Structure of Atom

ANSWERS

1. Orbitals having same energy belonging to the same subshell.

2. (i) Size of electron cloud
(ii) Energy of electron
(iii) Maximum number of electrons present in any principal shell

3. Dumb-bell shape.

4. 10 electrons

5. Radius of n^{th} Bohr's orbit = $0.53\ n^2$ Å

6. Lyman series are obtained by jump of electrons to $n = 1(K)$ from $n = 2, 3, 4$ *i.e.*, (L, M, N).

7. **(b) :** Number of orbitals in a sub-shell = $2l + 1$
Number of electrons = $2(2l + 1) = 4l + 2$.

8. **(d) :** For sulphur $Z = 16$.

9. **(a) :** Angular momentum = $\frac{nh}{2\pi} = \frac{5h}{2\pi} = \frac{2.5\ h}{\pi}$

10. **(a)** $Na(Z = 11) = 1s^2\ 2s^2\ 2p^6\ 3s^1$ *i.e.*, last electron has $l = 0$ hence, $m_l = 0$.

11. **(b)**

12. **(a)**

13. **(d) :** $3p$ orbital has one spherical node and one planar node.

14. **(d) :** d_{z^2} orbital has different shape and it has same energy.

15.

Cathode rays	Anode rays
They originate from the cathode.	They do not originate from the anode. They are produced from the gaseous atoms by knocking out of the electrons by high speed cathode rays.

16. (i) Photoelectric effect – Particle nature
(ii) Planck's equation – Both particle and wave nature
(iii) Black body radiation – Particle nature
(iv) Diffraction – Wave nature

OR

(i) ${}^{14}_{6}C$ (ii) ${}^{14}_{6}C$ (iii) ${}^{40}_{19}K$ (iv) ${}^{15}_{7}N$

17. The electronic configuration of atom having highest value of $n = 5$ is

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2$
(After $5s$, filling of $4d$ starts).
Hence, the maximum number of electrons present is 38.

18. For atom $3d^{10}\ 4s^2 \Rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}$
Atomic number is the number of electrons = 30
$3s^2\ 3p^6 \Rightarrow 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$
Atomic number = 18

19. The smallest quantity of energy that can be emitted or absorbed in the form of electromagnetic radiation is called quantum.

OR

The minimum frequency, υ_0 below which photoelectric effect is not observed is called threshold frequency.

20. (a) For $n = 5$, l can have five values, *i.e.*, $l = 0, 1, 2, 3$ and 4 (s, p, d, f and g).
(b) Fe^{2+} : [Ar] $3d^6$

21. **Similarities :**
(i) Both have spherical shape.
(ii) Both have same angular momentum
i.e., $\sqrt{l\,(l+1)}\,\frac{h}{2\pi} = \sqrt{0(0+1)}\,\frac{h}{2\pi} = 0$

Differences :
(i) Number of spherical or radial nodes = $(n - l - 1)$
For $2s$ orbital = $(2 - 0 - 1) = 1$ node
For $3s$ orbital = $(3 - 0 - 1) = 2$ nodes
(ii) Energy of $3s$ is greater than $2s$ orbital.
(iii) Size of $3s$ is larger than $2s$ orbital.

22. Angular momentum = $\sqrt{l\,(l+1)}\,\frac{h}{2\pi}$
(i) For $1s$, $l = 0$; Angular momentum = 0
(ii) For $2p$, $l = 1$; Angular momentum = $\sqrt{1(1+1)}\,\frac{h}{2\pi} = \sqrt{2}\,\frac{h}{2\pi}$
(iii) For $3d$, $l = 2$; Angular momentum = $\sqrt{2(2+1)}\,\frac{h}{2\pi} = \sqrt{6}\,\frac{h}{2\pi}$
(iv) For $4f$, $l = 3$; Angular momentum = $\sqrt{3(3+1)}\,\frac{h}{2\pi} = \sqrt{12}\,\frac{h}{2\pi}$

(v) For $5g, l = 4$; Angular momentum $= \sqrt{4(4+1)}\frac{h}{2\pi} = \sqrt{20}\frac{h}{2\pi}$

(vi) For $3s$, $l = 0$; Angular momentum = 0

23. According to the Bohr's theory, the angular momentum of an electron of mass m, moving with a velocity v along a path of radius of r, is quantised and can have only values *i.e.*, multiple of $\frac{h}{2\pi}$.

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr}$$

For the innertmost orbit, $n = 1$

$$v = \frac{1\times 6.626\times 10^{-34}}{2\times 3.14\times 9.1\times 10^{-31}\times 0.0529\times 10^{-9}}$$

$= 2.19 \times 10^6$ ms^{-1}

24. Ionization of hydrogen atom involves transition of an electron form the lowest orbit, $n = 1$, to the ionized state, $n = \infty$.

