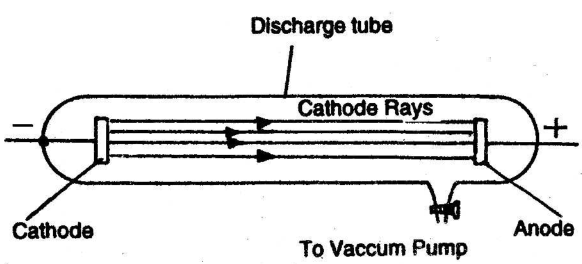
CHAPTER

8

ATOMS & NUCLEI

In the early 19th century, John Dalton developed his atomic theory that matter is made up of extremely small and indivisible particles of matter called atoms. In 1859, Plucker and others discovered that when a high potential of the order of 10,000 volts is applied to a discharge tube at low pressure of about 10^{-6} atmosphere, rays are liberated at the cathode. These rays are known as cathode rays consisting of negative charged particles.



These negatively charged particles are known as electron.

Properties of Cathode Rays

(*a*) Cathode rays always travel in a straightline.

(*b*) Cathode rays cast shadows of any solid object placed in their path.

(*c*) Cathode rays consist of negatively charged particles and therefore, they get deflected towards the positive place in an electric field.

(*d*) Cathode rays travel with high speed equivalent to that of velocity of light and penetrate through thin metallic sheets.

(*e*) The nature of these rays is independent of the gas and the cathode material used in the discharge tube.

(*f*) These rays ionize the gas through which they pass.

(*g*) These rays cause fluorescence and heat the object on which they fall due to the transfer of kinetic energy.

(*h*) Cathode rays consists of material particle and possess energy.

ELECTRON

Later in the 19th century, J.J. Thomson demonstrated that atoms are electromagnetically constituted and from them fundamental material units bearing electric charge that are now called electron can be extracted. Electrons are the universal constituents of all atoms as the electrons emitted in a cathode ray tube all possess the same mass and a unit electron-charge. The same is true of electron emitted, in the photoelectric cell or the thermionic value or by a radioactive source. Therefore, it may be said that electrons are prevalent in all forms of matter.

J.J. Thomson (1900-1906) studied the effect of magnetic field on cathode rays and found the ratio of change to mass (e/m) of an electron and calculated the mass of electron from it.

Charcteristics of the Electron

Mass and Charge: The mass of an electron is about 1/1840 time that of a hydrogen atom or proton.

$m_e = 9.109 \times 10^{-31}$ kg

An electron possesses a unit negative charge

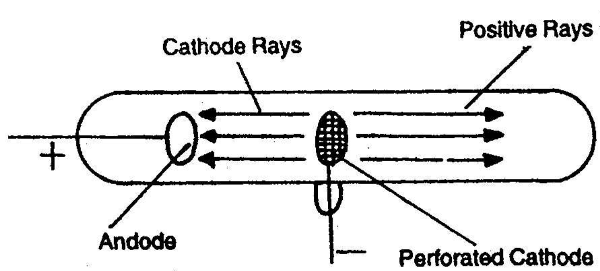
$e = 1.602 \times 10^{-19}$ coulombs

PROTONS

Goldstein (1886) in an experiment with discharge tube containing perforated cathode showed the presence of another type of radiation, that passed through hole in the cathode and carried positive charge. These rays consisting of positive charged particles were called positive rays or anode rays or canal rays and these positive charged particle are called proton.

Properties of Anode Rays

(*a*) Positive rays consist of positively charged particles.
(*b*) These rays travel in straight lines.
(*c*) These rays get deflected by an electrical field and bend towards the negative plate.
(*d*) The nature of these rays depend on the gas used in the discharge tube.
(*e*) These rays can produce mechanical as well as chemical change.
(*f*) Particle of these rays are heavier than the cathode ray particle.

