Chapter-3

Atomic Structure

Since ancient times man has been inquisitive about the change of form of matter, for example when salt is added to water it becomes invisible but its taste is there in the water. On being burnt coal converts into ash. Matter can be grounded to form fine powder. The invisibility and divisibility of matter was well known to the Greek and Bhartiya philosophers, way back before Christ.

It was way back in 6th BC, Maharshi Kanad, the Bhartiya philosopher, had said, "Matter can be divided into small particles but the utlimate minutest particle will remain indivisible." Kanad named it 'Parmanu'. Another Bhartiya Philosopher Kaccayana stated that these 'particles' are present in combined form which give different forms to matter. At about the same time, Greek philosophers Democratic and Leucippus called these indivisible particles as atoms which means 'cannot be cut' or 'indivisible' in other words which cannot be divided further. All these views were based on philosophy and did not have a practical basis. In 1808, scientist John Dalton gave the 'Atomic Theory' on the basis of chemical combination, conservation of matter and laws of definite proportions.

The main points of the theory are as under :

1. All the matter is composed of small particles called 'atoms'.
2. Atoms are indivisible particles which can neither be destroyed nor can be created.
3. All the atoms of an element are similar.
4. Atoms of different elements have different properties.
5. The atoms of different elements combine with each other in whole number proportions to form the molecule of compounds.
6. Chemical change is basically the combination, dissociation and reconfiguration of atoms.

By the end of nineteenth century, series of different experiments, made it clear that some small particles are present in atoms which are known as sub atomic particles.

3.1 Physical particles of atom and their discovery :

3.1.1 Electric immersion tube : There is a long glass tube having metal electrode on both ends. A vacuum pump is connected to it, with the help of which the pressure in the tube can be increased or decreased. Even vacuum can be created in the tube with its help.

3.1.2 Discovery of electron : J.J. Thomson created high vacuum in immersion tube and applied high voltage on the metal electrode. He observed that green fluorescence is generated on the walls of the tube.

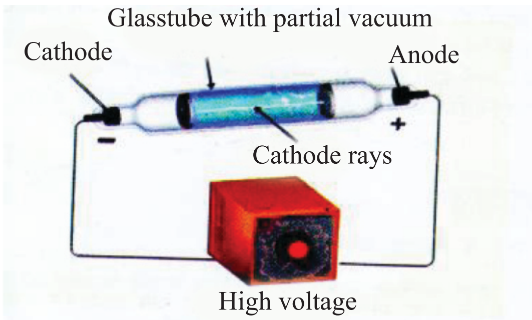


Fig. 3.1 : Formation of Cathode Rays in the Immersion tube

With the help of his experiments, Thomson confirmed that on applying high voltage in vacuum there is flow of electricity in the tube from cathode to anode, in the form of rays. Thomson termed these rays - the cathode rays.

Properties of Cathode rays :

1. They move in straight line.
2. They produce fluorescence.
3. They are affected by electric and magnetic fields.
4. When they pass through a gas, they ionise it.
5. They are made up of negatively charged

particles.

6. The e/m (charge/mass) i.e. ratio of charge to mass of these particles is uniform.
7. Primarily they are the matter waves.

According to J.J. Thomson, cathode rays are made up of negatively charged particles which he named as the electrons and their mass was found to be 1/1837 of the hydrogen atom.

Experiments on the properties of the cathode rays proved that in the atom there is a negatively charged particle, electron, which can be separated from the atom. The atomic electricity is neutral, hence the remaining part of the atom from which electron have been removed, should be positively charged.

3.1.3 Discovery of Proton : In 1886, E. Goldstein used perforated cathode in the immersion tube and observed new type of rays at low pressure and high voltage, which were termed as positive rays. They are also known as the anode rays.

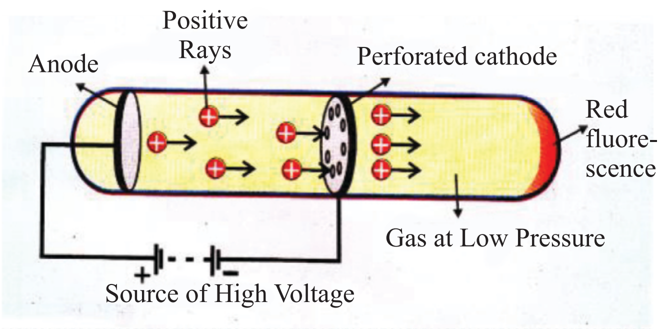


Fig 3.2 : Formation of positive rays in the immersion tube.

