

9th – Atomic Structure II



Bohr's Model of an Atom: To overcome the objections raised against Rutherford's model of the atom, Neil Bohr put forward the following postulates about the model of an atom:

1. Atom consists of positively charged nucleus around which electrons revolve in discrete orbits, i.e. electrons revolve in certain permissible orbits and not just in any orbit.

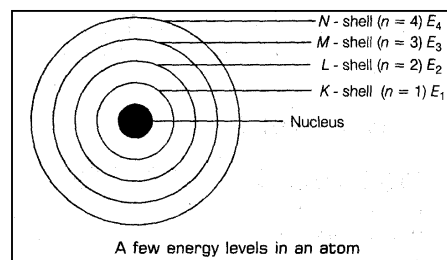
2. Each of these orbits are associated with certain value of energy. Hence, these orbits are called energy shells or energy levels. As the energy of an orbit is fixed (stationary), orbit is also called stationary state

3. Starting from nucleus, energy levels (orbits) are represented by numbers (1, 2, 3, 4 etc.) or by alphabets (K, L, M, N etc.).

4. Energy of an electron remains same as long as it remains in discrete orbit and it does not radiate energy while revolving.

5. When an electron jumps from a lower energy to a higher one, some energy is absorbed while some energy is emitted when the electron jumps from a higher energy level to a lower one.

6. Normally, the electrons present in first energy level (E_1) have lowest energy. Energies increases on going towards outer energy levels.



Evidences in Support of Divisibility of Atom: Following observations show that atom is made up of different particles like electrons, protons and neutrons, i.e. atom is divisible:

(i) Formation of ionic compounds is possible due to the formation of ions which involves the transfer of electrons.

(ii) Presence of isotopes for the same element is possible due to the difference in the number neutrons.

Distribution of electrons in different orbits (shells): The distribution of electrons into different orbits of an atom was suggested by Bohr and Bury. For writing the number of electrons in different levels or shells, some rules are followed. These are:

1. The maximum number of electrons present a shell is given by the formula $2n^2$, where, n is the orbit number or energy level 1, 2, 3.... Therefore, the maximum numbers of electrons in different shells are as follows:

1st orbit or K-shell = $2 \times (1)^2 = 2$ 2nd orbit or L-shell = $2 \times (2)^2 = 8$

3rd orbit or M-shell = $2 \times (3)^2 = 18$ 4th orbit or N-shell = $2 \times (4)^2 = 32$ and on.

2. The maximum number of electrons that can be accommodated in the outermost orbit is 8. This is a very important rule and is sometimes called the octet rule. According to this rule, the presence of 8 electrons in the outermost shell makes the atom very stable.

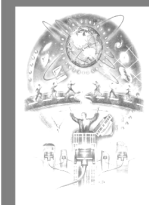
3. Electrons are not accommodated in a given shell, unless the inner shells are filled (i.e. the shells are filled in a stepwise manner).

Significance of electronic configuration: it plays an important role in determining the chemical behavior of an element.

1. When the atom of an element has a completely filled outermost shell, the element will be chemically unreactive. For example the noble gases (He, Ne, Ar, Kr, Xe, Rn) have completely filled outermost shell i.e. the outermost shells of the noble gases contain 8 electrons. Except helium which contains 2 electrons.

2. When the atom of an element has less than 8 electrons in its outermost shell, the element will be reactive. The exception to this is helium.





Subshells: it was found that shells have subshells. These subshells are termed as s,p,d and f. the maximum number of electrons that can go into these are 2,6,10 and 14 respectively.

Valency: The electrons present in the outermost shell of an atom are known as the valence electrons. They govern the chemical properties of atoms. The atoms of elements having completely filled outermost shell which has eight electrons (said to possess an octet) show little chemical activity, i.e. they are highly stable. Such elements are called inert elements. It means, their valency is zero.

- Of these inert elements, the helium atom has two electrons in its outermost shell and all other elements have atoms with eight electrons in the outermost shell. The tendency to react with atoms of the same or different elements to form molecules is an attempt to attain fully-filled outermost shell. It means, atoms react with other atoms in order to attain fully-filled outermost shell. An outermost shell, which had eight electrons, is called an octet.

