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PHYSICS QNA-ATOMS

03 CBSE

PHYSICS-CBSE-XII

QNA-ATOMS

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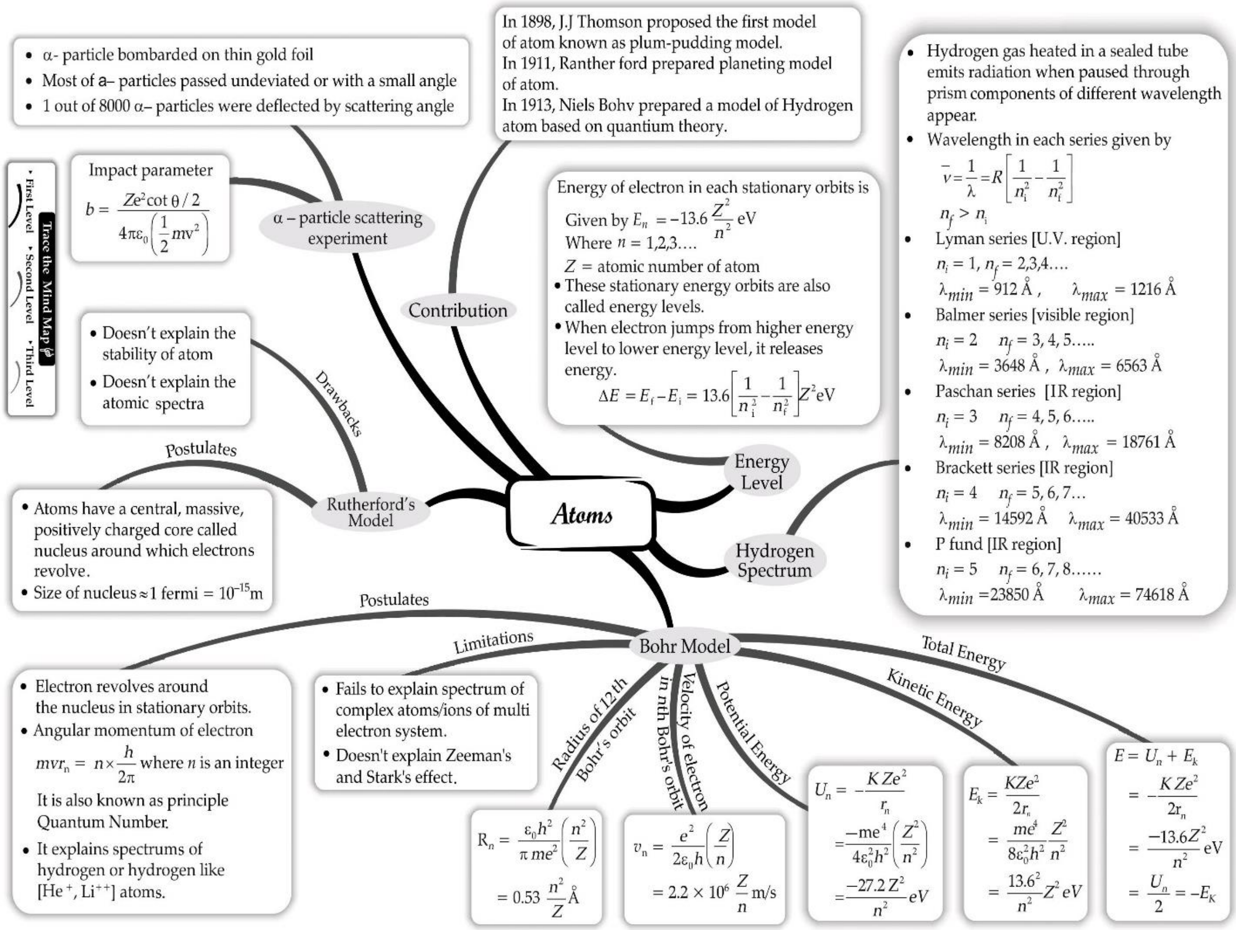
ATOMS



