Chapter 5: Atomic Structure

<H1>Review Questions

1. Give the numbers of neutrons, protons, and electrons in the atoms of each of the following isotopes. (Use the table of atomic masses and numbers printed inside the front cover for additional information, as needed.) (a) radium-226, (b) ^{206}Pb, (c) carbon-14, (d) ^{23}Na.

Solution

(a) Radium-226: neutrons = 138; protons = 88; electrons = 88
(b) ^{206}Pb: neutrons = 124; protons = 82; electrons = 82
(c) Carbon-14: neutrons = 8; protons = 6; electrons = 6
(d) ^{23}Na: neutrons = 12; protons = 11; electrons = 11

2. Which property of light waves is a measure of the brightness of the light? Which specifies the color of the light? Which is related to the energy of the light?

Solution

The property of light waves that is a measure of the brightness of the light is amplitude; wavelength specifies the color of light; frequency or wavelength is related to the energy of light.

3. Explain in detail the findings of Thomson's model of the atom. What were the shortcomings?

Solution

Thomson proposed a model of the atom in which the electrons are negatively charged particles embedded in the atomic sphere of approximate radius 10^{-10} m .The positive charge was assumed to be spread throughout the atom, forming a kind of pudding in which the negative electrons were suspended like plums; hence the name plum-pudding model. The mass of the atom is thus assumed to be distributed uniformly over the atom.

Limitation: The model proposed by Thomson could explain the neutrality of an atom, but could not account for results for later experiments by Rutherford about distribution of mass.

4. According to Rutherford's model of the atom, where is the positive charge concentrated? What does it predict about the relative size of the nucleus and the radius of the atom? What is the nucleus composed of according to his model?

Solution

The positive charge and most of the mass of the atom is concentrated in a small region of the atom, which he called nucleus.
Rutherford was able to estimate the size of the nucleus, and according to his calculations, the radius of the nucleus is at least 10,000 times smaller than the radius of the atom. If the radius of the atom is about 10^{-10} m, then the radius of the nucleus is 10^{-14} m.
The electrons surrounded the nucleus and moved at a high speed around the nucleus in circular paths called **orbits**. The electrons and nucleus were held together by the electrostatic forces. Electrons do not collapse into the nucleus due to this force of attraction, because the revolving of electrons around the nucleus produces centrifugal force that balances the force of attraction.

5. Where in an atom is nearly all of its mass concentrated? Explain your answer in terms of the particles that contribute to this mass.

Solution

Nucleus. Rutherford proposed the nuclear model of an atom. The important postulates of this model were:
1. The positive charge and most of the mass of the atom is concentrated in a small region of the atom, which he called nucleus. The vast majority of the volume of an atom is, therefore, empty space.

2. The electrons surrounded the nucleus and moved at a high speed around the nucleus in circular paths called orbits. This part of atom outside the nucleus in which the electrons are distributed is known as extra-nuclear part.
3. The electrons and nucleus were held together by the electrostatic forces. Electrons do not collapse into the nucleus due to this force of attraction, because the revolving of electrons around the nucleus produces centrifugal force that balances the force of attraction.

6. Arrange the following regions of the electromagnetic spectrum in order of increasing wavelength (i.e., shortest wavelength $\rightarrow$ longest wavelength): microwaves, TV, X-rays, ultraviolet, visible, infrared, gamma rays.
Solution
Gamma rays < X-rays < ultraviolet < visible < infrared < microwaves < TV waves

7. What are the names used to refer to the theories that apply the matter–wave concept to electrons in atoms?
Solution
Wave mechanics and quantum mechanics

8. What is an atomic spectrum? How does it differ from a continuous spectrum? What fundamental fact is implied by the existence of atomic spectra?
Solution
When a narrow beam of this light is passed through a prism, we do *not* see a continuous spectrum. Instead, only a few colors are observed, displayed as a series of individual lines. This series of lines is called the element's **atomic spectrum** or **emission spectrum**.
However, a **continuous spectrum** contains a continuous unbroken distribution of light of *all* colors. The red light with the longest wavelength deviates the least, while the violet light with the shortest wavelength deviates the most.

Chemists and physicists began using the spectroscope to catalog the wavelength of light emitted or absorbed by a variety of compounds and used this data to detect the presence of certain elements in minerals and in sunlight.

9. In the spectrum of sodium, there is a line with a wavelength of 589 nm. (a) What color is this line? (b) What is its frequency? (c) What is the energy of each of its photons?
Solution
(a) Yellow;
(b) $v = \dfrac{c}{\lambda} = \dfrac{3\times10^8}{589\times10^{-9}} = 5.09\times10^{14}\ \text{s}^{-1}$
(c) $E = hv = 6.6 \times 10^{-34} \times 5.09 \times 10^{14} = 3.37 \times 10^{-19}$ J

10. Consider the symbol ^a_bX, where X stands for the chemical symbol for an element. What information is given in locations *a* and *b*?
Solution
Symbol *a* corresponds to the mass number while symbol *b* corresponds to the atomic number.

11. What, if anything, is wrong with the following electron configurations for atoms in their ground states: (a) $1s^22s^12p^3$; (b) [Kr] $3d^74s^2$; (c) $1s^22s^22p^4$; (d) [Xe] $4f^{14}5d^86s^1$?
Solution
(a) $2p$ cannot be filled unless $2s$ is completely filled.

(b) [Kr] should be replaced by Ar.
(c) is correct.
(d) The filling of orbitals is incorrect. According to Aufbau principle, 6*s* should be filled first followed by 4*f* and 5*d*.

12. Calculate the percentage of higher isotope of neon that has atomic mass 20.2 and the isotopes have the mass numbers 20 and 22.
Solution
Let the two isotopes of neon having mass numbers 20 and 22 be present in the ratio x:y, where y = 10 – x. Now, the relative atomic mass of neon is 20.2, therefore,

$$\frac{[(x\times 20)+(10-x)(22)]}{10}=20.2$$

Solving, we get x = 9, so y = 10 – x = 1. Therefore, percentage of neon isotope having mass 22 is ^{22}Ne = 10%.

13. When a copper atom loses an electron to become a Cu^+ ion, what are the possible quantum numbers of the electron that was lost?
Solution
n = 4, l = 3, 2, 1, 0; m_l = –3 to +3 and m_s = +1/2.

14. The first shell may contain up to 2 electrons, the second shell up to 8, the third shell up to 18, and the fourth shell up to 32. Explain this arrangement in terms of quantum numbers.
Solution
1*s* = 2
2*s* + 2*p* = 8
3*s* + 3*p* + 3*d* = 18
4*s* + 4*p* + 4*d* + 4*f* = 32

15. What were the characteristics observed in the modified cathode ray experiment that led to the discovery of protons?
Solution
Protons were first observed by Goldstein but their nature was discovered by Thomson. To study these, a modification was made in the construction of the cathode ray tube to produce a new device called a mass spectrometer.

1. This apparatus was used to measure the charge-to-mass ratios of positive ions. (The removal of electrons from an atom gives a positively charged particle called an ion).
2. These ratios were found to vary, depending on the chemical nature of the gas in the discharge tube, showing that their masses also varied. The positively charged particles are different from electrons. The relative charge of a proton is equal in magnitude to that of an electron but opposite in sign (+1).
3. Their charge-to-mass ratio depends on the nature of the gas from which they originate. They may also carry multiple fundamental units of electrical charge.
4. Their pattern of behavior is opposite to that observed in electrons. The lightest positive particle observed was produced when hydrogen was in the tube, and its mass was about 1837 times as heavy as an electron.
5. The actual mass of proton is 1.674×10^{-24} g. The mass of a proton is only very slightly less than that of a hydrogen atom. When other gases were used, their masses always seemed to be whole-number multiples of the mass observed for hydrogen atoms. This suggested the

possibility that clusters of the positively charged particles made from hydrogen atoms made up the positively charged particles of other gases.

6. The hydrogen atom, minus an electron, thus seemed to be a fundamental particle in all matter and was named the proton, after the Greek word proteios, meaning "of first importance" and was characterized in 1919.

16. How does the behavior of very small particles differ from that of the larger, more massive objects that we meet in everyday life? Why don't we notice this same behavior for the larger, more massive objects?

Solution

Very small particles have properties that are reminiscent of both a particle and a wave. Massive particles also have this but the wavelike properties are too small to be observed.

17. (a) Name the first five series of lines that occur in the atomic spectrum of hydrogen and indicate the region in the electromagnetic spectrum where these series occur. (b) Give a general equation for the wave number applicable to all the series.

Solution

(a) Lyman – Ultraviolet; Balmer – Visible; Paschen, Brackett, Pfund – Infrared; (b) $\bar{v} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

18. Give the notation for subshells denoted by the following quantum numbers: (a) n = 6, l = 2; (b) n = 4, l = 3; (c) n = 4, l = 2; (d) n =5, l = 4.

Solution

(a) 6*d*, (b) 4*f*, (c) 4*d*, and (d) 5*g*.

19. How does the size of a given type of orbital vary with n?

Solution

The size of orbital increases with increase in the principal quantum number n.

