

CHEMISTRY

Study Material for JEE Main & Advanced preparation
Prepared by Career Point Kota Experts



CAREER POINT

CONTENTS OF THE PACKAGE AT A GLANCE

CHEMISTRY

Class 11

Basic Chemistry

- ◆ Atomic Structure
- ◆ Periodic Table
- ◆ Chemical Bonding
- ◆ Basic Concepts of Chemistry
- ◆ Redox & Volumetric Analysis

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- ◆ Gaseous State
- ◆ Chemical Energetics
- ◆ Chemical Equilibrium
- ◆ Acid Base & Ionic Equilibrium

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- ◆ Classification & Nomenclature
- ◆ Isomerism
- ◆ Hydrogen Family
- ◆ s-block elements
- ◆ p-block Elements [Boron Family]
- ◆ p-block Elements [Carbon Family]
- ◆ Environmental Chemistry

Class 12

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- ◆ Aromatic Chemistry
- ◆ Halogen Derivatives
- ◆ Alcohol, Ether & Phenol

[C]

- ◆ Carbonyl Compounds
- ◆ Carboxylic Acid & Its Derivatives
- ◆ Nitrogen Compounds, Amines
- ◆ Carbohydrates, Amino Acid, Protein & Polymers
- ◆ Practical Organic Chemistry
- ◆ Chemistry in Everyday Life

Inorganic Chemistry (II)

- ◆ p-block Elements [Nitrogen, Oxygen, Halogen & Noble gases]
- ◆ Salt Analysis
- ◆ Transitional Elements
- ◆ Metallurgy
- ◆ Co-Ordination Compound

Note to the Students

Career Point offers this must have Study Package in Physics to meet the complete curriculum needs of engineering aspirants. The set comprises of 6 books: **Chemistry** - set of 3 books for class 11 and set of 3 books for Class 12. The set caters to the different requirements of students in classes XI and XII. It offers complete and systematic coverage of **JEE Main** and **JEE Advanced** syllabi and aims to provide firm foundation in learning and develop competitive edge in preparation of the JEE and other engineering entrance examinations.

COMPONENTS OF EACH CHAPTER

These books are designed with an engaging and preparation-focused pedagogy and offer a perfect balance of conceptual learning and problem solving skills.

Theory & Concepts

Each chapter consists of high quality theory that covers all the topics, sub-topics and concepts of JEE syllabus.

Atomic Structure

1. INTRODUCTION

- (a) The word atom was first introduced by Ostwald (1803 - 1807) in scientific world.
- (b) According to him matter is ultimately made up of extremely small indivisible particles called atoms.
- (c) It takes part in chemical reactions.
- (d) Atom is neither created nor destroyed

2. DALTON'S ATOMIC THEORY

Dalton proposed the atomic theory on the basis of the law of conservation of mass and law of definite proportions. He also proposed the law of multiple proportion as a logical consequence of this theory. The salient features of this theory are-

- (a) Each element is composed by extremely small particles called atoms.
- (b) Atoms of a particular element are all alike but differ with the atoms of other elements.
- (c) Atom of each element is an ultimate particle, and has a characteristic mass but is structureless.
- (d) Atom is indestructible i.e. it can neither be destroyed nor created by simple chemical reactions.
- (e) Atom of an element takes part in chemical reaction to form molecule.
- (f) In a given compound, the relative number and kind of atom are same.
- (g) Atoms of different elements combine in fixed ratio of small whole numbers to form compound atoms (now called molecules).

◆ Merits and Demerits of Dalton's theory :

A. Merits :

- (a) Dalton's theory explains the law of conservation of mass and some other laws of chemical combination.
- (b) Atoms of elements take part in chemical reaction is true till today.

B. Demerits :

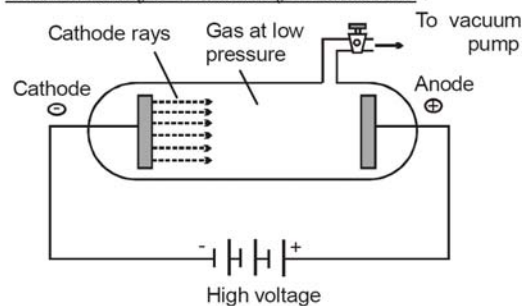
- (a) There is no mention of atomic weights of elements.
- (b) He could not explain that why do atoms of same element combined with each other.
- (c) The law of definite proportion fails if different isotopes are used.

3. EARLIER EFFORTS TO REVEAL STRUCTURE OF ATOM

◆ Evidence for the Electrical nature of matter :

- (a) In 1833 Michael Faraday gave the first important clue about the electrical nature of atoms
- (b) He observed that when electricity is passed through an electrolyte (in the molten state or dissolved state), it undergoes chemical changes.
- (c) This phenomenon is called electrolysis
- (d) Later on in 1874, Stoney pointed out that like matter, electricity is composed of small discrete units of electricity. He proposed the name electron for these discrete units of electricity

◆ Cathode Rays - discovery of electron :



- (a) The electron was discovered as a result of the studies of the passage of electricity through gases at extremely low pressures known as discharge tube experiments.
- (b) In 1859, Julius Plucker started the study of conduction of electricity through gases at low pressure (10^{-4} atm.) in a discharge tube.
- (c) When a high voltage of the order of 10,000 volts or more was impressed across the electrodes, some sort of invisible rays moved from the negative electrode to the positive electrodes these rays are called as cathode rays
- (d) Further investigations were made by W. Crookes, J. Perrin, J.J. Thomson and others.
- (e) Cathode rays have the following properties.
 - (i) Path of travelling is straight from the cathode with a very high velocity. As it produces shadow of an object placed in its path

Important Points

This part contains important concepts & formulas of chapter at one place in short manner, So that student can revise all these in short time.



Points to Remember

1. The wave character is of no significance in case of large objects like cricket ball, a car, a train etc.
2. The most important applications of de-Broglie concept is in the construction of electron microscope and the study of surface structure of solids by electron diffraction.
3. Smaller the wavelength of the electron wave, more is the resolving power of the electron microscope
4. Uncertainty in measurement is not due to lack of any experimental technique but due to nature of subatomic particle itself
5. Shapes of orbitals are functional representation of mathematical solutions of Schrodinger equations. They do not represent any picture of electric charge or matter.

Solved Examples (JEE Main/Advanced)

To understand the application of concepts, there is a solved example section. It contains large variety of all types of solved examples with explanation to ensure understanding the application of concepts.

SOLVED EXAMPLES

Ex.1 The ratio of the wave lengths of last lines of

Balmer and Lyman series is -

- (A) 4 : 1 (B) 27 : 5
(C) 3 : 1 (D) 9 : 4

Sol.(A) The wave length of a spectral line may be given by the following expression

$$\frac{1}{\lambda} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

For Lyman series $n_1 = 1$, For Balmer series $n_1 = 2$

For the last line in both the series $n_2 = \infty$

For Lyman series

$$\frac{1}{\lambda_L} = R \left(1 - \frac{1}{\infty} \right) = R(1 - 0) = R$$

$$\lambda_L = \frac{1}{R}$$

For Balmer series

$$\frac{1}{\lambda_B} = R \left(\frac{1}{4} - \frac{1}{\infty} \right) = \frac{R}{4}$$

$$\lambda_B = \frac{4}{R}$$

$$\frac{\lambda_B}{\lambda_L} = \frac{4}{R} \times \frac{R}{1} = \frac{4}{1}$$

(A) 96 Arbitrary units

(B) 192 Arbitrary units

(C) 288 Arbitrary units

(D) 384 Arbitrary units

Sol.(A) The energy of first Bohr's orbit of H-atom

$$- \frac{2\pi^2 m e^4}{h^2} = -864$$

The energy of third Bohr's orbit of H atom

$$= - \frac{2\pi^2 m e^4}{h^2} \times \frac{1}{3^2} = -864 \times \frac{1}{9}$$

= -96 Arbitrary units

Energy required to separate the electron

$$= E_\infty - E_n$$

$$= 0 - (-96)$$

$$= 96 \text{ Arbitrary units}$$

Ex.4 In an electronic transition, the wavelength of a spectral line is inversely related to -

(A) The nuclear charge of the atom

(B) The difference in energy levels

(C) The velocity of electron

(D) The number of orbitals involved in transition

$$\text{Sol.(A)} \quad \frac{1}{\lambda} = \frac{2\pi^2 m e^4 Z^2}{ch^3 (4\pi\epsilon_0)^2} = \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

Practice Exercises

Exercise Level - 1 : It contains objective questions with single correct choice to ensure sufficient practice to accurately apply formulae and concepts.

Exercise Level - 2 : It contains single objective type questions with moderate difficulty level to enhance the conceptual and application level of the student.

Exercise Level - 3 : It contains all variety of questions as per level of JEE Advanced such as MCQ, Column match, Passage based & Numerical type etc.

EXERCISE (Level-3)

Part-A : Multiple correct answer type questions

- Q.1** Which of the following properties is/are proportional to the energy of the electromagnetic radiation ?
 (A) Frequency (B) Wave number
 (C) Wavelength (D) Number of photons
- Q.2** Which of the following statements are incorrect?
 (A) There are five unpaired electrons in $(n-1)d$ suborbit in Fe^{3+}
 (B) Fe^{3+} , Mn^{+} and Cr all having 24 electrons will have same value of magnetic moment
 (C) Copper (I) chloride is coloured salt
 (D) Every coloured ion is paramagnetic
- Q.3** Which is not the correct orbital notation if the wave function is –

$$\psi = \frac{1}{81\sqrt{6\pi}} \left(\frac{r}{a_0}\right)^{3/2} \sigma^2 e^{-\sigma r/a_0} (3\cos^2\theta - 1);$$

 Here $\sigma = r/a_0$ and $a_0 = \frac{h^2 \epsilon_0}{\pi m c^2}$
 (A) 4s (B) $2P_x$ (C) $3P_y$ (D) $3d_{z^2}$
- Q.4** Which of the following orbitals have no spherical nodes ?
 (A) 1s (B) 2s
 (C) 2p (D) 3p
- Q.5** In which of the following sets of orbitals, electrons have equal orbital angular momentum ?
 (A) 1s and 2s (B) 2s and 2p
 (C) 2p and 3p (D) 3p and 3d
- Q.6** Which of the following sets of quantum number are correct ?
 (A) $n = 3, \ell = 2, m = +1, s = +\frac{1}{2}$
 (B) $n = 3, \ell = 3, m = +3, s = +\frac{1}{2}$
 (C) $n = 4, \ell = 0, m = 0, s = -\frac{1}{2}$
 (D) $n = 5, \ell = 2, m = +4, s = -\frac{1}{2}$
- Q.7** Rutherford's experiment established that :
 (A) Inside the atom there is a heavy positive centre
 (B) Nucleus contains protons and neutrons
 (C) Most of the space in the atoms is empty
 (D) Size of the nucleus is very small
- Q.8** Which of the following statements are incorrect ?
 (A) For designating orbitals three quantum numbers are needed
 (B) The second ionization energy of helium is 4 times, the first ionization of hydrogen
 (C) The third ionization energy of lithium is 9 times, the first ionization of hydrogen
 (D) Radius of third orbit of Li^{2+} is 3 times the radius of third orbit of hydrogen atom
- Q.9** Which of the following statements (regarding an atom of H) are correct ?
 (A) Kinetic energy of the electron is maximum in the first orbit
 (B) Potential energy of the electron is maximum in the first orbit
 (C) Radius of the second orbit is four times the radius of the first orbit
 (D) Various energy levels are equally spaced
- Q.10** Which of the following transition in H-atom would result in emission of radiations of same frequency ?
 (A) $4s \rightarrow 3p$ (B) $4d \rightarrow 3p$
 (C) $5s \rightarrow 4s$ (D) $3s \rightarrow 2p$
- Q.11** The radial distribution functions $[P(r)]$ is used to determine the most probable radius, which is used to find the electron in a given orbital $\frac{dP(r)}{dr}$ for 1s-orbital of hydrogen like atom having atomic number Z, is

$$\frac{dP}{dr} = \frac{4Z^3}{a_0^3} \left(2r - \frac{2Zr^2}{a_0}\right) e^{-2Zr/a_0}$$

 Then which of the following statements is/are connect ?
 (A) At the point of maximum value of radial distribution function $\frac{dP(r)}{dr} = 0$; One antinode is present
 (B) Most probable radius of Li^{2+} is $\frac{a_0}{3}$ pm
 (C) Most probable radius of He^+ is $\frac{a_0}{2}$ pm
 (D) Most probable radius of hydrogen atom is a_0 pm

Exercise Level - 4 : It contains previous years question of JEE Main (Section-A)/Advanced (Section-B) from Year 2005 to 2023.

EXERCISE (Level-4)

Old Examination Questions

Section-A [JEE Main]

- Q.1** In a multi-electron atom, which of the following orbitals described by the three quantum numbers will have the same energy in the absence of magnetic and electric fields? [AIEEE- 2005]
 (a) $n = 1, \ell = 0, m = 0$ (b) $n = 2, \ell = 0, m = 0$
 (c) $n = 2, \ell = 1, m = 1$ (d) $n = 3, \ell = 2, m = 1$
 (e) $n = 3, \ell = 2, m = 0$
 (A) (b) and (c) (B) (a) and (b)
 (C) (d) and (e) (D) (c) and (d)
- Q.2** Of the following sets which one does NOT contain isoelectronic species? [AIEEE- 2005]
 (A) CN^- , N_2 , C_2^{2-}
 (B) PO_4^{3-} , SO_4^{2-} , ClO_4^-
 (C) BO_3^{3-} , CO_3^{2-} , NO_3^-
 (D) SO_3^{2-} , CO_3^{2-} , NO_3^-
- Q.3** According to Bohr's theory, the angular momentum of an electron in 5^{th} orbit is - [AIEEE 2006]
 (A) $1.0 h/\pi$ (B) $10 h/\pi$
 (C) $2.5 h/\pi$ (D) $25 h/\pi$
- Q.4** Uncertainty in the position of an electron (mass = 9.1×10^{-31} kg) moving with a velocity 300 m/s, accurate upto 0.001 %, will be ($h = 6.63 \times 10^{-34}$ Js) [AIEEE 2006]
 (A) 5.76×10^{-2} m (B) 1.92×10^{-2} m
 (C) 3.84×10^{-2} m (D) 19.2×10^{-2} m
- Q.5** Which of the following sets of quantum numbers represents the highest energy of an atom? [AIEEE 2007]
 (A) $n = 3, \ell = 1, m = 1, s = +\frac{1}{2}$
 (B) $n = 3, \ell = 2, m = 1, s = +\frac{1}{2}$
 (C) $n = 4, \ell = 0, m = 0, s = +\frac{1}{2}$
 (D) $n = 3, \ell = 0, m = 0, s = +\frac{1}{2}$
- Q.8** Calculate the wavelength (in nanometer) associated with a proton moving at 1.0×10^8 m s^{-1} (Mass of proton = 1.67×10^{-27} kg and $h = 6.63 \times 10^{-34}$ Js) - [AIEEE 2009]
 (A) 0.032 nm (B) 0.40 nm
 (C) 2.5 nm (D) 14.0 nm
- Q.9** A gas absorbs a photon of 355 nm and emits at two wavelengths. If one of the emissions is at 680 nm, the other is at : [AIEEE 2011]
 (A) 1035 nm (B) 325 nm
 (C) 743 nm (D) 518 nm
- Q.10** The frequency of light emitted for the transition $n = 4$ to $n = 2$ of He^+ is equal to the transition in H atom corresponding to which of the following? [AIEEE 2011]
 (A) $n = 2$ to $n = 1$ (B) $n = 3$ to $n = 2$
 (C) $n = 4$ to $n = 3$ (D) $n = 3$ to $n = 1$
- Q.11** The electrons identified by quantum numbers n and ℓ [AIEEE-2012]
 (a) $n = 4, \ell = 1$ (b) $n = 4, \ell = 0$
 (c) $n = 3, \ell = 2$ (d) $n = 3, \ell = 1$
 can be placed in order of increasing energy as -
 (A) (d) < (b) < (c) < (a) (B) (b) < (d) < (a) < (c)
 (C) (a) < (c) < (b) < (d) (D) (c) < (d) < (b) < (a)
- Q.12** The following sets of quantum numbers represents four electrons in an atom :
 (i) $n = 4, \ell = 1$ (ii) $n = 4, \ell = 0$
 (iii) $n = 3, \ell = 2$ (vi) $n = 3, \ell = 1$
 The sequence representing increasing order of energy, is : [AIEEE Online-2012]
 (A) (i) < (iii) < (ii) < (iv) (B) (ii) < (iv) < (i) < (iii)
 (C) (iv) < (ii) < (iii) < (i) (D) (iii) < (i) < (iv) < (ii)
- Q.13** The limiting line in Balmer series will have a frequency of :
 (Rydberg constant, $R_\infty = 3.29 \times 10^{15}$ cycles/s)

Exercise Level - 5 : Advanced level a bit complex questions for students for solid rock preparation for Top Rankers.

Answer key

Answer key is provided at the end of the exercise sheets.

ANSWER KEY

EXERCISE (Level-1)

- | | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|
| 1. (C) | 2. (A) | 3. (C) | 4. (B) | 5. (B) | 6. (C) | 7. (C) |
| 8. (A) | 9. (B) | 10. (D) | 11. (D) | 12. (A) | 13. (D) | 14. (D) |
| 15. (B) | 16. (C) | 17. (D) | 18. (B) | 19. (C) | 20. (C) | 21. (A) |
| 22. (D) | 23. (D) | 24. (C) | 25. (C) | 26. (A) | 27. (D) | 28. (A) |
| 29. (D) | 30. (C) | 31. (A) | 32. (C) | 33. (C) | 34. (A) | 35. (C) |
| 36. (C) | 37. (C) | 38. (B) | 39. (A) | 40. (A) | | |

Revision Plan

We emphasize that every student should prepare his/her own revision plan. For this purpose there is Revision Plan Section in each chapter which student should prepare while going through the study material. This will be useful at the time of final revision before final exam for quick & effective revision.

Revision Plan		
Prepare Your Revision plan today!		
After attempting Exercise Sheet, please fill below table as per the instruction given.		
A. Write Question Number (QN) which you are unable to solve at your own in column A .		
B. After discussing the Questions written in column A with faculty, strike off them in the manner so that you can see at the time question number during Revision, to solve such questions again.		
C. Write down the Question Number you feel are important or good in the column B .		
EXERCISE	COLUMN A	COLUMN B
	Questions unable to solve in first attempt	Good or Important questions
Level-1		
Level-2		
Level-3		
Level-4		
Level-5		

Online Solutions

Self explanatory and detailed solution of all exercises above are available on Career Point website www.careerpoint.ac.in

ATOMIC STRUCTURE							
EXERCISE (Level-1)							
Answer Key & Solution							
Question Number	Solution	Question Number	Solution	Question Number	Solution	Question Number	Solution
1	Click Here	11	Click Here	21	Click Here	31	Click Here
2	Click Here	12	Click Here	22	Click Here	32	Click Here
3	Click Here	13	Click Here	23	Click Here	33	Click Here
4	Click Here	14	Click Here	24	Click Here	34	Click Here
5	Click Here	15	Click Here	25	Click Here	35	Click Here
6	Click Here	16	Click Here	26	Click Here	36	Click Here
7	Click Here	17	Click Here	27	Click Here	37	Click Here
8	Click Here	18	Click Here	28	Click Here	38	Click Here
9	Click Here	19	Click Here	29	Click Here	39	Click Here
10	Click Here	20	Click Here	30	Click Here	40	Click Here

ATOMIC STRUCTURE

JEE ADVANCED SYLLABUS

1. *Rutherford's model*
2. *Bohr's model*
3. *Quantum numbers*
4. *Electronic configuration of elements (upto atomic number 36) Aufbau principle*
5. *Pauli's exclusion principle and Hund's rule*
6. *Spectrum of hydrogen atom*
7. *de-Broglie relations*
8. *Uncertainty principle*
9. *Quantum mechanical model*
10. *Shapes of s, p and d-orbitals*

Revision Plan

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EXERCISE	COLUMN A	COLUMN B
	Questions unable to solve in first attempt	Good or Important questions
Topic wise practice questions		
Level-1		
Level-2		
Level-3		
Level-4		
Level-5		

Revision Strategy:

Whenever you wish to revision this chapter, follow the following steps-

Step-1: Review your theory notes.

Step-2: Solve Questions of column A

Step-3: Solve Questions of Column B

Step-4: Solve questions from other Question Bank, Problem book etc.

Atomic Structure

1. INTRODUCTION

- (a) The word atom was first introduced by Ostwald (1803 - 1807) in scientific world.
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- (e) Atom of an element takes part in chemical reaction to form molecule.
- (f) In a given compound, the relative number and kind of atom are same.
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◆ Merits and Demerits of Dalton's theory :

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B. Demerits :

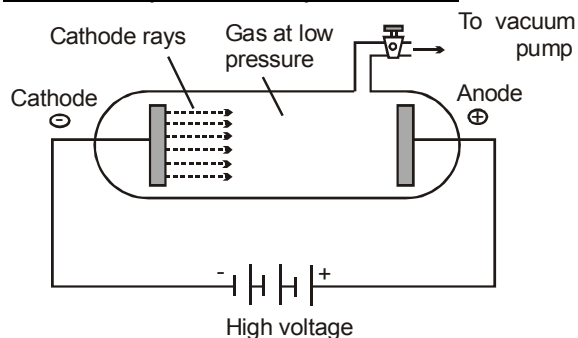
- (a) There is no mention of atomic weights of elements.
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3. EARLIER EFFORTS TO REVEAL STRUCTURE OF ATOM

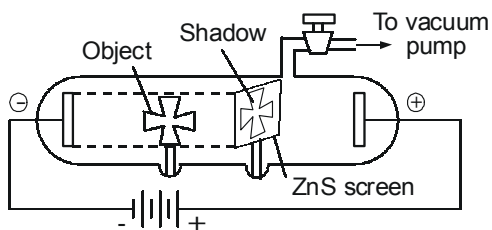
◆ Evidence for the Electrical nature of matter :

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- (b) He observed that when electricity is passed through an electrolyte (in the molten state or dissolved state), it undergoes chemical changes.
- (c) This phenomenon is called electrolysis
- (d) Later on in 1874, Stoney pointed out that like matter, electricity is composed of small discrete units of electricity. He proposed the name electron for these discrete units of electricity

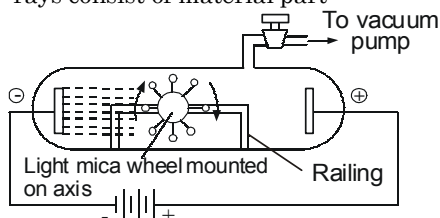
◆ Cathode Rays - discovery of electron :



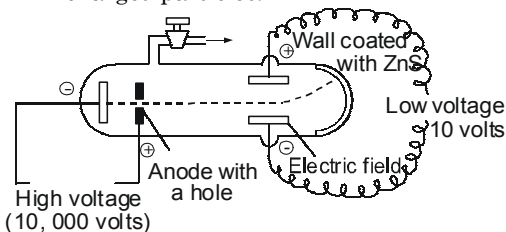
- (a) The electron was discovered as a result of the studies of the passage of electricity through gases at extremely low pressures known as discharge tube experiments.
- (b) In 1859, Julius Plucker started the study of conduction of electricity through gases at low pressure (10^{-4} atm.) in a discharge tube.
- (c) When a high voltage of the order of 10,000 volts or more was impressed across the electrodes, some sort of invisible rays moved from the negative electrode to the positive electrodes these rays are called as cathode rays
- (d) Further investigations were made by W. Crookes, J. Perrin, J.J. Thomson and others.
- (e) Cathode rays have the following properties.
 - (i) Path of travelling is straight from the cathode with a very high velocity. As it produces shadow of an object placed in its path



- (ii) Cathode rays produce mechanical effects. If a small paddle wheel is placed between the electrodes, it rotates. This indicates that the cathode rays consist of material part



- (iii) When electric and magnetic fields are applied to the cathode rays in the discharge tube, the rays are deflected thus establishing that they consist of charged particles.

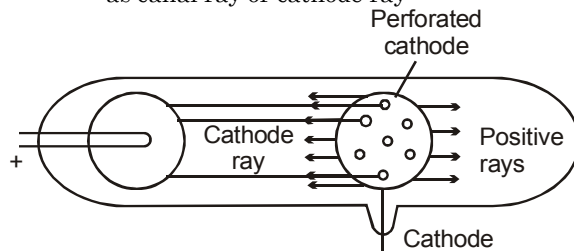


- (iv) Cathode rays produce X-rays when they strike against hard metals like tungsten, copper etc.
- (v) When the cathode rays are allowed to strike a thin metal foil, it gets heated up. Thus the cathode rays possess heating effect.
- (vi) They produce a green glow when strike the glass wall beyond the anode. Light is emitted when they strike the zinc sulphide screen.
- (vii) Cathode rays penetrate through thin sheets of aluminium and other metals.
- (viii) They affect the photographic plates
- (ix) The ratio of charge to mass i.e. charge/mass is same for all the cathode rays irrespective of the gas used in the tube.
- (f) In 1897, J.J. Thomson determined the e/m value (charge/mass) of the electron by studying the deflections of cathode rays in electric and magnetic fields. The value of e/m has been found to be -1.7588×10^8 coulomb/g
- (g) The first precise measurement of the charge on the electron was made by Robert A. Millikan, in 1909 by oil drop experiment. Its value was found to be -1.6022×10^{-19} coulomb.

- (h) The mass of electron can be calculated from the value of e/m and the value of e which is 9.1096×10^{-31} Kg.

◆ **Positive Rays-Discovery of Proton :**

- (a) The existence of positively charged particles in an atom was shown by E. Goldstein in 1886
- (b) He repeated the same discharge tube experiments by using a perforated cathode.
- (c) It was observed that when a high potential difference was applied between the electrodes, not only cathode rays were produced but also a new type of rays were produced simultaneously from anode moving towards cathode and passed through the holes or canal of the cathode. These termed as canal ray or cathode ray



- (d) Characteristics of Anode Rays are as follows.
- (i) These rays travel in straight lines and cast shadow of the object placed in their path.
- (ii) The anode rays are deflected by the magnetic and electric fields like cathode rays but direction is different that mean these rays are positively charged.
- (iii) These rays have kinetic energy and produces heating effect also.
- (iv) The e/m ratio of these rays is smaller than that of electrons
- (v) Unlike cathode rays, their e/m value is dependent upon the nature of the gas taken in the tube.
- (vi) These rays produce flashes of light on Zn-S screen
- (vii) These rays can pass through thin metal foils
- (viii) They are capable to produce ionisation in gases
- (ix) They can produce physical and chemical changes.
- (e) J.J. Thomson in 1906 accurately measured the charge to mass ratio of the particles. He obtained maximum value of e/m hydrogen, because it is the lightest particle. This value was $+9.579 \times 10^4$ coulomb/g
- (f) This was the maximum value for any positive particle & it compelled to assume that the positive particle given by the hydrogen represents a fundamental particle of positive charge. This particle was named proton by Rutherford in 1911.

- (g) Proton carries a charge of $+1.602 \times 10^{-19}$ coulomb, i.e., one unit positive charge.
- (h) Mass of proton is 1.672×10^{-27} kg or 1.0072 amu
- (i) A proton is defined as a sub-atomic particle which has a mass nearly 1 amu and a charge of +1 unit

◆ **Thomson's Model :**

- (Arrangement of electrons and protons in an atom)
- (a) After discovery of electron and proton attempts were made to find out their arrangement in an atom. The first simple model was proposed by J.J. Thomson known as Thomson's atomic model.
 - (b) He proposed that the positive charge is spread over a sphere of the size of the atom (i.e. 10^{-8} cm radius) in which electrons are embedded to make the atom as whole neutral.
 - (c) This model could not explain the experimental results of Rutherford's α -particle scattering, therefore it was rejected.

Example Based on Structure of atom

✎ **Example. 1**

- For cathode rays' the value of e/m
- (A) is independent of the nature of the cathode and the gas filled in the discharge tube
 - (B) is constant
 - (C) is -1.7588×10^8 coulombs/g
 - (D) is lowest when hydrogen gas is filled in discharge tube

Solution. (A), (B), (C)

Cathode rays consists of electrons which are fundamental particles of matter.

✎ **Example. 2**

- Which has highest e/m ratio :
- (A) He^{2+} (B) H^+ (C) He^{1+} (D) H

Solution. (B)

Mass of H^+ is minimum

✎ **Example. 3**

Arrange the following particles in increasing order of values of e/m ratio : Electron (e), proton (p), neutron (n) and α -particle (α)

- (A) n, p, e, α (B) n, α , p, e
- (C) n, p, α , e (D) e, p, n, α

Solution. (B)

	Electron	Proton	Neutron	α -particle
e	1 unit	1 unit	zero	2 unit
m	1/1837 unit	1 unit	1 unit	4 unit
e/m	1837	1	zero	1/2.

✎ **Example. 4**

Mass of neutron is times the mass of electron

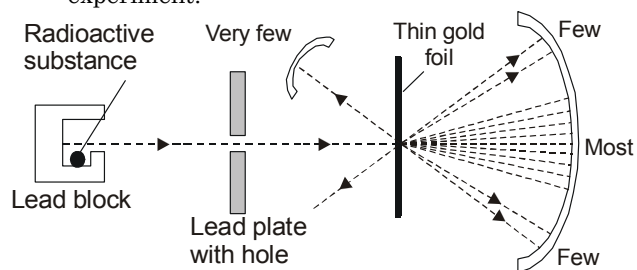
- (A) 1840 (B) 1480
- (C) 2000 (D) None

Solution. (A)

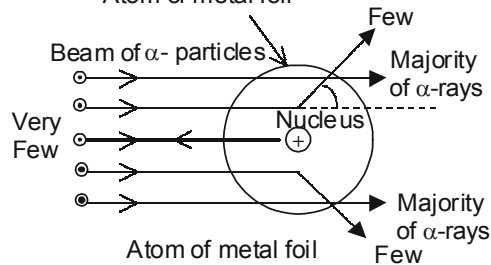
mass of neutron = 1.675×10^{-27} kg,
mass of electron = 9.108×10^{-31} kg

4. RUTHERFORD'S EXPERIMENT - (Discovery of nucleus)

Rutherford carried out experiment on the bombardment of atoms by high speed positively charged α - particles emitted from radium and gave the following observations, which was based on his experiment.



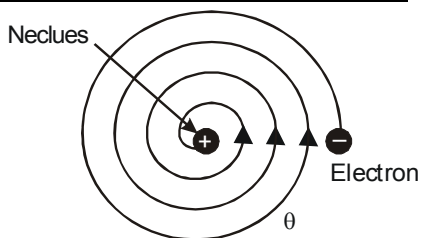
- (a) Most of the α - particles (nearly 99%) continued with their straight path.
- (b) Some of the α - particles passed very close to the centre of the atom and deflected by small angles.
- (c) Very few particles thrown back (180°).



◆ **Main features :**

- (a) Most of the α -particles were continued their straight path that means most of the space of the atom is empty.
- (b) The centre of an atom has a positively charged body called **nucleus** which repel positively charged α -particles and thus explained the scattering phenomenon.
- (c) Whole mass of an atom is concentrated in its nucleus and very few throw back means the size of the nucleus is very small 10^{-13} cm. It showed that the nucleus is 10^{-5} times small in size as compared to the total size of atom.
- (d) The size and volume of the nucleus is very small as compared to the total size and volume of atom.
- (e) As atomic number increases, the angle of deflection (θ) increases.

◆ **Drawbacks of Rutherford's model :**



- (a) According to classical electromagnetic theory, when an electron moves around the nucleus under the influence of the attractive force, the electron loses its energy continuously and move closer and closer to the nucleus in a spiral path, the ultimate result will be that it will fall into the nucleus but it can't be possible because an atom is quite stable.
- (b) If an electron loses energy continuously, the observed spectrum should be continuous but the actual observed spectrum consist of discontinuous well defined lines of definite frequencies.

Example Based on

Rutherford's Experiment

✎ **Example. 5**

Rutherford's scattering experiment is related to

- (A) Nucleus (B) Atom
(C) Electron (D) Neutron

Solution. (B)

to reveal structure of atom

✎ **Example. 6**

When the atoms of gold sheet are bombarded with a beam of α -particles, only a few α -particles get deflected whereas most of them go straight undeflected. This is because

- (A) The force of attraction on the α -particles by the oppositely charged electron is not sufficient
(B) The nucleus occupies much smaller volume as compared to the volume of atom
(C) the force of repulsion on fast moving α -particles is very small
(D) the neutrons in the nucleus do not have any effect on α -particles.

