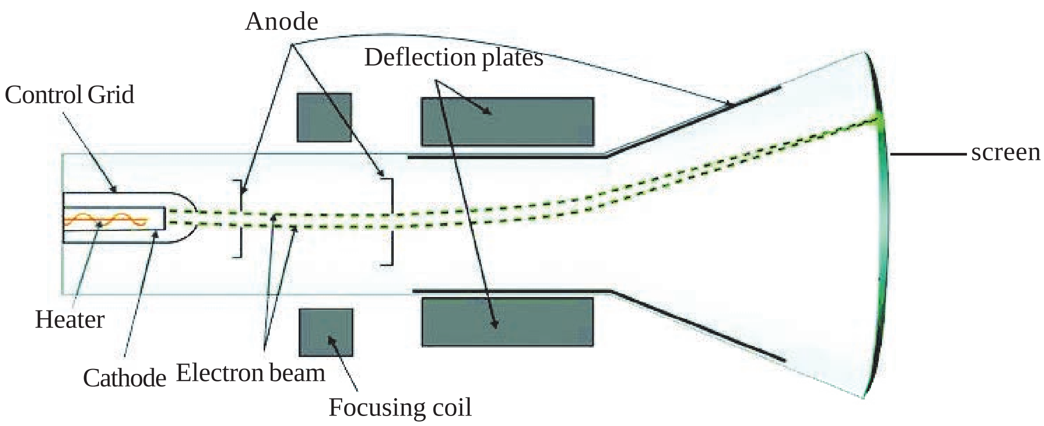



**Fig. 3 : Bending of cathode rays towards the anode**

## 3.3 Goldstein and Canal rays

Just as cathode rays were discovered, positively charged rays were also discovered by Goldstein in 1886 and were called canal or anode rays. On the basis of observations from his experiments, it was seen that canal rays were made of positively charged particles and their nature depended on the type of gas in the glass tube. Goldstein saw that the charge and mass of different anode rays were different. From this he concluded that the rays were being produced by the ionization of the gas in the glass tube. Thus, the discovery of canal rays helped establish the neutral nature of atoms, that is, atoms have positively and negatively charged particles and the charges being equal cancel each other.

## 3.4 Thomson's Atomic Model

J.J. Thomson gave the plum pudding model of atom. According to this model, the atom has a spherical cloud of positive charge in which the negatively charged particles are embedded in such a way that the charges are balanced. We can take the example of a watermelon to understand this model. The red portion of the watermelon is the positive cloud and the black seeds are the negatively charged electrons (Fig.4). Since the positive and negative charge in an atom is same therefore the atom is electrically neutral.

The atomic theory underwent many changes between 1908 and 1913 as more and more new information became available from different experiments. Let us read about these experiments.