20. On the basis of Heisenberg's principle, show why an electron cannot exist in the nucleus?

Solution

If an electron existed in the nucleus then, we have

$$\Delta x \times \Delta p \geq \frac{h}{4\pi}$$

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

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

Substituting $\Delta x = 10^{-15}$ m , $h = 6.626 \times 10^{-34}$, $m = 9.11 \times 10^{-31}$ kg, we get

$$\Delta v \geq \frac{6.626 \times 10^{-34}}{4 \times 3.14 \times 9.11 \times 10^{-31} \times 10^{-15}}$$

$$\Delta v \geq 5.79 \times 10^{10} \text{ ms}^{-1}$$

As Δv is much higher than the velocity of light, electron cannot exist within the nucleus.

21. If a transition from an upper level to n = 1 in hydrogen spectrum results in light of wavelength 9.50×10^{-8} m in being emitted, what is the principal quantum number of the higher level?

Solution

Here, λ = 9.50 × 10^{-8} m, R = 1.097 × 10^7 m, n_1 = 1Using formula and putting values

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

$$\frac{1}{9.5\times10^{-8}} = 1.09\times10^7\left(\frac{1}{1^2} - \frac{1}{n_2^2}\right)$$

$$\frac{10^8}{9.5\times1.09\times10^7} = \left(\frac{1}{1^2} - \frac{1}{n_2^2}\right)$$

$$0.9596 = \left(\frac{1}{1^2} - \frac{1}{n_2^2}\right)$$

$$\frac{1}{n_2^2} = 1 - 0.9596 = 0.0404$$

$$n_2^2 = 24.75$$

$$n_2 \simeq 5$$

22. Calculate the maximum number of electrons in the n = 1, n = 2, n = 3 and n = 4 shells.

Solution

Number of electrons = n^2

n = 1; number of electrons = 1

n = 2; number of electrons = 4

n = 3; number of electrons = 9

n = 4; number of electrons = 16

23. State Heisenberg's uncertainty principle. What is the uncertainty in the position of a particle, if the uncertainty in the momentum is 10^{-11} kg m s^{-1}.

Solution

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

$$\Delta x \cdot 10^{-11} \geq \frac{6.6\times10^{-34}}{4\times3.14}$$

$$\Delta x = 5.27\times10^{-34}$$

24. What is photoelectric effect? Calculate the frequency and energy of a photon of light with wavelength 520 nm.

Solution

Photoelectric effect is the phenomenon in which electrons are emitted from a metal surface when radiation of sufficient energy falls on it. Metals such as sodium, lithium and potassium show photoelectric effect with visible light, whereas metals like zinc, magnesium, and cadmium show photoelectric effect with ultraviolet light.

$$v = \frac{c}{\lambda} = \frac{3\times10^8}{520\times10^{-9}} = 0.0058\times10^{17}\ \text{s}^{-1}$$

$$E = hv = 6.6\times10^{-34}\times0.58\times10^{17} = 0.038\times10^{-17}\ \text{J}$$

25. The minimum energy required to eject an electron from a metal is 4.34×10^{-19} J. What is the minimum frequency of light required for photoelectric effect in the metal?

Solution

$E = h\nu_o$

$4.34 \times 10^{-19} = 6.6 \times 10^{-34} \cdot \nu_o$

$\nu_o = 0.65 \times 10^{-15}$ J

26. Give the names and symbols of the four quantum numbers required to define the energy of electrons in atoms. What do these quantum numbers relate to, and what numerical values are possible for each? Show how the shape of the periodic table is related to these quantum numbers.

Solution

Principal quantum number (n = 1, 2, 3, 4); azimuthal quantum number (l = 0 to n – 1); magnetic quantum number (m = 2l + 1); spin quantum number (s = +1/2 or –1/2).

The shape of the periodic table depends on the quantum number l, that is, to the left side of the periodic table are s block elements (in which the last electron enters s subshell) while to the right side of the periodic table are p block elements (in which the last electron enters p subshell). In between are d block elements or transition elements (in which last electron enters d subshell) and at the bottom are lanthanoids and actinoids (in which 4f and 5f filling takes place).

27. Give the values of the four quantum numbers for each electron in the ground state for (a) the oxygen atom, and (b) the scandium atom. (Use positive values for m_l and m_s first.)

Solution

(a) O = $1s^2\ 2s^2\ 2p^4$

For 2p, electron n = 2, l =1; m_l = –1, 0, and +1; and m_s = +1/2 and –1/2.

(b) Sc = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1$

For 3d electron, n = 3, l = 2, m_l = +2, and m_s = +1/2

28. Which of the following species does the Bohr theory apply to?

(a) H, (b) H^+, (c) He, (d) He^+, (e) Li, (f) Li^+, (g) Li^{+2}, (h) Be, (g) Be^+, (h) Be^{2+}, (i) Be^{3+}

Solution

It applies to hydrogen-like molecules: H, He^+, Li^{2+}, Be^{3+}.

29. How does the Bohr theory of the hydrogen atom differ from that of Schrödinger?

Solution

Bohr's theory ignores the de Broglie concept of dual nature of electron and also contradicts with the Heisenberg's uncertainty principle, while the Schrödinger equation is based on quantum mechanics which deals with the microscopic objects having both the particle as well as wave-like character.

30. What is the order of uncertainty in momentum if the uncertainty in position of a particle is 10^{-34}?

Solution

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

$$10^{-34} \cdot \Delta p \geq \frac{6.6 \times 10^{-34}}{4 \times 3.14}$$

$$\Delta p \geq 0.527$$

31. Explain why the effect of Heisenberg uncertainty principle is only significant in case of microscopic particles and not in macroscopic objects.

Solution
According to Heisenberg's principle, the more precisely we can define the position of an electron, the less certainly we are able to define its velocity, and vice versa. If Δx is the uncertainty in defining the position and Δp_x (or Δv_x) is the uncertainty in the momentum (or velocity), the uncertainty principle may be expressed mathematically as:

$$\Delta x \cdot \Delta p_x \geq \frac{h}{4\pi}$$

or

$$\Delta x \cdot \Delta(mv_x) \geq \frac{h}{4\pi} \Rightarrow \Delta x \cdot \Delta v_x \geq \frac{h}{4\pi m}$$

where h = Planck's constant = 6.626×10^{-34} J s. This implies that it is impossible to know both the position and the velocity exactly. This principle is more applicable to particles such as electrons and atoms because small particles when struck by radiation of light undergo considerable change in velocity or momentum. When visible light falls on macroscopic objects, they do not undergo any distinct change. The light is reflected back and we can see the object and hence determine its position and velocity.

32. Explain why three quantum numbers are required to describe an orbital. What feature of the three-dimensional structure of an orbital is specified by each of these quantum numbers?
Solution
The Schrodinger model uses three coordinates or quantum numbers to describe the orbital in which electrons can be found. Three of the quantum numbers (principal, azimuthal, magnetic) together represent the probability density of electron. Principal quantum number determines the size of the orbital, azimuthal quantum number determines the shape of the orbital and magnetic quantum number determines the orientation of the orbital.

33. Give two reasons why electrons tend to avoid each other.
Solution

Electrons tend to avoid each other due to coulombic repulsion between particles with the same charge. The repulsion also arises as a consequence of Pauli's exclusion principle and symmetry requirements. Electrons with same spin tend to avoid each other with force that is over and above the coulombic force of repulsion. They have zero probability of being at the same point in the space.

34. Describe the relationship between the atomic number, mass number, number of protons, number of neutrons and number of electrons in a calcium atom, ^{40}Ca.
Solution
Ca has atomic number = 20 and mass number = 40
Number of protons = Atomic number = 20
Number of neutrons = Mass number – Atomic number = 40 – 20 = 20
Number of electrons = Number of protons in neutral atom = 20

<H1>Numerical Problems
1. Identify the element that has atoms with mass numbers of 20 that contain 11 neutrons**.**
Solution
^{20}F

2. The number of electrons, protons, and neutrons in a species is equal to 10, 13, and 14, respectively. Assign the proper symbol to the species.
Solution

$^{27}_{13}Al^{3+}$

3. What is the range of frequencies of the waves used in a microwave oven?
Solution
3×10^{10} to 3×10^{12} Hz

4. Orchestras tune their instruments to the note "A," which has a frequency of 440 cycles s^{-1}, or 440 Hz. If the speed of sound is 340 m s^{-1}, what is the wavelength of this note?
Solution
$$v = \frac{c}{\lambda} = \frac{340}{440} = 0.773\,\text{m}$$

5. The human ear is capable of hearing sound waves with frequencies between 20 and 20,000 Hz. If the speed of sound is 340.3 m s^{-1} at sea level, what is the wavelength in meters of the longest wave the human ear can hear?
Solution
$$\lambda = \frac{c}{v} = \frac{340.3}{20} = 17.015\,\text{m}$$

6. The green line of barium atom emission has a wavelength of 554 nm. Calculate the frequency of this light and the energy of photon of this light.
Solution
$$v = \frac{c}{\lambda} = \frac{3\times10^8}{554\times10^{-9}} = 5.4\times10^{14}\ \text{Hz}$$ ν = c/λ = 3 x 10^8 / 554 x 10^{-9} = 5.4 x 10^{14} Hz
$$E = hv = 6.6\times10^{-34}\times5.4\times10^{14} = 3.58\times10^{-19}\ \text{J}$$