For H-atom,

$$\frac{1}{\lambda} = 109678\left[\frac{1}{1^2} - \frac{1}{\infty}\right] \text{cm}^{-1} = 109678 \text{ cm}^{-1}$$

$\lambda = 9.12 \times 10^{-6}$ cm

$$E = h\upsilon = \frac{hc}{\lambda} = \frac{6.626\times 10^{-27}\text{erg. sec}\times 3\times 10^{10}\text{cm/s}}{9.12\times 10^{-6}\text{cm}}$$

$= 2.1796 \times 10^{-11}$ erg

25. (i) **Aufbau Principle :** It states that in the ground state of the atom, the orbitals are filled in order of their increasing energies, starting with the orbital of lowest energy.

(ii) (a) $Mn(Z = 25) = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^2$

$Mn^{2+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

(b) $Zn(Z = 30) = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2$

$Zn^{2+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$

(c) $Fe(Z = 26) = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6\ 4s^2$

$Fe^{2+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

(d) $Cr(Z = 24) = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$

$Cr^{3+} = 1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3$

26. (i) Pauli's Exclusion Principle states that no two electrons in an atom can have the same set of four quantum numbers.

(ii) Hund's rule states that pairing of electrons in the orbitals belonging to the same subshell does not take place until each orbital belonging to that subshell has got one electron each *i.e.*, it is singly occupied.

(iii) $(n + l)$ rule :

(a) This rule states that an energy level for which $(n + l)$ is lower has lower energy.

(b) If $(n + l)$ is the same for two sub-shells, then the one having lower value of principal quantum number has low energy.

The energy level having lower energy is filled up first. In other words, sub-shells are filled with electrons in increasing order of energy.

OR

(i) Aluminium ($Z = 13$) $\Rightarrow 1s^2 2s^2 2p^6 3s^2 3p^1$

(ii) Argon ($Z = 18$) $\Rightarrow 1s^2 2s^2 2p^6 3s^2 3p^6$

(iii) Sodium ($Z = 11$) $\Rightarrow 1s^2 2s^2 2p^6 3s^1$

(iv) Oxygen ($Z = 8$) $\Rightarrow 1s^2 2s^2 2p^4$

(v) Sulphur ($Z = 16$) $\Rightarrow 1s^2 2s^2 2p^6 3s^2 3p^4$

(vi) Carbon ($Z = 6$) $\Rightarrow 1s^2 2s^2 2p^2$

27. (a) (i) Passing of a large number of α-particles through Gold foil without scattering concludes that most of the space inside the atom is empty.

(ii) Since some α-particles were deflected back and α-particles are heavy particles, these could be deflected back only when they strike some heavier body *i.e.*, whole mass is centred in the nucleus.

(iii) Since few α-particles were deflected through small angle and α-particles are positive particle thus, there can be deflected by positive particles only.

(b) Postulates of Rutherford's nuclear model of an atom :

(i) The positive charge and most of the mass of the atom was densely concentrated in an extremely small region. This very small portion of the atom was called nucleus by Rutherford.

(ii) The nucleus is surrounded by electrons that move around the nucleus with a very high speed in circular paths called orbits.

(iii) Electrons and nucleus are held together by electrostatic forces of attraction.

Drawbacks of Rutherford model :

(i) When a body is moving in an orbit, it achieves acceleration. Thus, an electron moving around nucleus in an orbit is under acceleration.

According to Maxwell's electromagnetic theory, charged particles when accelerated must emit electromagnetic radiation. Therefore, an electron in an orbit will emit radiations, the energy carried by radiation comes from electronic motion. Its path will become closer to nucleus and ultimately should spiral into nucleus within 10–8 s. But actually this does not happen.

(ii) Rutherford's model does not give any idea about distribution of electrons around the nucleus and about their energies.

OR

Electromagnetic wave theory : This theory was put forward by James Clark Maxwell in 1864. The main points of this theory are as follows :

(i) The energy is emitted from any source (like the heated rod or the filament of a bulb through which electric current is passed) continuously in the form of radiations and is called the radiant energy.

(ii) The radiations consist of electric and magnetic fields oscillating perpendicular to each other and both perpendicular to the direction of propagation of the radiation.

(iii) The radiations possess wave character and travel with the velocity of light *i.e.*, 3×10^8 m/sec.

(iv) These waves do not require any material medium for propagation. For example, rays from the sun reach us through space which is a non-material medium.

Limitations of electromagnetic wave theory : Electromagnetic wave theory was successful in explaining the properties of light such as interference, diffraction etc, but it could not explain the following :

(i) The phenomenon of black body radiation.

(ii) The photoelectric effect.

(iii) The variation of heat capacity of solids as a function of temperature.

(iv) The line spectra of atoms with reference to hydrogen.

Planck's quantum theory : To explain the phenomenon of 'black body radiation' and 'photoelectric effect', Max Planck in 1900, put forward a theory known as Planck's quantum theory. This theory was further extended by Einstein in 1905. The main points of this theory are as follows :

(i) The radiant energy is emitted or absorbed in the form of small packets of energy. Each such packet of energy is called a quantum.