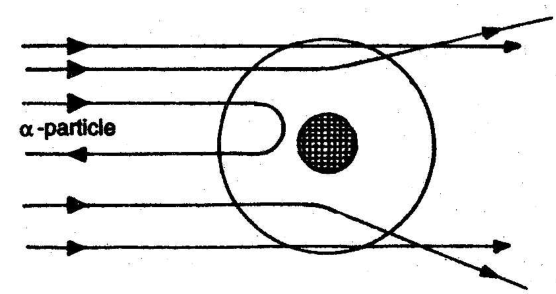


NEUTRONS

Rutherford (1920) suggested that in an atom, there must be present at least a third type of fundamental particles which should be electrically neutral and possess mass nearly equal to that of proton. He proposed the name for such fundamental particle as neutron. In 1932, **Chadwick** bombarded beryllium with a stream of α-particles. He observed that the penetrating radiations were produced which were not affected by electric and magnetic fields. These radiations consisted of neutral particles, which were called neutrons.

THE NUCLEUS

In the twentieth century, 1911, Rutherford performed a scattering experiment and in this experiment a thin gold of thickness 4×10^{-7} m was bombarded with α-particle. It was observed that most of the particles passed through the metallic foil without any deflection. But a few waves deflected from their most original path, some of them deflected backwards. From this observation, he arrived at the following conclusions:



(*a*) T α-particle pass through the Gold foil without suffering any change in their path shows that the atom consists largely of empty space.
(*b*) A few α-particle get deflected through wide angle or backwards shows that these must be present in each atom a heavy positively charged body at its centre and called its nucleus.
(*c*) The number of α-particles which undergoes such strong deflection is very small shows that the volume occupied by this heavy positively charged body is only a minute fraction of the total volume of the atom.

RUTHERFORD MODEL OF AN ATOM

On the basis of α-particle scattering experiment, Rutherfored put the nuclear model of the atom in 1912:
(*a*) The atom consists of positively charged nucleus on which entire mass of the atom resides.
(*b*) Electrons and the nucleus are held together by electrostatic forces of attraction.

BOHR'S ATOMIC MODEL

(*a*) The electrons keep on revolving in one or more of the infinite number of circular orbits about the nucleus without losing or gaining any energy.
(*b*) The electrons can move in only those circular orbits where the angular momentum (*mvr*) is a whole number multiple of $h/2\pi$.
(*c*) The absorption or emission of energy can occur only by transition of electron from lower to higher energy level or vice versa, respectively.

MODERN STRUCTURE OF ATOM

The modern structure of atom was developed in light of de Broglie and Heisenberg's uncertainty principle.

De Broglie Principle: All the moving material objects possess wave like characteristic. The de Broglie wavelength of material particle is given by

$$\lambda = \frac{h}{mv} = \frac{h}{p}$$

h = Planck's constant (J-sec)
m = Mass of particle (kg)
v = Velocity (ms^{-1})

SHAPES OF ATOMIC ORBITALS

The wave function for an electron is termed as atomic orbital, which is the region of finding an electron.

The diffuse electron cloud in an orbital has its greatest density near the nucleus which becomes thinner as the distance from the nucleus increases.

(*a*) **s-Orbital:** They are spherical in shape and have symmetrical orientation.
(*b*) **p-Orbital:** They are dumb bell in shape with two lobes.
(*c*) **d-Orbitals:** They are five in number (double dump-bell shaped)
(*d*) **f-Orbitals:** There are seven f-orbital, f-orbitals have 8 lobes and 3 nodes.

FILLING OF ORBITALS

(*a*) **Aufbau Principle:** It states that electrons are feeded in the orbitals in order of increasing energy and energy of the orbitals is governed by (n + 1) rule.
Therefore, orbitals of lower energy are filled first followed by orbitals of higher energy.
(*b*) **Pauli's Exclusion Principle:** It states that no two electrons can have the same value of the four quantum numbers.
(*c*) **Hund's Rule:** This rule states that pairing of electrons in degenerate orbitals belonging to a particular sub shell does not take place till each orbital is occupied by a single electron with a parallel spin.