7. The photoelectric work function for magnesium is 5.90×10^{-19} J. Calculate the minimum frequency of light required to eject electrons from the surface of magnesium. What is kinetic energy of the ejected electron when a light of wavelength 285 nm strikes the surface?
Solution
$$hv_o = 5.90\times10^{-19} \Rightarrow v_o = \frac{5.90\times10^{-19}}{6.626\times10^{-34}} = 0.890\times10^{15}\ \text{Hz}$$
$$E = hv = \frac{hc}{\lambda} = 6.626\times10^{-34}\times\frac{3\times10^8}{285\times10^{-9}} = 0.0697\times10^{-17}\ \text{J}$$
$$hv = hv_o + \text{KE}$$
$$\text{KE} = 6.95\times10^{-19} - 5.90\times10^{-19} = 1.07\times10^{-19}\ \text{J}$$

8. Calculate the frequency and the wavelength of the light emitted when the electron in hydrogen atom undergoes a transition from an orbit with $n = 5$ to $n = 3$.
Solution
$$\frac{1}{\lambda} = 109677\left(\frac{1}{3^2} - \frac{1}{5^2}\right)$$
$$\lambda = 1.28\times10^{-4}\ \text{cm} = 1.28\times10^{-6}\ \text{m}$$
$$v = \frac{c}{\lambda} = \frac{3\times10^8}{1.28\times10^{-6}} = 2.34\times10^{14}\ \text{Hz}$$

9. An electron in the lithium atom is in the third energy level. Is the atom in the ground state or excited state? Can the atom emit light? If so, how?

Solution

Excited state; Yes. Light is emitted when an electron falls to the ground state from an excited state.

10. The radius of an orbit is given by r_n= 0.0529 n^2 (nm). Calculate the radius of the third orbit.

Solution

$r = 0.0529 \times\cdot (3)^2 = 0.4761$ nm

11. What is the distance of separation between second and third orbits of hydrogen atoms?

Solution

$r_1 = 0.0529 \times (3)2 = 0.4761$ nm

$r_2 = 0.0529 \times (2)2 = 0.2116$ nm

$r_1 - r_2 = 0.4761 - 0.2116 = 0.2645$ nm

12. The ultraviolet emission line of magnesium is observed at 285 nm. What is the energy difference between the two levels responsible for this emission?

Solution

$$\Delta E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{285\times10^{-9}} = 6.97\times10^{-19}\ \text{J}$$

13. Calculate the wavelength (in nm) of an electron travelling with a speed of 2.79×10^6 m s^{-1}. (Mass of an electron is 9.11×10^{-31} kg.)

Solution

$$\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{9.1\times10^{-31}\times2.79\times10^{6}} = 2.607\times10^{-10}\,\text{m}$$

14. (a) The energy associated with the first orbit in the hydrogen atom is -2.18×10^{-18} J atom^{-1}. What is the energy associated with the fifth orbit?

(b) Calculate the radius of Bohr's fifth orbit for hydrogen atom.

Solution

(a) $E = \frac{-2.18\times10^{-18}}{5^2} = -8.72\times10^{-20}$ J

(b) $r = 0.0529 \times 5^2 = 1.3225$ nm

15. The electron energy in hydrogen atom is given by $E = (-21.7 \times 10^{-12})/n^2$ ergs. Calculate the energy required to remove an electron completely from the n = 2 orbit. What is the longest wavelength (in cm) of light that can be used to cause this transition? **[IIT-JEE 1984]**

Solution

$$E = \frac{-2.17\times10^{-12}}{2^2} = 5.42\times10^{-12}\ \text{ergs} = 5.42\times10^{-19}\ \text{J}$$

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{\lambda}$$

$$\lambda = \frac{6.626\times10^{-34}\times3\times10^{8}}{5.42\times10^{-19}} = 3.67\times10^{-7}\ \text{m=367 nm}$$

16. Calculate the number of electrons in a charged particle having a static electric charge of 7.25 × 10^{-16} C.

Solution

$q = ne$

$$n = \frac{q}{e} = \frac{7.25\times10^{-16}}{1.6\times10^{-19}} = 4525.6$$

17. In the visible spectrum, the wavelength of violet light is 450 nm and that of red light is 750 nm. Calculate the frequency and wavenumber of these radiations.

Solution

Violet:

$$v = \frac{c}{\lambda} = \frac{3\times10^{8}}{450\times10^{-9}}$$

$$v = 6.6\times10^{14}\ \text{Hz}$$

$$\bar{v} = \frac{1}{\lambda} = 2.2\times10^{12}\ \text{m}^{-1}$$

Red:

$$v = \frac{c}{\lambda} = \frac{3\times10^{8}}{750\times10^{-9}}$$

$$v = 4\times10^{14}\ \text{Hz}$$

$$\bar{v} = \frac{1}{\lambda} = 1.33\times10^{12}\ \text{m}^{-1}$$

18. How many times heavier is a ^{6}Li atom than a ^{1}H atom?

Solution

Li is 5.9842 times heavier than H atom.

19. Iodine molecule dissociates into after absorbing light of 4500 Å . If one quantum of radiation is absorbed by each molecule, calculate the kinetic energy of iodine atoms. (Bond energy of I_2 = 240 kJ mol^{-1}).

Solution

$$\begin{aligned}\text{Bond energy of } I_2 &= 240\ \text{kJ mol}^{-1}\\ &= 240\times10^{3}\ \text{J mol}^{-1}\\ &= 240\times10^{3} / 6.023\times10^{23} = 3.984\times10^{-19}\ \text{J}\end{aligned}$$

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{4500\ \times\ 10^{10}} = 4.417\times10^{-19}\ \text{J}$$

$$\text{Kinetic energy imparted to one molecule of } I_2 = 4.417\times10^{-19} - 3.984\times10^{-19} = 4.33\times10^{-20}\ \text{J}$$

$$\text{Kinetic energy imparted to each I atom} = \frac{4.33\times10^{-20}}{2} = 2.165\times10^{-20}\ \text{J}$$

20. What is energy of a photon of light whose (a) wavelength is 400 nm and (b) frequency is 1300 kHz**.**

Solution

(a) $E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{400 \times 10^{-9}} = 4.97\times10^{-19}$ J

(b) $E = h\nu = 6.6 \times 10^{-34} \times 1300 \times 10^{3} = 8586 \times 10^{-31}$ J $= 8.58 \times 10^{-28}$ J

21. Calculate the frequency and the wavelength of the light emitted when the electron in a hydrogen atom undergoes a transition from an orbit with $n = 4$ to an orbit with $n = 2$.

Solution

$$\frac{1}{\lambda} = 109677\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

$$\lambda = 486 \text{ nm}$$

$$\nu = \frac{c}{\lambda} = \frac{3\times10^{8}}{486\times10^{-9}} = 6.17\times10^{14} \text{ J}$$

22. If electromagnetic radiation with energy of 1166 kJ mol^{-1} was absorbed by a mole of hydrogen atoms in their lowest energy state, what would be the resulting energy of the hydrogen atoms? What would be the resulting energy level (i.e., what would be the value of n)?

Solution

Given that $n_1 = 1$, $\Delta E = 1166$ kJ mol^{-1}, therefore,

$$\Delta E = \left(\frac{-1312}{n_2^2}\right) - \left(\frac{-1312}{1^2}\right) \Rightarrow \frac{-1312}{n_2^2} = 1166 - 1312 \Rightarrow n_2 = \sqrt{\frac{1312}{146}} \approx 3$$

Hence, the resulting energy of the hydrogen atom is

$$E_{n=3} = \frac{-1312}{3^2} = -145.7 \text{ kJ mol}^{-1}$$

23. Calculate the frequency and the wavelength of the light emitted when the electron in hydrogen atom undergoes a transition from an orbit with $n = 5$ to $n = 3$.

Solution

$$\frac{1}{\lambda} = 19677\left(\frac{1}{3^2} - \frac{1}{5^2}\right)$$

$$\lambda = 1.28\times10^{-4} \text{ cm} = 1.28\times10^{-6} \text{ m}$$

$$\nu = \frac{c}{\lambda} = \frac{3\times10^{8}}{1.28\times10^{-6}} = 2.337\times10^{-14} \text{ s}^{-1}$$

24. The $n = 8$ and $n = 9$ energy levels are very close in energy. Using the Bohr model, describe how the wavelengths of light compare as an electron falls from these two energy levels to the $n = 1$ energy level.

Solution

Suppose λ is the wavelength when electron transition takes place from $n = 8$ to $n = 1$ and λ' is the wavelength when electron transition takes place from $n = 9$ to $n = 1$.

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{8^2}\right) = \frac{63\times R}{64} \qquad \text{(i)}$$

$$\frac{1}{\lambda'} = R\left(\frac{1}{1^2} - \frac{1}{9^2}\right) = \frac{80\times R}{81} \qquad \text{(ii)}$$

Dividing (ii) by (i), we get

$$\frac{\lambda'}{\lambda} = \frac{63 \times R}{64} \times \frac{81}{80 \times R} = 1.003$$

Hence, the wavelengths of light from the two transitions are very close together.

25. A microscope using suitable photons is employed to locate an electron in an atom within a distance of 0.1 Å. What is the uncertainty involved in the measurement of its velocity?