Properties of the Positive rays :

1. Positive rays move in a straight line.
2. Their charge to mass ratio (charge/mass i.e. e/m) depends on the nature of gas present in the tube.
3. They are affected by the electric and magnetic fields.
4. They are made up of positively charged particles.
5. They also are matter rays.

In 1919 this positive particle was identified as the proton and it was stated that in the atom the positively charged protons are also present along with the electrons. The atom is neutral because the number and charge of both is equal. The mass of proton is 1837 times greater than that of the electron.

3.2 Thomson's Atomic Model :

After the confirmation of the presence of electron and proton in the atom, Thomson in 1898 said that the atom is a positively charged sphere in which are embedded the negatively charged electrons. He compared it with the dessert "Plum pudding" in which dry fruits are present scattered within the cake. We can understand it by using the example of water melon. The fleshy part of which is the positive region and the seeds present in it may be considered the electron. This model was named as the ' Plum Pudding Model '.

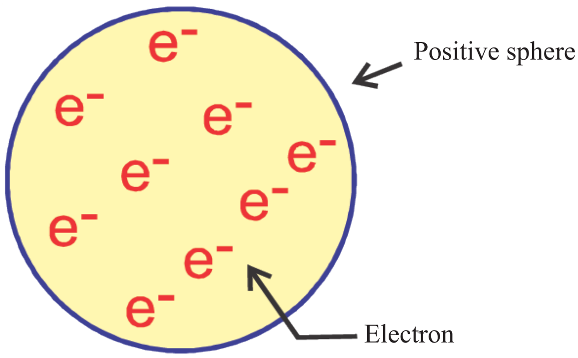


Fig. 3.3 Thomson's Atomic Model

Shortly, after some time, this model was rejected as it could not interpret the alpha particle dispersion experiments done by Rutherford.

3.3 Rutherford's Experiment and the Nuclear Atomic Model :

In 1911, Ernest Rutherford bombarded a thin screen i.e. foil of gold (100 nanometer or 10^{-7} meter thick) encoated with zinc sulphide, with alpha particles (Helium nuclei). The following observations were made by this experiment :

1. Most of the particles went out straight, without scattering.
2. Some particles scattered at an angle of 90° and some at 120° angle.
3. One out of 20,000 particles, however scattered at an angle of 180° i.e. returned on the same path after colliding with the foil.

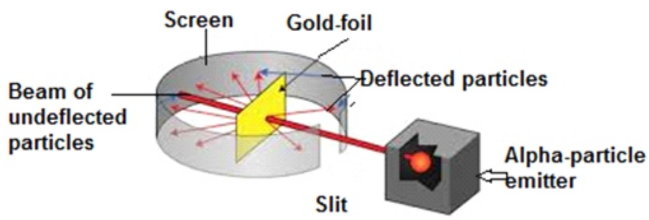


Fig. 3.4 Rutherford's Dispersal Experiment

3.3.1 Rutherford deduced the following inferences from his experiment of dispersal of alpha particles on the gold sheet :

1. Major part of an atom is a void.
2. The entire positive charge of the atom is concentrated at a point.
3. The space occupied by the positive charge is very less as compared to the volume of the atom.

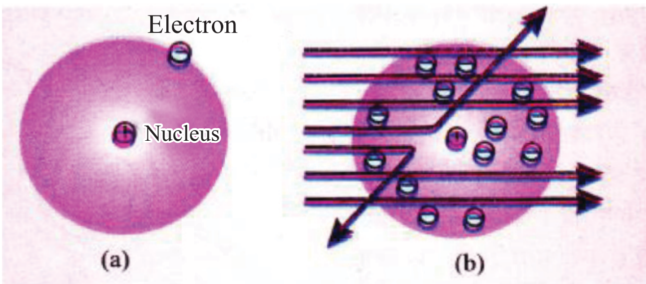


Fig. 3.5 Alpha particle dispersion by the nucleus of the metal atom

3.3.2 On the basis of these inferences Rutherford proposed the nuclear atomic model. The main points of this model are :

1. The entire positive charge and mass of an atom is concentrated in a small part, the nucleus, at its center. The radius of the nucleus is 10^{-15} meter.
2. Major part of the atom is void, in which the negatively charged electrons revolve at high speed on circular path, around the nucleus. These circular paths are known as orbit or shell or orbital.
3. The 'electrostatic force of attraction' between the positively charged nucleus and the negatively charged electrons is balanced by the centrifugal force of the electrons revolving at high speed.
4. The atom is electrically neutral because the total negative charge on electrons is equal to the total positive charge of the nucleus.