QUANTUM NUMBERS

The set of four integers required to define the state of electron in an atom are called quantum numbers.

(*a*) **Principal Quantum Number (n):** It has integral values 1, 2, 3, 4..... and denoted as K, L, M, N.....
(*b*) **Azimuthal Quantum Number (l):** For each value of n, l have values from 0, 1, 2, 3..... (n – 1).
(*c*) **Magnetic Quantum Number (m):** For each sub-energy shell, there can be ($2l$ + 1) number of orbitals.
(*d*) **Spin Quantum Number (s):** Each spinning electron can have two values $+\frac{1}{2}$ (clockwise spin), $-\frac{1}{2}$ (anticlockwise spin).

VALENCE

Valence, also known as valency or valence number, is a measure of the number of bonds formed by an atom of a given element. "Valence" can be defined as the number of valence bonds a given atom has formed, or can form, with one or more other atoms. For most elements the number of bonds can vary. The IUPAC definition limits valence to *the maximum number of univalent atoms that may combine with the atom,* that is the maximum number of valence bonds that is possible for the given element.

The valence of an element depends on the number of valence electrons that may be involved in the forming of valence bonds. A univalent (monovalent) atom, ion or group has a valence of one and thus can form one covalent bond. A divalent *molecular entity* has a valence of two and can form two sigma bonds to two different atoms or one sigma bond plus one pi bond to a single atom. Alkyl groups and hydroxyl ions are univalent examples; oxo ligands are divalent.

Covalence

The concept of covalence was developed in the middle of the nineteenth century in an attempt to rationalize the formulae of different chemical compounds. In 1919, Irving Langmuir, borrowed the term to explain Gilbert N. Lewis's cubical atom model by stating that "the number of pairs of electrons which any given atom shares with the adjacent atoms is called the *covalence* of that atom." The prefix co-means "together", so that a co-valent bond means that the atoms share valence. Hence, if an atom, for example, had a + 1 valence, meaning it has one valence electron beyond the complete shell, and another a – 1 valence, meaning it requires one electron to complete its outer shell (missing an electron), then a bond between these two atoms would result because they would be complementing or sharing their out of balance valence tendencies. Subsequent to this, it is now more common to speak of covalent bonds rather than "valence", which has fallen out of use in higher level work with the advances in the theory of chemical bonding, but is still widely used in elementary studies where it provides a heuristic introduction to the subject.

Common Valences

For elements in the main groups of the periodic table, the valence can vary between one to seven, but usually these elements form a number of valence bonds between one and four. The number of bonds formed by a given element was originally thought to be a fixed chemical property. In fact, in most cases this is not true. For example, phosphorus often has a valence of three, but can also have other valences.

Nevertheless, many elements have a common valence related to their position in the periodic table, following the octet rule. Elements in the main groups 1 (alkali metals) and 17 (halogens) commonly have a valence of 1; elements in groups 2 (alkaline earth metals) and 16 (chalcogens) valence 2; elements in groups 13 (boron group) and 15 (nitrogen group) valence 3; elements in group 14 (carbon group) valence 4.

Valence Vs Oxidation State

The "oxidation state" of an atom in a molecule gives the number of valence electrons it has gained or lost. In contrast to the *valency number,* the *oxidation state* can be positive (for an electropositive atom) or negative (for an electronegative atom).

Elements in a high oxidation state can have a valence larger than four. For example, in perchlorates, chlorine has seven valence bonds and ruthenium, in the +8 oxidation state in ruthenium (VIII) tetroxide, has even eight valence bonds.