Solution

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

$$0.1 \times 10^{-10} \times 9.1 \times 10^{-31} \cdot \Delta v \geq \frac{h}{4\pi}$$

$$\Delta v = 5.76 \times 10^{-6}\ \text{m s}^{-1}$$

26. Calculate the effective nuclear charge in 3*p* electron in silicon.

Solution

Si = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

$\sigma = 0.35 \times 3 + 0.85 \times 8 + 1 \times 2 = 9.85$

$Z^* = Z - \sigma = 14 - 9.85 = 4.15$

<H1>Additional Objective Questions

<H2>Single Correct Choice Type

1. During the emission spectrum, the first line of Lyman series of hydrogen atom occurs as $\lambda = x$ Å. The wave length of the first line of Lyman series of He^+ ion will occur at

(A) $4/x$ (B) $x/4$ (C) $3/x$ (D) $4x$

Solution

(B) As $n_2 = 2$, $n_1 = 1$,

$$\frac{1}{\lambda} = R_H \times \left[\frac{1}{1^2} - \frac{1}{2^2}\right] = R_H = x \text{ Å}$$

So, $R_H = \frac{4/3}{x}$

2. The quantum numbers of +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 that have no classical analog.

Solution

(D)

3. Which of the following describes an orbital?

(A) ψ (B) ψ^2 (C) $[\Psi^2]\ \Psi$ (D) none

Solution

(B) It represents the probability of finding an electron at a point within the atom

4. The wave function (ψ) of 2*s* 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 for 2*s*, r_0 in terms of a_0 is:
(A) $r_0 = a_0$ (B) $r_0 = 2a_0$ (C) $r_0 = a_0/2$ (D) $r_0 = 4a_0$
Solution
(B) The radial nodes occur when the radial probability function = zero. Therefore, for 2*s* orbital, at radial node, $r = r_0$, and

$$\frac{1}{2\sqrt{2\pi}}\left(\frac{1}{a_0}\right)^{1/2}\left\{2-\frac{r}{a_0}\right\}e^{-r/2a_0}=0 \Rightarrow \frac{r_0}{a_0}=2$$

5. Of the following transition in hydrogen atom, the one that gives an absorption line of maximum wavelength is
(A) $n = 1$ to $n = 2$ (B) $n = 3$ to $n = 8$
(C) $n = 2$ to $n = 1$ (D) $n = 8$ to $n = 3$
Solution
(B) Absorption line in the spectra arises when energy is absorbed, that is, electron shifts from lower to higher orbit out of *a* and *b*; *b* will have the maximum wavelength as this falls in the Paschen series.

6. The probabilities of finding an electron residing in a p_x orbital is zero in the
(A) *yz* plane (B) *xy* plane (C) *xz* plane (D) *y* and *z* directions
Solution
(A)

7. Maximum number of electrons in a subshell of an atom is determined by the following:
(A) $2n^2$ (B) $4l + 2$ (C) $2l + 1$ (D) $4l - 2$
Solution
(A) The maximum electron population of a shell is $2n^2$. For example, for $n = 2$, subshells are 2*s* and 2*p* with maximum electron population 2 + = 8 = 2 $(2)^2$.

8. The wave function for 1*s* orbital of hydrogen atom is given by:

$$\psi_{1s} = \frac{\pi}{\sqrt{2}}e^{-r/2a_0}$$

where, a_0 = Radius of first Bohr orbit
r = Distance from the nucleus (Probability of finding the electron varies with respect to it) What will be the ratio of probabilities of finding the electrons at nucleus of first Bohr's orbit a_0?
(A) e (B) e^2 (C) $\frac{1}{e^2}$ (D) zero

Solution
(D)

9. For which of the species, Bohr's theory is not applicable?
(A) Be^{3+} (B) Li^{2+} (C) He^{2+} (D) H
Solution
(C) Bohr's theory is not applicable to He^{2+} as it has no electrons.

10. The number of nodal planes in d_{xy} orbital is
(A) 0 (B) 1 (C) 2 (D) 3
Solution
(C) The d_{xy} orbital has *YZ* and *XZ* nodal planes.
11. The radial wave equation for hydrogen atom is:

$$\psi = \frac{1}{16\sqrt{4}}\left(\frac{1}{a_0}\right)^{3/2}[(x-1)(x^2-8x+12)]e^{-r/2}$$

where, $x = 2r/a_0$; a_0 = radius of first Bohr orbit.
The minimum and maximum position of radial nodes from nucleus are:

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

Solution

(B) Let the probability of finding an electron be 0. Then

$$\psi = \frac{1}{16\sqrt{4}}\left(\frac{1}{a_0}\right)^{3/2}[(x-1)(x^2-8x+12)]e^{-r/2} = 0$$

or $(x-1)(x^2-8x+12) = 0 \Rightarrow (x-1)(x-6)(x-2) = 0$

Therefore, the minimum value of x is 1 and maximum value is 6.
Given that $x = 2r/a_0$. Therefore, the minimum and maximum position of radial nodes from nucleus are:

$$\left(\frac{2r}{a_0} - 1\right) = 0 \Rightarrow r = \frac{a_0}{2} \quad \text{and} \quad \left(\frac{2r}{a_0} - 6\right) = 0 \Rightarrow r = 3a_0$$

12. For an electron, the product $v \times n$ (velocity × principal quantum number) will be independent of the

(A) principal quantum number. (B) velocity of the electron
(C) energy of the electron (D) frequency of its revolution.

Solution

(A) We know that $v \propto \frac{1}{n}$ and n = principal quantum number. Therefore, vn will be independent of the principal quantum number, that is, n.

13. When the electron of a hydrogen atom jumps from the $n = 4$ to the $n = 1$ state, the number of spectral lines emitted is

(A) 15 (B) 6 (C) 3 (D) 4 |

Solution

(B) N = Number of lines emitted $= \frac{1}{2}n(n-1) = \frac{1}{2} \times 4(4-1) = 6$ (when electron falls from $m = n$ to $n =$ 1)

14. Assume that the potential energy of a hydrogen atom in its ground state is zero. Then its energy in the first excited state will be

(A) 13.6 eV (B) 27.2 eV (C) 23.8 eV (D) 10.2 eV

Solution

(C) –PE = 2KE = 2 × (+13.6) = 27.2 eV.
Therefore, PE = –27.2 eV
PE with respect to ground state = 27.2 eV, which we assume to be zero.

$$\text{KE} = -\frac{13.6}{n^2}\ \text{eV}$$

For the first excited state, $n = 2$. Therefore,

$$\text{KE} = -\frac{13.6}{n^2}\ \text{eV} = -3.4\ \text{eV}$$

Total energy = (27.2 – 3.4) eV = 23.8 eV

15. In an atom two electrons move around the nucleus in circular orbits of radii R and $4R$. The ratio of the time taken by them to complete one revolution is:

(A) 1:4 (B) 4:1 (C) 1:8 (D) 8:7

Solution

(C) $t = \dfrac{2\pi R_n}{u_n} \Rightarrow t \propto \dfrac{R_n}{u_n} \Rightarrow t \propto \dfrac{1/n^2}{n} \Rightarrow t \propto n^3$

Hence, the ratio of the time taken by them to complete one revolution is

$$\frac{t_1}{t_2} = \frac{(n_1)^3}{(n_2)^3} = \frac{(\sqrt{R_1})^3}{(\sqrt{R_2})^3} = \frac{(\sqrt{R})^3}{(\sqrt{4R})^3} = \frac{1}{8}$$

16. Which of the following postulates does not belong to Bohr's model of the atom?

(A) Angular momentum is an in the orbit is stable of $h/2\pi$.

(B) The electron stationed in the orbit is stable.

(C) The path of an electron is circular.

(D) The change in the energy levels of electron is continuous.

Solution

(D) Postulates of Bohr's theory.

17. When the frequency of light incident on a metallic plate is doubled, the KE of the emitted photoelectron will be:

(A) doubled.

(B) halved.

(C) increased but more than double of the previous KE.

(D) remains unchanged Quantum number.

Solution

(C) $hv_1 = hv_0$ (Work function) + KE_1

$2hv_1 = hv_0 + KE_1$,

$KE = hv_1 - hv_0$

The value of kinetic energy will increase but more than double of the previous KE.

18. The orbital angular momentum of an electron in 2*s* orbital is

(A) $h/4p$ (B) zero (C) $h/2p$ (D) $\sqrt{2}h/2\pi$

Solution

(B) Orbital angular momentum = $\sqrt{l(l+1)}\dfrac{h}{2\pi} = \sqrt{0(0+1)}\dfrac{h}{2\pi} = 0$ (for *s* orbital, $l = 0$).

19. The triad of nuclei that is isotonic is

(A) ${}^{14}_{6}C$, ${}^{15}_{7}N$, ${}^{17}_{9}F$ (B) ${}^{12}_{6}C$, ${}^{14}_{7}N$, ${}^{19}_{9}F$

(C) ${}^{14}_{6}C$, ${}^{14}_{7}N$, ${}^{17}_{9}F$ (D) ${}^{14}_{6}C$, ${}^{14}_{7}N$, ${}^{19}_{9}F$

Solution

(A) Isotonic: Same number of neutrons, ${}^{14}_{6}C$ has 8 neutrons, ${}^{15}_{7}N$ has 8 neutrons, ${}^{17}_{9}F$ also has 8 neutrons.