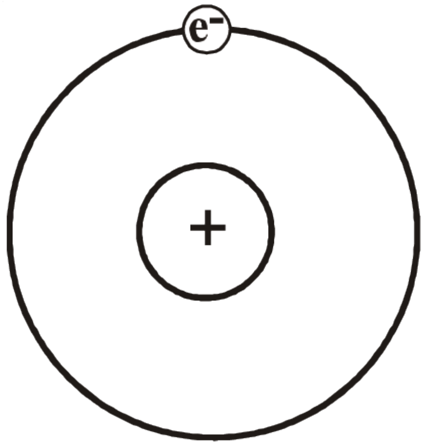


Fig. 3.6 Rutherford's Atomic Model

3.3.3 Drawback of the Rutherford's Atomic Model.

1. The negatively charged electron, revolving round the positively charged nucleus, will emit energy radiations because of acceleration; as a result, the energy will continuously decrease and ultimately the electron will fall into the nucleus. Hence the atom will not be stable.

2. Rutherford could not explain the definite path for electrons.

3.4 Discovery of Neutrons :

Atomic studies revealed that the mass of atom is more than total mass of electron and protons present therein. In 1920, Ernest Rutherford suggested the presence of neutral particles in the atom but in was difficult to identify them because they were without any charge. In 1932 the neutral particles, neutrons, were discovered, whose mass was found to be equal to that of protons. James Chadwick discovered neutrons.

3.5 Bohr's Model of Hydrogen Atom :

Rutherford's atomic model was not in accordance with the laws of Physics. In 1912 Neil Bohr presented a new atomic model based on concepts. The main postulates of the Bohr's hydrogen atom model, based on the quantum theory, are as under :

1. In the hydrogen atom electron moves in circular orbits of definite radius and energy. These orbits are represented by 1, 2, 3, 4 .... or K, L, M, N, O.

2. The angular velocity of electrons in these orbits (mvr) is equal to or $h/2\pi$ or its multiple. Here h is Planck's constant, m = mass of electron v = velocity of electron and r = radius of the orbit.

3. There is no change in energy of the electron revolving in a particular orbit but energy is emitted and absorbed respectively when electron moves from higher orbital to lower orbital or lower orbital to higher orbital.

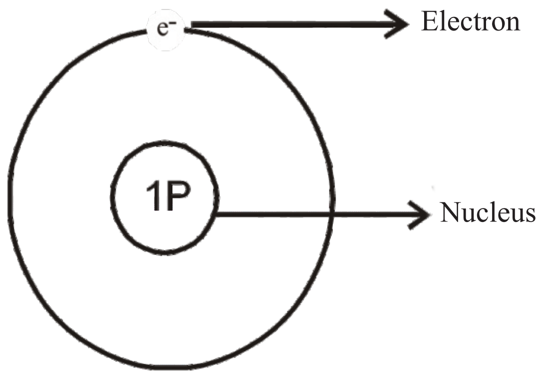


Fig. 3.7 Hydrogen Atom Model

Atomic radius is the distance between the nucleus and the outermost orbital (shell) of an atom dissociated from a compound. But neither can an atom be dissociated nor can the distance of the shell from outermost orbital, be measured in a simple way. Therefore the atomic radii can be explained in the following manner :

3.6.1 Covalent radius :

Covalent radius is half the distance of single covalent bond formed between similar atoms. For example half of the distance between the nuclei of two chlorine atoms is 99A° which is considered to be its atomci radius ($1A^o = 10^{-8}$ cm).

3.6.2 Metallic radius :

Metallic radius is half of the total distance between the nuclei of the two adjacent atoms in a metallic cluster. This is its atomic radius.