Solution. (B)

it was the logical conclusion of his experiment.

5. MOSELEY'S EXPERIMENT (Concept of Atomic number)

- (a) After discovery of X-rays by Roentgen in 1895, Moseley (1912 - 13), investigated the X-ray spectra of 38 different elements, starting from aluminium and ending in gold. ' (
- (b) He measured the frequency of principal lines of a particular series (the α -lines in the K series) of the spectra

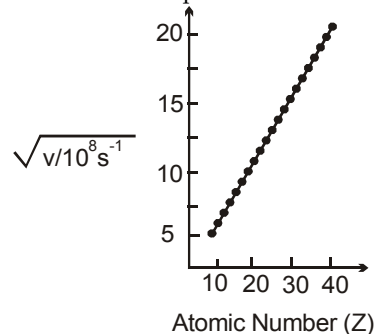
- (c) He observed that the frequency of a particular spectral line gradually increased with the increase of atomic mass of the element. But finally it was realised that the frequency of a particular line was very much related with the serial number of the element in the periodic table.
- (d) This serial number is termed as atomic number (Z).

He expressed it as $\sqrt{\nu} = a(Z - b)$

where ν = Frequency of X-rays

Z = atomic number, a & b = constants

This relation represents the following curve



$$a = \sqrt{3Rc/4}$$

Here b is taken into account considering screening due to spherical cloud of the remaining one electron in the K shell

◆ **Atomic number (Z) :**

The number of positive charge carried by the nucleus of an atom is termed as atomic no. (Z) or the number of protons in an atom of an element is equal to its atomic number. Since an atom is electrically neutral it contains an equal number of extra nuclear electrons.

Thus –

Atomic No. = Number of unit positive charge in nucleus = Number of protons = Number of electrons.

◆ **Mass number or Nucleon number (A) :**

The mass number being the sum of the number of protons and neutrons in the nucleus, which is always a whole number.

$$A = P + n \quad \text{or} \quad A = Z + n$$

where :

A = Mass number

P = Number of protons

n = Number of neutrons

Z = Atomic number

On the another side of that statement since mass of a proton or a neutron is not a whole number (on atomic weight scale), atomic weight is not necessarily a whole number.

For example : The isotopes of oxygen having mass number 17 and 18, have atomic weights equal to 17.00045 and 18.0037 respectively.

6. NEUTRON

- This was discovered 20 years after the structure of atom was elucidated by Rutherford.
- It has been found that for all atoms except hydrogen atomic mass is more than the atomic number. Thus Rutherford (1920) suggested that in an atom, there must be present at least a third type of fundamental particle.
- It should be electrically neutral and possess mass nearly equal to that of proton. He proposed its name as neutron.
- Chadwick (1932), bombarded beryllium with a stream of α -particles and observed electrically and magnetically neutral radiations.
- There were neutral particles which were called neutron. Nuclear reaction is as follows

$${}^9_4\text{Be} + {}^4_2\text{He} \longrightarrow {}^{12}_6\text{C} + {}^1_0\text{n}$$
- A neutron is a subatomic particle which has a mass 1.675×10^{-24} g, approximately 1 amu, or nearly equal to the mass of proton on hydrogen atom and carrying no electrical charge

7. OTHER FUNDAMENTAL PARTICLES

Besides protons, neutrons and electron, many more elementary particles have been discovered. These particles are also called Fundamental particles. Some of these particles are stable (electron, antiproton, positron, neutrino, photon, graviton) while the others are unstable particles (neutron, meson).

The main characteristics of the particles are tabulated below.

$$1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$$

$$1 \text{ Coulomb} = 3 \times 10^9 \text{ esu}$$

Example Based on

Moseley's Experiment

Example. 7

If frequency of the X-rays produced using an element as anti-cathode is found to be 2500 sec^{-1} , the atomic number of used element is given that, $a, b = 1$

- (A) 51 (B) 49 (C) 56 (D) 72

Solution. (A)

$$Z = \sqrt{\nu} + 1 \quad (\nu = \text{frequency})$$

$$\text{So } Z = \sqrt{2500} + 1 = 51$$

Example. 8

When beryllium is bombarded with α -particles, extremely penetrating radiations are produced which can not be deflected by electrical or magnetic field. These are -

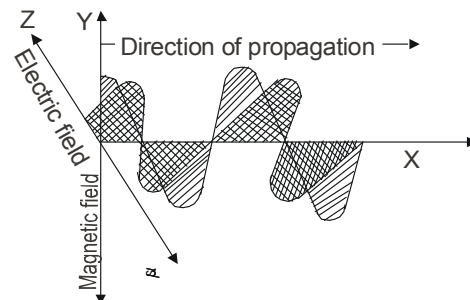
- (A) Protons (B) α -rays
 (C) Neutrons (D) X-rays

Solution. (C)
 Neutrons

8. ELECTROMAGNETIC RADIATIONS

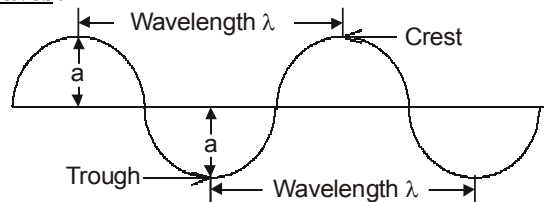
Light and other forms of radiant energy propagate without any medium in the space in the form of waves. These waves can be produced by a charged body moving in a magnetic field or a magnet in an electric field. e.g. α - rays, γ - rays, Cosmic rays, Ordinary light rays etc.

Characteristics of electromagnetic radiations :



- All electromagnetic waves move or travel with the same velocity equal to that of light.
- They do not require any medium to propagate.
- These consist of electric and magnetic field that oscillate in the direction perpendicular to each other and to the direction in which the wave is propagate.

Some Important characteristics of electromagnetic waves :



(a) Frequency (ν) :

It is defined as the no. of waves which pass through a given point in per sec. Its unit is expressed by cycle per second (cps) or Hertz (Hz). $\nu = c/\lambda$

NOTE A cycle is said to be completed when a wave consisting of crest and trough passes through a point.

(b) Wavelength (λ) :

The distance between two adjacent crest or troughs of the wave as shown in the fig. It is denoted by lambda (λ) a greek letter and unit is Angstrom (\AA) or nanometer (nm).

$$1 \text{ \AA} = 10^{-10} \text{ m or } 10^{-8} \text{ cm}$$

$$1 \text{ nm} = 10^{-9} \text{ m or } 10^{-7} \text{ cm}$$

$$\lambda = \frac{c}{\nu}$$

Particle	Symbol	Nature	Charge (in esu) $\times 10^{-10}$	Mass (in amu)	Discovered by
Positron	$e^+, 1e^0, \beta^+$	+	+ 4.8029	0.0005486	Anderson (1932)
Neutrino	ν	0	< 0.00002		Pauli
Anti-proton	p^-	-	4.8029	1.00787	Chamberlain Sugri & Weighland (1955)
Photon	$h\nu$	0	0	0	Planck
Graviton	G	0	0	0	
Positive mu meson	μ^+	+	+ 4.8029	0.1152	Yukawa (1935)
Netative mu meson	μ^-	-	- 4.8029	0.1152	Yukawa (1935)
Positive pi meson	π^+	+	+ 4.8029	0.1514	Powell (1947)
Negative pi meson	π^-	-	- 4.8029	0.1514	
Neutral pi meson	π^0	0	0	0.1454	

(c) **Wave No. ($\bar{\nu}$) :**

It is defined as the number of wave per cm and it is equal to the inverse of wavelength. Its unit is cm^{-1} .

$$\bar{\nu} = \frac{1}{\lambda}, \quad \nu = \frac{c}{\lambda} = c\bar{\nu}$$

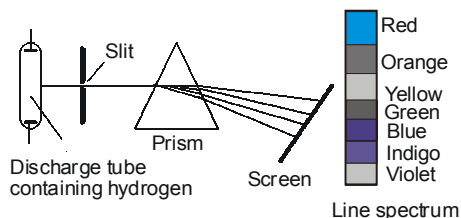
(d) **Amplitude (a) :**

It denotes the height of the crest or depth of the trough of a wave. It determines the intensity of brightness of radiation.

(e) **Velocity (v) :**

The distance traveled per sec by a wave called velocity of a wave. It is expressed by the unit of m/sec. or cm/sec.

9. SOLAR SPECTRUM



- (a) When sunlight is passed through a prism, it absorbs wavelength range of black colour radiation and other splits into a series of colour bands known as emission spectrum and black colour band which is known as absorption spectrum.
- (b) The splitting of light into seven colours is called emission **Spectrum**.
- (c) The characteristic range of wavelength of electromagnetic radiation situated in an increasing or decreasing order called electromagnetic spectrum.

10. ATOMIC SPECTRA OR LINE SPECTRA

Atomic spectra is line spectra. So atomic spectrum is also called line spectrum. It is of two types.

◆ **Emission spectrum :**

A substance gets excited on heating at a very high temperature or by giving energy and radiations are emitted. These radiations when analysed with the help of spectroscope, spectral lines are obtained. A substance may be excited as follows -

- (a) By heating at a higher temperature.
- (b) By passing electric current at a very low pressure in a discharge tube filled with gas.
- (c) By passing electric current into metallic filament.

Emission spectra is of three types -

- (i) Continuous spectrum
 - (ii) Line spectrum
 - (iii) Band spectrum
- (i) **Continuous spectrum :** When sunlight is passed through a prism, it gets dispersed into continuous bands of different colours. If the light of an incandescent object is resolved through prism or spectroscope, it also gives continuous spectrum of colours.
- (ii) **Line spectrum :** If the radiations obtained by the excitation of a substance are analysed with the help of a spectroscope a series of thin bright lines of specific colours are obtained. There is dark space in between two consecutive lines. This type of spectrum is called line spectrum or atomic spectrum. For example on heating sodium chloride or any other salt of sodium in Bunsen flame bright yellow light is emitted. The emitted light when viewed through a spectroscope two isolated yellow lines separated by dark space are obtained. The wave lengths of these lines are 5890\AA and 5896\AA .
- (iii) **Band spectrum :** it is originated by molecules and linear spectrum is originated by atoms.

◆ **Absorption Spectrum :**

When the white light of an incandescent substance is passed through any other substance, this substance absorbs the radiations of certain wavelength from the white light. On analysing the transmitted light we obtain a spectrum in which dark lines of specific wave lengths are observed. These lines constitute the absorption spectrum. The wave length of the dark lines correspond to the wavelength of light absorbed.

◆ **Difference between Emission and absorption spectra :**

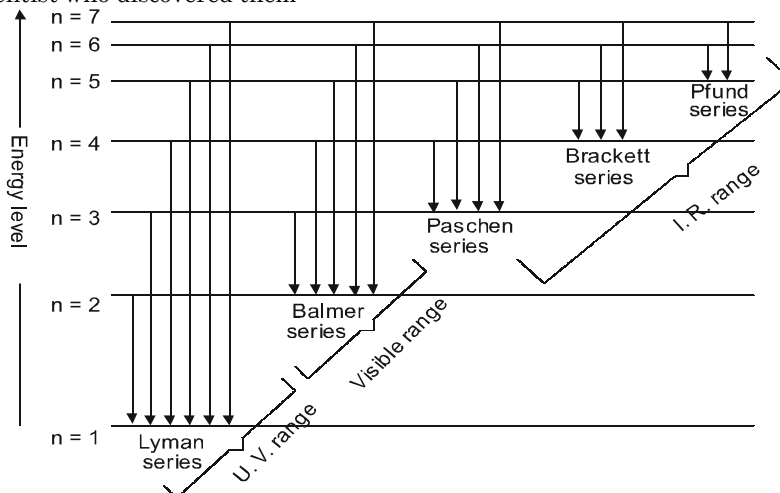
	Emission spectrum	Absorption spectrum
1	It is obtained when radiation emitted by the excited substance which is analysed in a spectroscope.	It is obtained when white light is passed through the substance either gases or in the form of solution.
2	This type of spectrum consist of bright coloured lines separated by dark spaces.	It consist of dark lines on a colour back ground.

11. HYDROGEN SPECTRUM

- (a) Hydrogen spectrum is an example of line emission spectrum or atomic emission spectrum
- (b) When an electric discharge is passed through hydrogen gas at low pressure, a bluish light is emitted.
- (c) This light shows discontinuous line spectrum of several isolated sharp lines through prism.
- (d) All these lines of H-spectrum have following six series

Spectral Series	Region
Lyman	U.V.
Balmer	Visible
Paschen	IR
Brackett	IR
Pfund	IR
Humphrey	Far I.R.

These spectral series were named by the name of scientist who discovered them



- (e) To evaluate wavelength of various H-lines Ritz introduced the following expression

$$\bar{\nu} = \frac{1}{\lambda} = \frac{v}{c} = R \left(\frac{1}{x^2} - \frac{1}{y^2} \right) = R$$

Where R is a universal constant known as Rydberg's constant its value is $109,678 \text{ cm}^{-1}$.

- (f) Although H - atom consists only one electron yet it's spectra consist of many spectral lines.

$$\frac{1}{\lambda} = \bar{\nu} = R_H \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

- (g) If an electron from n^{th} excited state comes to first energy states, the maximum spectral lines obtained will be $= \frac{n(n-1)}{2}$

◆ **Lyman Series :**

- (a) It is a first series of spectral series of H.
- (b) It was found out in ultraviolet region in 1898 by *Lyman*.
- (c) It's value of $n_1 = 1$ and $n_2 = 2, 3, 4$ where ' n_1 ' is ground state and ' n_2 ' is called excited state of electron present in a H - atom.
- (d) If the electron goes to $n_1 = 1$ to $n_2 = 2$ — first Lyman series
If the electron goes to $n_1 = 1$ to $n_2 = 3$ — Second Lyman series
If the electron goes to $n_1 = 1$ to $n_2 = 4$ — third Lyman series ...so on.

- (e) $\frac{1}{\lambda} = R_H \left[\frac{1}{1^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 1$ always.

- (f) The wavelength of marginal line $= \frac{n_1^2}{R_H}$ for

all series. So, for lyman series $\lambda = \frac{1}{R_H}$

◆ **Balmer series :**

- (a) It is the second series of H-spectral series.
- (b) It was found out in 1892 in visible region by **Balmer**.
- (c) Balmer series was found out before all series. Because it was found to be in visible region.
- (d) It's value of $n_1 = 2$ and $n_2 = 3, 4, 5, \dots, n$ where n_1 is ground state and n_2 is excited state.
- (e) If the electron goes to $n_1 = 2$ to $n_2 = 3$ — First Balmer series
If the electron goes to $n_1 = 2$ to $n_2 = 4$ — Second Balmer series
If the electron goes to $n_1 = 2$ to $n_2 = 5$ — third Balmer series..so on
- (f) The wavelength of marginal line of Balmer series = $\frac{n_1^2}{R_H} = \frac{2^2}{R_H} = \frac{4}{R_H}$
- (g) $\frac{1}{\lambda} = R_H \left[\frac{1}{2^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 2$ always

◆ **Paschen Series :**

- (a) It is the third series of H - spectrum.
- (b) It was found out in infra red region by **Paschen**.
- (c) It's value of $n_1 = 3$ and $n_2 = 4, 5, 6, \dots$ where n_1 is ground state and n_2 is excited state.
- (d) If the electron goes to $n_1 = 3$ to $n_2 = 4$ — First paschen series

If the electron goes to

$n_1 = 3$ to $n_2 = 5$ — second paschen series

If the electron goes to

$n_1 = 3$ to $n_2 = 6$ — third paschen series-----

so on.

- (e) The wavelength of marginal line of paschen series = $\frac{n_1^2}{R_H} = \frac{3^2}{R_H} = \frac{9}{R_H}$
- (f) $\frac{1}{\lambda} = R_H \left[\frac{1}{3^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 3$ always.

◆ **Brackett series :**

- (a) It is fourth series of H - spectrum.
- (b) It was found out in infra red region by **Brackett**.
- (c) It's value of $n_1 = 4$ and $n_2 = 5, 6, 7, \dots$ where n_1 is ground state and n_2 is excited state.
- (d) If the electron goes to $n_1 = 4$ to $n_2 = 5$ — first brackett series
If the electron goes to $n_1 = 4$ to $n_2 = 6$ — second brackett series
If the electron goes to $n_1 = 4$ to $n_2 = 7$ — third brackett series
----- so on.

Name	λ in Å	Origin
Radio waves	3×10^9 to 3×10^{14}	by the Alternating current of high frequency
Microwaves	3×10^6 to 3×10^9	by the generator of high quality
I.R.	7600 to 3×10^6	from the heated things
Visiblewave	3800 to 7600	
U.V. wave	150 to 3800	from the sun rays
α - rays	0.1 to 150	to put a metallic barrier in path of moving electron
γ - rays	0.01 to 0.1	by radio active disintegration
Cosmic rays	0 to 0.01	from the outer most part of sun

λ decreases —
 ν increases —
 \downarrow \downarrow

- (e) The wavelength of marginal line of

$$\text{brackett series} = \frac{n_1^2}{R_H} = \frac{4^2}{R_H} = \frac{16}{R_H}$$

- (f) $\frac{1}{\lambda} = R_H \left[\frac{1}{4^2} - \frac{1}{n_2^2} \right]$ Where $n_2 > 4$ always.

◆ **Pfund Series :**

- (a) It is fifth series of H - spectrum.
- (b) It was found out in infra red region by Pfund.

- (c) It's value of $n_1 = 5$ and $n_2 = 6, 7, 8, \dots$ where n_1 is ground state and n_2 is excited state.
- (d) If the electron goes to $n_1 = 5$ to $n_2 = 6$ — first Pfund series
If the electron goes to $n_1 = 5$ to $n_2 = 7$ — second Pfund series
If the electron goes to $n_1 = 5$ to $n_2 = 8$ — third Pfund series----- so on.

- (e) The wavelength of marginal line of Pfund

$$\text{series} = \frac{n_1^2}{R_H} = \frac{5^2}{R_H} = \frac{25}{R_H}$$

- (f) $\frac{1}{\lambda} = R_H \left[\frac{1}{5^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 5$ always.

◆ **Humfri Series :**

- (a) It is the sixth series of H - spectrum.
 (b) It was found out in infra-red region by **Humfri**.
 (c) It's value of $n_1 = 6$ and $n_2 = 7, 8, 9 \dots$ where n_1 is ground state of electron and n_2 is excited state.
 (d) If the electron goes to $n_1 = 6$ to $n_2 = 7$ — first Humfri series
 If the electron goes to $n_1 = 6$ to $n_2 = 8$ — second Humfri series
 If the electron goes to $n_1 = 6$ to $n_2 = 9$ — third Humfri series so on.
 (e) The wavelength of marginal line of Humfri series = $\frac{n_1^2}{R_H} = \frac{6^2}{R_H} = \frac{36}{R_H}$
 (f) $\frac{1}{\lambda} = R_H \left[\frac{1}{6^2} - \frac{1}{n_2^2} \right]$ where $n_2 > 6$.

12. CONCEPT OF QUANTIZATION

- (a) E.M. wave theory successfully explains about reflection, refraction, diffraction, etc. but it fails to explain black body radiations and photo electric effect
 (b) To explain all these things Max planck gave a new revolutionary theory in 1901, called as quantum theory of radiation.
 (c) According to this theory, a hot body emits radiant energy not continuously but discontinuously in the form of small packets of energy called quantum.
 (d) In case of light, the quantum of energy is often called photon.
 (e) The amount of energy associated with a quantum radiation is proportional to the frequency of light
 $E \propto \nu$ or $E = h\nu$
 where the proportionality constant, h is a universal constant known as Planck's constant. Its value is 6.63×10^{-34} J-sec
 (f) The total amount of energy emitted or absorbed by a body will be some whole number multiple of quantum, i.e. $E = nh\nu$
 where n is an integer such as 1, 2, 3

Example Based on

E.M. Radiation and Spectrum

✎ **Example. 9**

The wavelengths of two photons are 2000\AA and 4000\AA respectively. What is the ratio of their energies ?

- (A) 1/4 (B) 4 (C) 1/2 (D) 2

Solution. (D)

$$E_1 = h \cdot \frac{c}{\lambda_1} ; E_2 = h \cdot \frac{c}{\lambda_2}$$

$$\frac{E_1}{E_2} = \frac{hc}{\lambda_1} \times \frac{\lambda_2}{hc} = \frac{\lambda_2}{\lambda_1} = \frac{4000}{2000} = 2$$

✎ **Example. 10**

There are three energy levels in an atom. How many spectral lines are possible in its emission spectra ?

- (A) One (B) Two
 (C) Three (D) Four

Solution. (C)

$$\text{Number of spectral lines} = \frac{n(n-1)}{2} = \frac{3(3-1)}{2} = 3$$

✎ **Example. 11**

Which of the following transitions will emit the photons of highest frequency in hydrogen atom ?

- (A) From $n = 1$ to $n = 2$
 (B) From $n = 2$ to $n = 1$
 (C) From $n = 2$ to $n = 6$
 (D) From $n = 6$ to $n = 2$

Solution. (B)

The emission of photon is due to the transition of electrons from higher to lower energy levels. So the answer may be (2) or (4). From Planck's equation. $\nu \propto E$

i.e. The frequency of emitted photon is directly proportional to the difference of energies of two energy levels.

Energy of $n = 1$ for H-atom

$$E_1 = -13.6 \text{ eV}$$

Energy of $n = 2$ for H-atom

$$E_2 = -\frac{13.6}{4} \text{ eV}$$

Energy of $n = 6$ for H-atom

$$E_6 = -\frac{13.6}{36} \text{ eV}$$

$$\text{So } E_2 - E_1 = 13.6 - \frac{13.6}{4} = 13.6 \times \frac{3}{4}$$

$$E_6 - E_2 = \frac{13.6}{4} - \frac{13.6}{36} = 13.6 \left(\frac{1}{4} - \frac{1}{36} \right)$$

$$= 13.6 \times \frac{2}{9}$$

$$E_2 - E_1 > E_6 - E_2$$

Example. 12

Which type of radiation is not emitted by the electronic structure of atoms :

- (A) Ultraviolet light (B) X-rays
(C) Visible light (D) γ -rays

Solution. (D)

γ -rays emission occurs due to radioactive change, a nuclear phenomenon.

Example. 13

The wavelength of blue light is 480 nm. Calculate the frequency and wave number of this light.

Solution.

Wavelength of blue light (λ) = 480 nm
= 480×10^{-9} m

We know that frequency (ν) is related to wavelength as :

$$\lambda \times \nu = c \quad \text{or} \quad \nu = \frac{c}{\lambda}$$

Where, c, velocity of light = $3.0 \times 10^8 \text{ms}^{-1}$

$$\therefore \nu = \frac{3.0 \times 10^8 \text{ms}^{-1}}{480 \times 10^{-9} \text{m}} = \frac{3}{48} \times 10^{16} \text{s}^{-1}$$

$$= 6.25 \times 10^{14} \text{s}^{-1}$$

Again, wave number, $\bar{\nu} = \frac{1}{\lambda}$

$$\therefore \bar{\nu} = \frac{1}{480 \times 10^{-9} \text{m}} = \frac{1}{48} \times 10^8 \text{m}^{-1}$$

$$= 2.08 \times 10^6 \text{m}^{-1}$$

Therefore, frequency = $6.25 \times 10^{14} \text{s}^{-1}$ and wave number = $2.08 \times 10^6 \text{m}^{-1}$

Example. 14

Calculate and compare the energies of two radiations one with a wavelength of 800 nm and other with wavelength of 400 nm.

Solution.

Energy of photon, $E = h\nu = \frac{hc}{\lambda}$

Here $c = 3.0 \times 10^8 \text{m s}^{-1}$

In first case, $\lambda = 800 \text{nm} = 800 \times 10^{-9} \text{m}$

$$\therefore E_1 = \frac{(6.626 \times 10^{-34} \text{Js}) \times (3 \times 10^8 \text{ms}^{-1})}{800 \times 10^{-9} \text{m}}$$

$$= 2.48 \times 10^{-19} \text{J}$$

In second case, $\lambda = 400 \text{nm} = 400 \times 10^{-9} \text{m}$

$$\therefore E_2 = \frac{(6.626 \times 10^{-34} \text{Js}) \times (3 \times 10^8 \text{ms}^{-1})}{400 \times 10^{-9} \text{m}}$$

$$= 4.91 \times 10^{-19} \text{J}$$

Ratio of energy of first and second radiations,

$$\frac{E_1}{E_2} = \frac{2.48 \times 10^{-19} \text{J}}{4.97 \times 10^{-19} \text{J}} = \frac{1}{2}$$

$$E_1 : E_2 = 1 : 2 \quad \text{or} \quad E_2 = 2E_1$$

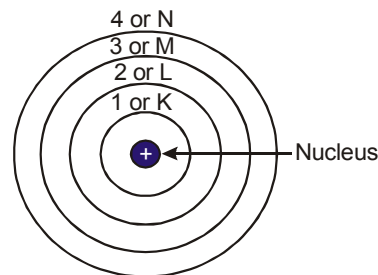
Thus, energy of the radiation with wavelength 400 nm is twice that of the radiation of wavelength 800 nm.

13. BOHR'S ATOMIC MODEL

Bohr developed atomic model for hydrogen and hydrogen like one electron species on the basis of Planck's quantum theory.

◆ The important postulates of Bohr model of an atom :

(a) Electron revolves around the nucleus in a fixed circular orbit of definite energy.



(b) Electron revolves only in those orbits whose angular momentum (mvr) is an integral multiple of the factor $h/2\pi$ (where 'h' is Planck's constant)

$$mvr = n \frac{h}{2\pi}$$

where : -

m = mass of the electron

v = velocity of the electron

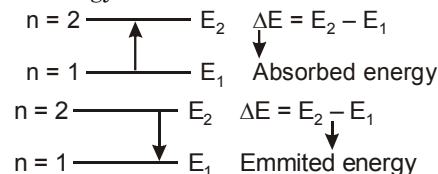
n = number of orbit in which electron revolves i.e. $n = 1, 2, 3, \dots$

r = radius of the orbit.

(c) As long as the electron occupy a definite energy level, it does not radiate out energy i.e. it does not lose or gain energy.

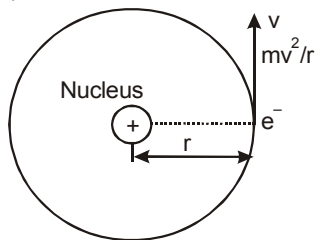
(d) The energy is emitted or absorbed only when the electron jumps from one energy level to another. If energy is supplied to an electron, It may jump higher energy level to the lower by the emission of energy. This higher energy level called excited state. Similarly in the reverse process it may absorb energy and jump from lower to higher energy level.

This amount of energy emitted or absorbed is given by the difference of the energies of the two energy levels concerned.



◆ **Mathematical term of Bohr's Postulates :**

A. Calculation of the radius of the Bohr's orbit :



Suppose that an electron having mass 'm' and charge 'e' revolving around the nucleus of charge 'Ze' (Z is atomic number & e = charge) with a tangential / linear velocity of 'v'. Further consider that 'r' is the radius of the orbit in which electron is revolving. According to **Coulomb's law**, the electrostatic force of attraction (F) between the moving electron and nucleus is -

$$F = \frac{KZe^2}{r^2}$$

Where :- $K = \text{constant} = \frac{1}{4\pi\epsilon_0}$

and the centrifugal force $F = \frac{mv^2}{r}$

For the stable orbit of an electron both the forces are balanced,

i.e. at equilibrium $\frac{mv^2}{r} = \frac{KZe^2}{r^2}$ then

$$v^2 = \frac{KZe^2}{mr} \quad \dots(1)$$

From the postulate of Bohr,

$$mvr = \frac{nh}{2\pi}, \quad v = \frac{nh}{2\pi mr}, \quad v^2 = \frac{n^2 h^2}{4\pi^2 m^2 r^2} \quad \dots(2)$$

From equation (1) and (2) ;

$$\frac{KZe^2}{mr} = \frac{n^2 h^2}{4\pi^2 m^2 r^2}$$

on solving, we will get $r = \frac{n^2 h^2}{4\pi^2 mZe^2}$

In C.G.S. unit $K = 1$,

$$\therefore r = \frac{n^2 h^2}{4\pi^2 mZe^2}$$

where ; $h = 6.62 \times 10^{-27}$ erg. sec.

$$m = 9.1 \times 10^{-28} \text{ g}$$

$$e = 1.6 \times 10^{-19} \text{ C.}$$

on putting the value of e, h, m then

$$r = 0.529 \times \frac{n^2}{Z} \text{ \AA}$$

Orbital frequency $f = \frac{v}{2\pi r}$

B. Calculation of velocity of an electron in Bohr's orbit :

Velocity of the revolving electron in n^{th} orbit is given by -

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr} \quad (1)$$

To put the value of 'r' on the equation (1)

$$\text{then } v = \frac{nh \times \pi^2 mZe^2}{2\pi mn^2 h^2}, \quad v = \frac{2\pi Ze^2}{nh}$$

on putting the values of π , e^- and h

$$v = 2.188 \times 10^8 \times \frac{Z}{n} \text{ Cm/sec.}$$

$$v \propto Z, \quad v \propto \frac{1}{n}$$

C. Calculation of energy of an electron :

The K.E. of an electron = $\frac{1}{2} mv^2$

and the P.E. of an electron = $-\frac{kZe^2}{r}$

Hence, $T.E. = \frac{1}{2} mv^2 - \frac{kZe^2}{r}$

We know that,

$$\frac{mv^2}{r} = \frac{kZe^2}{r^2} \quad \text{or} \quad mv^2 = \frac{kZe^2}{r}$$

substituting the value of mv^2 in the above equation :-

$$T.E. = \frac{kZe^2}{2r} - \frac{kZe^2}{r} = -\frac{kZe^2}{2r}$$

So, $T.E. = -\frac{kZe^2}{2r}$

In C.G.S. unit $K = 1$

$$\therefore T.E. = -\frac{Ze^2}{2r}$$

Substituting the value of 'r' in the equation of T.E. .

$$\text{Then, } E = -Ze^2 \times \frac{4\pi^2 Ze^2 m}{n^2 h^2} = -\frac{2\pi^2 Z^2 e^4}{n^2 h^2}$$

Thus, the total energy of an electron in n^{th} orbit is given by

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

NOTE The P.E. at the infinite = 0
The K.E. at the infinite = 0

D. Relation between P. E., K. E. & T. E. :

$$P. E. = -\frac{Ze^4}{r}, \quad K. E. = \frac{1}{2} \frac{Ze^2}{r},$$

$$T. E. = \frac{1}{2} \frac{Ze^2}{r}$$

$$\text{So, } \frac{\text{T.E.}}{\text{P.E.}} = \frac{-\frac{1}{2} \frac{Ze^2}{r}}{-\frac{Ze^2}{r}} = \frac{1}{2}$$

$$\text{Then } \text{T. E.} = 1/2 \text{ P. E.} \quad \dots (1)$$

$$\frac{\text{T.E.}}{\text{K.E.}} = \frac{-\frac{1}{2} \frac{Ze^2}{r}}{\frac{1}{2} \frac{Ze^2}{r}} = -1$$

$$\text{Then } \text{T. E.} = -\text{K. E.} \quad \dots (2)$$

$$\text{T. E.} = \frac{\text{P.E.}}{2} = -\text{K. E.} \quad \dots (3)$$

$$(a) \text{ T. E.} = -13.6 \times \frac{Z^2}{n^2} \text{ eV / atom}$$

$$(b) \text{ T. E.} = -21.8 \times 10^{-19} \times \frac{Z^2}{n^2} \text{ J / atom}$$

$$(c) \text{ T. E.} = -21.8 \times 10^{-12} \times \frac{Z^2}{n^2} \text{ erg / atom}$$

$$(d) \text{ T. E.} = -313.6 \times \frac{Z^2}{n^2} \text{ Kcal / mole}$$

$$\text{T. E.} \propto -Z^2 \quad Z \uparrow \text{ T. E.} \downarrow$$

$$\text{T. E.} \propto -\frac{1}{n^2} \quad n \uparrow \text{ T. E.} \uparrow$$

E. Conclusions from equation of energy :

- The negative sign of energy indicates that there is attraction between the negatively charged electron and positively charged nucleus.
- All the quantities of R.H.S. in the energy equation are constant for an element except 'n' which is an integer such as 1, 2, 3 etc. i. e. the energy of an electron is constant as long as the value of 'n' is kept constant.
- The energy of an electron is inversely proportional to the square of 'n' with negative sign.