20. The increasing order (lowest first) for the values of e/m (charge/mass) for electron (e), proton (p), neutron (n) and alpha particle (α) is

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

Solution

(D) Charge/mass for $n = 0,\ \alpha = \frac{2}{4}, p = \frac{1}{1}, e = \frac{1}{1/1837}$

So, the order is $n < \alpha < p < e$.

21. The maximum number of electrons that maybe present in all atomic orbitals with principle quantum number 3 and azimuthal quantum number 2 is

(A) 10 (B) 8 (C) 12 (D) 4

Solution

(A) With principle quantum number 3 and azimuthal quantum number 2, the orbital is 3*d*. As there are five atomic orbitals in 3*d* and each orbital can have a maximum of 2 electrons, so the maximum number of electrons that maybe present in all atomic orbitals of 3*d* is 10.

22. Rutherford's experiment on scattering of α-particles showed for the first time that the atom has

(A) electrons (B) protons (C) nucleus (D) neutrons **[IIT-JEE 1981]**

Solution

(C) Discovery of nucleus

23. The radius of which of the following orbit is same as that of the first Bohr's orbit of hydrogen atom

(A) He^{+} (n = 2) (B) Li^{+2} (n = 2) (C) Li^{2+} (n = 3) (D) Be^{3+} (n = 2)

Solution

(D) $r_{Be^{3+}} = \frac{0.529 \times (2)^2}{4} = 0.529$ as $r_n = \frac{0.529 \times n^2}{2}$ Å

24. The radial distribution curve of the *d*-orbital with double dumbbell shape in the 4th principle shell consists of '*n*' nodes; *n* is

(A) 2 (B) 0 (C) 1 (D) 3

Solution

(C) Number of nodes in double dumbbell shaped *d*-orbital in 4th principle shell is:

$$n - l - 1 = 4 - 2 - 1 = 1$$

25. The wavelength associated with a golf ball weighing 200 g and moving at a speed of 5 m h^{-1} is of the order

(A) 10^{-10} m (B) 10^{-20} m (C) 10^{-30} m (D) 10^{-40} m

Solution

(C) $\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{\frac{0.2 \times 5}{60 \times 60}} = 2.37 \times 10^{-30}$ m (de Broglie equation)

26. Magnetic moments of V (Z = 23), Cr (Z = 24), Mn (Z = 25) are *x*, *y*, *z*. Hence,

(A) $x = y = z$ (B) $x < y < z$

(C) $x < z < y$ (D) $z < y < x$

Solution

(C) Number of unpaired electrons in V, Cr, and Mn is 3, 6, and 5.

V(23) = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$ Cr(24) = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^5$

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

27. The outermost electronic configuration of the most electronegative element is **[IIT-JEE 1988]**

(A) ns^2np^3 (B) ns^2np^4 (C) ns^2np^5 (D) ns^2np^6

Solution

(C) Most electronegative element is F (i.e., halogens). Therefore, electronic configuration: ns^2np^5.

28. If $n = 6$, the correct sequence of filling of electrons will be

(A) $ns \to np \to (n-1)d \to (n-2)f$ (B) $ns \to n(n-2)f \to (n-1)d \to np$

(C) $ns \to n(n-1)d \to (n-2)f \to np$ (D) $ns \to (n-2)f \to np \to (n-1)d$

Solution

(B) According to Aufbau principle, the correct sequence for filling up orbitals when n = 6 is 6*s*, 4*f*, 5*d*, 6*p*.

29. The first emission line in the atomic spectrum of hydrogen in the Balmer Series appears at

(A) $\frac{9R_H}{400}$ cm^{-1} (B) $\frac{7R_H}{144}$ cm^{-1} (C) $\frac{3R_H}{4}$ cm^{-1} (D) $\frac{5R_H}{36}$ cm^{-1}

Solution

(D) $\frac{1}{\lambda} = R_H Z^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ For Balmer Series; $n_1 = 2$ because it is the first emission line and $n_2 = 2 + 1 = 3$. Hence,

$$\frac{1}{\lambda} = R_H \times 1^2 \left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{R_H 5}{36} \text{ cm}^{-1}$$

30. The ratio of energy of the electron in ground state of hydrogen to the electron in first excited state of Be^{+3} is

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

Solution

(B) $E_n = -13.6 \times \frac{z^2}{n^2}$. Therefore,

$$\frac{E_{n(H)}}{E_{n(Be^{+3})}} = \frac{1}{\frac{4^2}{4}} = \frac{1}{4} = 1:4$$

31. Correct set of four quantum numbers for the valence (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) Z = 37, so electronic configuration is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^1$.

For outermost electron, that is, $5s^1$ we have $n = 5$, $l = 0$, $m = 0$, $s = +\frac{1}{2}$.

32. The second line of Lyman series of H coincides with the 6th fine of Paschen series of an ionic species X. Find X assuming R to be same for both H and X?

(A) He^+ (B) Li^{+2} (C) Li^+ (D) H

Solution

(B) For hydrogen, Lyman series has $n_1 = 1$ and second line $n_2 = 1 + 2 = 3$

$$Z_H^2 = \left(\frac{1}{1} - \frac{1}{3^2}\right) = Z_X^2\left(\frac{1}{3^2} - \frac{1}{9^2}\right)$$

Sixth line of Paschen series = 9

$$\frac{8}{9} = Z_X^2\left(\frac{1}{9}-\frac{1}{81}\right) \Rightarrow \frac{8}{9} = Z^2\frac{8}{81} \Rightarrow Z^2 = 9 \Rightarrow Z = 3(\text{Li}^{+2})$$

33. The work function for a metal is 4 eV. To emit a photo electron of zero velocity from the surface of the metal, the wavelength of incident light should be:

(A) 2700 Å (B) 1700 Å (C) 5900 Å (D) 3100 Å

Solution

(D) $h\nu = h\nu_0 + \text{KE}$ zero velocity $\text{KE} = 0$ where $h\nu_0$ is work function. So, $h\nu = h\nu_0$.

Given that $h\nu$ = 4 eV. Therefore,

$$\frac{hc}{\lambda} = 4\text{ eV} \Rightarrow \lambda = \frac{h\times c}{4\text{ eV}} = \frac{6.626\times10^{-34}\times3\times10^{8}}{4\times1.6\times10^{-19}} = 3100\text{ Å}$$

34. An electron in an H-like atom is in an excited state. It has a total energy of –3.4 eV, calculate the de Broglie's wavelength?

(A) 66.5 Å (B) 6.66 Å (C) 60.6 Å (D) 6.06 Å

Solution

(B) Total energy $= \frac{e^2}{2r_n} = -3.4\text{ eV} = \frac{E_1}{n^2}$

Therefore, $n^2 = \frac{13.6}{-3.4} = 4 \Rightarrow n = 2$

The velocity in second orbit $\frac{U_1}{2} = \frac{2.18\times10^8}{2}(\text{cm sec}^{-1})$

$$\lambda = \frac{h}{mu} = \frac{6.626\times10^{-27}\times2}{9.1\times10^{-28}\times2.18\times10^{8}} = 6.6\times10^{-10} = 6.6\text{ Å}$$

35. The ionization energy of a hydrogen atom in terms of Rydberg constant (R_H) is given by the expression

(A) $R_H hc$ (B) $R_H c$ (C) $2R_H hc$ (D) $R_H hcN_A$

Solution

(A) $\frac{1}{\lambda} = R_H Z^2\left(\frac{1}{1^2}-\frac{1}{\infty}\right)$ For ionization energy, n_1 = 1 and $n_2 = \infty$

$$E = \frac{hc}{\lambda} = \frac{R_H hcZ^2}{1}$$

36. The fourth line of the Balmer series corresponds to electron transition between energy levels

(A) 6 and 2 (B) 5 and 2 (C) 4 and 1 (D) 5 and 1

Solution

(A) For Balmer series, $n_1 = 2$; therefore the fourth line is $n_2 = 2 + 4 = 6$. Therefore, 6 to 2.

37. If λ_1 and λ_2 denote the de Broglie wavelengths of two particles with same masses but charges in the ratio of 1:2 after they are accelerated from rest through the same potential difference, then

(A) $\lambda_1 = \lambda_2$ (B) $\lambda_1 < \lambda_2$ (C) $\lambda_1 > \lambda_2$ (D) None of these.

Solution

(C) $\lambda = \frac{h}{\sqrt{2m\text{KE}}}$; where KE is in eV.