Examples : (Valencies according to the *number of valence bonds* definition and conform oxidation state)

Compound	Formula	Valence		Oxidation State	
Hydrogen chloride	HCl	H = 1	Cl = 1	H = +1	Cl = –1
Chlorine	Cl_2	Cl = 1	Cl = 1	Cl = +1	Cl = –1
Perchlorate*	$HClO_4$	H = 1	Cl = 7	O = 2 H = +1	Cl = +7 O = –2
Sodium hydride	NaH	Na = 1	H = 1	Na = +1	H = –1
Ferrous oxide**	FeO	Fe = 2	O = 2	Fe = +2	O = –2
Ferric oxide**	Fe_2O_3	Fe = 3	O = 2	Fe = +3	O = –2

* The univalent perclhorate ion (ClO_4^-) has valence 1.

** Iron oxide appears in a crystal structure, so on typical molecule can be identified.

In ferrous oxide, Fe has oxidation number II, in ferric oxide, oxidation number III.

NUCLEAR REACTION

When nucleon comes into contact with a target, a new nucleus results and it is called a nuclear reaction. During nuclear reactions, the total mass number of reactants should be equal to total mass of products. The nuclear reaction in which energy is released is exogeric and in which energy are of two categories :

A. Reactions that depend on nature of bombarding particles.

B. Reactions which depend on transformation of target nucleus.

Nuclear Fission

In this process U-235 is hit by slow moving neutrons, it splits up into a number of fragments with the release of large amount of energy. The fission of an atom of U-235 releases 211.5 MeV of energy. Nuclear Reactor is a device in which nuclear fission is carried in a controlled manner.

Nuclear Fusion

It is the process in which lighter nuclei of atoms fuse together to form a heavier nucleus. The heavier nucleus has less mass. Fusion reaction occur at high temperature so these are called thermonuclear reactions.

Hydrogen bomb is based on nuclear fusion.

$$^2_1H + ^3_1H \rightarrow ^4_2He + ^1_0n + 17.6MeV$$

Radio-Carbon Dating and Carbon Dating

Radiocarbon Dating: It is the technique to find out the age of archaeological objects like plants and animals fossils.

Carbon Dating: C_{14} isotope produced in upper atmosphere is incorporated in CO_2 which is inhaled by plants and in turn consumed by human beings.

$$^{14}_7H + ^1_0n \rightarrow ^{14}_6C + ^1_1H$$

A plant animal carbon cycle exists in nature as long as it is alive the C-14 content remains same. When a plant or animal dies, the process of incorporation of $^{14}_6C$ stops and it starts decaying.

Age can be calculated by $t = \dfrac{2.303}{\lambda}\log\dfrac{N_0}{N_t}$

$$\lambda = \frac{.693}{5770}Y_r^{-1}$$

Half-Life Period

Is the time in which half of the original amount of the substance disintegrates.

Half life period $t_{1/2} = \dfrac{.693}{\lambda}$

Average life period

Average life $= \dfrac{1}{\lambda} = \dfrac{t_{1/2}}{.693} = 1.44t_{1/2}$

Artificial Radioactivity

Discovered by Madam Curie and her husband E. Joliot by artificial disintegration a stable nucleus is made radioactive isotope.

$$\underset{}{{}^{4}_{2}\text{He}} + \underset{\text{Stable}}{{}^{27}_{13}\text{Al}} \longrightarrow \underset{\text{Radioactive}}{{}^{30}_{15}\text{P}} + {}^{1}_{0}\text{n}$$

$${}^{30}_{15}\text{P} \xrightarrow{t_{1/2}=2.55\,\text{min}} {}^{30}_{14}\text{Si} + {}_{-1}\text{e}^{0} \text{ positive}$$

Phenomenon in which non-radioactive element is formed is called artificial radioactivity.

Artificial Transmutation of Elements

Transformation of an element into another by bombarding it with high energy particle is termed as artificial transmutation of elements. It was discovered by Rutherford.