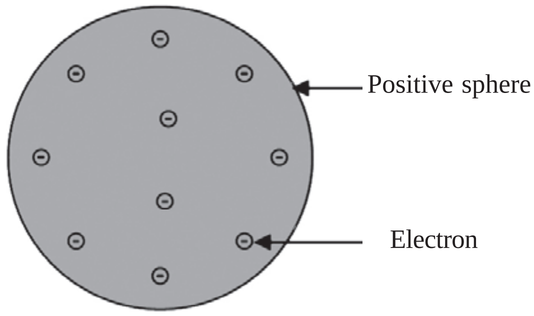
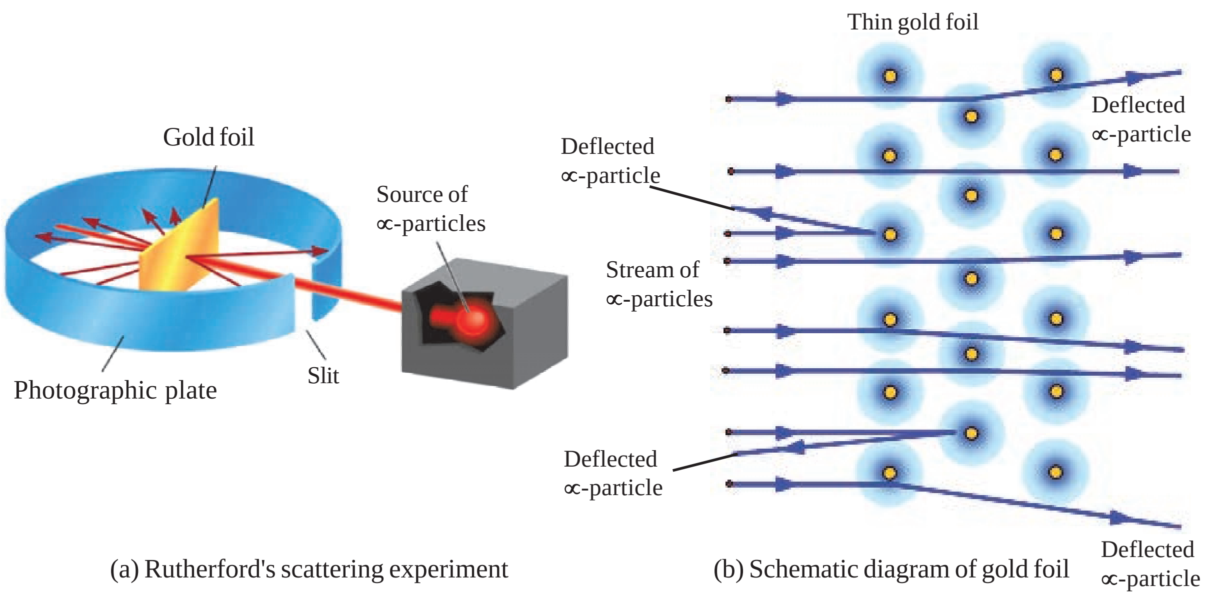



**Fig. 4 : Thomson's atomic model**

## 3.5 Alpha particle scattering experiment and Rutherford's Atomic Model

E. Rutherford and his students Geiger and Marsden carried out experiments to understand the structure of atoms. In one of the experiment, they bombarded a thin gold foil with high energy alpha particles (Fig. 5a and 5b). Alpha particles are positively charged and their mass is equal to the mass of helium atoms.




(a) Rutherford's scattering experiment (b) Schematic diagram of gold foil

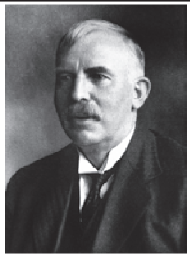
**Fig. 5 : Labled diagram of Rutherford's scattering experiment**

According to Thomson model, the mass of each gold atom in the foil should have been spread evenly over the entire atom. Therefore, Rutherford expected that the alpha particles would change directions (deflect) only by a small angles as they passed through the foil but this did not happen. Rutherford observed that:

1. Most of the alpha particles passed straight through the gold foil without deflecting which shows that most of the space in the atom is empty.

2. Only a small fraction of the alpha particles were deflected which shows that the positive charge of the atom is concentrated in a very small volume.
3. Only 1 in 20,000 particles was deflected by $180^o$ and went back on the same path when it collided with the gold foil. If the alpha particle is bouncing back then it means that the mass of the atom was densely concentrated in this extremely small region and not spread out uniformly. This means that the mass of the atom was concentrated in a very small volume.

E. Rutherford (1871-1937) was from New Zealand. He is also known as the father of nuclear chemistry and received the Nobel Prize in 1908 for his discovery of the nucleus of the atom. In the alpha particle scattering experiment, he bombarded an extremely thin (100 nm thick) gold foil with high energy alpha particles and concluded from this experiment that the radius of the nucleus was $10^5$ times smaller than the radius of the atom.


Rutherford

On the basis of these observations, Rutherford proposed that the positive charge and most of the mass of the atom was densely concentrated in an extremely small region. He called this very small portion of the atom nucleus. Electrons move around the nucleus in different circular paths called orbits. Thus, Rutherford came up with nuclear model of an atom on the basis of his experiments but did not describe the distribution of electrons. This was done by a Danish scientist, Niels Bohr.