◆ Calculation of Rydberg Constant :

Suppose that an electron transist from first energy level to second energy level. Then, the change of energy is given by

$$\Delta E = E_2 - E_1$$

$$h\nu = E_2 - E_1$$

$$h\nu = \left[\frac{-2\pi^2 mZ^2 e^4}{n_2^2 h^2} \right] - \left[\frac{-2\pi^2 mZ^2 e^4}{n_1^2 h^2} \right]$$

$$h\nu = \frac{2\pi^2 mZ^2 e^4}{n_1^2 h^2} - \frac{2\pi^2 mZ^2 e^4}{n_2^2 h^2}$$

$$\therefore \nu = \frac{c}{\lambda}$$

$$\frac{hc}{\lambda} = \frac{2\pi^2 mZ^2 e^4}{h^2} \times \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$$R_H = \frac{2\pi^2 me^4}{ch^3} \Rightarrow \text{Rydberg constant}$$

Then,

$$\text{Where } m = 9.1 \times 10^{-28} \text{ gram}$$

$$e = 4.8 \times 10^{-10} \text{ e.s.u.}$$

$$c = 3 \times 10^{10} \text{ cm/sec}$$

$$h = 6.625 \times 10^{-27} \text{ erg-sec}$$

by the theoretical value of $R_H = 109737 / \text{cm}$

by the practical value of $R_H = 109677 / \text{cm}$

by the calculative value of $R_H = 109700 / \text{cm}$

Rydberg constant for other atom $R = R_H \times Z^2$

◆ Failures / Limitations of Bohr's theory :

- He could not explain the line spectra of atoms containing more than one electron.
- He also could not explain the presence of multiple spectral lines.
- He was unable to explain the splitting of spectral lines in magnetic field (*Zeeman effect*) and in electric field (*Stark effect*).
- No one conclusion was given for the principle of quantisation of angular momentum.
- He was unable to explain the *de-Broglie's* concept of dual nature of matter.
- He could not explain *Heisenberg's* uncertainty principle.

Example Based on

Bohr's Atomic Model

Example. 15

The energy of electron in first Bohr's orbit of H-atom is -13.6 eV . What will be its potential energy in $n = 4$.

$$(A) -13.6 \text{ eV}$$

$$(B) -3.4 \text{ eV}$$

$$(C) -0.85 \text{ eV}$$

$$(D) -1.70 \text{ eV}$$

Solution. (D)

Energy of n^{th} Bohr's orbit of H-atom

$$= -13.6 \frac{Z^2}{n^2} \text{ eV} = -13.6 \frac{1^2}{4^2}$$

$$= 13.6 \times \frac{1}{16} \text{ eV} = -0.85 \text{ eV}$$

P.E. of electron in n^{th} orbit $= 2 \times E_n$

So P.E. of electron in 4^{th} orbit

$$= 2 \times (-0.85) = -1.70 \text{ eV}$$

Example. 16

The frequency of line spectrum of sodium is $5.09 \times 10^{14} \text{ sec}^{-1}$. Its wave length (in nm) will be- [$c = 3 \times 10^8 \text{ m/sec}$]

$$(A) 510 \text{ nm}$$

$$(B) 420 \text{ nm}$$

$$(C) 589 \text{ nm}$$

$$(D) 622 \text{ nm}$$

Solution. (C)

$$\lambda = \frac{3 \times 10^8 \text{ m. sec}^{-1}}{5.09 \times 10^{14} \text{ m. sec}^{-1}} = 0.5892 \times 10^{-6} \text{ m}$$

$$= 589.4 \times 10^{-9} \text{ m} = 589 \text{ nm}$$

Example. 17

The spectrum of He-atom may be considered similar to the spectrum of -

- (A) H (B) Li⁺
(C) Na (D) He⁺

Solution. (B)

The electronic configuration of He is similar to the electronic configuration of Li⁺. So its spectrum will be similar to the spectrum of Li⁺ and answer will be (B).

Example. 18

Supposing the energy of fourth shell for hydrogen atom is - 50 a.u. (arbitrary unit). What would be its ionization potential -

- (A) 50 (B) 800 (C) 15.4 (D) 20.8

Solution.

Ionization potential = $-E_1$

$$\therefore E_4 = \frac{E_1}{16}$$

$$\therefore -50 \times 16 = E_1$$

Hence ionization potential = $-(-800) = 800$ a.u.

Example. 19

Find the wavelengths of the first line of He⁺ ion spectral series whose interval with extreme lines is

$$\frac{1}{\lambda_1} - \frac{1}{\lambda_2} = 2.7451 \times 10^4 \text{ cm}^{-1}$$

Solution.

Extreme lines means first and last.

$$\frac{1}{\lambda_1} - \frac{1}{\lambda_2} = RZ^2 \left[\frac{1}{n_1^2} - \frac{1}{\infty^2} \right] = RZ^2$$

$$\left[\frac{1}{n_1^2} - \frac{1}{(n_1 + 1)^2} \right] = \frac{RZ^2}{(n_1 + 1)^2}$$

$$2.7451 \times 10^4 = \frac{109677.76 \times 2^2}{(n_1 + 1)^2}$$

$$(n_1 + 1) = 4$$

$$n_1 = 3$$

Wavelength of first line,

$$\frac{1}{\lambda} = 109677.76 \times 2^2 \times \left[\frac{1}{3^2} - \frac{1}{4^2} \right]$$

$$\lambda = 4689 \times 10^{-8} \text{ cm} = 4689 \text{ \AA}$$

Example. 20

The first ionization potential of hydrogen is 13.6 eV. It is exposed to electromagnetic radiation of 1028 \AA and gives out induced radiations. Calculate the wavelength of these induced radiations ($h = 6.625 \times 10^{-34}$ Js)

Solution.

We know that

$$E_n = \frac{E_1}{n^2}$$

$$E_n = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{1028 \times 10^{-10}} = 1.933 \times 10^{-18} \text{ J}$$

$$= 12.07 \text{ eV}$$

$$(1.6 \times 10^{-19} \text{ J} = 1 \text{ eV})$$

Energy of H-atom after excitation

$$= -13.6 + 12.07 = -1.53 \text{ eV}$$

$$\text{From (1), } -1.53 = \frac{E_1}{n^2} = \frac{-13.6}{n^2}$$

$$\therefore n = 3$$

First induced wavelength,

$$\lambda_1 = \frac{hc}{E_3 - E_1} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{(-1.53 + 13.6) \times 1.602 \times 10^{-19}}$$

$$= 1025 \times 10^{-10} \text{ m} = 1025 \text{ \AA}$$

Second induced wavelength

$$\lambda_2 = \frac{hc}{E_2 - E_1} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{(-3.4 + 13.6) \times 1.602 \times 10^{-19}}$$

$$= 1216 \times 10^{-10} \text{ metre} = 1216 \text{ \AA}$$

Third induced wavelength,

$$\lambda_3 = \frac{hc}{E_3 - E_2} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{(-1.53 + 3.4) \times 1.602 \times 10^{-19}}$$

$$= 6564 \times 10^{-10} \text{ m}$$

$$= 6564 \text{ \AA}$$

14. PHOTOELECTRIC EFFECT

When light of suitable frequency falls on the surface of a metal electrons are emitted. These emitted electrons are called as photoelectrons and this effect is called photoelectron. Work function or threshold energy may be defined as the minimum amount of energy required to eject electrons from a metal surface. According to Einstein,

Maximum kinetic energy of the ejected electron = absorbed energy - work function

$$\frac{1}{2} m v_{\text{max}}^2 = h\nu - h\nu_0 = hc \left[\frac{1}{\lambda} - \frac{1}{\lambda_0} \right]$$

Where ν_0 and λ_0 are threshold frequency and threshold wavelength.

- ◆ **Stopping potential** : The minimum potential at which the plate photoelectric current becomes zero is called stopping potential.

If V_0 is the stopping potential, then $eV_0 = h(\nu - \nu_0)$

15. DUAL NATURE OF ELECTRON

(a) Einstein had suggested that light can behave as a wave as well as like a particle i.e. it has dual character

(b) In 1924, de-Broglie proposed that an electron, behaves both as a material particle and as a wave.

- (c) This proposed a new theory wave mechanical theory of matter. According to this theory, the electrons protons and even atom when in motion possess wave properties

- (d) According to de-Broglie, the wavelength associated with a particle of mass m , moving with velocity v is given by the relation,

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

where h is Planck's constant.

- (e) This can be derived as follows according to Planck's equation

$$E = hv = \frac{h.c}{\lambda}$$

Energy of photon on the basis of Enstein's mass energy relationship

$$E = mc^2$$

$$\text{Equating both } \frac{h.c}{\lambda} = mc^2 \text{ or } \lambda = \frac{h}{mc}$$

Which is the same of de Broglie relation.

- (f) This was experimentally verified by Davisson and Germer by observing diffraction effects with an electron beam. Let the electron is accelerated with a potential of V than the kinetic energy is

$$\frac{1}{2}mv^2 = eV$$

$$m^2v^2 = 2eVm$$

$$mv = \sqrt{2eVm} = p$$

$$\lambda = \frac{h}{\sqrt{2eVm}}$$

- (g) If we associate Bohr's theory with de-Broglie Equation we find that the wavelength of an electron, moving in bohr's orbit is related with its circumference through a whole number multiple

$$2\pi r = n\lambda \text{ or } \lambda = \frac{2\pi r}{n}$$

From de-Broglie equation

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

$$\text{Thus } \frac{h}{mv} = \frac{2\pi r}{n} \text{ or } mvr = \frac{nh}{2\pi}$$

Example Based on

Dual nature of electron

Example. 21

If the Planck's constant $h = 6.6 \times 10^{-34}$ Js, the de-Broglie wavelength of a particle having momentum of 3.3×10^{-24} kg m s⁻¹ will be -

- (A) 0.002 Å (B) 0.02 Å
(C) 0.2 Å (D) 2 Å

Solution. (D)

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

Example. 22

K.E. of the electron is 4.55×10^{-25} J. Its de Broglie wave length is

- (A) 4700 Å (B) 8300 Å
(C) 7285 Å (D) 7400 Å

Solution. (C)

$$\lambda = \frac{h}{\sqrt{2mKE}}$$

Example. 23

For particles having same kinetic energy, the de Broglie wavelength is

- (A) directly proportional to its velocity
(B) inversely proportional to its velocity
(C) independent of velocity and mass
(D) unpredictable

Solution. (A)

$$\lambda = \frac{h}{mv} \text{ KE} = \frac{1}{2}mv^2$$

$$mv = \frac{2KE}{v}$$

$$\therefore \lambda = \frac{h}{2 \frac{KE}{v}}$$

$$\lambda = h \left(\frac{v}{2KE} \right)$$

Example. 24

Velocity of helium atom at 300K is 2.40×10^2 meter per sec. What is its wave length? (mass number of helium is 4) -

- (A) 0.416 nm (B) 0.83 nm
(C) 803 Å (D) 8000 Å

Solution. (A)

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

$$\text{mass of helium} = \frac{4.0 \times 10^{-3}}{6.023 \times 10^{23}} \text{ kg. and}$$

$$h = 6.62 \times 10^{-34}$$

$$\lambda = 6.62 \times 10^{-34} \times \frac{6.023 \times 10^{23}}{4.0 \times 10^{-3}} \times \frac{1}{2.4 \times 10^2}$$

$$= 0.416 \times 10^{-9} \text{ meter}$$

$$\lambda = 0.416 \text{ nm}$$

16. HEISENBERG'S UNCERTAINTY PRINCIPLE

- (a) While treating e^- as a wave it is not possible to ascertain simultaneously the exact position and velocity of the e^- more precisely at a given instant since the wave is extending throughout a region of space

- (b) As the photons of longer wavelengths are less energetic, hence they have less momentum and cannot be located exactly
- (c) In 1927, Werner Heisenberg presented a principle known as Heisenberg's uncertainty principle
- (d) According to this principle it is impossible to measure simultaneously the exact position and exact momentum of a body as small as an electron.
- (e) If uncertainty of measurement of position is Δx uncertainty of momentum is Δp or ΔmV . then according to Heisenberg

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi} \quad \text{or} \quad \Delta x \cdot \Delta m v \geq \frac{h}{4\pi}$$

where h is planck's constant

- (f) For other canonical conjugates of motion the equation for Heisenberg's uncertainty principle may be given as

$$\Delta E \Delta t \geq \frac{h}{4\pi} \quad (\text{for energy and time})$$

$$\Delta \phi \Delta \theta \geq \frac{h}{4\pi} \quad (\text{for angular motion})$$

Example Based on

Heisenberg's Uncertainty Principle

Example. 25

If uncertainty in position and momentum are equal, the uncertainty in velocity is :

- (A) $\sqrt{h/2\pi}$ (B) $\frac{1}{2m}\sqrt{h/\pi}$
- (C) $\sqrt{h/\pi}$ (D) None of these

Solution. (B)

$$\Delta x \cdot m \Delta v = \frac{h}{4\pi} \quad \text{or} \quad (m \Delta v)^2 = \frac{h}{4\pi}$$

$$m \Delta v = \sqrt{\frac{h}{4\pi}} \quad \text{or} \quad \Delta v = \sqrt{\frac{h}{4\pi m^2}} = \frac{1}{2m} \sqrt{\frac{h}{\pi}}$$

Example. 26

The uncertainty in position and velocity of a particle are 10^{-10} m and $5.27 \times 10^{-24} \text{ ms}^{-1}$ respectively. Calculate the mass of the particle ($h = 6.625 \times 10^{-34} \text{ J-s}$)

Solution.

According to Heisenberg's uncertainty principle,

$$\Delta x \cdot m \Delta v = \frac{h}{4\pi}$$

$$\text{or } m = \frac{h}{4\pi \Delta x \cdot \Delta v}$$

$$= \frac{6.625 \times 10^{-34}}{4 \times 3.143 \times 10^{-10} \times 5.27 \times 10^{-24}} = 0.099 \text{ kg.}$$

17. SCHRODINGER WAVE THEORY

Bohr's theory is based on the corpuscular nature of electron. This theory violates de-Broglie's relation and the uncertainty principle. Hence this theory is replaced by more complete theory called motion in one direction is

$$\left(\frac{\partial \Psi}{\partial x^2} \right)_t = \frac{1}{u^2} \left(\frac{\partial^2 \Psi}{\partial t^2} \right)_x \quad \dots (1)$$

Where ' Ψ ' is the amplitude of vibration at any point whose co-ordinate is 'x' at a time 't'.

u = speed of propagation of the wave.

if ' u ' does not depend on the time, the displacement ' Ψ ' can be written as a product of two functions one depending only on the space co-ordinates 'x' and the other depending periodically on the time.

Thus we have

$$\Psi = \Psi(x) \exp \{i(2\pi vt)\} \quad \dots (2)$$

Where ' v ' is frequency of the wave and

$$i = \sqrt{-1}$$

From equations (1) and (2) we have

$$\left(\frac{\partial^2 \Psi \exp \{i(2\pi vt)\}}{\partial x^2} \right)_t = \frac{1}{u^2} \left(\frac{\partial^2 \Psi \exp \{i(2\pi vt)\}}{\partial t^2} \right)_x$$

$$\text{or } \exp \{i(2\pi vt)\} \frac{\partial^2 \Psi}{\partial x^2}$$

$$= \frac{1}{u^2} \Psi (2\pi v)^2 \exp \{i(2\pi vt)\}$$

$$\text{or } \frac{\partial^2 \Psi}{\partial x^2} = -\frac{4\pi^2 v^2}{u^2} \Psi \quad \dots (3)$$

Relation between frequency of vibration ' v ' and speed is are related by the equation

$$u = \lambda v \quad \dots (4)$$

where ' λ ' is wavelength of the associated wave

From equation (3) and (4) we have

$$\frac{\partial^2 \Psi}{\partial x^2} = -\frac{4\pi^2}{\lambda^2} \Psi \quad \dots (5)$$

Equation (5) does not include the time variable $\exp \{i(2\pi vt)\}$ and thus gives only the variation of the amplitude function with 'x'.

In Equation (5) term $\frac{\partial^2}{\partial x^2}$ is an operator which on

operating on the function ' Ψ ' gives back the function ' Ψ ' multiplied by a constant $-\frac{4\pi^2}{\lambda^2}$. The

equation of the type is called as eigen value equation, the function Ψ is an eigen function and the constant $(-\frac{4\pi^2}{\lambda^2})$ is an eigen value (sometimes it is also called characteristic value). The function ' Ψ ' has acceptable solution only if it has to be consistent with the basic constraints. In case of a vibrating string, these are :

A. The function 'Ψ' must be zero at end of the string, since the system is fixed at these points and thus amplitudes are zero.

B. The 'Ψ' must be a single valued and finite between the limits of 'x' varying from one end to the other Equation (5) can be extended to three dimensions as

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} = -\frac{4\pi^2}{\lambda^2} \Psi \quad \dots (6)$$

$$\text{or} \quad \nabla^2 \Psi + \frac{4\pi^2}{\lambda^2} \Psi = 0 \quad \dots (7)$$

$$\text{where} \quad \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

∇² is called as Laplacian operator

Equation (7) can be applied to all subatomic particles (Electrons, protons etc.) is an atom. In order that this equation also takes case of wave - particle dual nature, Schrödinger replaced 'λ' is terms of momentum by using the de-Broglie's

relation, $\lambda = \frac{h}{p}$ with, this equation (7) becomes

$$\nabla^2 \Psi + \frac{4\pi^2 p^2}{h^2} \Psi = 0 \quad \dots (8)$$

For an electron in an atom, the total energy of the electron is the sum of its kinetic and potential energies.

$$E = KE + PE = \frac{1}{2} + V \quad \text{or} \quad E = \frac{P^2}{2m} + V$$

$$P^2 = 2m(E - V) \quad \dots (9)$$

From equations (8) and (9) we have

$$\nabla^2 \Psi + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0 \quad \dots (10)$$

Equation (10) is Schrödinger equation which describes the behavior of electron in an atom.

◆ **Physical significance of Ψ and Ψ² :**

The function 'Ψ' represents the amplitude of vibration of matter wave associated with electron.

In classical theory of electromagnetic radiation, the square of amplitude is proportional to the intensity of light. A very similar concept was suggested by Barn in quantum mechanics according to which the square of function 'Ψ' at any point is proportional to the probability of finding the system at the point This definition of probability is in agreement with the uncertainty principle as one cannot talk about the precise position of subatomic particles 'Ψ' may be real or imaginary. Since the probability of finding a material particle at a given point in space has to be real, the term Ψ² has to be replaced by Ψ* Ψ, when Ψ* is the complex conjugate of Ψ. The complex conjugate can be obtained by replacing i (√-1) by -i.

The probability of finding the particular system in small in space is proportional to

$$\Psi^* \Psi \, dx \, dy \, dz.$$

Integration over the whose of the configuration space gives a quantity which is proportional to the total probability of system

$$\int \Psi^* \Psi \, dx \, dy \, dz = N$$

$$\text{or} \quad \frac{1}{N} \int \Psi^* \Psi \, dx \, dy \, dz = 1$$

$$\text{or} \quad \int \left(\frac{1}{N^{1/2}} \Psi^* \right) \left(\frac{1}{N^{1/2}} \Psi \right) \, dx \, dy \, dz = 1$$

The factor is known as normalisation constant which is independent of the co-coordinate x, y and z.

The function $\frac{1}{N^{1/2}} \Psi$ is known as the normalisation

function.

Example Based on

Schrodinger wave theory

✎ **Example. 27**

The wave-mechanical model of atom is based upon (A) de Broglie concept of dual character of matter

(B) Heisenberg's uncertainty principle

(C) Schrödinger wave equation

(D) all the above three

Solution. (D)

✎ **Example. 28**

An orbital is correctly described by :

(A) ψ²

(B) ψ

(C) |ψ²|ψ

(D) None of these

Solution. (A)

18. QUANTUM NUMBERS

(a) The measurement scale by which the orbitals are distinguished, can be represented by sets of numbers called as quantum number.

(b) It is a very important number to specify and display to complete information about size, shape and orientation of the orbital. These are principle, azimuthal and magnetic quantum number, which follows directly from solution of Schrödinger wave equation.

(c) Except of these quantum numbers, one additional quantum number designated as spin quantum number, which specify the spin of electron in an orbital.

(d) Each orbital in an atom is specified by a set of three quantum numbers and each electron is designated by a set of four quantum numbers.

These quantum numbers are as follows :

◆ **Principal Quantum Number (n) :**

- (a) It was proposed by Bohr and denoted by 'n'.
- (b) It determines the average distance between electron and nucleus, means it is denoted the size of atom.
- (c) It determine the energy of the electron in an orbit where electron is present.
- (d) The maximum number of an electron in an orbit represented by this quantum number as $2n^2$.
- (e) It gives the information of orbit K, L, M, N,
- (f) The value of energy increases with the increasing value of n.
- (g) It represents the major energy shell from which the electron belongs.
- (h) An orbital momentum of any orbit = $\frac{nh}{2\pi}$

◆ **Azimuthal quantum number or angular quantum number (ℓ) :**

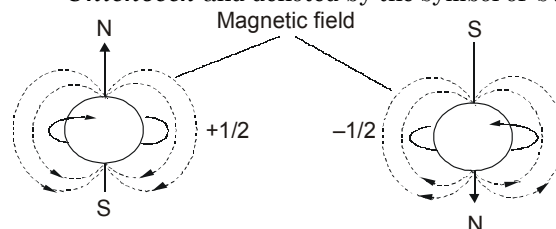
- (a) It was proposed by sommerfield and denoted by ' ℓ '.
- (b) It determines the number of subshells or sublevels to which the electron belongs.
- (c) It tells about the shape of subshells.
- (d) It also expresses the energies of subshells $s < p < d < f$ (Increasing energy).
- (e) The value of $\ell = (n - 1)$ always where 'n' is the number of principle shell.
- (f) Value of ℓ = 0 1 2 3 ----(n-1)
Name of subshell = s p d f
Shape of subshell = spherical Dumbbell Double dumbbell Complex
- (g) It represent the orbital angular momentum, which is equal to $\frac{h}{2\pi} \sqrt{\ell(\ell + 1)}$.
- (h) The number of electrons in subshell = $2(2\ell + 1)$.
- (i) For a given value of 'n' the total value of ' ℓ ' is always equal to the value of 'n'.
- (j) The energy of any electron is depend on the value of n & ℓ because total energy = $(n + \ell)$. The electron enters in that sub orbit whose $(n + \ell)$ value or the value of energy is less.

◆ **Magnetic quantum number (m) :**

- (a) It was proposed by Linde and denoted by 'm'.
- (b) It gives the number of permitted orientation of subshells.
- (c) The value of m varies from $-\ell$ to $+\ell$ through zero.
- (d) It tells about the splitting of spectral lines in the magnetic field i.e. this quantum number proved the Zeeman effect.
- (e) For a given value of 'n' the total value of 'm' is equal to n^2 .
- (f) For a given value of ' ℓ ' the total value of 'm' is equal to $(2\ell + 1)$.
- (g) *Degenerate orbitals* - Orbitals having the same energy are known as degenerate orbitals.
e.g. for P subshell $P_x P_y P_z$
- (h) The number of degenerate orbitals of s subshell = 0.

◆ **Spin quantum number (s) :**

- (a) It was proposed by **Goldschmidt & Uhlenbeck** and denoted by the symbol of 's'.



- (b) The value of 's' is $+\frac{1}{2}$ & $-\frac{1}{2}$, Which is signified the spin or rotation or direction of electron on it's axis during the movement.
- (c) The spin may be clockwise & anticlockwise.
- (d) It represents the value of spin angular momentum is equal to $\frac{h}{2\pi} \sqrt{s(s+1)}$.
- (e) Maximum spin of an atom = $\frac{1}{2} \times$ number of unpaired electron.

◆ **Relation between various quantum numbers :**

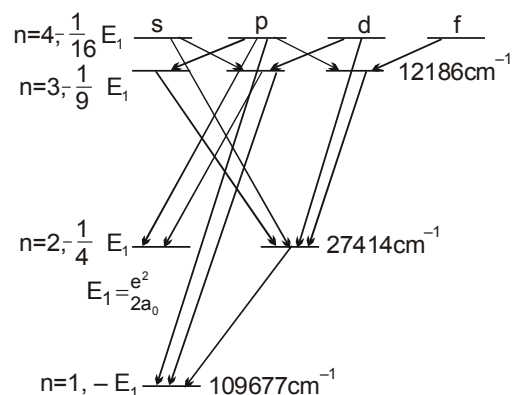
Energy level	Principal quantum number "n"	Total number of energy sub levels and their azimuthal quantum number "l"	Magnetic quantum number "m"	Spin quantum number "s"	Designation of orbital	Total number of electrons
K	1	0	0	$\pm \frac{1}{2}$	1s	2
L	2	0	0	$\pm \frac{1}{2}$	2s	6
		1	-1	$\pm \frac{1}{2}$	2 p _x	
			0	$\pm \frac{1}{2}$	2 p _z	
M	3	0	0	$\pm \frac{1}{2}$	3s	6
		1	-1	$\pm \frac{1}{2}$	3 p _x	
			0	$\pm \frac{1}{2}$	3 p _z	
		2	-2	$\pm \frac{1}{2}$	3 d _{x²-y²}	10
			-1	$\pm \frac{1}{2}$	3 d _{yz}	
			0	$\pm \frac{1}{2}$	3 d _{z²}	
			+1	$\pm \frac{1}{2}$	3 d _{zx}	
			+2	$\pm \frac{1}{2}$	3 d _{xy}	

◆ **Selection rules :**

The spectra of atoms are obtained when electron is transferred from one orbital to other.

According to quantum mechanical model of atom electronic transition obey certain selection rules. These are -

- (a) 'n' may change by any integer i.e. $\Delta n = \text{any value}$
- (b) ℓ must change by ± 1 i.e. $\Delta \ell = \pm 1$ and 'm' may change by ± 1 or not at all. $\Delta m = 0, \pm 1$



◆ **For example :**

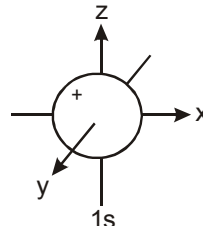
If an electron changes its principle quantum number from $n = 2$ to $n = 1$, it must go from a state of $\ell = 1$ to $\ell = 0$ i.e. the transition $1s \leftarrow 2p$ is allowed. The transition $1s \leftarrow 2s$ where $\ell = 0$ is forbidden. A few other possible transitions in the hydrogen atom are shown in figure above.

19. SHAPE OF ORBITALS

◆ **Orbital :**

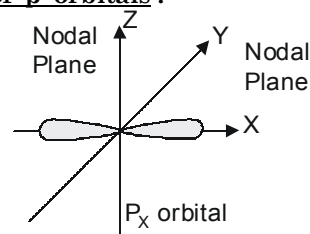
Orbital is the three dimensional region around the nucleus where there is a maximum tendency of finding an electron of definite energy

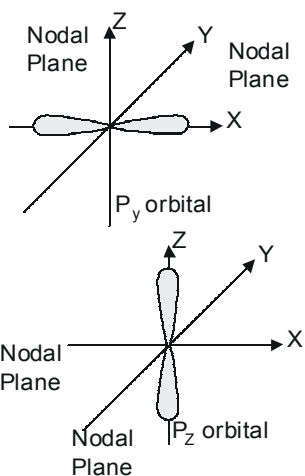
◆ **Shape of 's' orbital :**



- (a) For 's' orbital $\ell = 0$ & $m = 0$ so 's' orbitals have only one unidirectional orientation i.e. the probability of finding the electron is same in all directions.
- (b) The size and energy of 's' orbitals with increasing 'n' will be $1s < 2s < 3s < 4s$.
- (c) It does not consist of any directional property.

◆ **Shape of 'p' orbitals :**

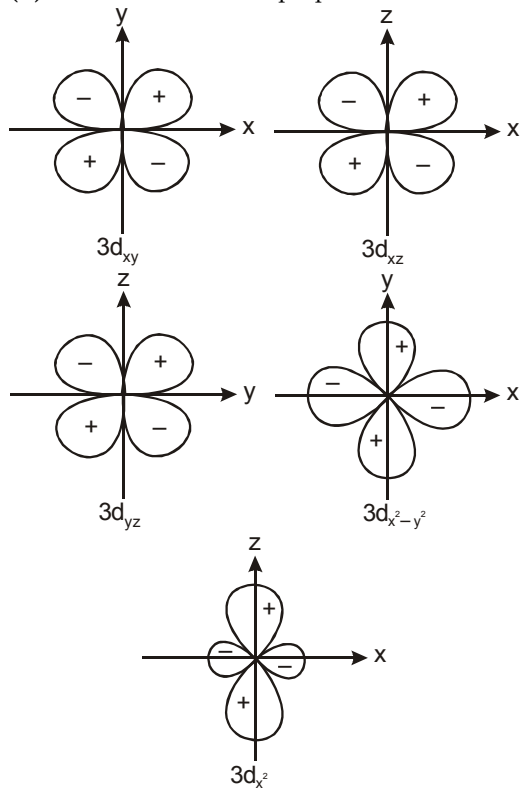




- (a) For 'p' orbital $\ell = 1$ & $m = +1, 0, -1$ means there are three 'p' orbitals, which is symbolised as p_x, p_y, p_z .
- (b) Shape of 'p' orbital is dumbbell in which the two lobes on opposite side separated by the nodal plane.
- (c) p-orbital has directional properties.

◆ **Shape of d-orbital :**

- (a) For the 'd' orbital $\ell = 2$ then the values of 'm' are $-2, -1, 0, +1, +2$. It shows that the 'd' orbitals are five as $d_{xy}, d_{yz}, d_{zx}, d_{x^2-y^2}, d_{z^2}$
- (b) Each 'd' orbital identical in shape, size and energy.
- (c) The 'd' orbital is bidumb-belled.
- (d) It has directional properties.



* Only for Target Course students

Example Based on
Quantum numbers and shape of orbitals

✎ **Example. 29**

The maximum number of atomic orbitals associated with a principal quantum number 5 is

- (A) 9 (B) 12
(C) 16 (D) 25

Solution. (D)

The number of orbitals in a principle shell is $n^2 = 5^2 = 25$.

✎ **Example. 30**

Beryllium's fourth electron will have the four quantum numbers :

	n	ℓ	m	s
(A)	1	0	0	1/2
(B)	1	1	1	1/2
(C)	2	0	0	-1/2
(D)	2	1	0	+1/2

Solution. (C) it is $2s^2$

✎ **Example. 31**

To give designation to an orbital, we need

- (A) Principal and azimuthal quantum number
(B) Principal and magnetic quantum number
(C) Azimuthal and magnetic quantum number
(D) Principal, azimuthal and magnetic quantum numbers.

Solution. (D)

Quantum numbers are signature of an electron of particular orbital

✎ **Example. 32**

- (a) An electron is in 5f-orbital. What possible values of quantum numbers n, l, m and s can it have ?
- (b) What designation is given to an orbital having (i) $n = 2, l = 1$ and (ii) $n = 3, l = 0$?

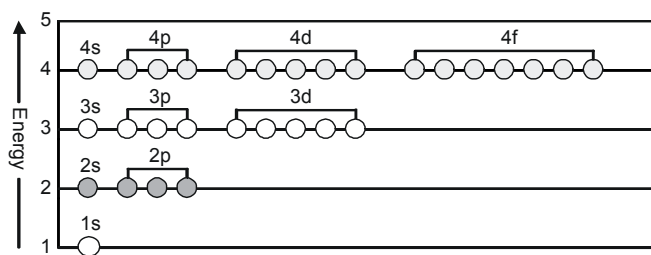
Solution. (a)

For an electron in 5f - orbital, quantum number are : $n = 5, \ell = 3$; $m = -3, -2, -1, 0, +1, +2, +3$ and $s =$ either $+1/2$ or $-1/2$

- (b) (i) 2p, (ii) 3s.