EXERCISE

1. Which of the following has the same atomic number and atomic weight?
A. Hydrogen B. Helium
C. Oxygen D. Nitrogen

2. Nuclides having the same atomic and mass numbers are known as
A. Isotones B. Isomers
C. Isobars D. Isotopes

3. Which of the following are α-emitters?
A. Polonium-212 B. Radium-226
C. Helium-5 D. Tritium

4. Which of the following is true for Thomson Model of the atom?
A. The radius of an electron can be calculated using Thomson Model.
B. In an undisturbed atom, the electrons will be at their equilibrium positions, where the attraction between the cloud of positive charge and the electrons balances their mutual repulsion.
C. When the electrons are disturbed by collision, they will vibrate around their equilibrium positions and emit electromagnetic radiation whose frequency is of the order of magnitude of the frequency of electromagnetic radiation of a vibrating electron.
D. Both (B) and (C)

5. Tritium is a radioactive isotope of hydrogen. It emits
A. β-particles B. α-particles
C. γ-rays D. neutrons

6. The SI unit of Radioactivity is:
A. Becquerel B. Curie
C. Weber D. Gauss

7. What are nucleons?
A. the sum of protons and neutrons present in the nucleus
B. the number of protons in the nucleus
C. the number of neutrons in the nucleus
D. the sum of protons, neutrons and electrons present in the nucleus

8. Isobars have:
A. same mass number but different atomic number
B. same number of neutrons but different mass number
C. same difference between number of protons and neutrons
D. same mass number and atomic number

9. Charge on fundamental particle neutrino is
A. 0 B. +1
C. −1 D. None of these

10. The fundamental particle that has least mass is
A. meson B. α-particle
C. electron D. neutron

11. Which of the following has highest mass?
A. Neutron B. Alpha particle
C. Electron D. Deuterium

12. The wavelength of an electron
A. is equal to that of light
B. remains constant with velocity
C. decreases with an increasing velocity
D. increases with an decreasing velocity

13. No two electrons in an atom can have the same values of all four quantum numbers according to
A. Hund's rule
B. Flemming rule
C. Pauli's exclusion principle
D. Bohr theory

14. The velocity of a photon is
A. dependent on its wavelength
B. dependent on its source
C. equal to cube of its amplitude
D. independent of its wavelength

15. Isotopes have different
A. arrangement of electrons
B. no. of P and e^-
C. no. of neutrons
D. no. of electrons

16. The electrons configuration of a dispositive ion M^{2+} is 2, 8, 14 and its mass number is 56. The number of neutrons present is
A. 32 B. 42
C. 30 D. 34

17. How many unpaired electrons are there in Ni^{2+}?
A. 0 B. 2
C. 4 D. 8

18. In two H atoms *A* and *B* the electrons move around the nucleus in circular orbits of radius r and $4r$ respectively. The ratio of the times taken by them to complete one revolution is
A. 1 : 4 B. 1 : 2
C. 1 : 8 D. 2 : 1

19. How many unpaired electrons are there in Ni^{2+}?
A. 0 B. 2
C. 4 D. 8

20. The number of electrons in the *M* shell of the element with atomic number 24 is
A. 24 B. 12
C. 13 D. 8

21. The atomic radius is of the order of
A. 10^{-8} cm B. 10^{8} cm
C. 10^{-12} cm D. 10^{-10} cm

22. Mass number of an element represents number of
A. Protons and neutrons
B. Protons and electrons
C. Electrons and neutrons
D. None of these

23. The symbol of a metal element which is used in making thermometers is:
A. Ag B. Hg
C. Mg D. Sg

24. If the value of principal quantum number is 3, the total possible values for magnetic quantum number will be
A. 1 B. 4
C. 9 D. 12

25. Which one of the following elements has an atomicity of 'one'?
A. helium B. hydrogen
C. sulphur D. ozone

26. The law of conservation of mass was given by
A. Dalton B. Proust
C. Lavoisier D. Berzelius

27. The atoms of which of the following pair of elements are most likely to exist in free state?
A. hydrogen and helium
B. argon and carbon
C. neon and nitrogen
D. helium and neon

28. Which of the following elements has the same molecular mass as its atomic mass?
A. nitrogen B. neon
C. oxygen D. chlorine