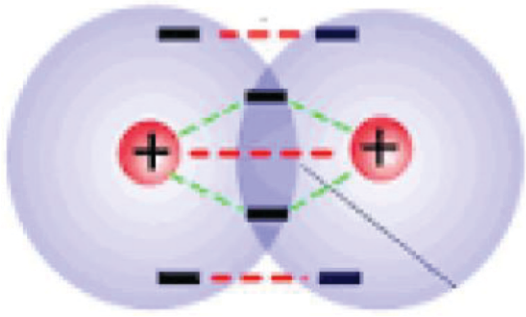


Fig. 3.8 Covalent Radii

3.7 Atomic Mass :

According to Dalton's atomic theory, each element has its characteristic atomic mass. Dalton's theory can easily explain the law of constant proportion, hence, inspired by it the scientists advanced towards measuring the atomic mass and relative atomic mass, using the combination rules. Practically the mass of atom is due to the protons and neutrons present in it. They are also known as nucleon because of their presence in the nucleus. Thus the entire mass of an atom is in its nucleus. The atomic mass of oxygen, which is, 16amu (atomic mass unit) is because of the presence of 8 protons and 8 neutrons in it. Similarly the mass of nitrogen atom is 14 amu (indicating 7 neutron + 7 protons). "The total number of nucleons (number of proton + neutron) present in the nucleus of an atom is known as its mass number." Mass number is represented by 'A'. "The number of protons present in an atom is known as the atomic number." It is denoted by 'Z'. It can be related to A as under :

$$A = Z + n$$

where A = mass number
Z = atomic number
n = Number of neutrons

3.8 Atomic weight :

With the studies regarding atomic structure, the knowledge of e/m (i.e. ratio of charge to mass) of the electron had developed. Over period of time, even the atomic weight was determined. In the beginning the weight of atoms was calculated in relation to that of the smallest atom, i.e. of hydrogen, which was taken as unit. The atomic weight was defined as - "The atomic weight of an element is that number which indicates how heavy is the atom of the element as compared to the hydrogen atom".

In 1961, the twelfth part of Carbon-12 isotope was accepted as the international standard atomic mass unit. According to this "the atomic weight of any element is the average weight of all the isotopes of that element as compared to one twelfth part of the carbon-12 isotope". In other words it is the ratio of the average mass of all the isotopes of that element to one twelfth of the mass of an atom of carbon-12.

Atomic weight of an element

$$= \frac{\text{Weight of one atom of the element}}{\text{Weight of 1/12 part of the C-12 isotope.}}$$

Atomic weight and atomic number of elements

S. No	Element	Atomic number	Mass number	Atomic weight in amu
1.	Hydrogen	1	1	1.008
2.	Helium	2	4	4.003
3.	Carbon	6	12	12.001
4.	Nitrogen	7	14	14.007
5.	Oxygen	8	16	15.99
6.	Sodium	11	23	22.99
7.	Magnesium	12	24	24.31
8.	Aluminium	13	27	26.98
9.	Chlorine	17	35	35.453

3.9 Avogadro Number

Hydrogen and oxygen reacts to form water :

$$2H_2 + O_2 \rightarrow 2H_2O$$

In this reaction 2 molecules of hydrogen react with one molecule of oxygen to form two molecules of water. The amount of substances taking part in a reaction can be determined easily and their amount can be easily represented by the number of its molecules or atoms. Hence, to make the understanding of the amount of substances, convenient, a new unit 'mole' was proposed. According to the mole hypothesis "The mass of one mole of a substance is equal to its gram atomic weight or the gram molecular weight."

According to this definition :

The weight of 1 mole of the substance

18 gms water (H_2O)

17 gms ammonia (NH_3)

44 gms carbon-di-oxide (CO_2)

12 gms carbon (C)

24 gms magnesium (Mg)

In one mole of every substance, the number of its particles (atoms, ions, molecules) is definite, which is known as the Avogadro number and its value is 6.022×10^{23}. In 18 gms of water there are 6.022×10^{23} molecules of water or 6.022×10^{23} atoms of oxygen and 2 (6.022×10^{23}) atoms of hydrogen. This has been named in honour of the Italian scientist Amedeo Avogadro.

The concept of mole can be understood with the help of an example :

Determine the number of oxygen and hydrogen atoms and of the water molecules in 2.5 moles of water.