(ii) The energy of each quantum is directly proportional to the frequency of the radiation *i.e.*,

$$E \propto \upsilon \quad \text{or} \quad E = h\upsilon$$

where h = proportionality constant, called Planck's constant, ($h = 6.626 \times 10^{-34}$ J sec.)

28. (a) The given wavelengths lie in the visible region. Hence, they are expected to belong to Balmer series. Thus, $n_1 = 2$. Let us calculate n_2 for the shortest wavelength, *viz.*, 410.29 nm

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

$$\frac{1}{410.29 \times 10^{-7}\ \text{cm}} = 109,677\left(\frac{1}{4} - \frac{1}{n_2^2}\right)\text{cm}^{-1}$$

This on solving gives $n_2 = 6$

Thus, the next line will be obtained for jump from $n_2 = 7$ to $n_1 = 2$, so

$$\frac{1}{\lambda} = 109,677\left(\frac{1}{2^2} - \frac{1}{7^2}\right)\text{cm}^{-1}$$

$$= 109,677 \times \left(\frac{1}{4} - \frac{1}{49}\right)\text{cm}^{-1}$$

$$= 109,677 \times \frac{45}{196}\text{cm}^{-1} = 25180.9\ \text{cm}^{-1}$$

or $$\lambda = \frac{1}{25180.90\ \text{cm}^{-1}} = 397.1 \times 10^{-7}\text{cm}$$

$$= 397.1\ \text{nm}$$

(b) Lyman, Balmer, Paschen, Brackett and Pfund.

For Lyman series, $n_1 = 1, n_2 = 2, 3, 4$ ...

For Balmer series, $n_1 = 2, n_2 = 3, 4, 5$ ...

For Paschen series, $n_1 = 3, n_2 = 4, 5, 6$ ...

For Brackett series, $n_1 = 4, n_2 = 5, 6, 7$ ...

For Pfund series, $n_1 = 5, n_2 = 6, 7, 8$ ...

OR

In 1913, Niels Bohr proposed a new model of atom on the basis of Planck's quantum theory. The main points of this model are as follows :

(i) Atom consists of a small, heavy and positively charged nucleus in centre, and electrons revolve around the nucleus in fixed paths called orbits.

(ii) Energy of an electron in the orbit does not change with time.

(iii) The electron can revolve only in those orbits whose angular momentum is an integral multiple of $h/2\pi$ *i.e.*, $mvr = \frac{nh}{2\pi}$, where n = 1, 2, 3 .....

(iv) When electron jumps from one level to another, energy is either emitted or absorbed.

(a) The energy difference between two levels is given by $\Delta E = E_2 - E_1$.

(b) As the distance of the orbits increases from the nucleus, the energy gap goes on decreasing, *i.e.*, $E_2 - E_1 > E_3 - E_2 > E_4 - E_3 > \ldots\ldots$

Limitations of Bohr's model :

(i) The theory could not explain the atomic spectra of the atoms containing more than one electron or multielectron atoms.

(ii) Bohr's theory failed to explain the fine structure of the spectral lines.

(iii) Bohr's theory could not offer any satisfactory explanation of Zeeman effect and Stark effect.

(iv) Bohr's theory failed to explain the ability of atoms to form molecules by chemical bonds.

29. (a) In 1924, de Broglie proposed that matter, like radiation, should also exhibit dual behaviour *i.e.*, both particle like and wave like properties.

(b) Applying uncertainty principle,

$$\Delta v = \frac{0.1\times10^{-4}}{100} = 1\times10^{-7}\ \text{cm s}^{-1}$$

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

$$\therefore\quad \Delta x = \frac{6.626\times10^{-27}}{4\times3.14\times10^{-11}\times1\times10^{-7}} = 5.27\times10^{-10}\ \text{cm}$$

$$\text{Uncertainty in position} = \frac{\Delta x}{\text{diameter}} = \frac{5.27\times10^{-10}}{10^{-4}}$$

$$= 5.27\times10^{-6}\ \text{cm}$$

30. **(i)** $E = h\upsilon_0$

$= 6.626\times10^{-34}\ \text{J s}\times4.8\times10^{14}\ \text{s}^{-1}$

$= 3.18\times10^{-19}\ \text{J}$

(ii) Frequency of light ($E \propto \upsilon$)

Greater the frequency of incident radiation, greater is the kinetic energy of the photoelectrons emitted.

(iii) Number of photoelectrons emitted per unit time depends upon intensity of incident radiations.

(iv) $W_0 = h\upsilon_0 = 6.626\times10^{-34}\ \text{J s}\times\upsilon_0 = 3.65\times10^{-19}\ \text{J}$

$$\upsilon_0 = \frac{3.65\times10^{-19}\ \text{J}}{6.626\times10^{-34}\ \text{Js}} = 5.508\times10^{14}\ \text{s}^{-1}$$

(v) Potential difference of 5 V will give kinetic energy to the electron = 5 eV.