29. Charge on a positron is equal to that of
A. proton B. electron
C. nucleon D. neutron

30. The atomic theory of matter was proposed by
A. John Kennedy B. Lavoisier
C. Proust D. John Dalton

31. Gamma radiation from a radioactive nucleus results in change in the number of
A. neutrons B. protons
C. Both (A) and (B) D. None of these

32. Smallest particle of an element or a compound which is capable of independent existence is called
A. Atom B. Molecule
C. Element D. Compound

33. The particles that display dual nature of both waves and particles are
A. Protons B. Electrons
C. Mesons D. Neutrons

34. Avogadro's number represents the number of atoms in
A. 12 g of C^{12} B. 320 g of sulphur
C. 32 g of oxygen D. 14.3 of sulphur

35. The total number of ions present in 111 g of $CaCl_2$ is
A. One mole B. Two mole
C. Four mole D. Three mole

36. The nuclides $^{40}_{18}Ar$ and $^{41}_{19}K$ are
A. isotopes B. isobars
C. isotones D. None of these

37. The law of the multiple proportion was proposed by
A. Dalton B. Dulong
C. Petit D. Lavoisier

38. Match the following:

	Term introduced		**Name of the Scientist**
(*a*)	Atom	(*i*)	Avogadro
(*b*)	Molecule	(*ii*)	Einstein
(*c*)	Element	(*iii*)	Robert Boyle
(*d*)	Mass energy relationship	(*iv*)	Dalton

	(*a*)	(*b*)	(*c*)	(*d*)
A.	(*iv*)	(*i*)	(*ii*)	(*iii*)
B.	(*iv*)	(*i*)	(*iii*)	(*ii*)
C.	(*iv*)	(*iii*)	(*i*)	(*ii*)
D.	(*iv*)	(*iii*)	(*ii*)	(*i*)

39. Give reason why atomic mass has no units
A. It is well defined physical quantity.
B. Properties of atoms are not measurable.
C. It is a ratio of masses.
D. It is the average mass.

40. Which of the following statement is true?
A. A photon is a waveform of light energy.
B. A photon is a positively charged nuclear particle.
C. A photon is a quantum of light.
D. A photon is a bundle of energy of definite magnitudes but not necessarily light energy.

41. The positron is as heavy as
A. electron B. neutron
C. alpha particle D. proton

42. An atom which doesn't have any neutron is
A. deutrium B. tritium
C. helium D. hydrogen

43. When $3p$ orbitals are completely filled, then the newly entering electron goes into
A. $4p$ B. $3d$
C. $4s$ D. $4d$

44. Bohr's model of atom is not in agreement with
A. Line spectra of hydrogen atom
B. Pauli's principle
C. Planck's theory
D. Heisenberg's principle

45. The total number of subshells in the nth main energy level are
A. n^2 B. $2n^2$
C. $(n - 1)$ D. n

46. How many electrons in $_{19}K$ have $n = 3$; $l = 0$
A. 1 B. 2
C. 4 D. 3

47. The maximum number of $3d$ electrons having spin quantum number $s = +\frac{1}{2}$ are
A. 10
B. 14
C. 5
D. any number from 1 to 10

48. In the Schrodinger's wave equation ψ represents
A. Orbit B. Wave function
C. Wave D. Radial probability

49. The valence electrons of $_{29}Cu$ lie in the
A. K-shell
B. M-shell
C. N-shell
D. both M and N shell

50. In the atomic spectrum of hydrogen, the spectral lines pertaining to electronic transition of $n = 4$ to $n = 2$ refers to
A. Lyman lines B. Balmer lines
C. Paschen lines D. Brackett lines

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	B	B	D	A	A	A	B	A	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	C	D	C	C	B	C	B	C
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
A	A	B	C	A	C	D	B	A	D
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
D	B	B	A	D	C	A	B	C	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	D	C	D	D	B	C	B	C	B