Solution :

Charge and mass of the fundamental particles of atom

Name the Particle	Symbol	Nature	Charge in Columb	Charge in Unit	Mass in amu	Mass in kg
Electron	e	negative	1.6×10^{-19}	–1	0.0005485	9.109×10^{-31}
Proton	p	positive	1.6×10^{-19}	+1	1.007277	1.672×10^{-27}
Neuton	n	neutral	zero	zero	1.008665	1.674×10^{-27}

Number of molecules in 1 mole of water

= Avogadro number

$= 6.022 \times 10^{23}$

$\therefore$ Number of molecules in 2.5 mole of water

$= 2.5 \times 6.022 \times 10^{23}$

$= 15.055 \times 10^{23}$ molecules of water

Number of hydrogen atoms in one molecule of water = 2

$= 2 \times 6.022 \times 10^{23}$ atoms

Therefore, number of hydrogen atoms in 2.5 moles of water

$= 2.5 \times 2 \times 6.022 \times 10^{23}$

$= 30.110 \times 10^{23}$ atoms of hydrogen

Number of oxygen atoms in one molecule of water = 1

Number of oxygen in one mole of water = $1 \times 6.022 \times 10^{23}$

Therefore, number of oxygen atoms in 2.5 moles of water

$= 2.5 \times 1 \times 6.022 \times 10^{23}$

$= 15.055 \times 10^{23}$.

The volume of one mole of a substance at normal temperature and pressure is 22.4 litre, i.e., at NTP the weight of 22.4 litre of every gas is equal to its molecular weight. This is used in related to weight calculations.

3.10 Position of electron :

In an atom the electrons revolve around the nucleus in definite orbitals. These orbitals were represented by Bohr as K, L, M, N, O or 1, 2, 3, 4, 5. The number of electrons in each orbital is $2n^2$ where n is the number of orbitals.

Accordingly, as per Bohr's hypothesis, the maximum number of electrons in the outermost shell can be eight.

Orbit	Name of the orbit	No. of electrons
1	K	$2 \times 1^2 = 2$
2	L	$2 \times 2^2 = 8$
3	M	$2 \times 3^2 = 18$
4	N	$2 \times 4^2 = 32$
5	O	$2 \times 5^2 = 50$

Accordingly, the distribution of electrons in the atoms of the first 20 elements of the periodic table will be as under :

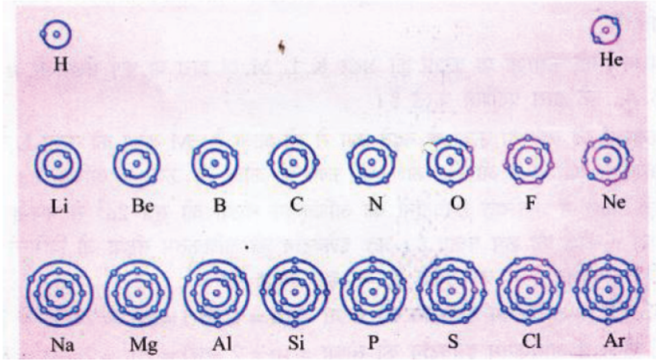


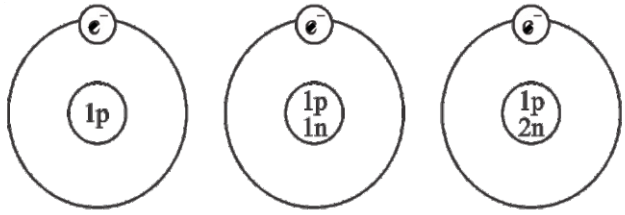
Fig. 3.9 Electron arrangement in Atoms

S. N.	Name of Element	Symbol	Atomic number	Electron arrangement
1.	Hydrogen	H	1	1
2.	Helium	He	2	2
3.	Lithium	Li	3	2, 1
4.	Berilium	Be	4	2, 2
5.	Boron	B	5	2, 3
6.	Carbon	C	6	2, 4
7.	Nitrogen	N	7	2, 5
8.	Oxygen	O	8	2, 6
9.	Fluorine	F	9	2, 7
10.	Neon	Ne	10	2, 8
11.	Sodium	Na	11	2, 8, 1
12.	Magnesium	Mg	12	2, 8, 2
13.	Aluminium	Al	13	2, 8, 3
14.	Silicon	Si	14	2, 8, 4
15.	Phosphorus	P	15	2, 8, 5
16.	Sulphur	S	16	2, 8, 6
17.	Chlorine	Cl	17	2, 8, 7
18.	Argon	Ar	18	2, 8, 8
19.	Potassium	K	19	2, 8, 8, 1
20.	Calcium	Ca	20	2, 8, 8, 2

Isotopes :

According to Dalton's Atomic Theory all the atoms of an element are similar. But later on, scientists found that this was not true. They found that the mass number of the atoms of the same element may differ. Hydrogen atom is an example which has three atomic species :

Hydrogen 99.98%, Deutirium 0.15% and Tritium is present in very minute quantities.