**Questions**

1. Can the alpha particle scattering experiment be carried out by using silver foil or extremely thin foils of other elements rather than gold? Explain your answer with reasons.
2. On what basis did Thomson challenge the theory of indivisibility of atom?

## 3.6 How are electrons distributed in different shells (orbits)?

According to Rutherford's nuclear model, the atom can be described as having a small, positively charged nucleus around which electrons revolve in circular paths. But this model does not explain how the electrons are distributed in the atom.We know that electrons are negatively charged. Then, should similarly charged electrons be repulsed by each other or will they collide with each other? What holds together the sub-atomic particles inside the atom? Niels Bohr, along with his associate Bury, struggled with these questions and came up with a model called the Bohr-Bury scheme to distribute electrons in the atom. According to the Bohr-Bury scheme, electrons revolve in shells around the nucleus and these shells are represented by the letters K,L,M,N….

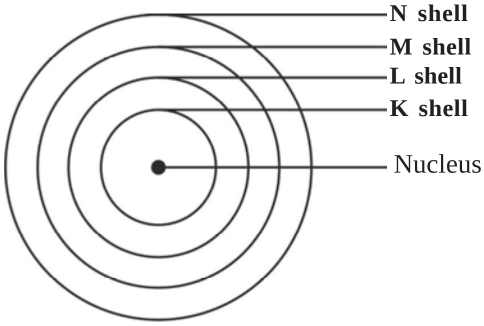


**Fig. 6 : Atomic shells**

The shell or orbit closest to the nucleus is called the K shell, the second shell is called L and the next shells are labelled M, N … respectively (Fig. 6).

## 3.7 Bohr-Bury scheme and distribution of electrons

1. The maximum number of electrons present in a shell is given by the formula $2n^2$, where 'n' is the shell number. For K shell (orbit), n=1 and for L,M, N shells n=2,3,4 respectively. The maximum number of electrons in first orbit or K-shell will be = $2 \times 1^2 = 2$ and similarly we can calculate the maximum number of electrons in other shells. The electrons present in the outermost shell are called valence electrons and this shell is called the valence shell.
2. The maximum number of electrons that can be accommodated in the outermost shell is 8 (exception is when K is the outermost shell and the maximum number of electrons is then 2).
3. Electrons are not accommodated in a given shell, unless the inner shells are filled. That is, the shells are filled in a step-wise manner.
4. Even when the capacity of the penultimate shell is more than 8, a ninth electron is placed in it only after 2 electrons have entered the last shell. For example, the atomic number of calcium is 20 but its electronic configuration is 2,8,8,2 and not 2,8,9,1.

The schematic atomic structure of the first 18 elements as per the Bohr-Bury scheme is given in Fig. 7.

