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Chapter : 2 [structure of the atom]

structure of the atom

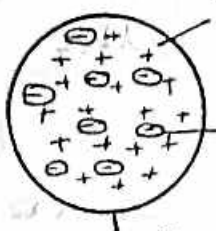
Introduction

An atom is the smallest particle of a chemical element possessing the chemical properties of the element.

The first model of an atom was given by J. J. Thomson.

1. **Thomson model :**

Thomson conceived his atomic model as a sphere of size $= 10^{-10}$ m and of positively charged matter in which electrons are embedded.



drawbacks

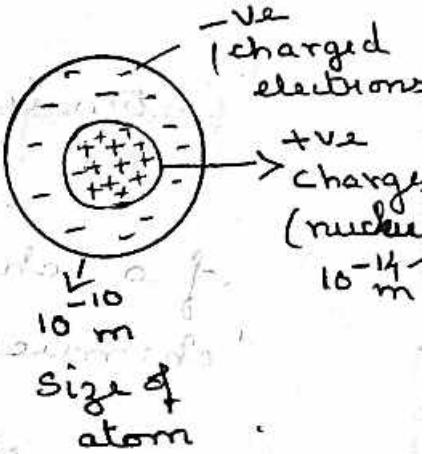
(1) it could not explain all features of optical spectra of hydrogen and other element.

(2) In 1911 Rutherford performed a number of experiments on scattering of α particles by a very thin gold foil. A collimated beam of alpha particles hitting a gold

showed deflections through large angles. Most of these particles went undeflected while a few were turned back. Thomson's model could not explain this result.

2. <u>Rutherford's model</u>:

He suggested that the atom consists of a central massive nucleus (dimensions of the order of 10^{-14} m) in which almost all the positive charges and most of the mass are concentrated. A cloud of negatively charg electrons surrounds this nucleus.

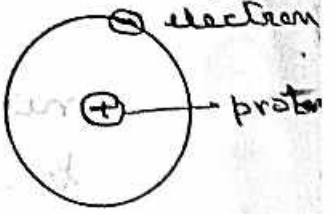


The dimensions of the nucleus and of the electrons are negligibly small as compared to the overall size of the atom. So most of the volume inside the atom is empty.

Since the electron distribution must give stability to the atom, the electrons could not be stationary. The electrons must be revolving around the nucleus in closed orbits, so that the centrifugal force due to the rotation of the electron is balanced by the force of electrostatic attraction between the nucleus and the

electrons. Thus Rutherford proposed a dynamic planetary model in which nucleus plays the role of the sun and electrons corresponds to the individual planets of the solar system.

Since most of the atom is empty, most of the α- particles pass through the foil without appreciable deflection, However, if an α- particle is moving in such a direction so as to have a head on collision with the nucleus, the α- particles will be scattered at larger angles. Sometimes, when a head on collision occurs, the α- particle is turned back. Thus Rutherford's model of the nucleus enables us to account for very large deviations.



Figure

Simple figure for Rutherford model.

<u>Drawbacks</u>.

1. The electrons in circular orbit experiences a centripetal acceleration. According to electromagnetic theory, an accelerated electrical charge must radiate energy in the form of electromagnetic waves. If the accelerated electron loses energy by radiation, the total energy of the electron continuously decreases and it must spiral down into the nucleus. Thus, the atom cannot be stable. But it is well known that most of the atoms are stable.

2. According to classical e.m theory, the accelerating electron must radiate energy at a frequency equal to the mechanical frequency of the orbiting electron and hence proportional to the angular velocity of the electron. Therefore as the electron spirals towards the nucleus, the angular velocity tends to infinity. This will result in a continuous spectrum with all possible wavelengths. Contrary to this we see experimentally that atoms like hydrogen emit line spectra of fixed wavelength only.

3. Bohr Atom Model:

Bohr assumed basically Rutherford nuclear-model of the atom and tried to overcome the defects of the model. He proposed the following two postulates

1.) An electron cannot revolve round, the nucleus, in all possible orbits as suggested by the classical theory. The electron can revolve round the nucleus only in those allowed or permissible orbits for which the angular momentum of the electron is an integral multiple of $h/2\pi$

h = planck's constant = 6.64×10^{-34} Js.

These orbits are called stationary orbits

and an electron revolving in these orbits does not radiate energy.