20. ENERGY LEVEL DIAGRAM

- (a) The representation of relative energy levels of various atomic orbital is made in the terms of energy level diagrams.
- (b) **One electron system :** In this system electron is in $1s^2$ level and all orbital of same principal quantum number have same energy, which is independent of (ℓ). In this system ℓ only determines the shape of orbital.



(c) **Multiple electron system :**
The energy levels of such system not only depend upon the nuclear charge but also upon the another electron present in them -

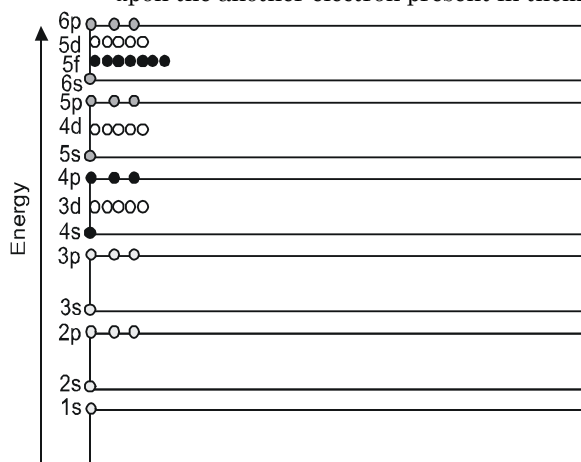
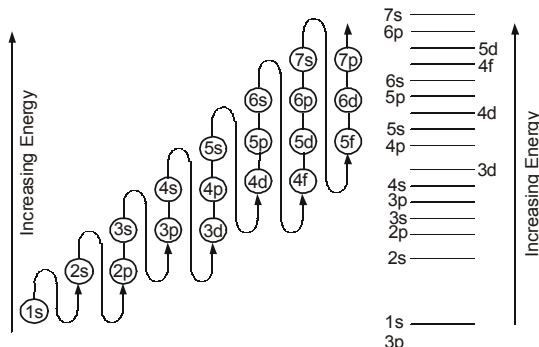


Diagram of multielectron atoms reveals the following points

- (d) As the distance of the shell increases from the nucleus, the energy level increases. For example energy level of $2 > 1$.
- (e) The different sub shells have different energy levels who have possess definite energy levels. For a definite shell, the subshell having higher value of ℓ possesses higher energy level. For example in 4th shell. Energy level order
 $4f > 4d > 4p > 4s$
 $\ell = 3 \quad \ell = 2 \quad \ell = 1 \quad \ell = 0$



- (f) The relative energy of sub shells of different energy shell can be explained in terms of the $(n + \ell)$ rule.
The subshell with lower values of $(n + \ell)$ possess lower energy level.

$$\text{For } 3d \quad n = 3 \quad \ell = 2 \quad \therefore n + \ell = 5$$

$$\text{For } 4s \quad n = 4 \quad \ell = 0 \quad n + \ell = 4$$

- (g) If the value of $(n + \ell)$ for two orbitals is same, one with lower values of 'n' possess lower energy level.

21. ELECTRONIC CONFIGURATION

The distribution of electrons in different orbitals is known as electronic configuration of the atoms. Filling up of orbitals in the ground state of atom is governed by the following rules :

◆ Aufbau Principle :

- (a) It is a German word, meaning 'building up'
 (b) According to this principle, "In the ground state, the atomic orbitals are filled in order of increasing energies". i.e. in the ground state the electrons occupy the lowest orbitals available to them.
 (c) The sequence of filling of e^- we have already discussed in previous article
 (d) In fact the energy of an orbital is determined by the quantum number n and ℓ with the help of $(n + \ell)$ rule or Bohr Bury rule
 (e) According to this rule
 (i) Lower the value of $(n + \ell)$, lower is the energy of the orbital and such an orbital will be filled up first
 (ii) When two orbitals have same value of $(n + \ell)$ the orbital having lower value of "n" has lower energy and such an orbital will be filled up first.

◆ Pauli's Exclusion Principle :

- (a) According to this principle, " No two electrons in an atom can have all the four quantum numbers n, ℓ, m and s identical.
 (b) In an atom, any two electrons may have three quantum numbers identical but fourth quantum number must be different.
 (c) Since this principle excludes certain possible combinations of quantum numbers for any two electrons in an atom, it was given the name exclusion principle. Its results are as follows
 (i) The maximum capacity of a main energy shell is equal to $2n^2$ electron
 (ii) The maximum capacity of a subshell is equal to $2(2\ell + 1)$ electrons
 (iii) Number of sub-shells in a main energy shell is equal to the value of n
 (iv) Number of orbitals in a main energy shell is equal to n^2
 (v) one orbital cannot have more than two electrons



Correct

Incorrect

◆ **Hund's Rule of Maximum Multiplicity :**

- (a) This rule governs the filling up of degenerate orbitals of the same sub-shell
- (b) According to this rule "Electron filling will not take place in orbitals of same energy untill all the available orbital of a given subshell contain one electron each with parallel spin."
- (c) This implies that electron pairing begins with fourth, sixth and eighth electron in p, d and f orbitals of the same sub-shell respectively.
- (d) The reason behind this rule is related to repulsion between identical charged electron present in the same orbital
- (e) They can minimise the repulsive forces between them serves by occupying different orbitals.
- (f) Moreover, according to this principle, the e^- entering the different orbitals of subshell have parallel spins. This keeps them farther apart and lowers the energy through electron exchange or resonance.
- (g) The term maximum multiplicity means that the total spin of unpaired e^- is maximum in case of correct filling of orbitals as per this rule.

22. EXTRA STABILITY OF HALF FILLED AND COMPLETELY FILLED SUB-SHELLS

Half-filled and completely filled sub-shells have extra stability due to the following reasons.

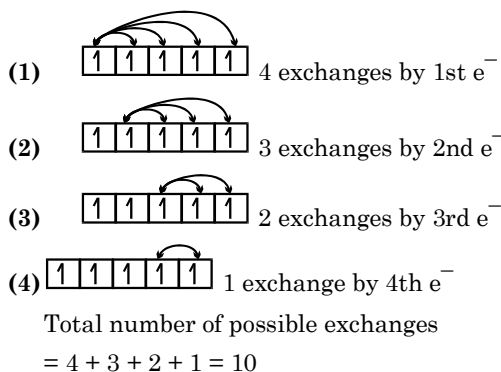
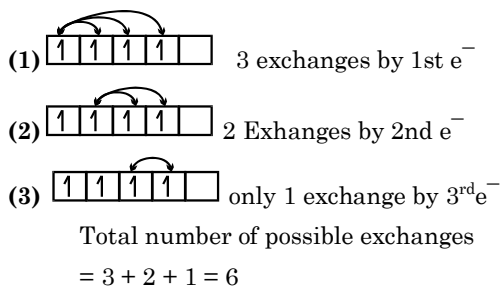
◆ **Symmetry of orbitals :**

- (a) It is a well known fact that symmetry leads to stability.
- (b) Thus, if the shift of an electron from one orbital to another orbital differing slightly in energy results in the symmetrical electronic configuration. it becomes more stable.
- (c) For example p^3 , d^5 , f^7 configurations are more stable than their near ones

◆ **Exchange Energy :**

- (a) The e^- in various subshells can exchange their positions, since e^- in the same subshell have equal energies.
- (b) The energy is released during the exchange process with in the same subshell.

- (c) In case of half filled and completely filled orbitals, the exchange energy is maximum and is greater than the loss of orbital energy due to the transfer of electron from a higher to a lower sublevel e.g. from 4s to 3d orbitals in case of Cu and Cr
- (d) The greater the number of possible exchanges between the electrons of parallel spins present in the degenerate orbitals, the higher would be the amount of energy released and more will be the stability
- (e) Let us count the number of exchange that are possible in d^4 and d^5 configuration among electrons with parallel spins :



23. ELECTRONIC CONFIGURATION OF ELEMENTS

Element	At. No.	1s	2s	2p	3s	3p	3d	4s	4p	4d	4f	5s	5p	6d	5f
H	1	1													
He	2	2													
Li	3	2	1												
Be	4	2	2												
B	5	2	2	1											
C	6	2	2	2											
N	7	2	2	3											
O	8	2	2	4											
F	9	2	2	5											
Ne	10	2	2	6											
Na	11	2	2	6	1										
Mg	12	2	2	6	2										
Al	13	2	2	6	2	1									
Si	14	2	2	6	2	2									
P	15	2	2	6	2	3									
S	16	2	2	6	2	4									
Cl	17	2	2	6	2	5									
Ar	18	2	2	6	2	6									
K	19	2	2	6	2	6		1							
Ca	20	2	2	6	2	6		2							
Sc	21	2	2	6	2	6	1	2							
Ti	22	2	2	6	2	6	2	2							
V	23	2	2	6	2	6	3	2							
*Cr	24	2	2	6	2	6	5	1							
Mn	25	2	2	6	2	6	5	2							
Fe	26	2	2	6	2	6	6	2							
Co	27	2	2	6	2	6	7	2							
Ni	28	2	2	6	2	6	8	2							
*Cu	29	2	2	6	2	6	10	2							
Zn	30	2	2	6	2	6	10	1							
Ga	31	2	2	6	2	6	10	2	1						
Ge	32	2	2	6	2	6	10	2	2						
As	33	2	2	6	2	6	10	2	3						
Se	34	2	2	6	2	6	10	2	4						
Br	35	2	2	6	2	6	10	2	5						
Kr	36	2	2	6	2	6	10	2	6						
Rb	37	2	2	6	2	6	10	2	6		1				
Sr	38	2	2	6	2	6	10	2	6		2				
Y	39	2	2	6	2	6	10	2	6	1	2				
Zr	40	2	2	6	2	6	10	2	6	2	2				
*Nb	41	2	2	6	2	6	10	2	6	4	1				
*Mo	42	2	2	6	2	6	10	2	6	5	1				
Tc	43	2	2	6	2	6	10	2	6	5	2				
*Ru	44	2	2	6	2	6	10	2	6	7	1				
*Rh	45	2	2	6	2	6	10	2	6	8	1				
*Pd	46	2	2	6	2	6	10	2	6	10					
*Ag	47	2	2	6	2	6	10	2	6	10	1				
Cd	48	2	2	6	2	6	10	2	6	10	2				
n	49	2	2	6	2	6	10	2	6	10	2	1			
Sn	50	2	2	6	2	6	10	2	6	10	2	2			
Sb	51	2	2	6	2	6	10	2	6	10	2	3			
Te	52	2	2	6	2	6	10	2	6	10	2	4			
I	53	2	2	6	2	6	10	2	6	10	2	5			
Xe	54	2	2	6	2	6	10	2	6	10	2	6			

Element	At. No.	K	L	M	4s	4p	4d	4f	5s	5p	5d	5f	6s	6p	6d	6f	7s
Cs	55	2	8	18	2	6	10		2	6			1				
Ba	56	2	8	18	2	6	10		2	6			2				
*La	57	2	8	18	2	6	10		2	6	1		2				
Ce	58	2	8	18	2	6	10	2	2	6			2				
Pr	59	2	8	18	2	6	10	3	2	6			2				
Nd	60	2	8	18	2	6	10	4	2	6			2				
Pm	61	2	8	18	2	6	10	5	2	6			2				
Sm	62	2	8	18	2	6	10	6	2	6			2				
Eu	63	2	8	18	2	6	10	7	2	6			2				
*Gd	64	2	8	18	2	6	10	7	2	6	1		2				
Tb	65	2	8	18	2	6	10	9	2	6			2				
Dy	66	2	8	18	2	6	10	10	2	6			2				
Ho	67	2	8	18	2	6	10	11	2	6			2				
Er	68	2	8	18	2	6	10	12	2	6			2				
Tm	69	2	8	18	2	6	10	13	2	6			2				
Yb	70	2	8	18	2	6	10	14	2	6			2				
Lu	71	2	8	18	2	6	10	14	2	6	1		2				
Hf	72	2	8	18	2	6	10	14	2	6	2		2				
Ta	73	2	8	18	2	6	10	14	2	6	3		2				
W	74	2	8	18	2	6	10	14	2	6	4		2				
Re	75	2	8	18	2	6	10	14	2	6	5		2				
Os	76	2	8	18	2	6	10	14	2	6	6		2				
Ir	77	2	8	18	2	6	10	14	2	6	7		2				
*Pt	78	2	8	18	32	2	6	9		1			1				
*Au	79	2	8	18	32	2	6	10		1			1				
Hg	80	2	8	18	32	2	6	10		2			2				
Tl	81	2	8	18	32	2	6	10		2	1		2	1			
Pb	82	2	8	18	32	2	6	10		2	2		2	2			
Bi	83	2	8	18	32	2	6	10		2	3		2	3			
Po	84	2	8	18	32	2	6	10		2	4		2	4			
At	85	2	8	18	32	2	6	10		2	5		2	5			
Rn	86	2	8	18	32	2	6	10		2	6		2	6			
Fr	87	2	8	18	32	2	6	10		2	6		2	6			
Ra	88	2	8	18	32	2	6	10		2	6		2	6			1
*Ac	89	2	8	18	32	2	6	10		2	6		2	6			2
*Th	90	2	8	18	32	2	6	10	0	2	6	0	2	6	1		2
*Pa	91	2	8	18	32	2	6	10	2	2	6	2	2	6	2		2
*U	92	2	8	18	32	2	6	10	3	2	6	3	2	6	1		2
Np	93	2	8	18	32	2	6	10	5	2	6	5	2	6	1		2
Pu	94	2	8	18	32	2	6	10	6	2	6	6	2	6	1		2
Am	95	2	8	18	32	2	6	10	7	2	6	7	2	6			2
*Cm	96	2	8	18	32	2	6	10	7	2	6	7	2	6			2
*Bk	97	2	8	18	32	2	6	10	8	2	6	8	2	6	1		2
Cf	98	2	8	18	32	2	6	10	10	2	6	10	2	6	1		2
Fs	99	2	8	18	32	2	6	10	11	2	6	11	2	6			2
Fm	100	2	8	18	32	2	6	10	12	2	6	12	2	6			2
Md	101	2	8	18	32	2	6	10	13	2	6	13	2	6			2
No	102	2	8	18	32	2	6	10	14	2	6	14	2	6			2
*Lw	103	2	8	18	32	2	6	10	14	2	6	14	2	6			2
Ku	104	2	8	18	32	2	6	10	14	2	6	14	2	6	1		2
Ha	105	2	8	18	32	2	6	10	14	2	6	14	2	6	2		2

Example Based on**Aufbau rule and e^- configuration****Example. 33**

For a given value of n (principal quantum number), the energy of different subshells can be arranged in the order of :

- (A) $f > d > p > s$ (B) $s > p < d > f$
 (C) $f > p > d > s$ (D) $s > f > p > d$

Solution. (A)

It is the rule

Example. 34

Correct set of four quantum numbers for the outermost electron of rubidium ($Z = 37$) is :

- (A) 5, 0, 0, $1/2$ (B) 5, 1, 0, $1/2$
 (C) 5, 1, 1, $1/2$ (D) 6, 0, 0, $1/2$

Solution. (A)

Its configuration is $5s^1$

Example. 35

The order of increasing energies of the orbitals follows :

- (A) 3s, 3p, 4s, 3d, 4p (B) 3s, 3p, 3d, 4s, 4p
 (C) 3s, 3p, 4s, 4p, 3d (D) 3s, 3p, 3d, 4p, 4s

Solution. (A)

Follow $(n + l)$ rule

Example. 36

The total spin resulting from a d^7 configuration is

- (A) $3/2$ (B) $1/2$
 (C) 2 (D) 1.

Solution. (A)

For d^7 , three unpaired electrons, $\text{spin} = 3 \times \frac{1}{2} = \frac{3}{2}$

Example. 37

Calculate total spin, magnetic for the atoms having at no. 7, 24, 34 and 36.

Solution.

The electronic configuration are

${}^7\text{N} : 1s^2, 2s^2 2p^3$ Unpaired electron = 3

${}^{24}\text{Cr} : 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^5, 4s^1$ unpaired electron = 6

${}^{34}\text{Se} : 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^4$ unpaired electron = 2

${}^{36}\text{Kr} : 1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^6$ unpaired electron = 0

\therefore Total spin for an atom = $\pm 1/2 \times$ no. of unpaired electron

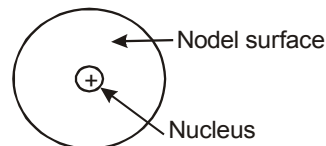
For ${}^7\text{N}$, it is = $\pm 3/2$; For ${}^{24}\text{Cr}$, it is = ± 3

For ${}^{34}\text{Se}$, it is = ± 1 ; For ${}^{36}\text{Kr}$, it is = 0

Also magnetic moment = $\sqrt{n(n+2)}$ Bohr magneton

For ${}^7\text{N}$, it is = $\sqrt{(15)}$; For ${}^{24}\text{Cr}$, it is = $\sqrt{(48)}$

For ${}^{34}\text{Se}$, it is = $\sqrt{(8)}$

24. SOME IMPORTANT DEFINITIONS**Nodal Surface :**

- (a) The place find in between two 's' orbitals where the value of electron density is equal to zero called **Nodal Surface**
 (b) The number of Nodal surfaces in an atom = $(n - 1)$, where 'n' is the number of total shell in an atom.

Nodal Plane :

The place for 'p' and 'd' orbitals where the value of electron density is equal to zero called

Nodal Plane.

For $p_x = yz$
 $p_y = xz$
 $p_z = xy$
 For $d_{xy} = yz, zx$
 $d_{yz} = xy, xz$
 $d_{x^2-y^2} = 0$
 $d_{zx} = xy, yz$
 $d_{z^2} = 0$

Nodal Point :

The nucleus of an atom called **Nodal Point**.

Isodiapheres :

The elements which have same value of $(n - p)$ is called **Isodiapheres**.

eg. ${}^7\text{N}^{14} {}^8\text{O}^{16}$
 Values of $(n - p)$ 0 0

Isotone :

Elements which contain same no. of neutron is called **Isotone**.

eg. ${}^{14}\text{Si}^{30}$ ${}^{15}\text{P}^{31}$ ${}^{16}\text{S}^{32}$
 number of neutrons 16 16 16

Isotopes :

- (a) First proposed by soddy.
 (b) The isotopes have same atomic number but different atomic weight.
 (c) They have same chemical properties because they have same atomic number.
 (d) They have different physical properties because they have different atomic masses.

eg.	${}^1\text{H}^1$	${}^1\text{H}^2$	${}^1\text{H}^3$
	Protonium	deuterium	Tritium
Z =	1	1	1
A =	1	2	3

◆ **Isobar :**

The two different atoms which have same atomic masses but different atomic number is called as **Isobar**.

eg.	${}_{18}\text{Ar}^{40}$	${}_{19}\text{K}^{40}$	${}_{20}\text{Ca}^{40}$
Atomic mass	40	40	40
Atomic number	18	19	20

◆ **Isomorphous :**

The two different type of compound which contain same crystalline structure called **Isomorphous** and this property called **Isomorphism**.

eg.	(a) $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ (Green vitriol)	Hepta hydrate Ferrous sulphate
	(b) $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (White vitriol)	Hepta hydrate Zinc Sulphate

◆ **Isomers :**

Species which have same molecular formula but different structural formula is called Isomer and this type of property is called Isomerism.

eg. $\text{C}_2\text{H}_6\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \text{ \& \ } \text{CH}_3\text{-O-CH}_3$

◆ **Isoelectronic :**

Ion or atom or molecule or species which have the same number of electron is called Isoelectronic species.

eg.	${}_{17}\text{Cl}^-$	${}_{18}\text{Ar}$	${}_{19}\text{K}^+$	${}_{20}\text{Ca}^{+2}$
No. of electron	18	18	18	18
eg.	$\text{CN}^- \text{ \& \ } \text{CO}$			
No. of electron	14	14		

◆ **Isosters :**

Substance which have same number of electron and atoms called Isosters.

eg.	CO_2	N_2O
No. of electron	22	22

◆ **Kernel :**

Orbit which present after removing the outer most orbit of that atom is called kernel and electrons which is present that orbit called kernel electrons.

eg. $\text{Mg} = 1s^2 2s^2 2p^6, 3s^2$
Total kernel electron = $2 + 2 + 6 = 10$

◆ **Core :**

(a) The outer most shell of an any atom called **Core** and the number of electron present of that shell is called **Core electron**.

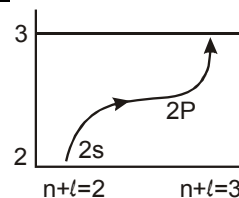
eg. $\text{Cl} = 1s^2 2s^2 2p^6 3s^2 3p^5$
Core electron = $2 + 5 = 7$

(b) If the core is unstable for an atom then that atom shows variable valency.

NOTE

When an electron is in the stationary state then the value of magnetic field for that electron is equal to zero.

◆ **Promotion :**



The transfer of electron between subshells in an orbit is called promotion. While the transfer of one energy level to another is called transition. After the completion of promotion the transition process is occurred.

eg. First promotion of an electron is 2s ($n + \ell = 2 + 0 = 2$) to 2p ($n + \ell = 2 + 1 = 3$) sub-shell and their transition to 2nd orbit to 3rd orbit or 2p to 3s.

◆ **Radial and angular functions :**

Schrodinger wave equation can be written in terms of polar coordinates as

$$\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \frac{\partial \Psi}{\partial r} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \Psi}{\partial \phi^2} + \frac{1}{r^2} \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \Psi}{\partial \theta} \right) + \frac{8\pi^2 m}{h^2} (E - V) \Psi = 0$$

The solution of this is of the form

$$y = R(r) \cdot \Theta(\theta) \cdot \Phi(\phi) \quad \dots (i)$$

$R(r)$ is a function that depends on the distance from the nucleus, which in turn depends on the quantum numbers n and ℓ .

q (q) is a function of q , which depends on the quantum number ℓ and m

f (f) is a function f , which depends only on the quantum number m

Equation (i) may be rewritten as

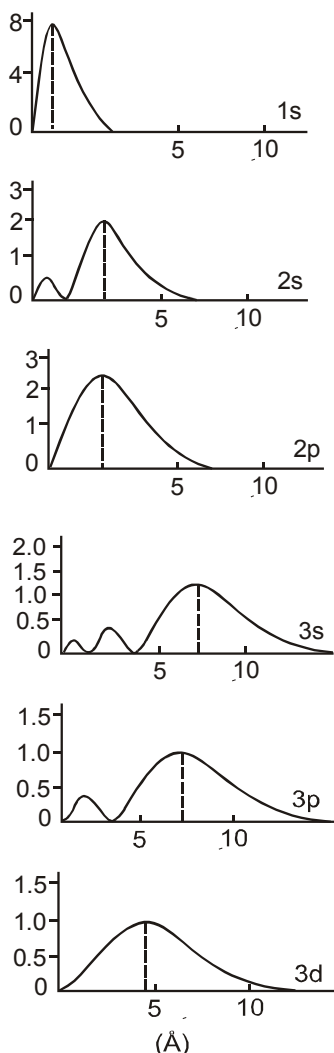
$$y = R(r)_{nl} \cdot A_{ml}$$

This splits the wave function into two parts which can be solved separately :

(i) $R(r)$ the radial function which depends on the quantum number n and ℓ .

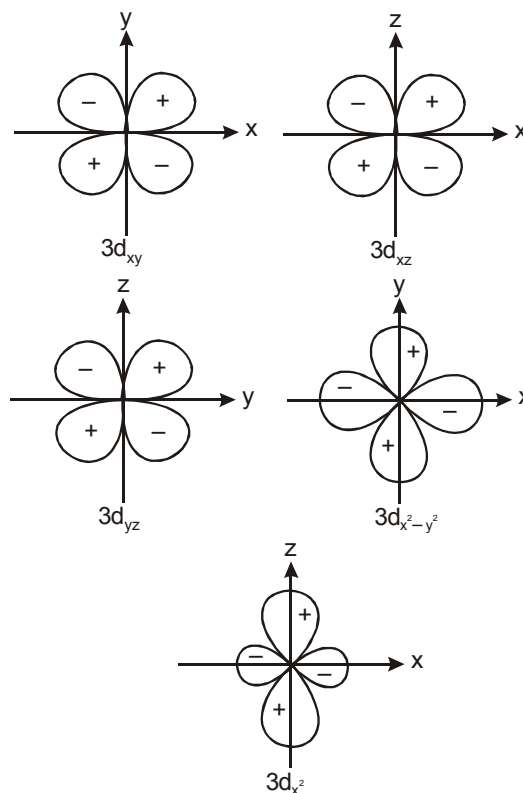
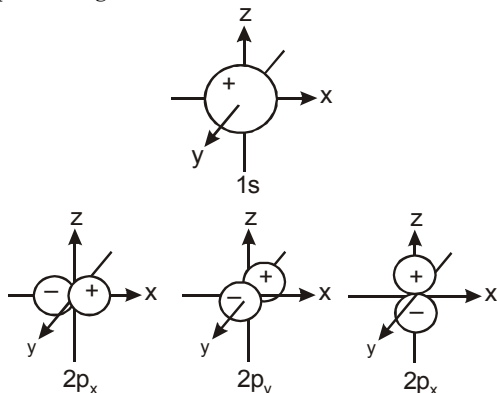
(ii) A_{ml} the total angular wave function, which depends on the quantum numbers m and ℓ .

The radial function R has no physical meaning but R^2 gives the probability of finding the electron in a small volume dv near the point at which R is measured. For a given value of r the number of small volumes is $4\pi r^2$, so the probability of the electron being at a distance r from the nucleus is $4\pi r^2 R^2$. This is called as radial distribution function for hydrogen its graph are as follows.



Radial distribution functions for various orbitals in the hydrogen atom.

The angular function A depends only on the direction and is independent of the distance from the nucleus (r). Thus A^2 is the probability of finding an electron at a given direction θ . This is plotted as polar diagram as shown below



Boundary surface for the angular part of the wave function

$A(\theta, \phi)$ for the 1s, 2p and 3d orbitals for a hydrogen atom shown as polar diagrams.

These polar diagrams do not represent the total wave function ψ but only the angular part of the wave function. These diagrams are commonly used to illustrate the overlap of orbitals giving bonding between atoms. Basically for bonding, like signs must overlap.



Points to Remember

1. The wave character is of no significance in case of large objects like cricket ball, a car, a train etc.
2. The most important applications of de-Broglie concept is in the construction of electron microscope and the study of surface structure of solids by electron diffraction.
3. Smaller the wavelength of the electron wave, more is the resolving power of the electron microscope.
4. Uncertainty in measurement is not due to lack of any experimental technique but due to nature of subatomic particle itself.
5. Shapes of orbitals are functional representation of mathematical solutions of Schrodinger equations. They do not represent any picture of electric charge or matter.

SOLVED EXAMPLES

Ex.1 The ratio of the wave lengths of last lines of Balmer and Lyman series is -

- (A) 4 : 1 (B) 27 : 5
(C) 3 : 1 (D) 9 : 4

Sol.(A) The wave length of a spectral line may be given by the following expression

$$\frac{1}{\lambda} = R \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

For Lyman series $n_1 = 1$, For Balmer series $n_1 = 2$

For the last line in both the series $n_2 = \infty$

For Lyman series

$$\frac{1}{\lambda_L} = R \left(1 - \frac{1}{\infty} \right) = R (1 - 0) = R$$

$$\lambda_L = \frac{1}{R}$$

For Balmer series

$$\frac{1}{\lambda_B} = R \left(\frac{1}{4} - \frac{1}{\infty} \right) = \frac{R}{4}$$

$$\lambda_B = \frac{4}{R}$$

$$\frac{\lambda_B}{\lambda_L} = \frac{4}{R} \times \frac{R}{1} = \frac{4}{1}$$

Ex.2 Consider an electron which is brought close to the nucleus of the atom from an infinite distance, the energy of the electron-nucleus system -

- (A) increases (B) decreases
(C) remains same (D) none of these

Sol.(B) The energy (P.E.) of the electron is a function of its distance from the nucleus and is given by Coulomb's law as

$$\text{P.E.} = - \frac{e^2}{r}$$

Total energy = K.E. + P.E.

$$= \frac{1}{2} mv^2 - \frac{e^2}{r} \left(\frac{1}{2} mv^2 = \frac{e^2}{2r} \right) = - \frac{e^2}{2r}$$

as 'r' decreases energy will go on decreasing.

Ex.3 Using arbitrary energy units we can calculate that 864 arbitrary units (a.u.) are required to transfer an electron in hydrogen atom from the most stable Bohr's orbit to the largest distance from the nucleus -

$$n = \infty \quad E = 0 \text{ Arbitrary units}$$

$$n = 4$$

$$n = 3$$

$$n = 2$$

$$n = 1$$

$$E = -864 \text{ Arbitrary units}$$

The energy required to transfer the electron from third Bohr's orbit to the orbit $n = \infty$ will be -

- (A) 96 Arbitrary units
(B) 192 Arbitrary units
(C) 288 Arbitrary units
(D) 384 Arbitrary units

Sol.(A) The energy of first Bohr's orbit of H-atom

$$= - \frac{2\pi^2 me^4}{h^2} = -864$$

The energy of third Bohr's orbit of H atom

$$= - \frac{2\pi^2 me^4}{h^2} \times \frac{1}{3^2} = -864 \times \frac{1}{9}$$

$$= -96 \text{ Arbitrary units}$$

Energy required to separate the electron

$$= E_\infty - E_n$$

$$= 0 - (-96)$$

$$= 96 \text{ Arbitrary units}$$

Ex.4 In an electronic transition, the wavelength of a spectral line is inversely related to -

- (A) The nuclear charge of the atom
(B) The difference in energy levels
(C) The velocity of electron
(D) The number of orbitals involved in transition

Sol.(A)
$$\frac{1}{\lambda} = \frac{2\pi^2 me^4 Z^2}{ch^3 (4\pi\epsilon_0)^2} = \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$$\lambda \propto \frac{1}{Z^2}$$

Ex.5 The ratio of time periods in first and second orbits of hydrogen atom is -

- (A) 1 : 4 (B) 1 : 8 (C) 1 : 2 (D) 2 : 1

Sol.(B) Time period in first orbit (T_1) = $\frac{2\pi r_1}{v_1}$

Time period in second orbit (T_2) = $\frac{2\pi r_2}{v_2}$

$$\frac{T_1}{T_2} = \frac{2\pi r_1}{v_1} \times \frac{v_2}{2\pi r_2}$$

$$= \frac{r_1}{r_2} \times \frac{v_2}{v_1}$$

Velocity of electron in first orbit

$$= \frac{2.188 \times 10^8}{1} \text{ cm s}^{-1}$$

Velocity of electron in second orbit

$$= \frac{2.188 \times 10^8}{2} \text{ cm s}^{-1}$$

Radius of first orbit

$$= 0.528 \times 10^{-8} \text{ cm}$$

Radius of second orbit

$$= 0.528 \times 10^{-8} \times 4 \text{ cm}$$

$$\frac{T_1}{T_2} = \frac{0.528 \times 10^{-8}}{0.528 \times 10^{-8} \times 4} \times \frac{2.188 \times 10^{-8}}{2 \times 2.188 \times 10^{-8}} = \frac{1}{8}$$

- Ex.6** In a hydrogen atom, the largest amount of energy will be required in -
 (A) $n_2 \rightarrow n_3$ transition
 (B) $n_\infty \rightarrow n_1$ transition
 (C) $n_1 \rightarrow n_2$ transition
 (D) $n_3 \rightarrow n_5$ transition

Sol.(C) $E_n = \frac{2\pi^2 me^4}{n^2 h^2 (4\pi\epsilon_0)^2}$ and

$$\Delta E = -\frac{2\pi^2 me^4}{h^2 (4\pi\epsilon_0)^2} \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

- Ex.7** The ion that is isoelectronic with CO is -
 (A) CN^- (B) O_2^+ (C) O_2^- (D) N_2^+

Sol.(A) $\text{CO } 6 + 8 = 14$
 $\text{CN}^- 6 + 7 + 1 = 14$
 $\text{O}_2^+ 8 \times 2 - 1 = 15$
 $\text{O}_2^- 8 \times 2 + 1 = 17$
 $\text{N}_2^+ 7 \times 2 - 1 = 13$

- Ex.8** Of the following, which of the statement(s) regarding Bohr theory is/are correct ?
 (A) Kinetic energy of an electron is half of the magnitude of its potential energy
 (B) Kinetic energy of an electron is negative of total energy of electron
 (C) Energy of electron decreases with increase in the value of principal quantum number
 (D) The ionization energy of H-atom in the first excited state is the negative of one fourth of the energy of an electron in the ground state

Sol.(A,B,D)

The energy of an electron in H-like atoms is given by

$$E = \text{K.E.} + \text{P.E.}$$

$$= \frac{1}{2} mv^2 - \frac{Ze^2}{(4\pi\epsilon_0)r}$$

From the stability of the circular motion of electron, we have

$$\frac{mv^2}{r} = \frac{Ze^2}{(4\pi\epsilon_0)r^2};$$

$$\text{Hence } E = \frac{1}{2} \frac{Ze^2}{(4\pi\epsilon_0)r} - \frac{Ze^2}{(4\pi\epsilon_0)r}$$

$$\text{or } E = -\frac{1}{2} \frac{Ze^2}{(4\pi\epsilon_0)r}$$

- Ex.9** An element with atomic mass Z consists of two isotopes of mass number $Z-1$ and $Z+2$. The percentage abundance of the heavier isotope is-

- (A) 0.25 (B) 33.3
 (C) 66.6 (D) 75

Sol.(B) $Z = \frac{(Z-1)x + (Z+2)(100-x)}{100}$

- Ex.10** Frequency ratio between violet (400 nm) and red (750 nm) radiations in the visible spectrum, is -

- (A) 8/15 (B) 4/15
 (C) 15/8 (D) None of these

Sol.(C) $v = \frac{c}{\lambda}$

For violet (400 nm) $v_1 = \frac{c}{400 \times 10^{-9}}$

For red (750 nm) $v_2 = \frac{c}{750 \times 10^{-9}}$

$$\frac{v_1}{v_2} = \frac{750}{400} = \frac{15}{8}$$

- Ex.11** The orbital angular momentum of an electron in 2s orbital is -

- (A) $+\frac{1}{2} \frac{h}{2\pi}$ (B) zero
 (C) $\frac{h}{2\pi}$ (D) $\sqrt{2} \frac{h}{2\pi}$

Sol.(B) orbital angular momentum = $\sqrt{\ell(\ell+1)} \frac{h}{2\pi}$

$$\sqrt{\ell(\ell+1)} = h \text{ for S-orbital } \ell = 0$$

So orbital angular momentum is zero.