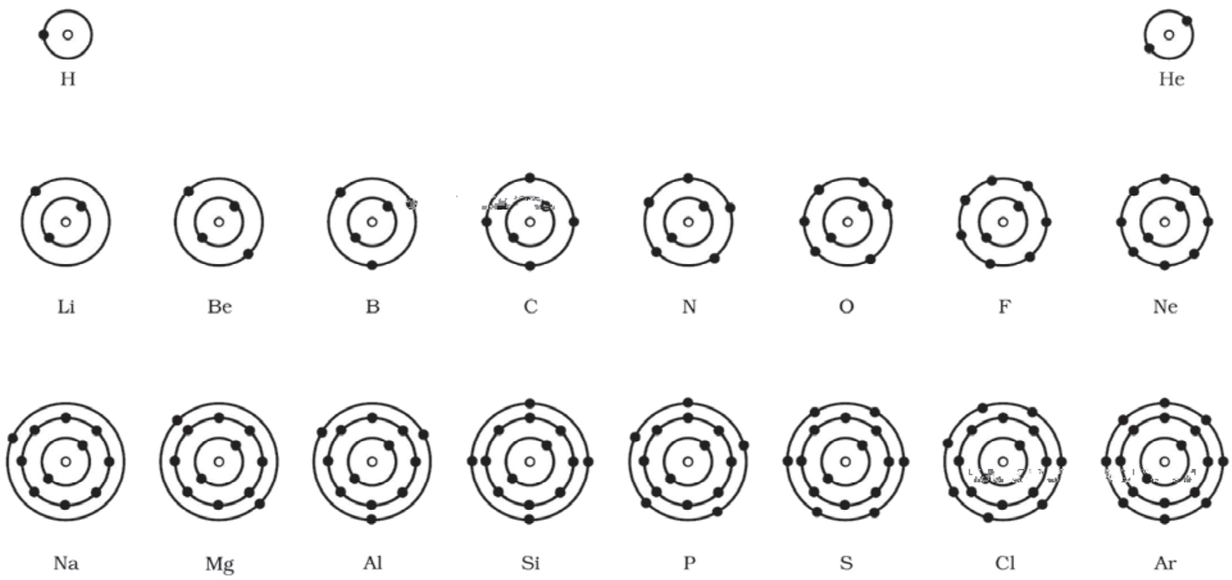



**Fig. 7 : Distribution of electrons in different shells**

Similarly, can you draw the atomic structures of elements having 19 and 20 electrons?

Some of the boxes in Table-1 have question marks, fill in the correct information.

**Table 1 : Distributions of electrons in different shells and electronic configuration**

| Element | Symbol | No. of electrons | Distribution of electrons in orbits | | | | Electronic configuration | Valence electron |
|---|---|---|---|---|---|---|---|---|
| | | | K | L | M | N | | |
| Hydrogen | H | 1 | 1 | | | | 1 | 1 |
| Lithium | Li | 3 | 2 | 1 | | | 2,1 | 1 |
| Carbon | C | 6 | 2 | ? | | | ? | ? |
| Oxygen | O | 8 | ? | ? | | | ? | ? |
| Sodium | Na | 11 | 2 | ? | 1 | | 2,8,1 | ? |
| Aluminium | Al | 13 | 2 | 8 | ? | | ? | ? |
| Phosphorus | P | 15 | 2 | 8 | ? | | ? | ? |
| Chlorine | Cl | 17 | ? | ? | ? | | ? | ? |
| Argon | Ar | 18 | 2 | 8 | 8 | | ? | ? |
| Potassium | K | 19 | 2 | 8 | 8 | ? | ? | 1 |
| Calcium | Ca | 20 | ? | ? | ? | 2 | ? | ? |

## 3.8 Atomic number and mass number

The canal rays discovered by Goldstein in 1886 were positively charged. These later led to the discovery of the second subatomic particle, proton. Proton is positively charged and its charge is equal in magnitude but opposite to that on an electron. In 1932, J. Chadwick discovered a third subatomic particle, neutron. Neutron had no charge and its mass was nearly equal to that of a proton. Neutrons are present in the nucleus of all atoms, except hydrogen.

We now know that an atom has different subatomic particles, namely protons, neutrons and electrons. Protons and neutrons are present in the nucleus whereas electrons are revolving in shells outside the nucleus. In a neutral atom, the number of protons is equal to the number of electrons. The total number of protons present in an atom is known as its atomic number and is denoted by the letter Z. Usually, the mass of an atom is taken as the sum of the masses of the neutrons and protons present in its nucleus and is called mass number. The unit for mass number is u (unified mass). The subatomic particles, neutrons and protons, present in the nucleus are also called nucleons.

In general, electrons are represented by $e^-$, protons by $p^+$ and neutrons by n. An atom can be represented using its atomic symbol, mass number and atomic number, as shown below:

**Mass number**

$\boxed{\textbf{Atomic symbol}}$

**Atomic number**

For example, the atomic number of sodium is 11 and its mass number is 23. It is written as $^{23}_{11}Na$ . The number of neutrons in lithium and calcium is 3 and 20 respectively, epict the atomic number and mass number of lithium and calcium in symbolic form.

In table-2 given below, the number of protons in the atoms of some elements and their mass numbers are given. Can you write down the number of neutrons for each?