Given that the mass is same, but charges are in the ratio 1:2, therefore, $KE_2 > KE_1$. Now,

$$\frac{\lambda_1}{\lambda_2} = \frac{\sqrt{KE_2}}{\sqrt{KE_1}} \Rightarrow \lambda_1 > \lambda_2$$

38. A1-kW radio transmitter operates at a frequency of 880 Hz. How many photons per second does it emit?

(A) 1.71×10^{21} (B) 1.71×10^{30} (C) 6.02×10^{23} (D) 2.85×10^{28}

Solution

(B) $E_2 = h\nu = (6.62 \times 10^{-34}\ \text{Js})(880\ \text{s}^{-1}) = 5.831 \times 10^{-31}\ \text{J}$

Now, P = 1000 W $\Rightarrow E_1 = 1000\ \text{J s}^{-1}$

Therefore, the number of photons per second emitted = $\frac{E_1}{E_2} = \frac{1000}{5.831 \times 10^{-31}} = 1.715 \times 10^{30}$

39. Which of the following electronic configurations have zero spin multiplicity?

(A) | ↑ | ↑ | ↑ | (B) | ↑ | ↑ | ↓ | (C) | ↑ | ↓ | ↓ | (D) | ↓ | ↓ | ↓ |

Solution

(C) Spin multiplicity = (2*s* + 1)

40. When the value of the azimuthal quantum number is 3, the maximum and the minimum values of the spin multiplicities are

(A) 4, 3 (B) 8, 1 (C) 1, 3 (D) 8, 2

Solution

(D) Spin multiplicity is 2S + 1. $l = 3$ corresponds to *s*, *p*, *d*, and *f* orbitals. Maximum multiplicity for the *f* orbitals (7 electrons) $= 2s + 1 = 2 \times \frac{7}{2} + 1 = 8$

Minimum multiplicity for the *f* orbital (1 electron) $= 2s + 1 = 2 \times \frac{1}{2} + 1 = 2$

41. The ratio of the radii of the first three Bohr orbits is:

(A) 1 : 0.5 : 0.33 (B) 1 : 2 : 3 (C) 1 : 4 : 9 (D) 1 : 8 : 27

Solution

(C) $r_n = r_0 \times \frac{n^2}{Z}$, where $Z = 1$.

Now, $r_1 = r_0$, $r_2 = 4r_0$, $r_3 = 9r_0$

Therefore, ratio = 1:4:9

42. An electron has wavelength 1 Å. The potential by which the electron is accelerated will be

(A) 0.0926 V (B) 0.0502 V (C) 0.0826 V (D) 51.2 V

Solution

(C) If electron is accelerated by *V* volt,

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

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

But $\lambda = 1$ Å, so

$$\frac{h}{\lambda} = \sqrt{2eVm} \Rightarrow V = \frac{h^2}{2em\lambda^2} = \frac{(6.626\times10^{-34})^2}{2\times1.6\times10^{-19}\times9.1\times10^{-31}\times(1\times10^{-10})^2} = 150.7 \text{ V}$$

43. If 10^{-17} J of light energy is needed by the interior of human eye to see an object, then photons of green light (λ = 550 nm) needed to see the object are

(A) 27 (B) 28 (C) 29 (D) 30

Solution

(B) Required energy $= 10^{-17}\text{ J} = n\times\frac{hc}{\lambda} \Rightarrow n\times\frac{6.625\times10^{-34}\times3\times10^{8}}{550\times10^{-9}}$ J

Therefore, $$n = \frac{10^{-17}}{\frac{6.626\times10^{-34}\times3\times10^{8}}{550\times10^{-9}}} = 27.8 \simeq 28$$

44. Which of the following arrangement of two electrons in two degenerated orbitals is not possible at all?

(A) | ↑ | ↓ | (B) | ↑↑ | | (C) | ↑↓ | | (D) All

Solution

(B) Violates Hund's law.

45. The number of unpaired electrons in $Mn^{4+} (Z = 25)$ is

(A) 4 (B) 2 (C) 5 (D) 3

Solution

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

Mn^{4+} = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^0\ 3d^3$

46. Atomic number of chromium is 24, then Cr^{3+} will be:

(A) diamagnetic. (B) paramagnetic. (C) ferromagnetic. (D) none of these.

Solution

(B) Number of unpaired electrons in $Cr^{3+} = 3$

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

Cr^{3+} = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^0\ 3d^3$

47. The energy for an electron is an orbit of hydrogen atom is given by; $E_n = -\frac{13.6}{n^2}Z^2\text{eV}$. Calculate the energy of the orbit having a radius $9r_1$, where r_1 is the radius of first orbit?

(A) –1.51 eV (B) 10.2 eV (C) 13.6 eV (D) 1.36 eV

Solution

(A) We know that $r_n = r_1' n^2$. Therefore,

$$9r_1 = r_1' n^2 \Rightarrow n^2 = 9 \Rightarrow n = 3$$

$$E_3 = \frac{13.6}{3^2} = -1.51 \text{ eV}$$

48. The total energy of the electron in the hydrogen atom in the ground state is –13.6 eV. The KE of this electron is:

(A) 13.6 eV (B) Zero (C) –13.6 eV (D) 6.8 eV

Solution

(A) The total energy is given by

$$E = \text{KE} + \text{PE} = \frac{1}{2}mv^2 - \frac{Ze^2}{r} \quad (1)$$

For an electron to stay in an orbital, the centripertal force must be balanced by the columbic force of the nucleus, therefore,

$$\frac{mv^2}{r} = \frac{Ze^2}{r^2} \Rightarrow v = e\sqrt{\frac{Z}{mr}}$$

Substituting expression of v in Eq. (1), we get

$$E = \text{KE} + \text{PE} = \frac{1}{2}m\,e^2\,\frac{Z}{mr} + \frac{Ze^2}{r} = -\frac{1}{2}\frac{Ze^2}{r}$$

Therefore, KE = $-E$ = 13.6 eV.

49. A compound of vanadium possesses a magnetic moment of 1.73 BM. the oxidation state of vanadium in this compound is:

(A) 1 (B) 2 (C) 4 (D) cannot be predicted

Solution

(C) $1.73 = \sqrt{n(n+2)} \Rightarrow n = 1$

V(23) = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$

V^{4+} = $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$

So, oxidation state is +4.

50. The number of spherical nodes in 3p orbitals is

(A) 1 (B) 3 (C) 2 (D) 0

Solution

(A) For the 3p orbital, n = 3, = 1. $n - l - 1$ for p orbital l = 1.

The number of spherical nodes = $n - l - 1 = 3 - 1 - 1 = 1$

51. In a sample of hydrogen atoms, electrons make transitions from n = 5 to n = 1. If all the spectral lines are observed, then the line having the third highest energy will correspond to

(A) $5 \rightarrow 3$ (B) $4 \rightarrow 1$ (C) $3 \rightarrow 1$ (D) $5 \rightarrow 4$

Solution

(C)

The energy change for the transitions is given by

$$\Delta E = 2.17 \times 10^{-18}\left(\frac{1}{(n_1)^2} - \frac{1}{(n_2)^2}\right)\text{J atom}^{-1}$$

For the given transitions, the energy changes are

For $5 \rightarrow 3$

$$\Delta E = 2.17 \times 10^{-18}\left(\frac{1}{(3)^2} - \frac{1}{(5)^2}\right)\text{J atom}^{-1} = 2.17 \times 10^{-18} \times \frac{16}{225}\text{J atom}^{-1} =$$

For $4 \rightarrow 1$

$$\Delta E = 2.17 \times 10^{-18}\left(\frac{1}{(1)^2} - \frac{1}{(4)^2}\right)\text{J atom}^{-1} = 2.17 \times 10^{-18} \times \frac{15}{16}\text{J atom}^{-1}$$

For $3 \rightarrow 1$

$$\Delta E = 2.17\times10^{-18}\left(\frac{1}{(1)^2}-\frac{1}{(3)^2}\right)\text{J atom}^{-1} = 2.17\times10^{-18}\times\frac{8}{9}\text{J atom}^{-1}$$

For $5 \to 4$

$$\Delta E = 2.17\times10^{-18}\left(\frac{1}{(4)^2}-\frac{1}{(5)^2}\right)\text{J atom}^{-1} = 2.17\times10^{-18}\times\frac{9}{400}\text{J atom}^{-1}$$

52. An energy of 24.6 eV is required to remove one of the electrons from helium atom. The energy required to remove both the electrons from helium atom is

(A) 38.2 eV (B) 49.2 eV (C) 51.8 eV (D) 79.0 eV

Solution

(D) After the removal of first electron, helium ion becomes a hydrogen like species, so the energy required to remove the second electron can be calculated as

$$E_n = \frac{13.6Z^2}{n^2} = 13.6\times4 = 54.4\text{ eV}$$

Therefore, the energy to remove both the electrons is 24.6 + 54.4 = 79.0 eV.

53. In Ψ_{321} the sum of angular momentum, spherical nodes and angular node is

(A) $\frac{\sqrt{6}h+4\pi}{2\pi}$ (B) $\frac{\sqrt{6}h}{2\pi}+3$ (C) $\frac{\sqrt{6}h+2\pi}{2\pi}$ (D) $\frac{\sqrt{6}h+8\pi}{2\pi}$

Solution

(A) Ψ_{321} means n = 3 and l = 2, m = 1 therefore, the angular momentum = $\frac{\sqrt{l(l+1)}h}{2\pi} = \frac{\sqrt{6}h}{2\pi}$, spherical nodes = n – l – 1 = 3 – 2 – 1 = 0 and angular nodes = l = 2. Hence, the sum is

$$\frac{\sqrt{6}h}{2\pi}+2 = \frac{\sqrt{6}h+4\pi}{2\pi}$$

54. The kinetic energy, E, of an electron is related to the kelvin temperature through the equation, $E = \frac{3}{2}kT$ where k = 1.38 × 10^{-23} J particle^{-1} K^{-1}. You are given an electron with a de Broglie wavelength of λ = 76.3 nm. What is the kelvin temperature of electron?