- Ex.12** The sub-shell that comes after f-sub-shell is called g-sub-shell. The number of g-sub orbitals in g-sub-shell and the total number of orbitals in the principal orbital respectively are-

- (A) 10 and 25 (B) 9 and 25
 (C) 11 and 23 (D) 15 and 45

Sol.(B) For a g-subshell : $n = 5$ and $\ell = 4$

$$\text{Number of orbitals g-subshell} = (2\ell + 1) = 9$$

$$\text{Total number of orbitals in atom} = n^2 = (5)^2 = 25$$

- Ex.13** Two isotopes of Boron are found in the nature with atomic weights 10.01(I) and 11.01 (II). The atomic weight of natural Boron is 10.81. The percentage of (I) and (II) isotopes in it are respectively -

- (A) 20 and 80 (B) 10 and 90
 (C) 15 and 75 (D) 30 and 70

- Sol.(A)** Let $x\%$ of I (10.01) is mixed with II (11.01) and the atomic weight become 10.81. Then

$$\frac{(10.01)x + (11.01)(100-x)}{100} = 10.81$$

$$10.01x - 11.01 \times + 1101 = 10.81 \times 100$$

$$\text{or } -x = 1081 - 1101$$

$$\text{or } -x = -20$$

$$\therefore x = 20$$

So ratio = 20% and 100 - 20 = 80%

Ex.14 For a d-electron, the orbital angular momentum is -

- (A) $\sqrt{6} h/2\pi$ (B) $\sqrt{2} h/2\pi$
 (C) $h/2\pi$ (D) $2.h/2\pi$

Sol.(A) Angular momentum L is given by

$$L = \sqrt{\ell(\ell+1)} \cdot \frac{h}{2\pi}$$

For d-orbital, $\ell = 2$, so

$$L = \sqrt{2(2+1)} \frac{h}{2\pi} = \sqrt{6} \frac{h}{2\pi}$$

Ex.15 The energy of the emitted photon when an electron in Be^{3+} ion returns from $n = 2$ level to ground state is -

- (A) $2.616 \times 10^{-17} \text{ J}$ (B) $26.16 \times 10^{-17} \text{ J}$
 (C) $216.6 \times 10^{-17} \text{ J}$ (D) $2616 \times 10^{-17} \text{ J}$

Sol.(A)
$$\frac{1}{\lambda} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

Ex.16 Calculate the wave-number of lines having the frequency of 5×10^{16} cycles per sec -

Sol. Given $c = 3 \times 10^8 \text{ m/sec}$
 $v = 5 \times 10^{16} \text{ cycles/sec}$
 $= ?$

We know that

$$\bar{\nu} = \frac{v}{c} = \frac{5 \times 10^{16}}{3 \times 10^8} = 1.666 \times 10^8 \text{ m}^{-1}$$

Ex.17 The minimum energy necessary to overcome the attractive forces between the electron and the surface of silver metal is $7.52 \times 10^{-19} \text{ J}$. What will be the maximum kinetic energy of the electrons ejected from silver metal which is being irradiated with uv light having a wavelength of 360 \AA .

Sol. K.E. = $h\nu - h\nu_0$

$$\text{K.E.} = \frac{hc}{\lambda} - h\nu_0$$

$$\text{K.E.} = \frac{(6.63 \times 10^{-34} \text{ Jsec})(3 \times 10^8 \text{ m/sec})}{3.60 \times 10^{-8} \text{ m}} - 7.52 \times 10^{-19} \text{ J}$$

$$= 4.77 \times 10^{-18} \text{ J}$$

Ex.18 The energy of the electron in the second and third Bohr orbits of the hydrogen atom is $-5.42 \times 10^{-12} \text{ ergs}$ and $-2.41 \times 10^{-12} \text{ ergs}$ respectively. calculate the wavelength of the emitted radiation when the electron drops from third to second orbit.

Sol. Here, $h = 6.62 \times 10^{-27} \text{ ergs}$

$$E_3 = -2.41 \times 10^{-12} \text{ ergs}$$

$$E_2 = -5.42 \times 10^{-12} \text{ ergs}$$

$$\therefore \Delta E = E_3 - E_2$$

$$= -2.41 \times 10^{-12} + 5.42 \times 10^{-12}$$

$$= 3.01 \times 10^{-12} \text{ ergs}$$

Now we know that, $\Delta E = h\nu$

$$\therefore \nu = \frac{\Delta E}{h} = \frac{3.01 \times 10^{-12}}{6.62 \times 10^{-27}}$$

$$= \frac{3.01}{6.62} \times 10^{15} \text{ cycles/sec}$$

But $\nu = \frac{c}{\lambda} \quad \therefore \lambda = \frac{c}{\nu}$

$$\text{or } \lambda = \frac{3 \times 10^{10} \times 6.62}{3.01 \times 10^{15}} = 6.6 \times 10^{-5} \text{ cm}$$

Since $1 \text{ \AA} = 10^{-8} \text{ cm}$

$$\therefore \lambda = \frac{6.6 \times 10^{-5}}{10^{-8}} = 6.6 \times 10^3 \text{ \AA}$$

Ex.19 Calculate the velocity (cm/sec.) of an electron placed in the third orbit of the hydrogen atom. Also calculate the number of revolutions per second that this electron makes around the nucleus.

Sol. Radius of 3rd orbit
 $= 3^2 \times 0.529 \times 10^{-8} = 4.761 \times 10^{-8} \text{ cm}$
 We know that

$$mvr = \frac{nh}{2\pi} \quad \text{or} \quad v = \frac{nh}{2\pi mr}$$

$$= \frac{3 \times 6.624 \times 10^{-27}}{2 \times 3.14 \times (9.108 \times 10^{-28}) \times (4.761 \times 10^{-8})}$$

$$= 0.729 \times 10^8 \text{ cm/sec}$$

$$\text{Time taken for one revolution} = \frac{2\pi r}{v}$$

Number of revolutions per second

$$= \frac{1}{\frac{2\pi r}{v}} = \frac{v}{2\pi r} = \frac{0.729 \times 10^8}{2 \times 3.14 \times 4.716 \times 10^{-8}}$$

$$= 2.4 \times 10^{14} \text{ revolutions/sec}$$

Ex.20 (a) Neglecting reduced-mass defects, what possible transition in the He^+ spectrum would have the same wavelength as the first Lyman transition of hydrogen ($n = 2$ to $n = 1$) ? (b) What is the radius of the first Bohr orbit of He^+ ?

Sol. (a) He^+ has only one electron, hence it can be classified as a hydrogen like species with $Z = 2$, and the Bohr equation may thus be applied.

$$\bar{\nu} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

The first Lyman transition for hydrogen ($Z = 1$) would be given by.

$$\bar{\nu} = R \left(\frac{1}{1^2} - \frac{1}{2^2} \right)$$

Since the reduced mass defect is neglected, the R for He^+ is same as for ^1H , the Z^2 term can be compensate by increasing n_1 to $2n_2$ and 4, i.e.

$$\bar{v} = RZ^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) = R(2^2) \left(\frac{1}{2^2} - \frac{1}{4^2} \right)$$

The transition in question is thus the transition from $n = 4$ to $n = 2$.

- (b) The radii of the Bohr's orbit of He^+ may be determined by the following relation

$$r = \frac{n^2}{Z} r_0$$

$$\text{Thus } r = \frac{1^2 \times 0.529}{2} = 0.264 \text{ \AA}$$

$$(\therefore r_0 = 0.529 \text{ \AA})$$

Ex.21 A neutral atom has 2K, 8L, 5M electrons. Find out the following from the data : (a) atomic number, (b) total number of s electrons, (c) total number of p electrons, (d) number of protons in the nucleus, and (e) valency of element.

- Sol.** (a) Atomic number = No. of protons = No. of electrons
Total number of electrons = $2 + 8 + 5 = 15$
Hence atomic number = 15
- (b) Total number of s electrons. To find out it, we are to write electronic configuration of At. No. = 15
 $1s^2, 2s^2, 2p^6, 3s^2, 3p^3$
 \therefore Total s electron = 6
- (c) Total number of p electrons = 9
- (d) No. of protons in the nucleus = No. of electrons in extra-nuclear part
 \therefore Number of protons = 15
- (e) Valency. The arrangement of electrons in orbits is 2, 8, 5. As the atom tends to gain three electrons, therefore it is trivalent electronegative (-3).

Ex.22 Find the number of quanta of radiations of frequency $4.67 \times 10^{13} \text{ s}^{-1}$ that must be absorbed in order to melt 5g of ice. The energy required to melt 1g of ice is 333 J.

- Sol.** Energy required to melt 5g of ice
 $= 5 \times 333 = 1665 \text{ J}$
Energy associated with one quantum
 $= h\nu = (6.62 \times 10^{-34}) \times (4.67 \times 10^{13})$
 $= 30.91 \times 10^{-21} \text{ J}$
Number of quanta required to melt 5 g of ice
 $= \frac{1665}{30.91 \times 10^{-21}} = 53.8 \times 10^{21} = 5.38 \times 10^{22}$

Ex.23 Applying de Broglie's equation, calculate the wavelength associated with the motion of the earth, a stone and an electron, the masses and velocities of which are given below.

Mass of earth = $6 \times 10^{27} \text{ g} = 6 \times 10^{24} \text{ kg}$

Mass of stone = $100 \text{ g} = 0.1 \text{ kg}$

Mass of electron = $10^{-27} \text{ g} = 10^{-30} \text{ kg}$

Velocity of orbital motion of the earth

$$= 3 \times 10^6 \text{ cm sec}^{-1} = 3 \times 10^4 \text{ m s}^{-1}$$

Velocity of stone = $100 \text{ cm sec}^{-1} = 1.0 \text{ ms}^{-1}$

Velocity of electron = $6 \times 10^7 \text{ cm sec}^{-1}$

$$= 6 \times 10^5 \text{ m s}^{-1}$$

$$h = 6.6 \times 10^{-27} \text{ erg-sec} = 6.6 \times 10^{-34} \text{ Js}$$

In case of which of these three objects, will the wavelength be measurable ?

Sol. Substituting the value of h , m and u of the three cases in the de Broglie relationship.

(a) In case of earth, $\lambda = \frac{h}{mv}$

$$\lambda = \frac{6.6 \times 10^{-34}}{(6 \times 10^{24}) \times (3 \times 10^4)} = 3.67 \times 10^{-63} \text{ m}$$

(b) In case of stone, $\lambda = \frac{6.6 \times 10^{-34}}{(0.1)(1.0)}$

$$= 6.6 \times 10^{-33} \text{ m}$$

(c) In case of the electron, λ

$$= \frac{6.6 \times 10^{-34}}{(10^{-30})(6 \times 10^5)}$$

$$= 1.1 \times 10^{-9} \text{ m}$$

The wavelength is measurable in case of electron.

Ex.24 Show that de Broglie's hypothesis applied to an electron moving in a circular orbit leads to Bohr's postulate of quantized angular momentum.

Sol. An electron in a circular orbit must have its path length equal to an integral number of wavelengths for reinforcement to occur.

Thus, $2\pi r = n\lambda$

$$\lambda = \frac{2\pi r}{n} = \frac{h}{mv} \quad ; \quad mvr = \frac{nh}{2\pi}$$

Ex.25 If the energy difference between two electronic states is $46.12 \text{ kcal mol}^{-1}$. What will be the frequency of the light emitted when the electrons drop from higher to lower states? ($Nh = 9.52 \times 10^{14} \text{ kcal sec mol}^{-1}$, where N is the Avogadro's number and h is the Planck's constant).

Sol. $\Delta E = 46.12 \text{ kcal mol}^{-1}$
According to Bohr's theory, $\Delta E = Nh\nu$

$$\text{or } \nu = \frac{\Delta E}{Nh} = \frac{46.12}{9.52 \times 10^{14}} = 4.48 \times 10^{14} \text{ cycles sec}^{-1}$$

Ex.26 An electron has a speed of $30,000 \text{ cm sec}^{-1}$ accurate upto 0.001%. What is the uncertainty in locating its position.

Sol. $\Delta v = \frac{0.001}{100} \times 30,000$
 $= 0.3 \text{ cm sec}^{-1}$

According to uncertainty principle,

$$\Delta x \cdot \Delta p \approx \frac{h}{4\pi} \quad ; \quad \Delta x \cdot \Delta p \approx \frac{h}{4\pi m}$$

$$\Delta x \times 9.1 \times 10^{-28} \times 0.3 \approx \frac{6.625 \times 10^{-27} \times 7}{4 \times 22}$$

$$\Delta x \approx 1.93 \text{ cm}$$

Ex.27 In the photoelectric effect, an absorbed quantum of light results in the ejection of an electron from the absorber. The K.E. of the ejected electron is equal to the energy of the absorbed photon minus the energy of the longest wavelength photon that causes the effect. Calculate the kinetic energy of the photoelectron produced in cesium by 400 nm light. The critical wavelength for the photoelectric effect in cesium is 660 nm.

Sol. K.E. of electron = $h\nu - h\nu_0$

$$= \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

$$= \frac{1240 \text{ nm.eV}}{400} - \frac{1240 \text{ nm.eV}}{660}$$

$$= 1.22 \text{ eV}$$

Ex.28 Show that the wavelength of a 150 g rubber ball moving with a velocity of 50 m sec^{-1} is short enough to be observed.

Sol. $u = 50 \text{ m sec}^{-1} = 50 \times 10^2 \text{ cm sec}^{-1}$, $m = 150 \text{ g}$
 Putting these values in the relation

$$\lambda = \frac{h}{mu} = \frac{6.625 \times 10^{-27}}{150 \times 50 \times 10^2}$$

$$= 8.83 \times 10^{-33} \text{ cm}$$

Since the above wavelength is much lesser than the wavelength of the visible region, it will not be visible.

Ex.29 On the basis of Heisenberg's uncertainty principle, show that the electron cannot exist within the nucleus.

Sol. Radius of the nucleus is of the order of 10^{-13} cm and thus uncertainty in position of electron i.e. (Δx), if it is within the nucleus will

be 10^{-13} cm . Now $\Delta x \cdot \Delta u \geq \frac{h}{4\pi m}$

$$\therefore \Delta u = \frac{6.626 \times 10^{-27}}{4 \times 3.14 \times 9.108 \times 10^{-28} \times 10^{-13}}$$

$$= 5.79 \times 10^{12} \text{ cm/sec}$$

i.e., order of velocity of electron will be 100 times greater than the velocity of light which is impossible. Thus possibility of electron to exist in nucleus is zero.

EXERCISE (Level-1)

Question based on Sub-Atomic particles and Dalton's atomic theory

- Q.1** Proton is -
(A) Nucleus of deuterium
(B) Ionised hydrogen molecule
(C) Ionised hydrogen atom
(D) An α -particle
- Q.2** Which is not deflected by magnetic field -
(A) Neutron (B) Positron
(C) Proton (D) Electron
- Q.3** According to Dalton's atomic theory, an atom can -
(A) Be created
(B) Be destroyed
(C) take part in a chemical reaction
(D) None of these
- Q.4** Arrange α -particle(α), electron (e^-), proton(p) and neutron (n) in increasing order of their e/m value (specific charge, consider magnitude only not sign) -
(A) $\alpha < e^- < p < n$ (B) $n < \alpha < p < e^-$
(C) $n < p < \alpha < e^-$ (D) $e^- < p < n < \alpha$

Question based on Rutherford's Experiment

- Q.5** Rutherford's alpha particle scattering experiment eventually led to the conclusion that -
(A) mass and energy are related
(B) electrons occupy space around the nucleus
(C) neutrons are buried deep in the nucleus
(D) the point of impact with matter can be precisely determined
- Q.6** Which of the following conclusion could not be derived from Rutherford's α -particle scattering experiment ?
(A) Most of the space in the atom is empty
(B) The radius of the atom is about 10^{-10} m while that of nucleus is 10^{-15} m.
(C) Electrons move in a circular path of fixed energy called orbits
(D) Electrons and the nucleus are held together by electrostatic forces of attraction

Question based on Electromagnetic waves, hydrogen spectra & concept of quantization

- Q.7** The line spectra of two elements are not identical because -
(A) the elements do not have the same number of neutrons
(B) they have different mass number
(C) their outermost electrons are at different energy levels
(D) they have different valencies

- Q.8** A certain radio station broadcasts on a frequency of 980 kHz (kilohertz). What is the wavelength of electromagnetic radiation broadcast by the radio station ?
(A) 306 m (B) 3.06 m
(C) 30.6 m (D) 3060 m
- Q.9** Calculate the wavelength of the spectral line when the electron in the hydrogen atom undergoes a transition from fourth energy level to second energy level ?
(A) 4.86 nm (B) 486 nm
(C) 48.6 nm (D) 4860 nm
- Q.10** The wave number of the first line of Balmer series of hydrogen is 15200 cm^{-1} . The wave number of the corresponding line of Li^{2+} ion is -
(A) 15200 cm^{-1} (B) 60800 cm^{-1}
(C) 76000 cm^{-1} (D) 136800 cm^{-1}
- Q.11** The frequency of one of the lines in Paschen series of a hydrogen atom is $2.34 \times 10^{14} \text{ Hz}$. The higher orbit, n_2 , which produces this transitions is -
(A) three (B) four
(C) six (D) five
- Q.12** In hydrogen spectrum, the series of lines appearing in ultra violet region of electromagnetic spectrum are called -
(A) Lyman lines (B) Balmer lines
(C) Pfund lines (D) Brackett lines
- Q.13** Which of the following series of lines in the atomic spectrum of hydrogen appear in the visible region ?
(A) Lyman (B) Paschen
(C) Brackett (D) Balmer
- Q.14** Which of the following is not correct according to Planck's quantum theory ?
(A) Energy is emitted or absorbed discontinuously
(B) Energy of a quantum is directly proportional to its frequency
(C) A photon is also a quantum of light
(D) Energy less than a quantum can also be emitted or absorbed
- Q.15** To which electronic transition between Bohr orbits in hydrogen, the second line in the Balmer series belongs ?
(A) $3 \rightarrow 2$ (B) $4 \rightarrow 2$
(C) $5 \rightarrow 2$ (D) $6 \rightarrow 2$

Question based on

Bohr's atomic model

- Q.16** The ratio of the radii of first three Bohr orbits is
(A) 1 : 05 : 3 (B) 1 : 2 : 3
(C) 1 : 4 : 9 (D) 1 : 8 : 27
- Q.17** The ionization energy of per mole of hydrogen atom in terms of Rydberg constant (R_H) is given by the expression -
(A) $R_H hc$ (B) $R_H c$
(C) $2 R_H hc$ (D) $R_H N_A hc$
- Q.18** The frequency of first line of Balmer series in hydrogen atom is ν_0 . The frequency of corresponding line emitted by singly ionised helium atom is -
(A) $2\nu_0$ (B) $4\nu_0$
(C) $\nu_0/2$ (D) $\nu_0/4$
- Q.19** Energy of third orbit of Bohr's atom is -
(A) - 13.6 eV
(B) - 3.4 eV
(C) - 1.51 eV
(D) None of the three
- Q.20** If the radius of first Bohr orbit be a_0 , then the radius of the third orbit would be -
(A) $3 \times a_0$ (B) $6 \times a_0$
(C) $9 \times a_0$ (D) $1/9 \times a_0$
- Q.21** In H-atom electron jumps from 3rd to 2nd energy level, the energy released is -
(A) $3.03 \times 10^{-19} \text{ J/atom}$
(B) $1.03 \times 10^{-19} \text{ J/atom}$
(C) $3.03 \times 10^{-12} \text{ J/atom}$
(D) $6.06 \times 10^{-19} \text{ J/atom}$
- Q.22** The ratio of ionization energy of H and Be^{+3} is-
(A) 1 : 1 (B) 1 : 3
(C) 1 : 9 (D) 1 : 16
- Q.23** The ionization energy of hydrogen atom (in the ground state) is x kJ. The energy required for an electron to jump from 2nd orbit to the 3rd orbit will be -
(A) $x/6$ (B) $5x$
(C) $7.2x$ (D) $5x/36$
- Q.24** In two H atoms X and Y 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

Question based on

Photoelectric effect, Dual Nature of electron & Heisenberg's uncertainty principle

- Q.25** If threshold wavelength (λ_0) for ejection of electron from metal is 330 nm, then work function for the photoelectric emission is -
(A) $1.2 \times 10^{-18} \text{ J}$ (B) $1.2 \times 10^{-20} \text{ J}$
(C) $6 \times 10^{-19} \text{ J}$ (D) $6 \times 10^{-12} \text{ J}$
- Q.26** The kinetic energy of the electron emitted when light of frequency $3.5 \times 10^{15} \text{ Hz}$ falls on a metal surface having threshold frequency $1.5 \times 10^{15} \text{ Hz}$ is ($h = 6.6 \times 10^{-34} \text{ Js}$)
(A) $1.32 \times 10^{-18} \text{ J}$ (B) $3.3 \times 10^{-18} \text{ J}$
(C) $6.6 \times 10^{-19} \text{ J}$ (D) $1.98 \times 10^{-19} \text{ J}$
- Q.27** Light of wavelength λ shines on a metal surface with intensity x and the metal emits y electrons per second of average energy, z . What will happen to y and z if x is doubled?
(A) y will be doubled and z will become half
(B) y will remain same and z will be doubled
(C) both y and z will be doubled
(D) y will be doubled but z will remain same
- Q.28** A 200g cricket ball is thrown with a speed of $3.0 \times 10^3 \text{ cm sec}^{-1}$. What will be its de Broglie's wavelength? [$h = 6.6 \times 10^{-27} \text{ g cm}^2 \text{ sec}^{-1}$]
(A) $1.1 \times 10^{-32} \text{ cm}$ (B) $2.2 \times 10^{-32} \text{ cm}$
(C) $0.55 \times 10^{-32} \text{ cm}$ (D) $11.0 \times 10^{-32} \text{ cm}$
- Q.29** If uncertainty in the position of an electron is zero, the uncertainty in its momentum would be
(A) zero (B) $< h/(4\pi)$
(C) $> h/(4\pi)$ (D) infinite
- Q.30** Heisenberg uncertainty principle states that -
(A) Moving bodies exhibit both particle and wave character
(B) Neither the position nor the momentum of a particle can be precisely determined
(C) Simultaneous determination of position and momentum of a microscopic particle is not possible.
(D) Moving charged particles resemble electromagnetic waves in their behavior
- Q.31** Calculate the uncertainty in velocity of a cricket ball of mass 150 g if the uncertainty in its position is 1 \AA ($h = 6.6 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$)
(A) $3.5 \times 10^{-24} \text{ ms}^{-1}$
(B) $4.5 \times 10^{-24} \text{ ms}^{-1}$
(C) $3.5 \times 10^{-24} \text{ cms}^{-1}$
(D) $4.5 \times 10^{-24} \text{ cms}^{-1}$

Question based on

Schrodinger wave theory, quantum number & shape of orbitals

- Q.32** Which of the following statements is incorrect?
 (A) Probabilities are found by solving Schrodinger wave equation
 (B) Energy of the electron in an atom at infinite distance is zero and yet it is maximum
 (C) Some spectral lines of an element may have the same wave number
 (D) The position and momentum of a rolling ball can be measured accurately
- Q.33** For s-orbitals, since (ψ orbital wave function) is independent of angles, the probability density (ψ^2) is -
 (A) also independent of angles
 (B) spherically symmetric
 (C) both (A) and (B) are correct
 (D) both (A) and (B) are incorrect
- Q.34** With the increasing principal quantum number, the energy difference between adjacent energy levels in H-atom -
 (A) decreases
 (B) increases
 (C) remains constant
 (D) decreases for low value of Z and increases for higher value of Z
- Q.35** How many electrons can fit into the orbitals that comprise the 3rd quantum shell $n = 3$?
 (A) 2 (B) 8
 (C) 18 (D) 32
- Q.36** Which of the following statements concerning the four quantum numbers is false -
 (A) n gives idea of the size of an orbital
 (B) l gives the shape of an orbital
 (C) m_s gives the energy of the electron in the orbital in absence of magnetic field
 (D) m_s gives the direction of spin angular momentum of the electron in an orbital
- Q.37** Which of the following statements is not correct ?
 (A) The shape of an atomic orbital depends on the azimuthal quantum number
 (B) The orientation of an atomic is given by magnetic quantum number
 (C) The energy of an electron in an atomic orbital of multi electron atom depends on the principal quantum number only
 (D) The number of degenerate atomic orbitals of one type depends on the values of azimuthal and magnetic quantum numbers

Question based on

Aufbau rule and e- configuration

- Q.38** The manganese ($Z = 25$) has the outer configuration
- (A) $4s \leftarrow \boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \rightarrow 3d$
- (B) $4s \leftarrow \boxed{\uparrow\downarrow} \quad \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \rightarrow 3d$
- (C) $4s \leftarrow \boxed{\uparrow\downarrow} \quad \boxed{\uparrow\downarrow} \boxed{\uparrow\downarrow} \boxed{\uparrow} \boxed{} \boxed{} \rightarrow 3d$
- (D) $4s \leftarrow \boxed{} \quad \boxed{\uparrow\downarrow} \boxed{\uparrow\downarrow} \boxed{\uparrow} \boxed{\uparrow} \boxed{\uparrow} \rightarrow 3d$
- Q.39** If the electronic structure of oxygen atom is written as $1s^2, 2s^2$ $\overbrace{\boxed{\uparrow\downarrow} \boxed{\uparrow\downarrow} \boxed{}}^{2p}$ it would violate -
 (A) Hund's rule
 (B) Pauli's exclusion principle
 (C) Both Hund's and Pauli's principles
 (D) None of these
- Q.40** A given orbital is labelled by the magnetic quantum number $m = -1$. This can not be -
 (A) s-orbital (B) d-orbital
 (C) p-orbital (D) f-orbital

EXERCISE (Level-2)

- Q.1** What is the maximum number of electrons in an atom that can have the quantum numbers $n = 4, m_l = +1$?
 (A) 4 (B) 15 (C) 3 (D) 6
- Q.2** Arrange the orbitals of H-atom in the increasing order of their energy -
 $3p_x, 2s, 4d_{xy}, 3s, 4p_z, 3p_y, 4s$
 (A) $2s < 3s = 3p_x = 3p_y < 4s = 4p_z = 4d_{xy}$
 (B) $2s < 3s < 3p_x = 3p_y < 4s = 4p_z = 4d_{xy}$
 (C) $2s < 3s < 3p_x = 3p_y < 4s = 4p_z = 4d_{xy}$
 (D) $2s < 3s < 3p_x = 3p_y < 4s < 4p_z < 4d_{xy}$
- Q.3** If the I.P. of Li^{+2} is 122.4 eV. Find out 6th I.P. of carbon -
 (A) $122.4 \times 4\text{eV}$ (B) $122.4 \times 2\text{eV}$
 (C) $122.4 \times 3\text{eV}$ (D) $122.4 \times 5\text{eV}$
- Q.4** The energy difference between two electronic states is 46.12 kcal/mole. What will be the frequency of the light emitted when an electron drops from the higher to the lower energy state (Planck's constant = 9.52×10^{-14} kcal sec mole⁻¹)
 (A) 4.84×10^{15} cycles sec⁻¹
 (B) 4.84×10^{-5} cycles sec⁻¹
 (C) 4.84×10^{-12} cycles sec⁻¹
 (D) 4.84×10^{14} cycles sec⁻¹
- Q.5** If the kinetic energy of an electron is increased 4 times, the wavelength of the de Broglie wave associated with it would become :
 (A) 4 times (B) 2 times
 (C) 1/2 times (D) 1/4 times
- Q.6** Multiple of fine structure of spectral lines is due to-
 (A) Presence of main energy levels
 (B) Presence of sub-levels
 (C) Presence of electronic configuration
 (D) Is not a characteristics of the atom.
- Q.7** Wave mechanical mode of the atom depends upon-
 (A) de-Broglie concept of dual nature of electron
 (B) Heisenberg uncertainty principle
 (C) Schrodinger uncertainty principle
 (D) All
- Q.8** Calculate total no. of e⁻ having $m = 0$ in Cr atom -
 (A) 12 (B) 13 (C) 5 (D) 24
- Q.9** Which of the following subshell can accommodate as many as 10 electrons -
 (A) 2d (B) 3d (C) $3d_{xy}$ (D) $3d_{z^2}$
- Q.10** How many spherical nodes are present in a 4s orbital in hydrogen atom -
 (A) 0 (B) 1 (C) 2 (D) 3
- Q.11** Assuming the velocity to be same which subatomic particle possesses smallest de-Broglie wavelength -
 (A) An electron
 (B) A proton
 (C) An α -particle
 (D) All have same wavelength
- Q.12** I.P. of hydrogen atom is equal to 13.6 eV. What is the energy required for the process :
 $\text{He}^+ + \text{energy} \longrightarrow \text{He}^{+2} + \text{e}^-$
 (A) 2×13.6 eV (B) 1×13.6 eV
 (C) 4×13.6 eV (D) None of these
- Q.13** If elements with principal quantum number $n > 4$ is not allowed in nature, the number of possible elements would be -
 (A) 60 (B) 32 (C) 64 (D) 50
- Q.14** If the value of $(n + l)$ is not > 3 , then the maximum number of electrons in all the orbitals would be -
 (A) 12 (B) 10 (C) 2 (D) 6
- Q.15** It is not possible to explain the Pauli's exclusion principle with the help of this atom -
 (A) B (B) Be (C) C (D) H
- Q.16** How fast is an electron moving if it has a wavelength equal to the distance it travels in one second -
 (A) $\sqrt{\frac{h}{m}}$ (B) $\sqrt{\frac{m}{h}}$ (C) $\sqrt{\frac{h}{p}}$ (D) $\sqrt{\frac{h}{2(\text{KE})}}$
- Q.17** An atom has a mass of 0.02 kg & uncertainty in its velocity is 9.218×10^{-6} m/s then uncertainty in position is
 ($h = 6.626 \times 10^{-34}$ J - s)
 (A) 2.86×10^{-28} m (B) 2.86×10^{-32} cm
 (C) 1.5×10^{-27} m (D) 3.9×10^{-10} m
- Q.18** Energy of H-atom in the ground state is -13.6 eV, Hence energy in the second excited state is -
 (A) -6.8 eV (B) -3.4 eV
 (C) -1.51 eV (D) -4.3 eV
- Q.19** Uncertainty in position of a particle of 25 g in space is 10^{-5} m. Hence uncertainty in velocity (ms^{-1}) is (Planck's constant $h = 6.6 \times 10^{-34}$ Js)
 (A) 2.1×10^{-28} (B) 2.1×10^{-34}
 (C) 0.5×10^{-34} (D) 5.0×10^{-24}
- Q.20** The orbital angular momentum for an electron revolving in an orbit is given by $\sqrt{\ell(\ell+1)} \cdot \frac{h}{2\pi}$. This momentum for an s-electron will be given by
 (A) $\frac{h}{2\pi}$ (B) $\sqrt{2} \cdot \frac{h}{2\pi}$
 (C) $+\frac{1}{2} \cdot \frac{h}{2\pi}$ (D) zero