**Table 2 : Atomic number & mass number**

| **Element** | **Symbol** | **No. of protons** | **Mass number** | **No. of neutron** |
|---|---|---|---|---|
| Hydrogen | H | 1 | 1 | |
| Lithium | Li | 3 | 6 | |
| Carbon | C | 6 | 12 | |
| Oxygen | O | 8 | 16 | |
| Sodium | Na | 11 | 23 | |
| Aluminium | Al | 13 | 27 | |
| Phosphorus | P | 15 | 31 | |
| Chlorine | Cl | 17 | 35 | |
| Argon | Ar | 18 | 40 | |
| Potassium | K | 19 | 39 | |
| Calcium | Ca | 20 | 40 | |

You may know that the nucleus is $10^5$ times smaller than an atom. We also know that both neutrons and protons are present in the nucleus. Now, the size of the sodium atom is $1.86 \times 10^{-10}$ m. Can you answer the following questions about the sodium atom:

1. What will be the size of its nucleus?
2. Keeping in mind the ratio of the size of the nucleus to the atomic size, how will you show a sodium atom? Can you pictorially depict a sodium atom accurately?

## 3.9 Isotopes, Atomic mass and Isobars

If we look at carbon in nature, it is seen that the mass number of carbon atoms in some cases is 12 and in some cases it is 14. Why is this so? Actually, carbon-12 and carbon-14 atoms have different number of neutrons. While carbon-12 has 6 neutrons, the number of neutrons in carbon-14 is 8.

In nature, a number of elements are present whose atoms have the same number of protons but different number of neutrons. The atoms of such elements, where the atomic number is same but mass numbers are different, are called isotopes of each other. For example, chlorine-35 and chlorine-37 are two isotopes of chlorine. Isotopes have many applications in our lives. For example, an isotope of cobalt is used in treating cancer, an isotope of iodine is used in goiter treatment, an isotope of uranium is used as fuel in nuclear reactors etc.

**Relative atomic weight**

Atomic weight is a fundamental concept in chemistry. Atomic weight is a means of establishing a relationship between the absolute weight of an element and the number of atoms present in it. Dalton knew that it was not possible to weigh a single atom so he concentrated on finding out relative atomic weights.

Since at that time hydrogen was the lightest element known, therefore he assigned one as the mass of one hydrogen atom. Because the atomic weights of atoms of other elements were calculated against the weight of the hydrogen atom therefore they were called relative atomic weights. It was also seen that oxygen reacts with more elements as compared to hydrogen so some people felt that oxygen should be made the standard. Nowadays, the atomic weights of elements are calculated against one atom of carbon-12.

We can now understand why the atomic number of most elements are not whole numbers. This is because it may have more than one isotope in nature. We can understand this through an example. Chlorine occurs in nature in two isotopic forms, chlorine-35 and chlorine-37 in the ratio of 3:1 or 75% and 25% respectively. The average atomic weight can be calculated as :

$[(75 \times 35) + (25 \times 37)] \div 100 = 3550/100 = 35.5$

Thus, the atomic weight of chlorine is 35.5 u.

**Table 3 : Atomic weight of elements**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1<br>H<br>1.008 | 2<br>He<br>4.003 | 3<br>Li<br>6.941 | 4<br>Be<br>9.012 | 5<br>B<br>10.81 | 6<br>C<br>12.01 | 7<br>N<br>14.01 | 8<br>O<br>16.00 | 9<br>F<br>19.00 | 10<br>Ne<br>20.18 |
| 11<br>Na<br>22.99 | 12<br>Mg<br>24.31 | 13<br>Al<br>26.98 | 14<br>Si<br>28.09 | 15<br>P<br>30.97 | 16<br>S<br>32.07 | 17<br>Cl<br>35.45 | 18<br>Ar<br>39.95 | 19<br>K<br>39.10 | 20<br>Ca<br>40.02 |

If we consider carbon-14 (an isotope of carbon) and nitrogen-14 we find that their mass numbers are same but atomic numbers are 6 and 7 respectivly. Atoms of different elements with different atomic numbers but the same mass number, are known as isobars.