- Atoms would thus react, so as to achieve an octet in the outermost shell. This was done by sharing, gaining or the loss of electrons. The number of electrons lost or gained or shared by an atom to become stable or to achieve an octet in the outermost shell is known as valency of that element. In other words, it is the combining capacity of the atom of an element with the atom(s) of other element(s) in order to complete its octet. The valencies of elements of some groups are described below:

1. Hydrogen, lithium, sodium and potassium atoms contain one electron each in their outermost shell, therefore, each one of them can lose one electron to become stable. Hence, their valency is 1.

2. The valency of each of Mg, Ca and Be is 2 because all of these have 2 valence electrons and they can lose these 2 electrons to make the octet of electrons in the outermost shell or to become stable.

3. The valency of boron and aluminium is 3 because each has 3 valence electrons.

4. The valency of carbon and silicon is 4 because each has 4 valence electrons.

5. Nitrogen and phosphorus each has 5 valence electrons, so their valency is 3 because they can gain 3 electrons (instead of losing five electrons) to become stable. Hence, their valency is determined by subtracting five electrons from the octet i.e. $8-5 = 3$. However, P can also share 5 electrons; hence it shows a valency of 5 alongwith 3.

6. Oxygen and sulphur each has 6 valence electrons, therefore, their valency is 2 because they can gain 2 electrons or share 2 electrons to complete their octet.

7. Similarly, fluorine and chlorine each has 7 valence electrons, their valency is 1 because they can gain 1 electron or share 1 electron to complete their octet.

8. All the inert elements, i.e. He, Ne, Ar etc., have completely filled outermost shells. Therefore, their valency is zero.

Note: For metals, generally valency = Number of valence electrons, for non-metals, valency = $8 -$ number of valence electrons.

Atomic number and mass number:

Atomic Number: It is defined as the number of protons present in the nucleus of an atom. All the atoms of the same element have the same of protons in their nuclei and hence, they have the same atomic number. It is denoted by Z and written as the subscript towards the left of the symbol. E.g. ${}^2\text{He}^4$, ${}^3\text{Li}^7$, Z = 2 and 3 for He and Li respectively.

Note: In neutral atom, atomic number = number of protons = number of electrons

Mass Number: It is defined as the sum of number of protons and neutrons in the nucleus of an atom. Protons and neutrons together are called as nucleons. Mass number is denoted by A. Mass number (A) = Number of protons + number of neutrons. Eg: He, Li, A = 4 and 7 for He and Li respectively.

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Number of neutrons = Mass number - atomic number

Atomic number = Number of protons

Mass number is written as a superscript towards the left of the symbol. In the notation for an atom, the atomic number, mass and symbol of the element are to be written as:

Mass number
14
N Symbol of element
7
Atomic number

Atomic Weight: Mass of an individual atom is called atomic mass or atomic weight. It is nearly equal to the mass number. It is nearly twice the atomic number for many atoms.

Carbon: atomic number (Z) = 6, Mass number (A) = 12, Atomic mass = 12.01 u

Oxygen: atomic number (Z) = 8, Mass number (A) = 16, Atomic mass = 15.99 u

Note:

- If number of electrons < number of protons, the atom carries positive charge and called cation.
- If number of electrons > number of protons, the atom carries negative charge and called anion.
- If number of electrons = number of protons, the atom carries no charge, i.e. it is neutral.

Different atomic species:

Isotopes: These are defined as the atoms of the same element, having the same atomic number but different mass numbers. E.g. there are 3 isotopes of hydrogen atom, namely protium (¹H), deuterium (²H) and tritium (³H).

In other words, it can be said that isotopes have same number of protons but differ in the number of neutrons. Each isotope of an element is a pure substance. Since, chemical properties of elements largely depend on their electronic configuration or outermost electrons and as the isotopes of an element have similar electronic configuration, therefore, isotopes of an element have the same chemical properties. We know that, masses of isotopes of elements are different. Since, physical properties such as density, light scattering etc., depend on mass therefore, these are different for isotopes of an element.

Average Atomic Mass: If an element has no isotopes, the mass of its atom would be the same as the sum of protons and neutrons in it. But if an element occurs in isotopic forms, then from the percentage of each isotopic form, the average mass is calculated as:

Average atomic mass of an element

[(Atomic mass of isotope I x percentage of isotope I) + (Atomic mass of isotope II x percentage of isotope II) + ...]