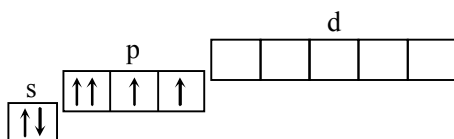
- Q.21** Which of the following sets of quantum numbers is correct for an electron in 4f orbital ?
 (A) $n = 4, \ell = 3, m = +4, s = +\frac{1}{2}$
 (B) $n = 4, \ell = 4, m = -4, s = -\frac{1}{2}$
 (C) $n = 4, \ell = 3, m = +1, s = +\frac{1}{2}$
 (D) $n = 3, \ell = 3, m = -2, s = +\frac{1}{2}$
- Q.22** Consider the ground state of Cr atom ($Z = 24$). The number of electrons with the azimuthal quantum numbers, $\ell = 1$ and 2 are, respectively
 (A) 12 and 4 (B) 12 and 5
 (C) 16 and 4 (D) 16 and 5
- Q.23** The triad of nuclei that is isotonic is -
 (A) ${}^{14}_6\text{C}, {}^{15}_7\text{N}, {}^{17}_9\text{F}$ (B) ${}^{12}_6\text{C}, {}^{14}_7\text{N}, {}^{19}_9\text{F}$
 (C) ${}^{14}_6\text{C}, {}^{14}_7\text{N}, {}^{17}_9\text{F}$ (D) ${}^{14}_6\text{C}, {}^{14}_7\text{N}, {}^{19}_9\text{F}$
- Q.24** The orbital angular momentum of an electron in 2s orbital is -
 (A) $+\frac{1}{2} \cdot \frac{h}{2\pi}$ (B) zero
 (C) $\frac{h}{2\pi}$ (D) $\sqrt{2} \cdot \frac{h}{2\pi}$
- Q.25** In potassium atom, electronic energy level is in the following order -
 (A) $4s > 3d$ (B) $4s < 2p$
 (C) $4s < 3d$ (D) $4s > 4p$
- Q.26** Which of the following has maximum number of unpaired electron ?
 (A) Mg^{2+} (B) Ti^{3+}
 (C) V^{3+} (D) Fe^{2+}
- Q.27** The first use of quantum theory to explain the structure of atom was made by -
 (A) Heisenberg (B) Bohr
 (C) Planck (D) Einstein
- Q.28** For a d-electron, the orbital angular momentum is -
 (A) $\sqrt{6} \hbar$ (B) $\sqrt{2} \hbar$ (C) \hbar (D) $2\hbar$
- Q.29** Which of the following statement is not correct ?
 (A) The electronic configuration of Cr is $[\text{Ar}] 3d^5 4s^1$. (Atomic No. of Cr = 24)
 (B) The magnetic quantum number may have a negative value
 (C) In silver atom, 23 electrons have a spin of one type of 24 of the opposite type (Atomic No. of Ag = 47)
 (D) The electronic configuration of Cr is $[\text{Ar}] 3d^4 4s^2$
- Q.30** The energy of an electron in the first Bohr orbit of H atom is -13.6 eV. The possible energy value (s) of the excited state(s) for electrons in Bohr orbits of hydrogen is (are) -
 (A) -3.4 eV (B) -4.2 eV
 (C) -6.8 eV (D) $+6.8$ eV
- Q.31** The energy of the electron in the first orbit of He^+ is -871.6×10^{-20} J. The energy of the electron in the first orbit of hydrogen would be
 (A) -871.6×10^{-20} J (B) -435.8×10^{-20} J
 (C) -217.9×10^{-20} J (D) -108.9×10^{-20} J
- Q.32** The number of nodal planes in a p_x orbitals is -
 (A) two (B) one (C) three (D) zero
- Q.33** The wavelength associated with a golf ball weighing 200g and moving at a speed of 5 m/h is of the order -
 (A) 10^{-10} m (B) 10^{-20} m (C) 10^{-30} m (D) 10^{-40} m
- Q.34** The quantum numbers $+1/2$ and $-1/2$ for the electron spin represent -
 (A) rotation of the electron in clockwise and anticlockwise direction respectively
 (B) rotation of the electron in anticlockwise and clockwise direction respectively
 (C) magnetic moment of the electron pointing up and down respectively
 (D) two quantum mechanical spin states which have no classical analogue
- Q.35** Rutherford's experiment, which established the nuclear model of the atom, used a beam of -
 (A) β -particles, which impinged on a metal foil and got absorbed
 (B) γ -rays, which impinged on a metal foil and ejected electrons
 (C) helium atoms, which impinged on a metal foil and got scattered
 (D) helium nuclei, which impinged on a metal foil and got scattered
- Q.36** If the nitrogen atom had electronic configuration 1s, it would have energy lower than that of the normal ground state configuration $1s^2 2s^2 2p^3$ because the electrons would be closer to the nucleus yet, $1s^7$ is not observed because it violates -
 (A) Heisenberg Uncertainty principle
 (B) Hund's rule
 (C) Pauli's exclusion principle
 (D) Bohr postulates of stationary orbits
- Q.37** For which of the following the radius will be same as for hydrogen atom $n = 1$
 (A) $\text{He}^+, n = 2$ (B) $\text{Li}^{2+}, n = 2$
 (C) $\text{Be}^{3+}, n = 2$ (D) $\text{Li}^{2+}, n = 3$
- Q.38** Maximum numbers of electrons in a subshell is given by -
 (A) $(2\ell+1)$ (B) $2(2\ell+1)$
 (C) $(2\ell+1)^2$ (D) $2(2\ell+1)^2$

- Q.39** Which of the following statements about nodal planes is/are not true -
 (A) A plane on which there is zero probability of finding an electron
 (B) A plane on which there is maximum probability that the electron will be found
 (C) Ψ^2 is non zero at nodal plane
 (D) None of these

- Q.40** For the energy levels in an atom which one of the following statement is correct ?
 (A) The 4s sub-energy level is at a higher energy than the 3d sub-energy level
 (B) The M-energy level can have maximum of 32 electrons
 (C) The second principal energy level can have four orbitals and contain a maximum of 8 electrons
 (D) The 5th main energy level can have maximum of 49 electrons

- Q.41** The electronic configurations of Cr^{24} and Cu^{29} are abnormal -
 (A) Due to extra stability of exactly half filled and exactly fully filled sub shells
 (B) Because they belong to d-block
 (C) Both the above
 (D) None of the above

- Q.42** The below configuration is not correct as it violates



- (A) Only Hund's rule
 (B) Only Pauli's exclusion principle
 (C) $(n + l)$ rule
 (D) (Hund + Pauli) rule

- Q.43** Wavelength of the first line of Paschen Series is - ($R = 109700 \text{ cm}^{-1}$)
 (A) $[18750 \text{ \AA}]$ (B) $[2854 \text{ \AA}]$
 (C) $[3452 \text{ \AA}]$ (D) $[6243 \text{ \AA}]$

- Q.44** The maximum probability of finding electron in the d_{xy} orbital is -
 (A) Along the x-axis
 (B) Along the y-axis
 (C) At an angle of 45° from the x and y-axis
 (D) At an angle of 90° from the x and y-axis

- Q.45** The nucleus of an atom is located at $x = y = z = 0$. If the probability of finding an s-orbital electron in a tiny volume around $x = a, y = z = 0$ is 1×10^{-5} , what is the probability of finding the electron in the same sized volume around $x = z = 0, y = a$?
 (A) 1×10^{-5} (B) $1 \times 10^{-5} \times a$
 (C) $1 \times 10^{-5} \times a^2$ (D) $1 \times 10^{-5} \times a^{-1}$

- Q.46** If n and ℓ are respectively the principal and azimuthal quantum numbers, then the expression for calculating the total number of electrons in any energy level is -

$$(A) \sum_{\ell=0}^{\ell=n} 2(2\ell + 1) \quad (B) \sum_{\ell=1}^{\ell=n-1} 2(2\ell + 1)$$

$$(C) \sum_{\ell=0}^{\ell=n+1} 2(2\ell + 1) \quad (D) \sum_{\ell=0}^{\ell=n-1} 2(2\ell + 1)$$

- Q.47** A photon was absorbed by a hydrogen atom in its ground state and the electron was promoted to the fifth orbit. When the excited atom returned to its ground state, visible quanta were emitted when electron made transition -
 (A) $5 \rightarrow 2$ (B) $2 \rightarrow 1$ (C) $3 \rightarrow 1$ (D) $4 \rightarrow 1$

- Q.48** What is the change in the orbit radius when the electron in the hydrogen atom (Bohr model) undergoes the first Paschen transition ?
 (A) $4.23 \times 10^{-10} \text{ m}$ (B) $0.35 \times 10^{-10} \text{ m}$
 (C) $3.7 \times 10^{-10} \text{ m}$ (D) $1.587 \times 10^{-10} \text{ m}$

- Q.49** In centre-symmetrical system, the orbital angular momentum, a measure of the momentum of a particle travelling around the nucleus, is quantised. Its magnitude is -

$$(A) \sqrt{\ell(\ell + 1)} \frac{h}{2\pi} \quad (B) \sqrt{\ell(\ell - 1)} \frac{h}{2\pi}$$

$$(C) \sqrt{s(s + 1)} \frac{h}{2\pi} \quad (D) \sqrt{s(s - 1)} \frac{h}{2\pi}$$

- Q.50** Ultraviolet light of 6.2 eV falls on a aluminium surface (work function = 4.2 eV). The kinetic energy (in joule) of the fastest electron emitted is approximately -
 (A) 3×10^{-21} (B) 3×10^{-19}
 (C) 3×10^{-17} (D) 3×10^{-15}

- Q.51** An electron, a proton and an alpha particle have kinetic energies of 16E, 4E and E respectively. What is the qualitative order of their de-Broglie wavelengths ?
 (A) $\lambda_e > \lambda_p = \lambda_\alpha$ (B) $\lambda_p = \lambda_\alpha > \lambda_e$
 (C) $\lambda_p > \lambda_e > \lambda_\alpha$ (D) $\lambda_\alpha < \lambda_e >> \lambda_p$

- Q.52** One energy difference between the states $n = 2$ and $n = 3$ is E eV, in hydrogen atom. The ionisation potential of H atom is -
 (A) 3.2 E (B) 5. 6E
 (C) 7.2 E (D) 13.2 E

- Q.53** Magnetic moments of $\text{V}(Z = 23)$, $\text{Cr}(Z = 24)$, $\text{Mn}(Z = 25)$ are x, y, z. Hence -
 (A) $x = y = z$ (B) $x < y < z$
 (C) $x < z < y$ (D) $z < y < x$

- Q.54** If the shortest wavelength of H atom in Lyman series is x, then longest wavelength in Balmer series of He^+ is -
 (A) $\frac{9x}{5}$ (B) $\frac{36x}{5}$ (C) $\frac{x}{4}$ (D) $\frac{5x}{9}$

Q.55 The specific charge of a proton is $9.6 \times 10^7 \text{C kg}^{-1}$, then for an α -particles it will be
 (A) $2.4 \times 10^7 \text{C kg}^{-1}$ (B) $4.8 \times 10^7 \text{C kg}^{-1}$
 (C) $19.2 \times 10^7 \text{C kg}^{-1}$ (D) $38.4 \times 10^7 \text{C kg}^{-1}$

Q.56 The dissociation energy of H_2 is $430.53 \text{KJ mol}^{-1}$. If H_2 is dissociated by illuminating with the radiation of wavelength 253.7 nm , the fraction of the radiant energy which will be converted into kinetic energy is given by -
 (A) 8.76 % (B) 12.33 %
 (C) 11.3 % (D) 100%

Q.57 In an electron microscope, electrons are accelerated to great velocities. Calculate the wavelength of an electron travelling with a velocity of 7.0 megameters per second. The mass of an electron is $9.1 \times 10^{-28} \text{g}$
 (A) $1.0 \times 10^{-13} \text{ m}$ (B) $1.0 \times 10^{-7} \text{ m}$
 (C) 1.0 m (D) $1.0 \times 10^{-10} \text{ m}$

Q.58 What are the values of the orbital angular momentum of an electron in the orbitals 1s, 3s, 3d and 2p ?
 (A) $0, 0, \frac{h}{2\pi}\sqrt{6}, \frac{h}{2\pi}\sqrt{2}$
 (B) $1, 1, \frac{h}{2\pi}\sqrt{4}, \frac{h}{2\pi}\sqrt{2}$
 (C) $0, 1, \frac{h}{2\pi}\sqrt{6}, \frac{h}{2\pi}\sqrt{3}$
 (D) $0, 0, \frac{h}{2\pi}\sqrt{20}, \frac{h}{2\pi}\sqrt{6}$

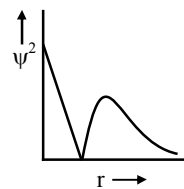
Q.59 The energy difference between two electronic states is 46.12 kcal/mole . What will be the frequency of the light emitted when an electron drops from the higher to the lower energy state? (Planck' constant = $9.52 \times 10^{-14} \text{ kcal sec mole}^{-1}$)
 (A) $4.84 \times 10^{15} \text{ cycles sec}^{-1}$
 (B) $4.84 \times 10^{-5} \text{ cycles sec}^{-1}$
 (C) $4.84 \times 10^{-12} \text{ cycles sec}^{-1}$
 (D) $4.84 \times 10^{14} \text{ cycles sec}^{-1}$

Q.60 The radii of two of the first four Bohr orbits of the hydrogen atom are in the ratio 1 : 4. The energy difference between them may be -
 (A) Either 12.09 eV or 3.4 eV
 (B) Either 2.55 eV or 10.2 eV
 (C) Either 13.6 eV or 3.4 eV
 (D) Either 3.4 eV or 0.85 eV

Q.61 It is known that atoms contain protons, neutrons and electrons. If the mass of neutron is assumed to be half of its original value whereas that of electron is assumed to be twice of this original value. The atomic mass of ${}^{12}_6\text{C}$ will be-
 (A) Twice (B) 75% less
 (C) 25% less (D) one-half of its

Q.62 Calculate total no. of e^- having $m = 0$ in Cr atom -
 (A) 12 (B) 13 (C) 5 (D) 24

Q.63 The following graph between Ψ^2 probability density and distance from the nucleus represents-

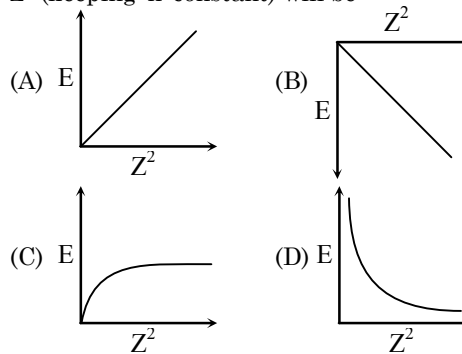


(A) 2s (B) 3s (C) 1s (D) 2p

Q.64 In an atomic orbital the sign of the lobes indicates the -
 (A) Sign of the probability distribution
 (B) Sign of charge
 (C) Sign of wave function
 (D) presence or absence of electron

Q.65 Which of the following symbols represent an atomic orbital ?
 (A) $\Psi_{n, \ell, m} = R_n \Theta_\ell \Phi_m$
 (B) $\Psi_{n, \ell, m} = R_{n, \ell} \Theta_\ell \Phi_m$
 (C) $\Psi_{n, \ell, m} = R_n \Theta_{\ell, m} \Phi_m$
 (D) $\Psi_{n, \ell, m} = R_{n, \ell} \Theta_{\ell, m} \Phi_m$

Q.66 The energy of an electron moving in n^{th} Bohr's orbit of an element is given by $E_n = \frac{-13.6}{n^2} Z^2 \text{ eV/atom}$ ($Z = \text{atomic number}$). The graph of E Vs Z^2 (keeping 'n' constant) will be -



Q.67 If in Bohr's model, for unielectronic atom, time period of revolution is represented as $T_{n,z}$ where n represents shell no. and Z represents atomic number then the value of $T_{1,2} : T_{2,1}$ will be -
 (A) 8 : 1 (B) 1 : 8 (C) 1 : 1 (D) 1 : 32

Q.68 An excited state of H atom emits a photon of wavelength λ and returns in the ground state, the principal quantum number of excited state is given by -

(A) $\sqrt{\lambda R(\lambda R - 1)}$ (B) $\sqrt{\frac{\lambda R}{\lambda R - 1}}$
 (C) $\sqrt{\lambda R(\lambda R - 1)}$ (D) $\sqrt{\frac{(\lambda R - 1)}{\lambda R}}$

Q.69 The Schrodinger wave equation for hydrogen atom is

$$\Psi_{2s} = \frac{1}{4\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{3/2} \left(2 - \frac{r}{a_0} \right) e^{-r/a_0}$$

where a_0 is Bohr's radius. If the radial node in 2s be at r_0 , then r_0 would be equal to-

- (A) $\frac{a_0}{2}$ (B) $2a_0$ (C) $\sqrt{2}a_0$ (D) $\frac{a_0}{\sqrt{2}}$

Q.70 The Schrodinger wave equation for hydrogen

$$\text{atom is } - \Psi (\text{radial}) = \frac{1}{16\sqrt{4}} \left(\frac{Z}{a_0} \right)^{3/2}$$

$$[(\sigma-1)(\sigma^2-8\sigma+12)] e^{-\sigma/2}$$

Where a_0 and Z are the constant in which answer can be expressed and $\sigma = \frac{2Zr}{a_0}$

minimum and maximum position of radial nodes from nucleus are respectively -

- (A) $\frac{a_0}{Z}, \frac{3a_0}{Z}$ (B) $\frac{a_0}{2Z}, \frac{a_0}{Z}$
 (C) $\frac{a_0}{2Z}, \frac{3a_0}{Z}$ (D) $\frac{a_0}{2Z}, \frac{4a_0}{Z}$

Q.71 A light source of wavelength λ illuminates a metal and ejects photo-electrons with

Another light source of wavelength $\frac{\lambda}{3}$, ejects

photo-electrons from same metal with $(K.E.)_{\max} = 4\text{eV}$. Find the value of work function?

- (A) 1 eV (B) 2 eV
 (C) 0.5 eV (D) None of these

Q.72 A small particle of mass m moves in such a way

that P.E. = $-\frac{1}{2}mkr^2$, where k is a constant and

r is the distance of the particle from origin. Assuming Bohr's model of quantization of angular momentum and circular orbit, r is directly proportional to -

- (A) n^2 (B) n
 (C) \sqrt{n} (D) None of these

Q.73 What is the angular velocity (ω) of an electron occupying second orbit of Li^{2+} ion?

- (A) $\frac{8\pi^3me^4}{h^3}$ (B) $\frac{8\pi^3me^4}{9h^3}$
 (C) $\frac{64}{9} \times \frac{\pi^3me^4}{h^3}$ (D) $\frac{9\pi^3me^4}{h^3}$

Q.74 If radiation corresponding to second line of "Balmer series of Li^{2+} ion, knocked out electron from first excited state of H-atom, then kinetic energy of ejected electron would be -

- (A) 2.55 eV (B) 4.25 eV
 (C) 11.25 eV (D) 19.55 eV

Q.75 An element undergoes a reaction as shown -
 $X + 2e^- \rightarrow X^{2-}$, energy released = 30.87 eV/atom.

If the energy released, is used to dissociate 4 gms of H_2 molecules, equally into H^+ and H^* , where H^* is excited state of H atoms where the electron travels in orbit whose circumference equal to four times its de Broglie's wavelength. Determine the least moles of X that would be required. Given : 1.E. of H = 13.6 eV/atom, bond energy of $\text{H}_2 = 4.526$ eV/molecule

- (A) 1 (B) 2
 (C) 3 (D) 4

Q.76 If the energy of H-atom in the ground state is -E, the velocity of photo-electron emitted when a photon having energy E_p strikes a stationary Li^{2+} ion in ground state, is given by -

- (A) $v = \sqrt{\frac{2(E_p - E)}{m}}$ (B) $v = \sqrt{\frac{2(E_p + 9E)}{m}}$
 (C) $v = \sqrt{\frac{2(E_p - 9E)}{m}}$ (D) $v = \sqrt{\frac{2(E_p - 3E)}{m}}$

Q.77 For a 3x-orbital

$$\Psi(3s) = \frac{1}{9\sqrt{3}} \left(\frac{1}{a_0} \right)^{3/2} (6-6\sigma + 6\sigma^2)^{-\sigma/2}; \text{ where}$$

$$\sigma = \frac{2r \cdot Z}{3a_0}$$

What is the maximum radial distance of node from nucleus?

- (A) $\frac{(3+\sqrt{3})a_0}{Z}$ (B) $\frac{a_0}{Z}$
 (C) $\frac{3}{2} \frac{(3+\sqrt{3})a_0}{Z}$ (D) $\frac{2a_0}{Z}$

Q.78 The energy of a I, II and III energy levels of a certain atom are $E, \frac{4E}{3}$ and $2E$ respectively. A

photon of wavelength λ is emitted during a transition from III to I. What will be the wavelength of emission for transition II to I?

- (A) $\frac{\lambda}{2}$ (B) λ (C) 2λ (D) 3λ

Q.79 In the measurement of quantum efficiency of photosynthesis in green plants, it was found that 10 quanta of red light of wavelength 6850 Å were needed to release one molecule of O_2 . The average energy storage in this process is 112 kcal/mol O_2 evolved. What is the energy conversion efficiency in this experiment?

(Given : 1 cal = 4.18 J; $N_A = 6 \times 10^{23}$;
 $h = 6.63 \times 10^{-34}$ J.s)

- (A) 23.5 (B) 26.9
 (C) 66.34 (D) 73.1

EXERCISE (Level-3)

Part-A : Multiple correct answer type questions

Q.1 Which of the following properties is/are proportional to the energy of the electromagnetic radiation ?

- (A) Frequency (B) Wave number
(C) Wavelength (D) Number of photons

Q.2 Which of the following statements are incorrect?

- (A) There are five unpaired electrons in $(n-1)d$ suborbit in Fe^{3+}
(B) Fe^{3+} , Mn^{+} and Cr all having 24 electrons will have same value of magnetic moment
(C) Copper (I) chloride is coloured salt
(D) Every coloured ion is paramagnetic

Q.3 Which is not the correct orbital notation if the wave function is –

$$\psi = \frac{1}{81\sqrt{6\pi}} \left(\frac{1}{a_0} \right)^{3/2} \sigma^2 e^{-\sigma/3} (3\cos^2\theta - 1);$$

Here $\sigma = r/a_0$ and $a_0 = \frac{h^2 \epsilon_0}{\pi m e^2}$

- (A) 4s (B) $2P_x$ (C) $3P_y$ (D) $3d_z^2$

Q.4 Which of the following orbitals have no spherical nodes ?

- (A) 1s (B) 2s
(C) 2p (D) 3p

Q.5 In which of the following sets of orbitals, electrons have equal orbital angular momentum ?

- (A) 1s and 2s (B) 2s and 2p
(C) 2p and 3p (D) 3p and 3d

Q.6 Which of the following sets of quantum number are correct ?

- (A) $n = 3, \ell = 2, m = +1, s = +\frac{1}{2}$
(B) $n = 3, \ell = 3, m = +3, s = +\frac{1}{2}$
(C) $n = 4, \ell = 0, m = 0, s = -\frac{1}{2}$
(D) $n = 5, \ell = 2, m = +4, s = -\frac{1}{2}$

Q.7 Rutherford's experiment established that :

- (A) Inside the atom there is a heavy positive centre
(B) Nucleus contains protons and neutrons
(C) Most of the space in the atoms is empty
(D) Size of the nucleus is very small

Q.8 Which of the following statements are incorrect ?

- (A) For designating orbitals three quantum numbers are needed
(B) The second ionization energy of helium is 4 times, the first ionization of hydrogen
(C) The third ionization energy of lithium is 9 times, the first ionization of hydrogen
(D) Radius of third orbit of Li^{2+} is 3 times the radius of third orbit of hydrogen atom

Q.9 Which of the following statements (regarding an atom of H) are correct ?

- (A) Kinetic energy of the electron is maximum in the first orbit
(B) Potential energy of the electron is maximum in the first orbit
(C) Radius of the second orbit is four times the radius of the first orbit
(D) Various energy levels are equally spaced

Q.10 Which of the following transition in H-atom would result in emission of radiations of same frequency ?

- (A) $4s \rightarrow 3p$ (B) $4d \rightarrow 3p$
(C) $5s \rightarrow 4s$ (D) $3s \rightarrow 2p$

Q.11 The radial distribution functions $[P(r)]$ is used to determine the most probable radius, which is used to find the electron in a given orbital $\frac{dP(r)}{dr}$ for 1s-orbital of hydrogen like atom

having atomic number Z , is

$$\frac{dP}{dr} = \frac{4Z^3}{a_0^3} \left(2r - \frac{2Zr^2}{a_0} \right) e^{-2Zr/a_0}$$

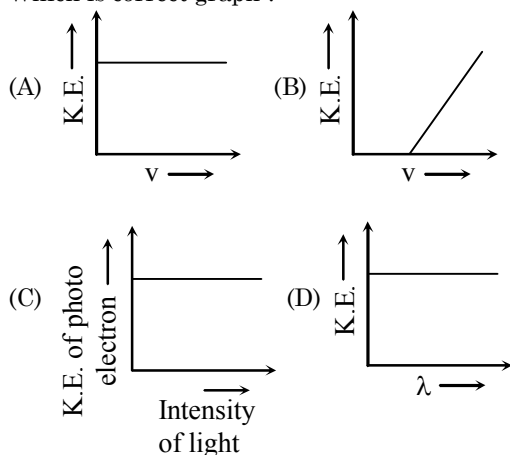
Then which of the following statements is/are correct ?

- (A) At the point of maximum value of radial distribution function $\frac{dP(r)}{dr} = 0$; One antinode is present
(B) Most probable radius of Li^{2+} is $\frac{a_0}{3}$ pm
(C) Most probable radius of He^+ is $\frac{a_0}{2}$ pm
(D) Most probable radius of hydrogen atom is a_0 pm

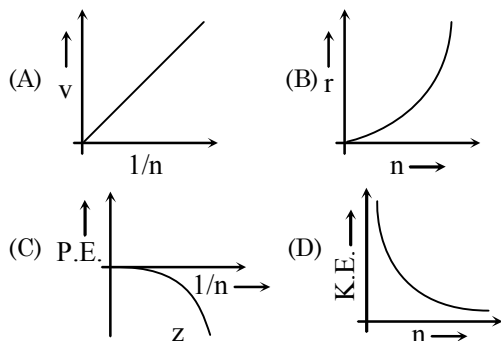
- Q.12** Select the correct statement (s) -
 (A) An orbital with $\ell = 0$ is symmetrical about the nucleus
 (B) An orbital with $\ell = 0$ is spherically symmetrical about the nucleus
 (C) $3d_{z^2}$ is spherically symmetrical about the z-axis
 (D) All are correct

- Q.13** Select the correct statement (s) -
 (A) Radial function depends only on the direction, and is independent on quantum number n only the nucleus
 (B) Angular function depends only on the direction and is independent to the distance from the nucleus
 (C) $\Psi^2(r, \theta, \phi)$ is the probability density of finding the electron at a particular point in space
 (D) Radial distribution function ($4\pi r^2 R^2$) gives the probability of the electron being present at a distance r from the nucleus

- Q.14** Which is correct graph ?



- Q.15** Select the correct curve (s) -
 If v = Velocity of electron in Bohr's orbit
 r = Radius of electron in Bohr's orbit
 P.E. = Potential energy of electron in Bohr's orbit
 K.E. = Kinetic energy of electron in Bohr's orbit



- Q.16** Select the correct statement(s) -
 (A) An electron near the nucleus is attracted by the nucleus and has a low potential energy
 (B) According to Bohr's theory, an electron continuously radiate energy if it stayed in one orbit
 (C) Bohr's model could not explain the spectra of multielectron atoms
 (D) Bohr's model was the first atomic model based on quantisation of energy

- Q.17** Choose the correct statement(s) -
 (A) The shape of an atomic orbital depends upon azimuthal quantum number
 (B) The orientation of an atomic orbital depends upon the magnetic quantum number
 (C) The energy of an electron in an atomic orbital of multi-electron atom depends upon principal quantum number only
 (D) The number of degenerate atomic orbital of one type depends upon the value of azimuthal and magnetic quantum number

- Q.18** For radial probability curves, which of the following is/are correct ?
 (A) The number of maxima in 2s orbital are two
 (B) The number of spherical or radial nodes is equal to $n-l-1$
 (C) The number of angular nodes are ' l '
 (D) $3d_{z^2}$ has 3 angular nodes

- Q.19** Select the correct statement(s) -
 (A) Radial distribution function indicates that there is a higher probability of finding the 3s electron close to the nucleus than in case of 3p and 3d electrons
 (B) Energy of 3s orbital is less than for the 3p and 3d orbitals
 (C) At the node, the value of the radial function changes from positive to negative
 (D) The radial function depends upon the quantum numbers n and l

- Q.20** Choose the incorrect statement(s) -
 (A) For a particular orbital in hydrogen atom, the wave function may have negative value
 (B) Radial probability distribution function though may have zero value but can never have negative value
 (C) $3d_{x^2-y^2}$ orbital has two angular nodes and one radial node
 (D) yz and xz planes are nodal planes for d_{xy} orbital

- Q.21** Select the correct statement(s) -
 (A) Heisenberg's principle is applicable to stationary e^-
 (B) Pauli's exclusion principle is not applicable to photons
 (C) For an e^- , the product of velocity and principal quantum number will be independent of principal quantum number
 (D) Quantum numbers l and m determine the value of angular wave function
- Q.22** Choose the correct statements among the following -
 (A) A node is a point in space where the wave-function Ψ has zero amplitude
 (B) The number of maxima (peaks) in radial distribution in $n-l$
 (C) Radial probability is $4\pi r^2 R_{n,\ell}^2(r)$
 (D) Ψ^2 represents probability of finding $3P_y$ orbital
- Q.23** Select the correct statement(s) regarding $3P_y$ orbital
 (A) Total no. of nodes are 2
 (B) Number of maxima in the curve $4\pi r^2 R^2(r)$ Vs r is one
 (C) Quantum no. n , l and m for orbital may be, 3, 1, -1 respectively
 (D) The magnetic quantum number may have a positive value

Part-B : Assertion Reason type Questions

The following questions 24 to 27 consists of two statements each, printed as Assertion and Reason. While answering these questions you are to choose any one of the following four responses.

- (A) If both Assertion and Reason are true and the Reason is correct explanation of the Assertion.
 (B) If both Assertion and Reason are true but Reason is not correct explanation of the Assertion.
 (C) If Assertion is true but the Reason is false.
 (D) If Assertion is false but Reason is true
- Q.24** **Assertion** : The charge to mass ratio of the particles in anode rays depends on nature of the gas taken in the discharge tube.
Reason : The particles in anode rays carry positive charge.
- Q.25** **Assertion** : s-orbital cannot accommodate more than two electrons.
Reason : s-orbitals are spherically symmetrical.
- Q.26** **Assertion** : Kinetic energy of photoelectrons is directly proportional to the intensity of the incident radiation
Reason : Each photon of light causes the emission of only one photo electron.

- Q.27** **Assertion** : The existence of three unpaired electrons in phosphorous atom can be explained on the basis of Hund's rule.

Reason : According to Hund's rule, the degenerate orbitals are first singly occupied and only then pairing takes place.