### Questions

1. If the atomic number of an atom is 15 and mass number is 31 then what is the number of sub-atomic particles present in the atom?
2. If the K and L shells of an atom are full and the M shell has 2 electrons then what is the atomic number of the atom?
3. Write the electronic configuration of the following: $^{23}_{11}Na$, $^{12}_{6}C$, $^{35}_{17}Cl$

We learnt that a nucleus is present at the centre of the atom. Most of the mass of the atom is concentrated in the nucleus. Electrons are present around the nucleus. Attempts are continuously being made to observe the atom. You should also use the internet, books, magazines and audio-video sources to answer your questions about the atom.

### Keywords

orbit or shell, atomic number, atomic weight, isotope, isobar, cathode, anode,canal ray,sub- atomic, nucleon, electron, proton, neutron, relative atomic weight, mass number, nucleus, law of multiple proportions

### What we have learnt

- The early models of the atom imagined that it was indivisible.
- Dalton was the first scientist to talk about the shape and weight of an atom. In his law of multiple proportions, Dalton said that the number of atoms of an element at the end of a reaction is the same number at the beginning (that is, atom cannot be destroyed).
- According to J.J. Thomson, atom has a cloud of positive charges into which the negatively charged particles are embedded.
- Rutherford's alpha-particle scattering experiment led to the discovery of the atomic nucleus.
- Rutherford's alpha particle scattering experiment established that the atom has a very small nucleus and electrons revolve around this nucleus.
- Niels Bohr proposed that atoms have discrete shells designated as K,L,M,N…Electrons are distributed in these shells.

- The outermost shell of an atom has 8 electrons (except for helium and hydrogen atoms). The electrons present in the outermost shell are known as valence electrons.
- The number of protons present in an atom is known as the atomic number.
- The sum of the number of protons and neutrons present in the nucleus is known as the mass number.
- In a neutral atom, the number of electrons is equal to the number of protons.
- Isobars are atoms of different elements having the same mass number but different atomic numbers.
- Isotopes are atoms of the same element, which have same atomic number but different mass numbers.
- The average atomic weight depends on how many isotopes of an element are present in nature and in what percentages.

## Exercises

1. Choose the correct option:

   (i) Isotopes have different:

   (a) electrons (b) protons

   (c) neutrons (d) both electrons and neutrons

   (ii) Who first included electrons in his atomic model?

   (a) Dalton (b) Thomson

   (c) Rutherford (d) Bohr

   (iii) Which of the following statements is true for $^{39}_{19}K$ atom

   (a) The atom has 39 electrons (b) The atom has 39 protons

   (c) The atom has 19 protons (d) None of the above

2. Choose the appropriate option to fill in the blanks:

   (i) All atoms of an element are ................................ (similar/different)

   (ii) The number of .......................................... (electrons/neutrons) is equal to the number of protons in a neutral atom.

   (iii) $^{14}_{6}C$ and $^{14}_{7}N$ are ........................................ (isotopes/isobars) of each other.

3. How was the atom proposed by Thomson different from the atom proposed by Dalton?

4. $^{16}_{8}O$ and $^{16}_{7}N$ are isobars. Use this example to explain isobars.
5. Bromine-79 and bromine-81 are found in nature in the ratios 50.69 and 49.31. What will be the average atomic weight of bromine?
6. Find out the number of valence electrons in $^{16}_{8}O$ and $^{14}_{7}N$ .
7. Describe Bohr's atomic model.
8. Apart from oxygen-16, oxygen-17 and oxygen-18 are also known to exist in nature. Are these atoms isotopes or isobars? Explain.
9. Explain Dalton's atomic theory. What are its limitations?
10. What was the alpha particle scattering experiment carried out by Rutherford? What conclusions did he draw from this experiment regarding the structure of an atom?
11. Write the rules proposed for electron distribution under the Bohr-Bury scheme. Use the rules to write the electronic configuration of given atoms. Also give the number of neutrons present in each atom. $^{19}_{9}F$, $^{24}_{12}Mg$, $^{28}_{14}Si$, $^{31}_{15}P$, $^{35}_{17}Cl$