(A) 0.50 (B) 1.00 (C) 1.50 (D) 2.00

Solution

(D) Given that de Broglie wavelength is

$$\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$$

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\times m\times\frac{h^2}{m^2\lambda^2} = \frac{h^2}{2m\lambda^2}$$

Therefore,

$$E = \frac{3}{2}kT \Rightarrow T = \frac{2E}{3k} = \frac{1}{3k}\times\frac{h^2}{m\lambda^2} = 2\text{ K}$$

<H2>Multiple Correct Choice Type

1. Which of the following statements is correct about angular nodes?

(A) These nodes are directional in nature.

(B) These nodes are dependent on angle θ and ϕ.

(C) These nodes are independent from the radial wave function (R).
(D) These nodes are dependent on the radial wave function.
Solution
(A, B, C) Angular nodes being directional only depend on θ and ϕ but not on the radial wave function (R).

2. Five valence electrons of ${}^{30}_{15}P$ are labeled as

3s	3p		
pq	x	y	z

If the spin quantum number of q and z is +(1/2), the group of electrons with three of the quantum numbers same are:
(A) pq (B) (xyz),(pq) (C) (pq),(xyz),(pz) (D) (pq),(xyz),(qy)
Solution
(A, B)

3. Which of the following orbitals are associated with the angular nodes?
(A) s-orbitals (B) p-orbitals (C) d-orbitals (D) f-orbitals
Solution
(B, C, D) Angular nodes are only associated with direction orbitals.

4. Let A_n be the area electrons by the nth orbit in a hydrogen atom. The graph of ln (A_n/A_1) against ln (n)
(A) will pass through origin. (B) will be straight line with slope = 4.
(C) will be a monotonically increasing non-linear curve. (D) will be a circle.
Solution
(A, B, C)

5. 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 maximas (peaks) in radial distribution is $n - 1$.
(C) Radial probability density is $4\pi r^2 R^2_{nf(r)}$.
(D) $|\psi^2|$ represents probability of finding electron.
Solution
(A, B, C, D)

6. The quantum numbers that are derived from the solution of Schrodinger's wave equation are:
(A) Principal quantum number (B) Azimuthal quantum number
(D) Magnetic quantum number (D) Spin quantum number
Solution
(A, B, C)

7. Which of the following is the nodal plane of d_{xy} orbital?
(A) xy (B) yz (C) zx (D) All of these.
Solution
(B, C)

8. Many elements have non-integral atomic masses because **(IIT-JEE 1984)**
(A) they have isotopes.

(B) their isotopes have non-integral masses.
(C) their isotopes have different masses.
(D) the constituents neutrons, protons, and electrons combine to give fractional masses.
Solution
(A, C)
<H2>Assertion–Reasoning Type
Choose the correct option from the following:
(A) Statement 1 is True; Statement 2 is True; Statement 2 is a correct explanation for Statement 1.
(B) Statement 1 is True; Statement 2 is True; Statement 2 is not a correct explanation of Statement 1.
(C) Statement 1 is True; Statement 2 is False.
(D) Statement 1 is False; Statement 2 is True.
1. Statement 1: Hydrogen has one electron in its orbit but it produces several spectral lines.
Statement 2: There are many excited energy levels available.
Solution
(A)

2. Statement 1: Maximum possible number of electrons in any energy level is fixed.
Statement 2: Total number of electrons in a shell = 2 (2l + 1).
Solution
(C) Energy of the electron is quantized in the energy level or energy shell; hence, possible number of electrons in any energy level is fixed.
Total number of electrons in a shell = $2n^2$

3. Statement 1: The number of radial nodes for 3p orbital is 1.
Statement 2: Number of radial nodes = l.
Solution
(C) Number of radial nodes = $n - l - 1$

4. Statement 1: Photoelectric effect is easily pronounced by caesium metal.
Statement 2: Photoelectric effect is easily pronounced by the metals having high ionization enthalpy.
Solution
(C) Photoelectric effect is easily pronounced by the metals having low ionization enthalpy.

5. Statement 1: Electronic energy for hydrogen atom of different orbitals follow the following sequence: $1s < 2s = 2p < 3s = 3p = 3d$.
Statement 2: Electronic energy for hydrogen atom depends only on n and is independent of l and m_l values.
Solution
(A)

<H2>Comprehension Type
Read the paragraphs and answer the questions that follow.
Paragraph I
The wave functions for any one-electron system, such as hydrogen atom, can be expressed as $\psi = k^r e^{-\kappa r}$ where k and k^r are constants. For hydrogen atom, we have

$$\Psi_{1s} = \sqrt{\frac{1}{\pi a_0^3}} \cdot e^{Zr/a_0}$$

$$\psi_{2s} = \left(\frac{Z}{2a_0}\right)^{1/2}\left(2 - \frac{Zr}{a_0}\right)e^{Zr/a_0}$$

The number of angular nodes is given by the value of angular quantum number and angular node is directional in nature. The total number of nodes is nothing but the sum of radial nodes ($n - l - 1$) and angular nodes (l).

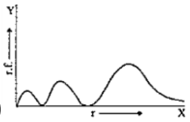
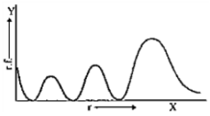
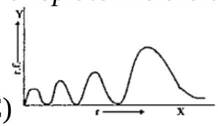
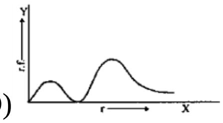
1. If the nodes at infinity are not neglected, then what is the total number of radial and angular nodes of $3p_x$ orbitals?

(A) 4 (B) 3 (C) 5 (D) Infinity

Solution

(B) Total number of radial and angular nodes = n

2. Which of the following is the correct representation of plot radial function (r,f) in y-axis vs. distance from the nucleus in x-axis for 1-electron of $3p$ atomic orbital?

(A)  (B)  (C)  (D) 

Solution

(D) Number of radial nodes = $n - l - 1$

3. The distance from the nucleus of the radial nod of $2s$ electron of Li^{2+} ion (a_0 = Bohr's radius) is equal to

(A) $0.67a_0$ (B) $2a_0$ (C) a_0 (D) $0.5a_0$

Solution

(A) $\Psi_{2s} = \left(\frac{Z}{2a_0}\right)^{1/2}\left(2 - \frac{Zr}{a_0}\right)e^{\frac{Zs}{a_0}} = 0 \Rightarrow \left(2 - \frac{Zr}{a_0}\right) = 0$

Therefore, $r = \frac{2a_0}{Z} = \frac{2a_0}{3}$

Paragraph II

Heisenberg gave the principle that there is uncertainty in simultaneous measurement of position and momentum of small particles. If any one of these two quantities is measured with higher accuracy, the measurement of the other becomes less accurate. The product of the uncertainty in position (Δx) and uncertainty in momentum (Δp) is always constant and is equal to or greater than $h/4\pi$, where h is Plank's constant.

4. The uncertainty in position of an electron ($m = 9.1 \times 10^{-28}$ g) moving with a velocity 3×10^4 cm s^{-1} accurate upto 0.001%will be

(A) 3.84 cm (B) 1.92 cm (C) 7.68 cm (D) 5.76 cm.

Solution

(B) $\Delta v = \frac{h}{4\pi m\Delta v} = \frac{6.6\times10^{-27}}{4\times3.14\times9.1\times10^{-28}\times0.3} = 1.92$ cm

5. If uncertainty in position is twice the uncertainty in momentum, then uncertainty velocity will be

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

Solution

(D) $\Delta x = 2\Delta p$ and $\Delta x \cdot \Delta p = \dfrac{h}{4\pi}$

6. 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.

Solution

(D) When $\Delta x = 0, \Delta p = \infty$, so

$$\Delta x \times \Delta p = \frac{h}{4\pi} \Rightarrow 2(\Delta p)^2 = \frac{h}{4\pi} \Rightarrow \Delta p = \frac{1}{\sqrt{2}\times 2}\sqrt{\frac{h}{\pi}}$$

Therefore, $$\Delta v = \frac{1}{2\sqrt{2m}}\sqrt{\frac{h}{\pi}}$$

Paragraph III

For one-electron species, the wave number of radiation emitted during the transition of electron from a higher energy state (n_2) to a lower energy state (n_1) is given by:

$$\bar{v} = \frac{1}{\lambda} R_{\mathrm{H}} \times Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \tag{1}$$

where $R_{\mathrm{H}} = \dfrac{2\pi m_e k^2 e^4}{h^3 c}$ is Rydberg constant for hydrogen atom. Now, considering nuclear motion, the most accurate measurement would be obtained by replacing mass of electron (m_e) by the reduced mass (μ) in the above expression, defined as

$$\mu = \frac{m_n \times m_e}{m_n + m_e}$$

where m_n = mass of nucleus. For Lyman series, n_1 = 1 (fixed for all the lines) while n_2 = 2, 3, 4…. For Balmer series: n_1 = 2 (fixed for all the lines) while n_2 = 3, 4, 5…..