Part-C : Column Matching type Questions

Q.28

Column-A		Column-B	
(A)	If P.E. = -13.6 eV	(i)	21
(B)	Ionization energy of electron from 2 nd shell of Na^{10+}	(ii)	10
(C)	Number of spectral lines when electron 7 th to 3 rd shell	(iii)	Total energy = -6.8 eV
(D)	Number of spectral lines when electron comes from 7 th shell to 1 st shell	(iv)	411.4 eV

Q.29

Column-A		Column-B	
(A)	Orbitals having equal energy	(i)	3p, 3d
(B)	Orbitals having zero orbital angular momentum	(ii)	2s and 3s
(C)	Orbitals with only one spherical node	(iii)	Degenerate orbitals
(D)	Orbitals having directional character	(iv)	2s and 3p

Q.30 Match the column :

Column-A		Column-B	
(A)		(i)	$3p_z$
(B)		(ii)	$4p_y$
(C)	Angular probability is dependent on θ and ϕ	(iii)	3s
(D)	At least one angular node is present	(iv)	$3p_x$

Part-D : Passage based objective questions

Passage-1 (Ques. 31 to 33)

Electron moves around the nucleus in circular orbitals in fixed energy paths. As far as electron moves in these orbits neither energy is absorbed nor liberated. But when electron move from lower energy level to higher energy level energy is absorbed while when it comes back from higher energy level to lower energy level energy is liberated in the form of photon & a spectral line is formed. Corresponding to different possible transitions different lines are formed which form the particular serieses viz. Lyman, Balmer, Paschen, Brackett, Pfund, Humphrey etc. Suppose e^- in hydrogen atom is present in 10^{th} excited state, then answer the following questions based on paragraph :

- Q.31** If electron present in 10^{th} excited state liberate one visible quanta then next quanta liberated will correspond to following transition -
 (A) $10 \rightarrow 2$ (B) $11 \rightarrow 2$
 (C) $11 \rightarrow 1$ (D) $2 \rightarrow 1$
- Q.32** Total number of spectral lines which can be obtained during the transition to ground level -
 (A) 45 (B) 55 (C) 66 (D) 36
- Q.33** Minimum value of wavelength that can be obtained during the transition -
 (A) $\frac{121}{120R}$ (B) $\frac{11}{10R}$ (C) $\frac{100}{99R}$ (D) $\frac{10}{9R}$

Where R is Rydberg constant.

Passage-2 (Ques. 34 to 36)

Suppose Bohr theory is applicable to a negatively charged particle of mass $2m_e$ and charge $2e$ revolving around the nucleus of positive charge Ze . Let r_1, v_1 and E_1 be the radius of the orbit speed of the particle in the orbit and energy of the particle in the orbit respectively. The values for the electron revolving in the corresponding orbit are r, v and E respectively.

- Q.34** Which of the following expression regarding the ratio of radii is correct ?
 (A) $\frac{r_1}{r} = 2$ (B) $r_1/r = \frac{1}{2}$
 (C) $\frac{r_1}{r} = 4$ (D) $\frac{r_1}{r} = \frac{1}{4}$
- Q.35** Which of the following expression regarding the ratio of speeds is correct?
 (A) $\frac{v_1}{v} = 2$ (B) $\frac{v_1}{v} = \frac{1}{2}$
 (C) $\frac{v_1}{v} = 4$ (D) $\frac{v_1}{v} = \frac{1}{4}$

- Q.36** Which of the following expression regarding the ratio of energies is correct ?

(A) $\frac{E_1}{E} = 4$ (B) $\frac{E_1}{E} = \frac{1}{4}$
 (C) $\frac{E_1}{E} = 8$ (D) $\frac{E_1}{E} = \frac{1}{8}$

Passage-3 (Ques. 37 to 39)

Assume that there were four possible values $(-1, \frac{1}{2}, +\frac{1}{2}, +1)$ for the spin quantum number m_s . Principal quantum number n is defined as usual. However, quantum number ℓ & m_ℓ are defined as follows :

ℓ : 1 to $(n+1)$ in integral steps
 m_ℓ : $-\ell/2$ to $+\ell/2$ (including zero, if any) in integral steps.

The orbitals corresponding to $\ell = 1, 2, 3, \dots$ designated as A, B, C,.....respectively. Further, the values of m_ℓ for a given value of ℓ give the number of sub-orbitals in an orbital.

The principles for filling electrons in the shells remain unchanged. The order of energies of various orbitals is : $A < B < C, \dots$ for the same shell.

- Q.37** The second period would begin with -
 (A) Fluorine (B) Sodium
 (C) Calcium (D) Scandium
- Q.38** If Aufbau's principle is not to be violated i.e. $(n + \ell)$ rule must be followed, the outermost electronic configuration of an element with at. no. 100 would be -
 (A) $3B^8 4A^4$ (B) $3C^{16} 4A^8$
 (C) $3C^{12} 4B^8$ (D) $4B^{12} 5A^8$
- Q.39** The number of sub-orbitals & the maximum number of electrons that can be filled in an E-orbitals are respectively -
 (A) 6, 24 (B) 5, 20
 (C) 7, 28 (D) can't be determined

Passage-4 (Q.40 to Q.42)

Orbital wave function Ψ can be given as

$$\Psi(r, \theta, \phi) = R(r) \cdot \theta(\theta) \cdot \phi(\phi)$$

For various orbitals of H-atom and H-like atoms values of R (radial wave function) are

For 1s-orbital : $R_{1s} = 2 \left(\frac{z}{a_0} \right)^{3/2} e^{-zr/a_0}$

For 2s-orbital :

$$R_{2s} = \left(\frac{z}{2a_0} \right)^{3/2} \left(2 - \frac{zr}{a_0} \right) e^{-zr/2a_0}$$

For 1p-orbital

$$R_{2p} = \frac{1}{\sqrt{3}} \left(\frac{z}{2a_0} \right)^{3/2} \left(\frac{zr}{a_0} \right) \times e^{-zr/2a_0}$$

For 3s-orbital

$$R_{3s} = \frac{2}{3} \left(\frac{z}{3a_0} \right)^{3/2} \left(3 - \frac{2zr}{a_0} + \frac{2z^2 r^2}{9a_0^2} \right) \times e^{-zr/3a_0}$$

etc. Here $a_0 = \text{bohr radius} = \frac{4\pi\epsilon_0 \hbar^2}{\mu e^2}$

$z = \text{atomic number}$

Similarly angular functions θ and ϕ can also be given

For s-orbital θ and ϕ can be given as

$$\theta(\theta) = \frac{1}{\sqrt{2}} \quad \text{and} \quad \phi(\phi) = \frac{1}{\sqrt{2\pi}}$$

So for 1s-orbital Ψ can be given as -

$$\Psi_{1s} = R_{1s} \cdot \theta_{1s} \cdot \phi_{1s} \\ = \frac{1}{\sqrt{\pi}} \left(\frac{z}{a_0} \right)^{3/2} e^{-zr/a_0}$$

Q.40 Probability density of finding an electron at distance r from nucleus in H-atom (in ground state) is -

- (A) Ψ (B) R^2
(C) $\frac{1}{\pi} \left(\frac{z}{a_0} \right)^3 e^{-2zr/a_0}$ (D) None of these

Q.41 Value of r at which radial node is found for 2s-orbital is -

- (A) a_0 (B) $2a_0$ (C) $3a_0$ (D) $4a_0$

Q.42 Radial nodes for 3s-orbital is/are at -

- (A) $r = 1.9 a_0$ (B) $r = 7.1 a_0$
(C) $r = 2a_0$ (D) Both (A) and (B)

Part-E : Numeric Response Type Questions

Q.43 The line at 434 nm in the Balmer series of the hydrogen spectrum corresponds to a transition of an electron from the n^{th} to second Bohr orbit. What is the value of n ?

Q.44 A particle of charge equal to that of an electron and mass 400 times the mass of the electron moves in a circular orbit around the nucleus of charge $+4e$. Assuming that the Bohr model of the atom is applicable to this system find the value of n for which the

Part-F : Subjective Type Questions

Q.45 When would the wavelength associated with an electron be equal to wavelength of proton?
(mass of $e = 9 \times 10^{-28}$ g ;
mass of proton = 1.6725×10^{-24} g)

Q.46 Point out the angular momentum of an electron in
(a) 4s orbital (b) 3p orbital
(c) 4th orbit

Q.47 (a) The wave number of the first line in the Balmer series of Be^{3+} is $2.43 \times 10^5 \text{ cm}^{-1}$. What is the wave number of the second line of the Paschen series of Li^{2+} ?
(b) In ions like He^+ , Li^{2+} , Be^{3+} how and why does the value of the Rydberg constant vary ?

Q.48 Calculate the wavelength in \AA of the photon that is emitted when an electron in Bohr orbit with $n = 2$ returns to orbit with $n = 1$ in H atom. The ionisation potential of the ground state of H-atom is 2.17×10^{-11} erg.

Q.49 Two particles A and B are in motion. If the wavelength associated with the particle A is 5×10^{-8} m, calculate the wavelength of particle B if its momentum is half of A.

Q.50 The first ionization energy of H is 21.79×10^{-19} J. Determine the second ionization energy of He atom.

Q.51 How many times larger is the spacing between the energy levels with $n = 3$ and $n = 8$ spacing between the energy level with $n = 8$ and $n = 9$ for the hydrogen atom ?

Q.52 Calculate the minimum uncertainty in velocity of a particle of mass 1.1×10^{-27} kg if uncertainty in its position is 3×10^{-10} cm.

Q.53 Calculate the number of photons emitted in 10 hours by a 60 W sodium lamp.
($\lambda_{\text{photon}} = 5893 \text{ \AA}$).

Q.54 Calculate total spin, magnetic moment for the atoms having atomic number 7, 24, 34 and 36.

Q.55 Magnetic moment of X^{3+} ion of 3d series is $\sqrt{35}$ B.M. What is atomic number of X^{3+} ?

Q.56 When a certain metal was irradiated with light of frequency 3.2×10^{16} Hz, the photoelectrons emitted had twice the kinetic energy as did photoelectrons emitted when the same metal was irradiated with light of frequency 2.0×10^{16} Hz. Calculate v_0 for the metal.

Q.57 Calculate the circumference of the 4th Bohr orbit for an electron travelling with a velocity of $2.19 \times 10^6 \text{ m/s}$.

Q.58 1.53 g of hydrogen is excited by irradiation. At a certain instant, 10% of the atoms are at the excited level of energy -328 kJ mol^{-1} and 2% of the atoms are at the excited level of energy $-146 \text{ kJ mole}^{-1}$. The remaining atoms are in the ground state. Calculate how much energy will be evolved when all the excited atoms return to the ground state.

- Q.59** Electrons of energy 12.1 eV are fired at the hydrogen atom in a gas discharge tube. Determine the wavelength of the lines that can be emitted by hydrogen.
- Q.60** Calculate the angular frequency ($\omega = v/r$) of an electron occupying the second Bohr orbit of He^+ ion.
- Q.61** A single electron atom has nuclear charge $+Ze$ where Z is atomic number and e is electronic charge. It requires 47.2 eV to excite the electron from the second Bohr orbit to third Bohr orbit. Find.
- The atomic number of element.
 - The energy required for transition of electron from third to fourth orbit.
 - The wavelength required to remove electron from first Bohr orbit to infinity.
 - The kinetic energy of electron in first Bohr orbit.
- Q.62** The de Broglie wavelength of electron of He^+ ion is 3.329 Å. If the photon emitted upon de-excitation of this He^+ ion is made to hit H-atom in its ground state so as to liberate electron from it, what will be the de-Broglie's wavelength of photoelectron.
- Q.63** The subshell that arises after f is called g subshell.
- How many g orbitals are present in the g subshell ?
 - In what principal electronic shell would the g subshell first occur and what is the total number of orbitals in this principal shell ?
- Q.64** What is the speed of an electron whose de Broglie's wavelength is 1 nm ?

EXERCISE (Level-4)

Old Examination Questions

Section-A [JEE Main]

- Q.1** In a multi-electron atom, which of the following orbitals described by the three quantum numbers will have the same energy in the absence of magnetic and electric fields? [AIEEE-2005]
 (a) $n = 1, \ell = 0, m = 0$ (b) $n = 2, \ell = 0, m = 0$
 (c) $n = 2, \ell = 1, m = 1$ (d) $n = 3, \ell = 2, m = 1$
 (e) $n = 3, \ell = 2, m = 0$
 (A) (b) and (c) (B) (a) and (b)
 (C) (d) and (e) (D) (c) and (d)
- Q.2** Of the following sets which one does NOT contain isoelectronic species? [AIEEE-2005]
 (A) CN^- , N_2 , C_2^{2-}
 (B) PO_4^{3-} , SO_4^{2-} , ClO_4^-
 (C) BO_3^{3-} , CO_3^{2-} , NO_3^-
 (D) SO_3^{2-} , CO_3^{2-} , NO_3^-
- Q.3** According to Bohr's theory, the angular momentum of an electron in 5th orbit is - [AIEEE 2006]
 (A) $1.0 h/\pi$ (B) $10 h/\pi$
 (C) $2.5 h/\pi$ (D) $25 h/\pi$
- Q.4** Uncertainty in the position of an electron (mass = 9.1×10^{-31} kg) moving with a velocity 300 m/s, accurate upto 0.001 %, will be ($h = 6.63 \times 10^{-34}$ Js) [AIEEE 2006]
 (A) 5.76×10^{-2} m (B) 1.92×10^{-2} m
 (C) 3.84×10^{-2} m (D) 19.2×10^{-2} m
- Q.5** Which of the following sets of quantum numbers represents the highest energy of an atom? [AIEEE 2007]
 (A) $n = 3, \ell = 1, m = 1, s = +\frac{1}{2}$
 (B) $n = 3, \ell = 2, m = 1, s = +\frac{1}{2}$
 (C) $n = 4, \ell = 0, m = 0, s = +\frac{1}{2}$
 (D) $n = 3, \ell = 0, m = 0, s = +\frac{1}{2}$
- Q.6** The ionization enthalpy of hydrogen atom is 1.312×10^6 J mol⁻¹. The energy required to excite the electron in the atom from $n = 1$ to $n = 2$ is [AIEEE 2008]
 (A) 6.56×10^5 J mol⁻¹
 (B) 7.56×10^5 J mol⁻¹
 (C) 9.84×10^5 J mol⁻¹
 (D) 8.51×10^5 J mol⁻¹
- Q.7** In an atom, an electron is moving with a speed of 600 m/s with an accuracy of 0.005%. Certainty with which the position of the electron can be located is ($h = 6.6 \times 10^{-34}$ kg m²s⁻¹, mass of electron, $m_e = 9.1 \times 10^{-31}$ kg) [AIEEE 2009]
 (A) 1.52×10^{-4} m (B) 5.10×10^{-3} m
 (C) 1.92×10^{-3} m (D) 3.84×10^{-3} m
- Q.8** Calculate the wavelength (in nanometer) associated with a proton moving at 1.0×10^8 m s⁻¹ (Mass of proton = 1.67×10^{-27} kg and $h = 6.63 \times 10^{-34}$ Js) - [AIEEE 2009]
 (A) 0.032 nm (B) 0.40 nm
 (C) 2.5 nm (D) 14.0 nm
- Q.9** A gas absorbs a photon of 355 nm and emits at two wavelengths. If one of the emissions is at 680 nm, the other is at : [AIEEE 2011]
 (A) 1035 nm (B) 325 nm
 (C) 743 nm (D) 518 nm
- Q.10** The frequency of light emitted for the transition $n = 4$ to $n = 2$ of He^+ is equal to the transition in H atom corresponding to which of the following? [AIEEE 2011]
 (A) $n = 2$ to $n = 1$ (B) $n = 3$ to $n = 2$
 (C) $n = 4$ to $n = 3$ (D) $n = 3$ to $n = 1$
- Q.11** The electrons identified by quantum numbers n and ℓ [AIEEE-2012]
 (a) $n = 4, \ell = 1$ (b) $n = 4, \ell = 0$
 (c) $n = 3, \ell = 2$ (d) $n = 3, \ell = 1$
 can be placed in order of increasing energy as -
 (A) (d) < (b) < (c) < (a) (B) (b) < (d) < (a) < (c)
 (C) (a) < (c) < (b) < (d) (D) (c) < (d) < (b) < (a)
- Q.12** The following sets of quantum numbers represents four electrons in an atom :
 (i) $n = 4, \ell = 1$ (ii) $n = 4, \ell = 0$
 (iii) $n = 3, \ell = 2$ (vi) $n = 3, \ell = 1$
 The sequence representing increasing order of energy, is : [AIEEE Online-2012]
 (A) (i) < (iii) < (ii) < (iv) (B) (ii) < (iv) < (i) < (iii)
 (C) (iv) < (ii) < (iii) < (i) (D) (iii) < (i) < (iv) < (ii)
- Q.13** The limiting line in Balmer series will have a frequency of :
 (Rydberg constant, $R_\infty = 3.29 \times 10^{15}$ cycles/s) [AIEEE Online-2012]
 (A) 3.65×10^{14} s⁻¹ (B) 8.22×10^{14} s⁻¹
 (C) 3.29×10^{15} s⁻¹ (D) 5.26×10^{13} s⁻¹
- Q.14** If the kinetic energy of an electron is increased four times, the wavelength of the de-Broglie wave associated with it would become : [AIEEE Online-2012]
 (A) Two times (B) Half
 (C) One fourth (D) Four times
- Q.15** Which pair of elements with the given atomic numbers is expected to have similar properties? [AIEEE Online-2012]
 (A) 11, 12 (B) 40, 72
 (C) 20, 36 (D) 10, 28

- Q.16** If the radius of first orbit of H atom is a_0 , the de-Broglie wavelength of an electron in the third orbit is : **[AIEEE Online-2012]**
 (A) $6\pi a_0$ (B) $8\pi a_0$
 (C) $2\pi a_0$ (D) $4\pi a_0$
- Q.17** In an atom how many orbital (s) will have the quantum numbers, $n = 3$, $\ell = 2$ and $m_\ell = +2$? **[JEE Main Online-2013]**
 (A) 5 (B) 3
 (C) 1 (D) 7
- Q.18** The wave number of the first emission line in the Balmer series of H-Spectrum is – (R = Rydberg constant) **[JEE Main Online-2013]**
 (A) $\frac{5}{36}R$ (B) $\frac{9}{400}R$
 (C) $\frac{7}{6}R$ (D) $\frac{3}{4}R$
- Q.19** The numbers of protons, electrons and neutrons in a molecule of heavy water are respectively : **[JEE Main Online-2013]**
 (A) 8, 10, 11 (B) 10, 10, 10
 (C) 10, 11, 10 (D) 11, 10, 10
- Q.20** The de Broglie wavelength of a car of mass 1000kg and velocity 36 km/hr is : $(h = 6.63 \times 10^{-34} \text{ Js})$ **[JEE Main Online-2013]**
 (A) $6.626 \times 10^{-34} \text{ m}$ (B) $6.626 \times 10^{-38} \text{ m}$
 (C) $6.626 \times 10^{-31} \text{ m}$ (D) $6.626 \times 10^{-30} \text{ m}$
- Q.21** Energy of an electron is given by $E = -2.178 \times 10^{-18} \text{ J} \left(\frac{Z^2}{n^2} \right)$. Wavelength of light required to excite an electron in an hydrogen atom from level $n = 1$ to $n = 2$ will be : $(h = 6.62 \times 10^{-34} \text{ Js}$ and $c = 3.0 \times 10^8 \text{ ms}^{-1})$ **[JEE-Main 2013]**
 (A) $6.500 \times 10^{-7} \text{ m}$ (B) $8.500 \times 10^{-7} \text{ m}$
 (C) $1.214 \times 10^{-7} \text{ m}$ (D) $2.816 \times 10^{-7} \text{ m}$
- Q.22** The correct set of four quantum numbers for the valence electrons of rubidium atom ($Z = 37$) is - **[JEE Main 2014]**
 (A) 5, 1, 0 + $\frac{1}{2}$ (B) 5, 1, 1 + $\frac{1}{2}$
 (C) 5, 0, 1 + $\frac{1}{2}$ (D) 5, 0, 0 + $\frac{1}{2}$
- Q.23** Given
 (a) $n = 5$, $m_\ell = +1$
 (b) $n = 2$, $l = 1$, $M_\ell = -1$, $m_s = -1/2$
- The maximum number of electron (s) in an atom that can have the quantum numbers as given in (a) and (b) are respectively – **[JEE Main Online - 2014]**
 (A) 25 and 1 (B) 8 and 1
 (C) 2 and 4 (D) 4 and 1
- Q.24** Ionization energy of gaseous Na atoms is 495.5 kJmol⁻¹. The lowest possible frequency of light that ionizes a sodium atom is **[JEE Main Online - 2014]**
 $(h = 6.626 \times 10^{-34} \text{ Js}$, $N_A = 6.022 \times 10^{23} \text{ mol}^{-1})$
 (A) $7.50 \times 10^4 \text{ s}^{-1}$ (B) $4.76 \times 10^{14} \text{ s}^{-1}$
 (C) $3.15 \times 10^{15} \text{ s}^{-1}$ (D) $1.24 \times 10^{15} \text{ s}^{-1}$
- Q.25** If m and e are the mass and charge of the revolving electron in the orbit of radius r for hydrogen atom, the total energy of the revolving electron will be: **[JEE Main Online - 2014]**
 (A) $\frac{1}{2} \frac{e^2}{r}$ (B) $-\frac{e^2}{r}$
 (C) $\frac{me^2}{r}$ (D) $-\frac{1}{2} \frac{e^2}{r}$
- Q.26** The de-Broglie wavelength of a particle of mass 6.63 g moving with a velocity of 100 ms⁻¹ is : **[JEE Main Online - 2014]**
 (A) 10^{-33} m (B) 10^{-35} m
 (C) 10^{-31} m (D) 10^{-25} m
- Q.27** Excited hydrogen atom emits light in the ultraviolet region at $2.47 \times 10^{15} \text{ Hz}$. With this frequency, the energy of a single photon is : $(h = 6.63 \times 10^{-34} \text{ Js})$ **[JEE Main Online - 2014]**
 (A) $8.041 \times 10^{-40} \text{ J}$ (B) $2.680 \times 10^{-19} \text{ J}$
 (C) $1.640 \times 10^{-18} \text{ J}$ (D) $6.111 \times 10^{-17} \text{ J}$
- Q.28** The energy of an electron in first Bohr orbit of H-atom is -13.6 eV. The energy value of electron in the excited state of Li^{2+} is : **[JEE Main Online - 2014]**
 (A) -27.2 eV (B) 30.6 eV
 (C) -30.6 eV (D) 27.2 eV
- Q.29** If λ_0 and λ be the threshold wavelength and wavelength of incident light, the velocity of photoelectron ejected from the metal surface is: **[JEE Main Online - 2014]**
 (A) $\sqrt{\frac{2h}{m}(\lambda_0 - \lambda)}$ (B) $\sqrt{\frac{2hc}{m}(\lambda_0 - \lambda)}$
 (C) $\sqrt{\frac{2hc}{m} \left(\frac{\lambda_0 - \lambda}{\lambda \lambda_0} \right)}$ (D) $\sqrt{\frac{2h}{m} \left(\frac{1}{\lambda_0} - \frac{1}{\lambda} \right)}$

Q.30 A stream of electrons from a heated filament was passed between two charged plates kept at a potential difference V esu. If e and m are charge and mass of an electron, respectively, then the value of h/λ (where λ is wavelength associated with electron wave) is given by :

[JEE Main - 2016]

- (A) meV (B) $2meV$
 (C) \sqrt{meV} (D) $\sqrt{2meV}$

Q.31 The radius of the second Bohr orbit for hydrogen atom is –

(Planck's Const. $h = 6.6262 \times 10^{-34}$ Js; mass of electron = 9.1091×10^{-31} kg; charge of electron $e = 1.60210 \times 10^{-19}$ C; permittivity of vacuum $\epsilon_0 = 8.854185 \times 10^{-12}$ $\text{kg}^{-1}\text{m}^{-3}\text{A}^2$)

[JEE Main Offline - 2017]

- (A) 0.529 \AA (B) 2.12 \AA
 (C) 1.65 \AA (D) 7.76 \AA

Q.32 The group having isoelectronic species is

[JEE Main Offline - 2017]

- (A) O^{2-} , F^- , Na , Mg^{2+}
 (B) O^- , F^- , Na^+ , Mg^{2+}
 (C) O^{2-} , F^- , Na^+ , Mg^{2+}
 (D) O^- , F^- , Na , Mg^+

Q.33 If the Shortest wavelength in Lyman series of hydrogen atom is A , then the longest wavelength in Paschen series of He^+ is –

[JEE Main Online - 2017]

- (A) $\frac{5A}{9}$ (B) $\frac{36A}{7}$ (C) $\frac{36A}{5}$ (D) $\frac{9A}{5}$

Q.34 The electron in the hydrogen atom undergoes transition from higher orbitals to orbital of radius 211.6 pm. This transition is associated with :

[JEE Main Online - 2017]

- (A) Lyman series (B) Balmer series
 (C) Brackett series (D) Paschen series

Q.35 In the molecular orbital diagram for the molecular ion, N_2^+ , the number of electrons in the σ_{2p} molecular orbital is :

[JEE-Main Online-2018]

- (A) 0 (B) 2 (C) 3 (D) 1

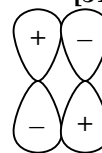
Q.36 Which of the following arrangements shown the schematic alignment of magnetic moments of antiferromagnetic substance?

[JEE-Main Online -2018]

- (A) $\uparrow \downarrow \downarrow \downarrow \downarrow \uparrow$
 (B) $\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow$
 (C) $\uparrow \uparrow \downarrow \uparrow \uparrow \downarrow$
 (D) $\uparrow \downarrow \uparrow \downarrow \uparrow \downarrow$

Q.37 Which of the following best describes the diagram of molecular orbital ?

[JEE-Main Online -2018]



- (A) A bonding π orbital
 (B) A non-bonding orbital
 (C) An antibonding σ orbital
 (D) An antibonding π orbital

Q.38 The de-Broglie's wavelength of electron present in first Bohr orbit of 'H' atom is -

[JEE-Main Online -2018]

- (A) $4 \times 0.529 \text{ \AA}$ (B) $2\pi \times 0.529 \text{ \AA}$
 (C) $\frac{0.529}{2\pi} \text{ \AA}$ (D) 0.529 \AA

Q.39 Which of the following conversions involves change in both shape and hybridization ?

[JEE-Main Online-2018]

- (A) $\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+$ (B) $\text{BF}_3 \rightarrow \text{BF}_4^-$
 (C) $\text{CH}_4 \rightarrow \text{C}_2\text{H}_6$ (D) $\text{NH}_3 \rightarrow \text{NH}_4^+$

Q.40 For emission line of atomic hydrogen from $n_1 = 8$ to $n_f = n$, the plot of wave number ($\bar{\nu}$)

against $\left(\frac{1}{n^2}\right)$ will be (The Rydberg constant,

R_H is wave number unit)

[Main -2019]

- (A) Linear with slope $-R_H$
 (B) Linear with slope R_H
 (C) Non linear
 (D) Linear with intercept $-R_H$

Q.41 Which of the following combination of statements is true regarding the interpretation of the atomic orbitals ?

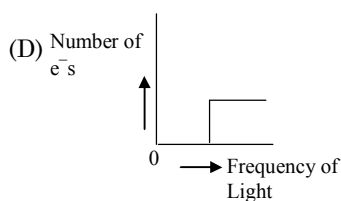
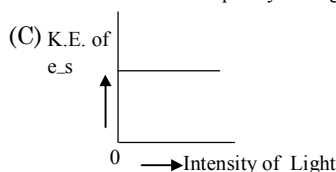
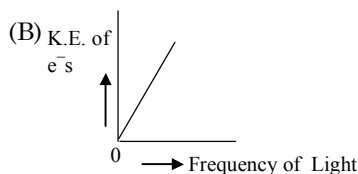
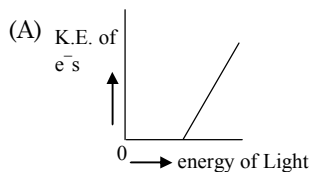
[Main -2019]

- (a) An electron in an orbital of high angular momentum stays away from the nucleus than an electron in the orbital of lower angular momentum.
 (b) For a given value of the principal quantum number, the size of the orbit is inversely proportional to the azimuthal quantum number.
 (c) According to wave mechanics, the ground state angular momentum is equal to $h/2\pi$.
 (d) The plot of ψ Vs r for various azimuthal quantum numbers, shows peak shifting towards higher r value.

- (A) (b), (c) (B) (a), (d)
 (C) (a), (b) (D) (a), (c)

- Q.42** Which primitive unit cell has unequal edge lengths ($a \neq b \neq c$) and all axial angles different from 90° ? [Main -2019]
 (A) Hexagonal (B) Tetragonal
 (C) Triclinic (D) Monoclinic

- Q.43** Which of the graphs shown below does not represent the relationship between incident light and the electron ejected from metal surface? [Main -2019]



- Q.44** A compound of formula A_2B_3 has the hcp lattice. Which atom forms the hcp lattice and what fraction of tetrahedral voids is occupied by the other atoms : [Main -2019]

- (A) hcp lattice - A, $\frac{1}{3}$ Tetrahedral voids-B
 (B) hcp lattice - B, $\frac{1}{3}$ Tetrahedral voids -A
 (C) hcp lattice - A, $\frac{2}{3}$ Tetrahedral voids -B
 (D) hcp lattice -B, $\frac{2}{3}$ Tetrahedral voids-A

- Q.45** The ground state energy of hydrogen atom is -13.6 eV. The energy of second excited state of He^+ ion in eV is : [Main -2019]
 (A) -6.04 (B) -54.4
 (C) -27.2 (D) -3.4

- Q.46** Heat treatment of muscular pain involves radiation of wavelength of about 900 nm.

Which spectral line of H-atom is suitable for this purpose ?