E.g. the two isotopic forms of chlorine atom with masses 35u and 37u occur in the ratio of 3:1. Therefore, the average atomic mass of chlorine atom, can be calculated as:

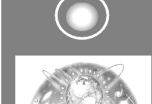
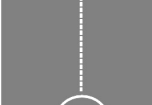
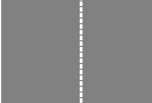
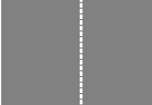
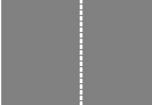
$$\begin{aligned}\text{The average atomic mass of chlorine atom} &= \left(35 \times \frac{75}{100} + 37 \times \frac{25}{100}\right) \\ &= \left(\frac{105}{4} + \frac{37}{4}\right) = \frac{142}{4} = 35.5 \text{ u}\end{aligned}$$

Here, 35.5 u is not the atomic mass of any one atom of chlorine but it shows that its given amount contains both the isotopes and their average atomic mass is 35.5 u.

NOTE: The fractional atomic masses of elements are due to the fact that all elements have isotopes. The isotopes of an element have different atomic masses. Since the atomic mass of an element is the average atomic mass of all the natural isotopes of that element, most elements have fractional atomic masses.

Applications of Isotopes:

1. An isotope of uranium (U-235) is used as a fuel for the production of electricity in nuclear reactors.
2. U-238 is used to determine the age of very old rocks and even the age of the earth.

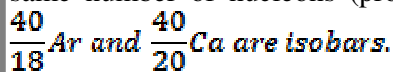


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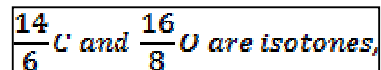
- An isotope of cobalt (Co-60) is used to remove brain tumours and in the treatment of cancer.
- An isotope of carbon (C-14) is used to determine the age of old specimen of wood or old bones of living organisms.
- An isotope of iodine (I-131) is used in the treatment of goiter (thyroid complications).

Isobars: Atoms of different elements with different atomic numbers but same mass number are known as isobars. In other words, isobars are the atoms of different elements that have same number of nucleons (protons + neutrons) but differ in the number of protons. e.g.



Since, isobars have different atomic number as well as different electronic configuration. Thus, they also have different chemical properties.

Isotones: Atoms of different elements having the same number of neutrons are called isotones. e.g., as both have 8 neutrons [(14 - 6 = 8) and (16 - 8 = 8)].



Worksheet

Q1. An atom of an element A may be written as ${}_{12}\text{A}^{24}$

- What does the superscripts 24 indicate?
- What does the subscripts 12 indicate?
- What are the number of protons, neutrons and electrons in an atom A?
- Write the symbol of ion formed by an atom of element A.

Q2. The atomic number of an element is 12. How many protons and electrons are there in an atom of the element?

Q3. The nucleus of an atom contains 11 protons and 12 neutrons. Determine the atomic number and mass number of the element.

Q4. The atomic number and the mass number of an element M are 12 and 24 respectively. Calculate the number of neutrons in an atom.

Q5. An element has 2 electrons in the M shell. What is the atomic number of the element?

Q6. Which of the two elements would be more reactive, element A of atomic number or element B of atomic number 19? And Why?

Q7. Consider the following pairs: a) ${}_{26}\text{A}^{58}, {}_{28}\text{B}^{58}$ b) ${}_{35}\text{X}^{79}, {}_{35}\text{Y}^{80}$

- Which of the above pairs are isotopes and isobars?
- What factors are responsible for the change in superscripts, 79, 80 (in case II), though the element is the same?
- Give the nuclear composition of A.

Q8. The atomic number of Al and Cl are 13 and 17 respectively. What will be the number of electrons in Al^{3+} and Cl^- ?

Q9. Identify the isotopic pairs out of the following species? ${}_{8}\text{C}^{16}, {}_{6}\text{C}^{14}, {}_{7}\text{N}^{14}, {}_{8}\text{O}^{18}, {}_{7}\text{N}^{16}$

Q10. The atomic mass of an element is 7u. It has 2 electrons in K shell and one electron in L shell. How many neutrons does it have?

