III. Long Answer Type Questions

Question 1. (a) What is the limitations of Rutherford model of atoms?
(b) How has Bohr's theory helped in calculating the energy of hydrogen electron in different energy levels?
Answer:
(a) Limitations of Rutherford Model:
(i) When a body is moving in an orbit, it achieves acceleration (even if body is moving with constant speed in an orbit, it achieves acceleration due to change in direction). So an electron moving around nucleus in an orbit is under acceleration. However, according to radiation theory of Maxwell, the charged particles when accelerated must emit energy as electromagnetic radiations. This means that the revolving electron must also lose energy continuously in the form of electromagnetic radiation. The loss of energy in revolution of the electron around the nucleus must bring it closer to the nucleus and the electron must ultimately fall into the nucleus by the spiral path. This means that the atom must collapse. But we all know that atom is quite stable in nature.
(ii) Rutherford's model could not explain the existence of different spectral lines in the hydrogen spectrum.
(b) Based upon the postulates of Bohr's theory, it is possible to calculate the energy of the hydrogen electron and also one electron species. (He^+, Li^{2+} etc.) The mathematical expression for the energy in the nth orbit is

$$E_n = -\frac{2\pi^2 m_e e^4 Z^2}{n^2 h^2}$$

By substituting the values of m_e (mass of electron), e (charge of electron) and h (Planck's constant), the value of energy comes out to be

$$E_n = -\frac{2 \cdot 178 \times 10^{-18} \times Z^2}{n^2} \text{ J per atom.}$$

$$= -\frac{1312 \times Z^2}{n^2} \text{ KJ mol}^{-1}$$

For hydrogen electron,

$$Z = 1$$

$$E_n = -\frac{1312}{n^2} \text{ KJ mol}^{-1}$$

The value for $n = 1$, gives the energy of the hydrogen electron in the ground state.
By assigning values, energy in different excited states can be calculated.

Question 2. Define atomic number, mass number and neutron. How are the three related to each other?
Answer: Atomic Number (Z): The atomic number of an element is equal to the number of protons present inside the nucleus of its atoms.
Since, an isolated atom has no net charge on it, in neutral atoms, the total number of electrons is equal to its atomic number.
Atomic number (Z) = Number of protons in the nucleus of an atom = Number of electrons in the neutral atoms
Mass Number (A): The sum of the number of neutrons and protons in the nucleus of an atom is called its mass number. Mass number is denoted by A. Thus, for an atom, Mass number (A) = Number of protons (p) + Number of neutrons (n)
A = p + n
Neutron: It is neutral particle. It is present in the nucleus of an atom.

Expect hydrogen (which contains only one electron and one proton but no neutron), the atoms of all other elements including isotopes of hydrogen contain all the three fundamental particles called neutron, proton and electron.
The relation between mass number, Atomic no. and no. of neutrons is given by the equation:

$$A = Z + n$$

Where A = Mass number
Z = Atomic number n = Number of neutrons in the nucleus.

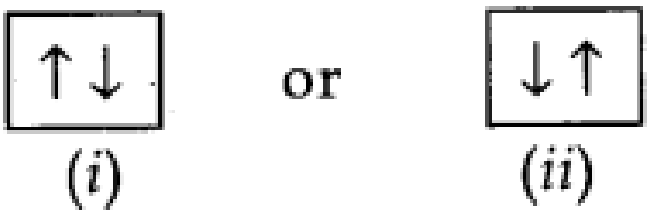
Question 3. What were the weaknesses or limitations of Bohr's model of atoms ? Briefly describe the quantum mechanical model of atom.
Answer: Limitations of Bohr's model of an atom:

- It could not explain spectrum of multi-electron atoms.
- It could not explain Zeeman and Stark effects.
- It could not explain shape of molecules.
- It was not in accordance with Heisenberg's uncertainty principle.
  Quantum Mechanical Model: It was developed on the basis of Heisenberg's uncertainty principle and dual behaviour of matter.

Main features of this model are given below :

- The energy of electrons in an atom is quantized i.e. can only have certain values.
- The existence of quantized electronic energy levels is a direct result of the wave like properties of electrons.
- Both, the exact position and velocity of an electron in an atom cannot be determined simultaneously.
- The orbitals are filled in increasing order of energy. All the information about the electron in an atom is stored in orbital wave function Ψ.
- From the value of Ψ^2 at different points within atom, it is possible to predict the region around the nucleus where electron most probably will be found.

Question 4. State and explain the following:
(i) Aufbau principle
(ii) Pauli exclusion principle.
(iii) Hund's rule of maximum multiplicity.
Answer:
(i) Aufbau Principle: In the ground state of the atoms, the orbitals are filled in the order of their increasing energies. In other words, electrons first occupy the lowest-energy orbital available to them and enter into higher energy orbitals only after the lower energy orbitals are filled.
The order in which the energies of the orbitals increase and hence the order in which the orbitals are filled is as follows:
Is, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f, 6d,7p.....
(ii) Pauli Exclusion Principle: An orbital can have maximum of two electrons and these must have opposite signs.
For example: Two electrons in an orbital can be represented by

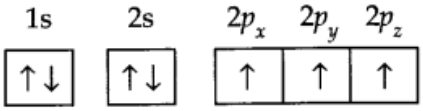


(i) (ii)

The two electrons have opposite spin, if one is revolving clockwise, the other is revolving anticlockwise or vice versa.

(iii) Hund's Rule of Maximum Multiplicity: Electron pairing in p, d and/orbitals cannot occur until each orbital of a given subshell contains one electron each or is single occupied.

For example: For the element nitrogen which contains 7 electrons, the following configuration can be written.



Total spin of unpaired electrons

$$= \frac{1}{2}+\frac{1}{2}+\frac{1}{2} = 1\frac{1}{2}.$$

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