- [$R_H = 1 \times 10^5 \text{ cm}^{-1}$, $h = 6.6 \times 10^{-34} \text{ Js}$, $c = 3 \times 10^8 \text{ ms}^{-1}$] [Main -2019]
 (A) Balmer, $\infty \rightarrow 2$ (B) Paschen, $5 \rightarrow 3$
 (C) Paschen, $\infty \rightarrow 3$ (D) Lyman, $\infty \rightarrow 1$

- Q.47** The radius of the largest sphere which fits properly at the centre of the edge of a body centred cubic unit cell is : (Edge length is represented by 'a') [Main -2019]
 (A) $0.134 a$ (B) $0.067 a$
 (C) $0.047 a$ (D) $0.027 a$

- Q.48** The de Broglie wavelength (λ) associated with a photoelectron varies with the frequency (ν) of the incident radiation as, [ν_0 is threshold frequency] : [Main -2019]

- (A) $\lambda \propto \frac{1}{(\nu - \nu_0)^{\frac{3}{2}}}$ (B) $\lambda \propto \frac{1}{(\nu - \nu_0)^4}$
 (C) $\lambda \propto \frac{1}{(\nu - \nu_0)}$ (D) $\lambda \propto \frac{1}{(\nu - \nu_0)^{\frac{1}{2}}}$

- Q.49** What is the work function of the metal if the light of wavelength 4000\AA generates photoelectrons of velocity $6 \times 10^5 \text{ ms}^{-1}$ from it ? (Mass of electron = $9 \times 10^{-31} \text{ kg}$; Velocity of light = $3 \times 10^8 \text{ ms}^{-1}$; Planck's constant = $6.626 \times 10^{-34} \text{ Js}$; Charge of electron = $1.6 \times 10^{-19} \text{ JeV}^{-1}$) [Main -2019]

- (A) 4.0 eV (B) 0.9 eV
 (C) 2.1 eV (D) 3.1 eV

- Q.50** If the de Broglie wavelength of the electron in n^{th} Bohr orbit in a hydrogenic atom is equal to $1.5 \pi a_0$ (a_0 is Bohr radius), then the value of n/z is - [Main -2019]

- (A) 0.75 (B) 0.40
 (C) 1.50 (D) 1.0

- Q.51** The quantum number of four electrons are given below : [Main -2019]

- I. $n = 4, l = 2, m_l = -2, m_s = -\frac{1}{2}$
 II. $n = 3, l = 2, m_l = 1, m_s = +\frac{1}{2}$
 III. $n = 4, l = 1, m_l = 0, m_s = +\frac{1}{2}$
 IV. $n = 3, l = 1, m_l = 1, m_s = -\frac{1}{2}$

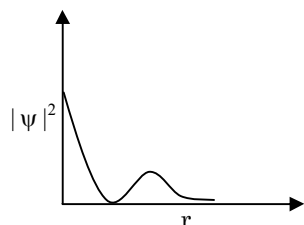
The correct order of their increasing energies will be -

- (A) $I < III < II < IV$ (B) $IV < II < III < I$
 (C) $I < II < III < IV$ (D) $IV < III < II < I$

- Q.52** The size of the iso-electronic species Cl^- , Ar and Ca^{2+} is affected by - **[Main -2019]**
 (A) nuclear charge
 (B) azimuthal quantum number of valence shell
 (C) electron-electron interaction in the outer orbitals
 (D) principal quantum number of valence shell

- Q.53** For silver, $C_p(\text{JK}^{-1} \text{mol}^{-1}) = 23 + 0.01 T$. If the temperature (T) of 3 moles of silver is raised from 300 K to 1000 K at 1 atm pressure, the value of ΔH will be close to- **[Main -2019]**
 (A) 13 kJ (B) 16 kJ
 (C) 62 kJ (D) 21 kJ

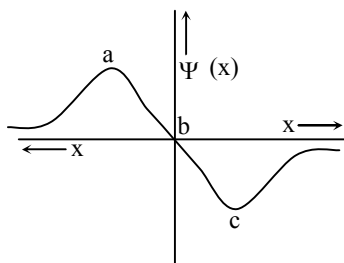
- Q.54** The graph between $|\psi|^2$ and r (radial distance) is shown below. This represents : **[Main -2019]**



- (A) 3s orbital (B) 2s orbital
 (C) 2p orbital (D) 1s orbital

- Q.55** The ratio of the shortest wavelength of two spectral series of hydrogen spectrum is found to be about 9. The spectral series are: **[Main -2019]**
 (A) Paschen and Pfund
 (B) Balmer and Brackett
 (C) Lyman and Paschen
 (D) Brackett and Pfund

- Q.56** The electrons are more likely to be found : **[Main -2019]**



- (A) in the region a and c
 (B) only in the region c
 (C) in the region a and b
 (D) only in the region a

- Q.57** The group number, number of valence electrons, and valency of an element with atomic number 15, respectively, are: **[Main -2019]**
 (A) 16, 6 and 3 (B) 15, 6 and 12
 (C) 16, 5 and 2 (D) 15, 5 and 3

- Q.58** An element has a face-centred cubic (fcc) structure with a cell edge of a. The distance between the centres of two nearest tetrahedral voids in the lattice is : **[Main -2019]**
 (A) a (B) $\frac{3}{2}a$ (C) $\frac{a}{2}$ (D) $\sqrt{2}a$

- Q.59** The ratio of number of atoms present in a simple cubic, body centered cubic and face centered cubic structure are, respectively : **[Main -2019]**
 (A) 8 : 1 : 6 (B) 4 : 2 : 1
 (C) 1 : 2 : 4 (D) 4 : 2 : 3

- Q.60** The number of orbitals associated with quantum numbers $n = 5$, $m_s = +\frac{1}{2}$ is : **[Main -2020]**
 (A) 15 (B) 50 (C) 11 (D) 25

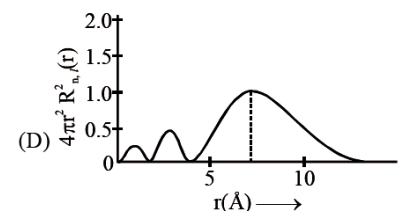
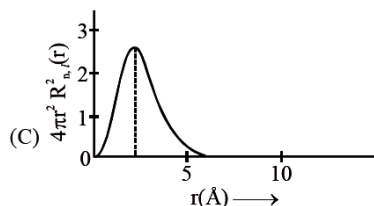
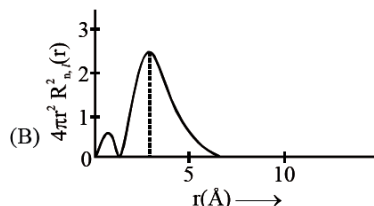
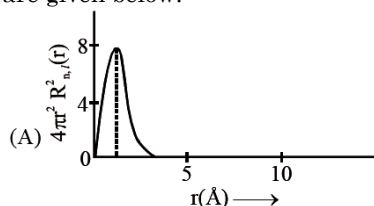
- Q.61** For the Balmer series in the spectrum of H atom, $\bar{\nu} = R_H \left\{ \frac{1}{n_1^2} - \frac{1}{n_2^2} \right\}$, the correct statements among (I) to (IV) are : **[Main -2020]**
 (I) As wavelength decreases, the lines in the series converge
 (II) The integer n_1 is equal to 2
 (III) The lines of longest wavelength corresponds to $n_2 = 3$
 (IV) The ionization energy of hydrogen can be calculated from wave number of these lines
 (A) (II), (III), (IV) (B) (I), (III), (IV)
 (C) (I), (II), (III) (D) (I), (II), (IV)

- Q.62** Which of the following are isostructural pairs ? **[Main -2021]**
 A. SO_4^{2-} and CrO_4^{2-}
 B. SiCl_4 and TiCl_4
 C. NH_3 and NO_3^-
 D. BCl_3 and BrCl_3
 (A) C and D only (B) A and B only
 (C) A and C only (D) B and C only

- Q.63** According to Bohr's atomic theory :-
 (A) Kinetic energy of electron is $\propto \frac{Z^2}{n^2}$
 (B) The product of velocity (v) of electron and principal quantum number (n), ' vn ' $\propto Z^2$.
 (C) Frequency of revolution of electron in an orbit is $\propto \frac{Z^3}{n^3}$
 (D) Coulombic force of attraction on the electron is $\propto \frac{Z^3}{n^4}$

Choose the most appropriate answer from the options given below : **[Main -2021]**
 (A) (C) Only (B) (A) Only
 (C) (A), (C) and (D) only (D) (A) and (D) only

- Q.64** The plots of radial distribution functions for various orbitals of hydrogen atom against 'r' are given below: **[Main -2021]**



The correct plot for 3s orbital is:

- (A) (B) (B) (A) (C) (D) (D) (C)

- Q.65** The orbital having two radial as well as two angular nodes is - **[Main -2021]**

- (A) 3p (B) 4f (C) 4d (D) 5d

- Q.66** If the radius of the 3rd Bohr's orbit of hydrogen atom is r_3 and the radius of 4th Bohr's orbit is r_4 . Then : **[Main -2022]**

- (A) $r_4 = \frac{9}{16} r_3$ (B) $r_4 = \frac{16}{9} r_3$
(C) $r_4 = \frac{3}{4} r_3$ (D) $r_4 = \frac{4}{3} r_3$

- Q.67** Hydrogen has three isotopes: protium (¹H), deuterium (²H or D) and tritium (³H or T). They have nearly same chemical properties but different physical properties. They differ in **[Main -2022]**

- (A) Number of protons
(B) Atomic number
(C) Electronic configuration
(D) Atomic mass

- Q.68** Which of the following statements are correct ?
(a) The electronic configuration of Cr is [Ar] 3d⁵4s¹.
(b) The magnetic quantum number may have a negative value.
(c) In the ground state of an atom, the orbitals are filled in order of their increasing energies.
(d) The total number of nodes are given by $n - 2$.
Choose the **most appropriate** answer from the options given below : **[Main -2022]**
(A) (a), (c) and (d) only (B) (a) and (b) only
(C) (a) and (c) only (D) (a), (b) and (c) only

- Q.69** The correct decreasing order of energy for the orbitals having, following set of quantum numbers: **[Main -2022]**

- (1) $n = 3, \ell = 0, m = 0$
(2) $n = 4, \ell = 0, m = 0$
(3) $n = 3, \ell = 1, m = 0$
(4) $n = 3, \ell = 2, m = 1$
(A) (4) > (2) > (3) > (1) (B) (2) > (4) > (3) > (1)
(C) (3) > (2) > (4) > (1) (D) (2) > (3) > (4) > (1)

- Q.70** If the uncertainty in velocity and position of a minute particle in space are, 2.4×10^{-26} (m s⁻¹) and 10^{-7} (m) respectively. The mass of the particle in g is _____. (Nearest integer) (Given : $h = 6.626 \times 10^{-34}$ Js) **[Main -2022]**

- Q.71** Consider the following set of quantum numbers.

	n	l	m_l
A.	3	3	-3
B.	3	2	-2
C.	2	1	+1
D.	2	2	+2

The number of correct sets of quantum numbers is _____. **[Main -2022]**

- Q.72** Consider an imaginary ion ${}_{22}^{48}\text{X}^{3-}$. The nucleus contains 'a%' more neutrons than the number of electrons in the ion. The value of 'a' is _____. [nearest integer] **[Main -2022]**

- Q.73** Maximum number of electrons that can be accommodated in shell with $n = 4$ are :

- (A) 72 (B) 32 (C) 16 (D) 50 **[Main -2023]**

- Q.74** The wave function (Ψ) of 2s is given by

$$\Psi_{2s} = \frac{1}{2\sqrt{2\pi}} \left(\frac{1}{a_0} \right)^{1/2} \left(2 - \frac{r}{a_0} \right) e^{-r/2a_0}$$

At $r = r_0$, radial node is formed, Thus, r_0 in term of a_0 **[Main -2023]**

- (A) $r_0 = 2a_0$ (B) $r_0 = 4a_0$
(C) $r_0 = a_0$ (D) $r_0 = \frac{a_0}{2}$

Q.75 The radius of the 2nd orbit of Li²⁺ is x. The expected radius of the 3rd orbit of Be³⁺ is :
[Main -2023]

- (A) $\frac{9}{4}x$ (B) $\frac{16}{27}x$ (C) $\frac{27}{16}x$ (D) $\frac{4}{9}x$

Q.76 If the radius of the first orbit of hydrogen atom is α_0 , then de Broglie's wavelength of electron in 3rd orbit is
[Main -2023]

- (A) $\frac{\pi\alpha_0}{6}$ (B) $\frac{\pi\alpha_0}{3}$
(C) $6\pi\alpha_0$ (D) $3\pi\alpha_0$

Q.77 The total number of isoelectronic species from the given set is _____.
O²⁻, F⁻, Al, Mg²⁺, Na⁺, O⁺, Mg, Al³⁺, F
[Main -2023]

Section-B [JEE Advanced]

Q.1 The number of radial nodal surface in 3s and 2p
[IIT-2005]

- (A) 2, 0 (B) 2, 1 (C) 1, 0 (D) 0, 2

Q.2 Give answer : [IIT-2005]

- (a) For first orbit of hydrogen atom, calculate the velocity of electron ($r = a_0 = 0.529 \text{ \AA}$)
(b) Calculate the de-broglie wavelength of electron in first Bohr orbit
(c) Calculate the orbital angular momentum of 2p orbital in terms of $h/2\pi$ units

Q.3 According to Bohr's theory, [IIT-2006]

- E_n = Total energy ;
 K_n = Kinetic energy
 V_n = Potential energy
 r_n = Radius of nth orbit
Match the following :

Column-I		Column-II	
(A)	$V_n/K_n = ?$	(P)	0
(B)	If radius of nth orbital is r_n , $r_n \propto E_n^x$, $x = ?$	(Q)	-1
(C)	Angular momentum in lowest orbital	(R)	-2
(D)	$\frac{1}{r^n} \propto Z^y$, $y = ?$	(S)	1

Q.4 Match the entries in column-I with the correctly related quantum no. (s) in column-II [IIT-2008]

Column-I		Column-II	
(A)	orbital angular momentum of the electron in a hydrogen like atomic orbital	(P)	Principal quantum number

(B)	A hydrogen like one electron wave function obeying Pauli's number principle	(Q)	Azimuthal quantum number
(C)	Shape, size and orientation of hydrogen like atomic orbital	(R)	magnetic quantum number
(D)	Probability density of electron at the nucleus in hydrogen like atom	(S)	Electron spin quantum number

Passage based objective questions

Passage :1 (Ques. 5 to 7)

The hydrogen like species Li²⁺ is in a spherically symmetric state S₁ with one radial node. Upon absorbing light the ion undergoes transition to a state S₂. The state S₂ has one radial node and its energy is equal to the ground state energy of the hydrogen atom.

[IIT-2010]

Q.5 The state S₁ is -

- (A) 1s (B) 2s (C) 2p (D) 3s

Q.6 Energy of the state S₁ in units of the hydrogen atom ground state energy is -

- (A) 0.75 (B) 1.50 (C) 2.25 (D) 4.50

Q.7 The orbital angular momentum quantum number of the state S₂ is -

- (A) 0 (B) 1 (C) 2 (D) 3

Q.8 The maximum number of electrons that can have principal quantum number, $n = 3$ and spin quantum number, $m_s = -1/2$, is. [IIT-2011]

Q.9 The work function (ϕ) of some metals is listed below. The number of metals which will show photoelectric effect when light of 300 nm wavelength falls on the metal is. [IIT-2011]

Metal	Li	Na	K	Mg	Cu	Ag	Fe	Pt	W
ϕ (eV)	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

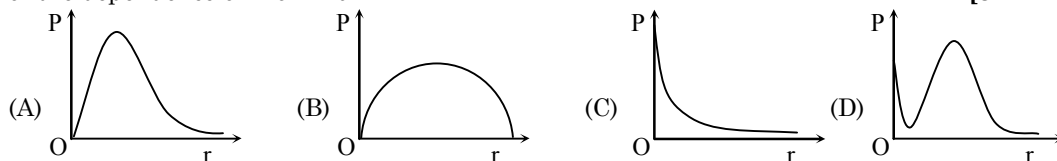
Q.10 The kinetic energy of an electron in the second Bohr orbit of a hydrogen atom is [a_0 is Bohr radius] [IIT-2012]

- (A) $\frac{h^2}{4\pi^2 ma_0^2}$ (B) $\frac{h^2}{16\pi^2 ma_0^2}$
(C) $\frac{h^2}{32\pi^2 ma_0^2}$ (D) $\frac{h^2}{64\pi^2 ma_0^2}$

Q.11 In an atom, the total number of electrons having quantum numbers $n = 4$, $|m_l| = 1$ and $m_s = -1/2$ is [JEE-Advance-2014]

Q.12 Not considering the electronic spin, the degeneracy of the second excited state ($n = 3$) of H atom is 9, while the degeneracy of the second excited state of H^- is - **[JEE-Advance-2015]**

Q.13 P is the probability of finding the 1s electron of hydrogen atom in a spherical shell of infinitesimal thickness, dr , at a distance r from the nucleus. The volume of this shell is $4\pi r^2 dr$, The qualitative sketch of the dependence of P on r is- **[JEE-Advance-2016]**



Passage : 2 (Ques. 14 to 16)

Answer Q.14, Q.15 and Q.16 by appropriately matching the information given in the three columns of the following table **[JEE-Advance-2017]**

The wave function, Ψ_{n,ℓ,m_1} is a mathematical function whose value depends upon spherical polar coordinates (r, θ, ϕ) of the electron and characterized by the quantum numbers n, ℓ and m_1 . Here r is distance from nucleus, θ is colatitude and ϕ is azimuth. In the mathematical functions given in the Table, Z is atomic number and a_0 is Bohr radius

Column 1	Column 2	Column 3
(I) 1s orbital	(i) $\Psi_{n,\ell,m_1} \propto \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} e^{-\left(\frac{Zr}{a_0}\right)}$	(P)
(II) 2s orbital	(ii) One radial node	(Q) Probability density at nucleus $\propto \frac{1}{a_0^3}$
(III) 2p _z orbital	(iii) $\Psi_{n,\ell,m_1} \propto \left(\frac{Z}{a_0}\right)^{\frac{5}{2}} r e^{-\left(\frac{Zr}{2a_0}\right)} \cos \theta$	(R) Probability density is maximum at nucleus
(IV) 3d _{z²} orbital	(iv) xy- plane is a nodal plane	(S) Energy needed to excite electron from $n = 2$ state to $n = 4$ state is $\frac{27}{32}$ times the energy needed to excite electron from $n = 2$ state to $n = 6$ state

Q.14 For the given orbital in Column 1, the only **CORRECT** combination for any hydrogen-like species is
 (A) (III) (iii) (P) (B) (II) (ii) (P) (C) (IV) (iv) (R) (D) (I) (ii) (S)

Q.15 For He^+ ion, the only **INCORRECT** combination is
 (A) (I) (i) (R) (B) (I) (i) (S) (C) (I) (iii) (R) (D) (II) (ii) (Q)

Q.16 For hydrogen atom, the only **CORRECT** combination is
 (A) (I) (i) (S) (B) (I) (iv) (R) (C) (I) (i) (P) (D) (II) (i) (Q)

Q.17 At 143 K, the reaction of XeF_4 with O_2F_2 produces a xenon compound Y. The total number of lone pair(s) of electron present on the whole molecule of Y is ____

[JEE-Advanced-2019]

Q.18 The ground state energy of hydrogen atom is -13.6 eV. Consider an electronic state ψ of He^+ whose energy, azimuthal quantum number and magnetic quantum number are -3.4 eV, 2 and 0, respectively. Which of the following statement(s) is(are) true for the state ψ ?

[MCQ]

[JEE-Advanced-2019]

- (A) The nuclear charge experienced by the electron in this state is less than $2e$, where e is the magnitude of the electronic charge
 (B) It has 2 angular nodes
 (C) It has 3 radial nodes
 (D) It is a 4d state

Q.19 Consider the Bohr's model of a one-electron atom where the electron moves around the nucleus. In the following, List-I contains some quantities for the n^{th} orbit of the atom and List-II contains options showing how they depend on n .

[JEE-Advanced-2019]

LIST-I

LIST-II

- | | |
|--|-----------------------|
| (I) Radius of the n^{th} orbit | (P) $\propto n^{-2}$ |
| (II) Angular momentum of the electron in the n^{th} orbit | (Q) $\propto n^{-1}$ |
| (III) Kinetic energy of the electron in the n^{th} orbit | (R) $\propto n^0$ |
| (IV) Potential energy of the electron in the n^{th} orbit | (S) $\propto n^1$ |
| | (T) $\propto n^2$ |
| | (U) $\propto n^{1/2}$ |

- (A) (III), (P) (B) (III), (S)
 (C) (IV), (U) (D) (IV), (Q)

Q.20 Consider the Bohr's model of a one-electron atom where the electron moves around the nucleus. In the following, List-I contains some quantities for the n^{th} orbit of the atom and List-II contains options showing how they depend on n .

[JEE-Advanced-2019]

LIST-I

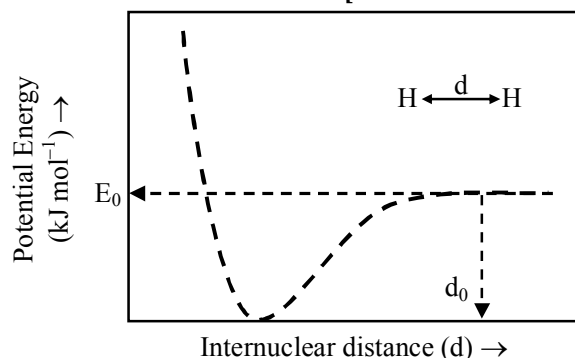
LIST-II

- | | |
|--|-----------------------|
| (I) Radius of the n^{th} orbit | (P) $\propto n^{-2}$ |
| (II) Angular momentum of the electron in the n^{th} orbit | (Q) $\propto n^{-1}$ |
| (III) Kinetic energy of the electron in the n^{th} orbit | (R) $\propto n^0$ |
| (IV) Potential energy of the electron in the n^{th} orbit | (S) $\propto n^1$ |
| | (T) $\propto n^2$ |
| | (U) $\propto n^{1/2}$ |

- (A) (I), (P) (B) (I), (T)
 (C) (II), (R) (D) (II), (Q)

Q.21 The figure below is the plot of potential energy verses internuclear distance (d) of H_2 molecule in the electronic ground state. What is the value of the net potential energy E_0 (as indicated in the figure) in kJ mol^{-1} , for $d = d_0$ at which the electron-electron repulsion and the nucleus-nucleus repulsion energies are absent ? as reference, the potential energy of H atom is taken as zero when its electron and the nucleus are infinitely far apart.

Use Avogadro constant as $6.023 \times 10^{23} \text{ mol}^{-1}$
 [JEE-Advanced-2020]



Q.22 Consider a helium (He) atom that absorbs a photon of wavelength 330 nm. The change in the velocity (in cm s^{-1}) of He atom after the photon absorption is ____.

(Assume : Momentum is conserved when photon is absorbed.)

Use : Planck constant = $6.6 \times 10^{-34} \text{ J s}$,
 Avogadro number = $6 \times 10^{23} \text{ mol}^{-1}$, Molar mass of He = 4 g mol^{-1}
 [JEE-Advanced-2021]

Q.23 For diatomic molecules, the correct statement(s) about the molecular orbitals formed by the overlap of two $2p_z$ orbitals is (are)

[JEE-Advanced-2022]

- (A) σ orbital has a total of two nodal planes.
 (B) σ^* orbital has one node in the x-z plane containing the molecular axis.
 (C) π orbital has one node in the plane which is perpendicular to the molecular axis and goes through the center of the molecule.
 (D) π^* orbital has one node in the xy-plane containing the molecular axis.

Q.24 For He^+ , a transition takes place from the orbit of radius 105.8 pm to the orbit of radius 26.45 pm. The wavelength (in nm) of the emitted photon during the transition is ____.

[Use: Bohr radius, $a = 52.9 \text{ pm}$; Rydberg constant, $R_H = 2.2 \times 10^{-18} \text{ J}$; Planck's constant, $h = 6.6 \times 10^{-34} \text{ J s}$; Speed of light, $c = 3 \times 10^8 \text{ m s}^{-1}$]

[JEE-Advanced-2023]

EXERCISE (Level-5)

Review Exercise

- Q.1** An electron is accelerated from a very low velocity (\sim zero speed) by the application of a potential difference of V volts. If the de Broglie wavelength should change (i.e., decrease) by 1.0% what percent increase in V causes it-
- Q.2** An electron first accelerated through 100 volts suffers successively two retardations (i) through 19 volts and then (ii) through 32 volts. Its de Broglie wavelengths in the three situations are respectively λ_1 , λ_2 and λ_3 . Calculate $\frac{\lambda_3 - \lambda_2}{\lambda_1}$.
- Q.3** Photons having energy equivalent to binding energy of 2nd state of Li^+ ion are used at metal surface of work function 10.6 eV. If the ejected electrons are further accelerated through the potential difference of 5 V then the minimum value of de-Broglie wavelength associated with the electron is -
- Q.4** A hydrogen atom in its ground state absorbs a photon and goes into the first excited state. It then absorbs a second photon which just ionizes it. What is the ratio of the wavelengths of the first photon and the second photon ?
- Q.5** A hydrogen like atom with atomic number 'Z' is in higher excited state of quantum number 'n'. This excited state atom can make a transition to the first excited state by successively emitting two photons of energies 10 eV and 17 eV respectively. Alternatively, the atom from the same excited state can make a transition to the 2nd excited state by emitting two photons of energies 4.25 eV and 5.95 eV respectively. The 'n' and 'Z' are-
- Q.6** The Schrodinger wave equation for hydrogen atom is
- Q.7** For a hypothetical hydrogen like atom, the potential energy of the system is given by $U(r) = \frac{-Ke^2}{r^3}$, where r is the distance between the two particles. If Bohr's model of quantization of angular momentum is applicable then velocity of particle is given by:
- Q.8** An element undergoes a reaction as shown: $X + 2e^- \rightarrow X^{2-}$, energy released = 30.87 eV/atom. If the energy released, is used to dissociate 4 gms of H_2 molecules, equally into H^+ and H^* , where H^* is excited state of H atoms where the electron travels in orbit whose circumference equal to four times its de Broglie's wavelength. Determine the least moles of X that would be required: Given: I.E. of H = 13.6 eV/atom, bond energy of H_2 = 4.526 eV/molecule
- Q.9** In a measurement of quantum efficiency of photosynthesis in green plants, it was found that 10 quanta of red light of wavelength 6850 Å were needed to release one molecule of O_2 . The average energy storage in this process is 112 kcal/mol O_2 evolved. What is the energy conversion efficiency in this experiment ? Given: 1 cal = 4.18 J; $N_A = 6 \times 10^{23}$; $h = 6.63 \times 10^{-34}$ J. s
- Q.10** Find the value of wave number ($\bar{\nu}$) in terms of Rydberg's constant, when transition of electron takes place between two levels of He^+ ion whose sum is 4 and difference is 2.

$$\Psi(\text{radial}) = \frac{1}{16\sqrt{4}} \left(\frac{Z}{a_0} \right)^{3/2}$$

$[(\sigma - 1)(\sigma^2 - 8\sigma + 12)] e^{-\sigma/2}$
where a_0 and Z are the constant in which answer can be expressed and $\sigma = \frac{2Zr}{a_0}$
minimum and maximum position of radial nodes from nucleus are.....respectively.

ANSWER KEY

EXERCISE (Level-1)

- | | | | | | | |
|---------|---------|---------|---------|---------|---------|---------|
| 1. (C) | 2. (A) | 3. (C) | 4. (B) | 5. (B) | 6. (C) | 7. (C) |
| 8. (A) | 9. (B) | 10. (D) | 11. (D) | 12. (A) | 13. (D) | 14. (D) |
| 15. (B) | 16. (C) | 17. (D) | 18. (B) | 19. (C) | 20. (C) | 21. (A) |
| 22. (D) | 23. (D) | 24. (C) | 25. (C) | 26. (A) | 27. (D) | 28. (A) |
| 29. (D) | 30. (C) | 31. (A) | 32. (C) | 33. (C) | 34. (A) | 35. (C) |
| 36. (C) | 37. (C) | 38. (B) | 39. (A) | 40. (A) | | |

EXERCISE (Level-2)

- | | | | | | | |
|---------|---------|---------|-----------|---------|---------|---------|
| 1. (D) | 2. (A) | 3. (A) | 4. (D) | 5. (C) | 6. (B) | 7. (D) |
| 8. (A) | 9. (B) | 10. (D) | 11. (C) | 12. (C) | 13. (A) | 14. (A) |
| 15. (D) | 16. (A) | 17. (A) | 18. (C) | 19. (A) | 20. (D) | 21. (C) |
| 22. (B) | 23. (A) | 24. (B) | 25. (C) | 26. (D) | 27. (B) | 28. (A) |
| 29. (D) | 30. (A) | 31. (C) | 32. (B) | 33. (C) | 34. (D) | 35. (D) |
| 36. (C) | 37. (C) | 38. (B) | 39. (B,C) | 40. (C) | 41. (A) | 42. (B) |
| 43. (A) | 44. (C) | 45. (A) | 46. (D) | 47. (A) | 48. (C) | 49. (A) |
| 50. (B) | 51. (A) | 52. (C) | 53. (C) | 54. (A) | 55. (B) | 56. (A) |
| 57. (D) | 58. (A) | 59. (D) | 60. (B) | 61. (C) | 62. (A) | 63. (A) |
| 64. (C) | 65. (D) | 66. (B) | 67. (D) | 68. (B) | 69. (B) | 70. (C) |
| 71. (C) | 72. (C) | 73. (D) | 74. (D) | 75. (B) | 76. (C) | 77. (C) |
| 78. (D) | 79. (B) | | | | | |

EXERCISE (Level-3)

Part-A

- | | | | | | | |
|--------------|---------------|-------------|---------------|-------------|-------------|-------------|
| 1. (A,B,D) | 2. (B,C,D) | 3. (A,B,C) | 4. (A,C) | 5. (A,C) | 6. (A,C) | 7. (A,C,D) |
| 8. (D) | 9. (A,C) | 10. (A,B) | 11. (A,B,C,D) | 12. (A, B) | 13. (B,C,D) | 14. (B,C) |
| 15. (A,B) | 16. (A,C,D) | 17. (A,B,D) | 18. (A,B,C) | 19. (A,C,D) | 20. (B,C) | 21. (B,C,D) |
| 22. (AB,C,D) | 23. (A,B,C,D) | | | | | |

Part-B

- | | | | |
|---------|---------|---------|---------|
| 24. (B) | 25. (B) | 26. (D) | 27. (A) |
|---------|---------|---------|---------|

Part-C

- | | | | |
|----------------|------------------|-----------------|---------------------|
| 28. A → (iii); | B → (iv); | C → (ii); | D → (i) |
| 29. A → (iii); | B → (ii); | C → (iv); | D → (i) |
| 30. A → (iii); | B → (ii), (iii); | C → (ii), (iv); | D → (i), (ii), (iv) |

Part-D

31. (D) 32. (B) 33. (A) 34. (D) 35. (A) 36. (C) 37. (D)
38. (B) 39. (A) 40. (C) 41. (B) 42. (D)

Part-E

43. $n = 5$ 44. $n = 40$

Part-F

45. $\frac{V_e}{V_p} = 1.858 \times 10^3$ 46. (a) 0 (b) $\frac{h}{\sqrt{2}\pi}$ (c) $\frac{2h}{\pi}$
47. (a) $7 \times 10^6 \text{ m}^{-1}$ (b) $R_H = R_H Z^2$
48. 1221 Å 49. $10 \times 10^{-8} \text{ m}$ 50. $87.16 \times 10^{-19} \text{ J}$
51. 3.235 52. $1.598 \times 10^{-4} \text{ m/sec.}$ 53. 6.4×10^{24}
54. Total spin = $\pm 3/2, \pm 3, \pm 1, 0$: magnetic moment = $\sqrt{15}, \sqrt{48}, \sqrt{8}, 0$ 55. 26
56. $8 \times 10^{15} \text{ Hz}$ 57. $13.297 \times 10^{-10} \text{ m}$ 58. 184.2 kJ
59. 1212 Å, 1022 Å, 5545 Å 60. $2.067 \times 10^{16} \text{ sec}^{-1}$
61. (a) 5 ; (b) $23.9 \times 10^{-19} \text{ J}$; (c) 36.5 Å ; (d) $5.45 \times 10^{-10} \text{ erg}$ 62. 2.351 Å
63. (a) 9 (b) 25 64. $7.36 \times 10^5 \text{ m/s}$

EXERCISE (Level-4)

SECTION-A

1. (C) 2. (D) 3. (C) 4. (B) 5. (B) 6. (C) 7. (C)
8. (B) 9. (C) 10. (A) 11. (A) 12. (C) 13. (B) 14. (B)
15. (B) 16. (A) 17. (C) 18. (A) 19. (B) 20. (B) 21. (C)
22. (D) 23. (B) 24. (D) 25. (D) 26. (A) 27. (C) 28. (C)
29. (C) 30. (D) 31. (B) 32. (C) 33. (B) 34. (B) 35. (D)
36. (D) 37. (D) 38. (B) 39. (B) 40. (B) 41. (B) 42. (C)
43. (B) 44. (B) 45. (A) 46. (C) 47. (B) 48. (D) 49. (C)
50. (A) 51. (B) 52. (A) 53. (C) 54. (B) 55. (C) 56. (A)
57. (D) 58. (C) 59. (C) 60. (D) 61. (C) 62. (B) 63. (D)
64. (C) 65. (D) 66. (B) 67. (D) 68. (D) 69. (A) 70. [22.00]
71. [2.00] 72. [4.00] 73. (B) 74. (A) 75. (C) 76. (C) 77. (5)

SECTION-B

1. (A) 2. (a) 2.18×10^8 cm/sec (b) 3.3 \AA (C) $\sqrt{2} \frac{h}{2\pi}$ 3. a \rightarrow R; b \rightarrow Q; c \rightarrow P; d \rightarrow S
4. a \rightarrow Q, R; b \rightarrow P, Q, R, S; c \rightarrow P, Q, R; d \rightarrow P, Q
- 5.(B) 6.(C) 7.(B) 8.[9] 9.[4] 10. (C) 11. [6]
12. [3] 13. (A) 14.(B) 15.(C) 16.(A) 17. [19.00] 18. (B,D)
19. (A) 20. (B) 21. [-5246.50] 22. [30] 23. [A, D] 24. [30]

EXERCISE (Level-5)

1. $V = 2\%$ 2. $\frac{20}{63}$ 3. 2.45 \AA 4. 0.33 5. $n \approx 6$
6. $r_1 = \frac{a_0}{2Z}, \frac{a_0}{Z}, \frac{3a_0}{Z}$ 7. $v = \frac{n^3 h^3}{24K e^2 \pi^3 m^2}$ 8. 2 9. 26.9% 10. $\frac{32R}{9}$