2). An atom radiate energy only when an electron jumps from a stationary orbit of higher energy to the one of lower energy. If the electron jumps from an initial orbit of energy E_i to the final orbit of energy E_f ($E_i > E_f$), a photon of frequency $\nu = \frac{E_i - E_f}{h}$ is emitted.

A. Sommerfeld's relativistic atom model.

Introduction:

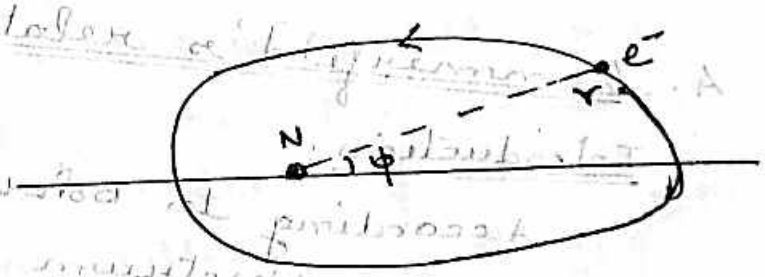
According to Bohr, the lines in the hydrogen spectrum should each have a well defined wavelength. Spectrograph of high resolving power showed that the H_α, H_β and H_γ lines of hydrogen are not single. Each spectral line actually consist of several very close lines packed together. These close lines is called fine structure of the spectral lines. Bohr's theory could not explain this fine structure.

To explain the fine structure of spectral lines Sommerfeld introduced

two main modifications in Bohr's theory.

1) According to sommerfeld the path of an electron around the nucleus in general, is an ellipse with the nucleus at one of the foci. The circular orbits of Bohr are a special case of this.

2). The velocity of the electron moving in an elliptical orbit varies considerably at different parts of the orbit. This causes relativistic variation of the mass of the electron with velocity. Hence this is known as relativistic atom model.



5. Vector atom model:

Introduction:

* Bohr's theory was able to explain only the series spectra of the simplest hydrogen atom. It could not explain the multiple structure of spectral lines in the simplest hydrogen atom.

* Sommerfeld's theory was able to give an explanation of the fine structure of the spectral lines of hydrogen However could not predict the correct

number of the fine structure lines. Moreover it gave no information about the relative intensities of the lines. Sommerfeld's theory could not explain the complex spectra of alkali metals like sodium.

** These older theories were inadequate to explain new discoveries like Zeeman effect and Stark effect in which the spectral lines could be split up under the influence of magnetic and electric fields.

*** Another drawback of Bohr model was it could not explain how the orbital electrons in an atom were distributed around the nucleus.

Therefore, in order to explain the complex spectra of atoms and their relation to atomic structure, the vector atom model was introduced. The two distinct features of the vector atom model are

(1) the concept of spatial quantisation
(2) the spinning electron hypothesis.

Spatial quantisation

According to Bohr's theory, the orbits are quantised as regards their magnitude (size and form only). But

according to quantum theory, the direction or orientation of the orbits in space also should be quantised. To specify the orientation of the electron orbit in space, we need a fixed reference axis. This reference line is chosen as the direction of an external magnetic field that is applied to the atom. The different permitted orientation of an electron orbit are determined by the fact that the projection of the quantised orbits on the field direction must themselves be quantised. The idea of space quantisation leads to an explanation of zeeman effect. The stern-gerlach experiment provided an excellent proof of the space quantisation of atom.

Spinning electron

To account for the observed fine structure of spectral lines and to explain the anomalous zeeman effect, the concept of spinning electron was introduced by Uhlenbeck and Goudsmit in 1926. According to their hypothesis, the electron spins about an axis of its own, while it also moves around the nucleus of the atom in its orbit. The spin of the electron is analogous to the spinning of a planet around its own axis and it moves in an elliptical orbit around the sun. In other words, the electron is endowed

with a spin motion over and above the orbital motion. According to quantum theory, the spin of the electron also should be quantised. Hence a new number called the spin quantum number is introduced. Since the orbital and spin motions are both quantised in magnitude and direction according to the idea of space quantisation, they are considered as quantised vectors. Hence the atom model based on these quantised vectors is called the vector atom model to which vector laws apply.

According to the older theories, the electron was supposed to have only orbital motion round the nucleus. Hence only the orbital angular momentum and orbital magnetic moment were considered. The spin endows the electron with spin angular momentum sh and a spin magnetic moment. Hence the total angular momentum of an atom should be the vector sum of the orbital angular momentum and spin angular momentum. Similarly, the total magnetic moment of an atom should be the vector sum of the orbital and spin magnetic moments.