7. If proton in hydrogen nucleus is replaced by a positron having the same mass as that of proton but same charge as that of proton, then considering the nuclear motion, the wavenumber of the lowest energy transition of He^+ ion in Lyman series will be equal to
(A) $2R_{\mathrm{H}}$ (B) $3R_{\mathrm{H}}$ (C) $4R_{\mathrm{H}}$ (D) R_{H}

Solution

(B) $\dfrac{1}{\lambda} = \bar{v} = R_H Z^2\left[\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right]$

For lowest energy transition of He^+ ion in Lyman series $\bar{v} = R_H 2^2\left[\dfrac{1}{1^2} - \dfrac{1}{1^2}\right] = 3R_H$

8. The ratio of the wave numbers for the highest energy transition of electron in Lyman and Balmer series of hydrogen atom is
(A) 4:1 (B) 6:1 (C) 9:1 (D) 3:1

Solution

(A) Lyman series, n_1 = 1

$$\frac{1}{\lambda_1} = \bar{v}_1 = R_H \cdot 1^2\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$$

Balmer series, n_2 = 1

$$\frac{1}{\lambda_2} = \bar{v}_2 = R_H \cdot 1^2 \left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$$

For highest energy transition,
For Lyman series $n_2 = \infty$
For Balmer series $n_2 = \infty$

Therefore, $$\frac{\bar{v}_1}{\bar{v}_2} = \frac{4}{1}$$

<H2>Integer Answer Type
The answer is a non-negative integer.

1. The wave function of an orbital is represented as $\psi_{420.}$ The azimuthal quantum number of the orbital is ____.
Solution
(2) ψ_{nlm}

2. The number of spectral lines produced when an electron jumps from 5th orbit to 2nd orbit in the hydrogen atom is ____.
Solution
(6) Number of spherical lines produced if electron falls from n_2 to n_1.

$$\frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2} = \frac{(5-2)(5-2+1)}{2} = 6$$

3. The Schrödinger wave equation for hydrogen atom is

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

where a_0 is Bohr's radius. If the radial node in 2s be at $r = 4a_{0,}$ then x would be equal to _____.
Solution
(2) For a radial node $\psi_2 = 0$; thus, on solving the equation we have

$$a_0 x^2 = 4a_0 \Rightarrow x^2 = 4 \Rightarrow x = 2$$

4. The angular momentum of an electron is h/π. The Bohr's orbit in which the electron is revolving is ___.
Solution
(2) $mvr = n\frac{h}{2\pi} \Rightarrow \frac{h}{\pi} = n\frac{h}{2\pi} \Rightarrow n = 2$

5. Magnetic moment of M^{x+} is $\sqrt{24}$ BM. The number of unpaired electrons in M^{x+} is ___.
Solution
(4) $\sqrt{n(n+2)} = \sqrt{24} \Rightarrow n(n+2) = 24 \Rightarrow n = 4$

6. The number of nodes in the radial distribution curve of 2s orbital is ___.
Solution
(1) Number of radial nodes = $n - l - 1 = 2 - 0 - 1 = 1$.

7. The number of electrons with $l = 2$ in the ground state of chromium atom is ___.
Solution

(5) l = 2, and the number of d-electrons = 5

8. The circumference of the second orbit of electron in hydrogen atom is 400 nm, the de Broglie wavelength of electron corresponding to the circumference of same orbit is 200 nm. The number of waves made by an electron is ___.

Solution

(2) Number of waves $n = \frac{\text{Circumference}}{\text{Wavelength}}$, where $2\pi r = n\lambda$

$$n = \frac{400}{200} = 2$$

So, $n\lambda = 2\pi r \Rightarrow n \times 200 = 400 \Rightarrow n = 2$.

9. The value of n of the highest excited state that an electron of hydrogen atom in the ground state can reach when 12.09 eV energy is given to the hydrogen atom is ___.

Solution

(3) $E_n = -13.6 + 12.09 = -1.51$ $E_n = \frac{E_1}{n^2}$

Therefore, $n^2 = \frac{-13.6}{-1.51} = 9 \Rightarrow n = 3$

10. The number of d electrons in Cu^{2+} (atomic number = 29) that can have the spin quantum (–1/2) is ___.

Solution

(5) $Cu^{+} = [Ar]3d^{10}4s^{0}$

Five d-electrons have $+\frac{1}{2}$ spin

Five d-electrons have $-\frac{1}{2}$ spin

11. The number of elements that have the last electron with quantum numbers of n = 4 and l = 1 is ___.

Solution

(6) n = 4, l = 1 represents 4p subshell containing six electrons. Thus, there will be six elements having $4p^1$ *to* $4p^6$ electronic configuration.

<H2>Matrix–Match Type

1. Match the atoms/ions with the characteristics of the electron they contain.

Column-I		**Column-II**	
(A)	H	(p)	Radius of 4th orbital = 0.53 × 4 Å
(B)	He^{+}	(q)	Energy of 2nd orbit = –13.6 eV
(C)	Be^{2+}	(r)	Radius of 2nd orbit =0.53 × 4 Å
(D)	Li^{3+}	(s)	Velocity of electron in the 3rd orbit = 2.18×10^8 Å
		(t)	Energy of 4th orbit = –13.6 eV

Solution

A → (r); B → (q), C → (p, t), D → (s)

(A) For H, radius of 2nd orbit $= 0.53 \times \frac{2^2}{1} = 0.53 \times 4$ Å

(B) For He^+, energy of 2nd orbit $= -13.6 \times \frac{2^2}{2^2} = -13.6$ eV

(C) For Be^{2+}, radius of 4th orbit $= 0.53 \times \frac{4^2}{4} = 0.53 \times 4$ Å

Also, energy of 4th orbit $= -13.6 \times \frac{4^2}{4^2} = -13.6$ eV

(D) For Li^{3+}, velocity of electron in 3rd orbit $= 2.18 \times 10^8 \times \frac{2}{3} = 2.18 \times 10^8$ Å

2. Match the angle between the axes of the orbitals with their value.

	Column I		Column II
(A)	The angle between the *z*-component of orbital angular momentum of electron of p_x atomic orbital and *z*- axis (assume $m = +1$)	(p)	135°
(B)	The angle between the *z*-component of orbital angular momentum of electron of p_z of atomic orbital and *z*-axis.	(q)	45°
(C)	The angle between the *z*-component of orbital angular momentum of electron of p_y atomic orbit and *z*-axis is	(r)	Less than 45° or more than 135°
(D)	The angle between the *z*-component of orbital angular momentum of electron of $3d_{x^2-y^2}$ orbital and *z*-axis.	(s)	90°

Solution

(A) → (q); (B) → (s), (C) → (p), (D) → (r)

If θ is the angle between the angular momentum vector and *z*-axis then

$\sqrt{1(1+1)}\cos\theta = m$

m = magnetic quantum number

For p_x atomic orbital $l = 1$, $m = 1$.

For p_z atomic orbital $l = 1$, $m = 0$.

For p_y atomic orbital $l = 1$, $m = -1$.

For $d_{x^2-y^2}$, $l = 2$, $m = \pm 2$

Hence, the answer is (A) → (q); (B) → (s), (C) → (p), (D) → (r).

3. Match the series of hydrogen spectrum with their characteristics.

Column I		**Column II**	
(A)	Lyman series	(p)	Visible region
(B)	Balmer series	(q)	Infrared region
(C)	Paschen series	(r)	Ultraviolet region

(D)	Bracket series	(s)	$n_2 = 4$ to $n_2 = 3$
		(t)	$n_2 = 5$ to $n_2 = 1$

Solution

A → (r, t); B → (p), C → (q, s), D → (q)

Lyman series is ($n_1 = 1$) and falls in UV region.

Balmer series is ($n_1 = 2$) and falls in visible region.

Paschen series is ($n_1 = 3$) and falls in infrared region.

4. Match the orbitals with the number of nodes/quantum numbers present in them.

Column I	Column II
(A) 2*p* orbital	(p) Number of spherical nodes = 0
(B) 3*d* orbital	(q) Number of nodal plane = 0
(C) 2*s* orbital	(r) Orbital angular momentum number = 0
(d) 4*f* orbital	(s) Azimuthal quantum number = 0

Solution

A → (p); B → (p), C → (q, r, s), D → (p)

For 2*p* orbital, number of spherical nodes = $n - l - 1 = 2 - 1 - 1 = 0$; nodal planes $\neq 0$; $l = 1$; $m = 1, 0, -1$.

For 3*d* orbital, number of spherical nodes = $n - l - 1 = 3 - 2 - 1 = 0$; nodal planes $\neq 0$; $l = 2$; $m = 2, 1, 0, -1, -2$.

For 4*f* orbital, number of spherical nodes = $n - l - 1 = 4 - 3 - 1 = 0$; nodal planes $\neq 0$; $l = 3$; $m = 3, 2, 1, 0, -1, -2, -3$.

For 2*s* orbital, number of spherical nodes = $n - l - 1 = 2 - 0 - 1 = 1$; nodal planes $\neq 0$; $l = 0$; $m = 0$.

5. Match the name of the equation with its expression.

(A)	Moseley's equation	(p)	$\sqrt{l(l+1)}\dfrac{h}{2\pi}$
(B)	Potential energy of electron	(q)	$\dfrac{eh}{2\pi mc}\sqrt{S(S+1)}$
(C)	Orbital angular momentum	(r)	$\dfrac{Zke^2}{r_n}$
(D)	Spin magnetic moment	(s)	$\sqrt{\nu} = a(Z-b)$

Solution

A → (s); B → (r), C → (p), D → (q) Concept based.