Hydrogen H^1_1H Deutirium D^2_1H Tritium T^3_1H

Fig 3.10 Isotopes of Hydrogen

In these atoms it was observed that in the nucleus of the hydrogen, available in excess, there is only one proton in the nucleus, while in Deuterium nucleus there is one neutron along with one proton and in the nucleus of Tritium there are two neutrons and a single proton. Thus, their atomic number is one but mass number is 1, 2 and 3 respectively. From this example we can define isotope as "Atoms of the same element whose atomic number is the same but mass number is different, are known as isotopes."

Other examples include two isotopes of chlorine : Chlorine 35 and Chlorine 37; two isotopes of carbon : Carbon -12 and Carbon-14; three isotopes of oxygen : Oxygen-16, Oxygen-17 and Oxygen 18.

3.11.1 Uses of Isotopes :

1. Uranium isotope is used as fuel in atomic reactor.
2. Radioactive isotopes are used in treatment of various diseases. For example : Iodine -131 in goiter disease and Cobalt-60 for treatment of cancer.
3. Isotopes are used to study the mechanism of chemical reactions.
4. Sodium-24 is used to study the blood circulation in human beings.

3.12 Isobars :

Isobars are the atoms of different elements whose mass number is the same but atomic number differs. For example, the mass number of calcium and argon, both, is 40 but their atomic number are 18 and 20 respectively. Similarly, mass number of Carbon-14 and Nitrogen-14, is 14 hence they are Isobars. In ths type of atoms the sum of protons and neutron is the same but in both the number of protons is different.

Important Points

1. The basic particles of atom are electron, proton and neutron.
2. The negatively charged particles in the atom are electrons.
3. The numeric value of the charge on electron and proton is the same but their sign is opposite.
4. James Chadwick discovered neutrons.
5. There are 6.022×10^{23} particles in one mole. This is known as the Avogadro number.
6. The NTP volume of 1 mole of a gas is 22.4 litres.
7. The formula to determine the maximum number of electrons in a shell is $2n^2$.
8. When the atomic number is the same but mass number is different they are known as Isotopes.
9. Isobars are elements having different atomic number and the same mass number.
10. There are three isotopes of hydrogen, Protium, Deutirium and Tritium.

Questions

Objective type Questions :

1. The Plum Pudding Model of atom was given by:
   (a) Neil Bohr
   (b) Thomson
   (c) Ernest Rutherford
   (d) Goldstein
2. The discoverer of neutron was :
   (a) C.V. Raman (b) Rutherford
   (c) J.J. Thomson (d) James Chadwick
3. The size of atom is :
   (a) 10^{-6} cm (b) 10^{-15} cm
   (c) 10^{-2} cm (d) 10^{-8} cm
4. The number of neutrons in the Deutirium Isotope of hydrogen is /are :
   (a) one (b) Two
   (c) Three (d) Not even one

Very short answer type questions :

5. What are Isotopes?
6. What are Isobar Element?
7. Write the names of the basic particles present in atoms.
8. Define atomic weight.
9. What is Atomic Number?
10. What is the charge on neutron?
11. Write the value of Avogadro number.
12. Write the name of the discoverer of proton.

Short answer type questions :

13. What is immersion tube? Explain with the help of diagram.
14. Explain the atomic model of Thomson.
15. What is mole concept? Explain.
16. Write the main points of the Dalton's Atomic Theory.
17. Write the characteristic properties of Cathode Rays.
18. Explain the Covalent Radius of atom with the help of an example.

Essay type questions :

19. Elucidate the atomic model based on Rutherford's observations of Gold foil particle scattering experiments.
20. Write the main concept of the Neil Bohr atomic model and on its basis draw the atomic structure of sodium and potassium element.
21. What are positive rays? How can they be obtained? Write their properties.

Numerical Problems :

22. The number of neutrons in an isotope of an element is 9 and mass number is 17. Name the element and state its atomic number.
23. Write the weight of 22.4 litre nitrogen at NTP in terms of gram.
24. How many atoms of carbon are present in 1.5 moles of carbon?
25. What is the number of total atoms present in 9 grams of water.

Answer Key

1. (b) 2. (d) 3. (d) 4. (a)