Atoms
• α- particle bombarded on thin gold foil
• Most of a– particles passed undeviated or with a small angle
• 1 out of 8000 α– particles were deflected by scattering angle
α – particle scattering experiment
Impact parameter
$b = \frac{Ze^2 \cot\theta/2}{4\pi\varepsilon_0\left(\frac{1}{2}mv^2\right)}$
Trace the Mind Map
• First Level • Second Level • Third Level
Contribution
In 1898, J.J Thomson proposed the first model of atom known as plum-pudding model.
In 1911, Ranther ford prepared planeting model of atom.
In 1913, Niels Bohv prepared a model of Hydrogen atom based on quantum theory.
Drawbacks
• Doesn't explain the stability of atom
• Doesn't explain the atomic spectra
Rutherford's Model
Postulates
• Atoms have a central, massive, positively charged core called nucleus around which electrons revolve.
• Size of nucleus ≈ 1 fermi = 10^{-15}m
Energy Level
Energy of electron in each stationary orbits is
Given by $E_n = -13.6\frac{Z^2}{n^2}$ eV
Where n = 1,2,3….
Z = atomic number of atom
• These stationary energy orbits are also called energy levels.
• When electron jumps from higher energy level to lower energy level, it releases energy.
$\Delta E = E_f - E_i = 13.6\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]Z^2$eV
Hydrogen Spectrum
• Hydrogen gas heated in a sealed tube emits radiation when paused through prism components of different wavelength appear.
• Wavelength in each series given by
$\bar{v} = \frac{1}{\lambda} = R\left[\frac{1}{n_i^2} - \frac{1}{n_f^2}\right]$
$n_f > n_i$
• Lyman series [U.V. region]
$n_i = 1$, n_f = 2,3,4….
λ_{min} = 912 Å, λ_{max} = 1216 Å
• Balmer series [visible region]
$n_i = 2$ n_f = 3, 4, 5…..
λ_{min} = 3648 Å, λ_{max} = 6563 Å
• Paschan series [IR region]
$n_i = 3$ n_f = 4, 5, 6…..
λ_{min} = 8208 Å, λ_{max} = 18761 Å
• Brackett series [IR region]
$n_i = 4$ n_f = 5, 6, 7…
λ_{min} = 14592 Å λ_{max} = 40533 Å
• P fund [IR region]
$n_i = 5$ n_f = 6, 7, 8……
λ_{min} = 23850 Å λ_{max} = 74618 Å
Bohr Model
Postulates
• Electron revolves around the nucleus in stationary orbits.
• Angular momentum of electron
$mvr_n = n \times \frac{h}{2\pi}$ where n is an integer
It is also known as principle Quantum Number.
• It explains spectrums of hydrogen or hydrogen like [He^+, Li^{++}] atoms.
Limitations
• Fails to explain spectrum of complex atoms/ions of multi electron system.
• Doesn't explain Zeeman's and Stark's effect.
Radius of 12th Bohr's orbit
$R_n = \frac{\varepsilon_0 h^2}{\pi me^2}\left(\frac{n^2}{Z}\right) = 0.53\frac{n^2}{Z}$Å
Velocity of electron in nth Bohr's orbit
$v_n = \frac{e^2}{2\varepsilon_0 h}\left(\frac{Z}{n}\right) = 2.2 \times 10^6 \frac{Z}{n}$ m/s
Potential Energy
$U_n = -\frac{KZe^2}{r_n} = \frac{-me^4}{4\varepsilon_0^2 h^2}\left(\frac{Z^2}{n^2}\right) = \frac{-27.2Z^2}{n^2}eV$
Kinetic Energy
$E_k = \frac{KZe^2}{2r_n} = \frac{me^4}{8\varepsilon_0^2 h^2}\frac{Z^2}{n^2} = \frac{13.6^2}{n^2}Z^2 eV$
Total Energy
$E = U_n + E_k = -\frac{KZe^2}{2r_n} = \frac{-13.6Z^2}{n^2}$eV $= \frac{U_n}{2} = -E_K$

Syllabus

➢ *Alpha-particle scattering experiment; Rutherford's model of atom; Bohr model, energy levels, hydrogen spectrum.*

Trend Analysis

List of Concepts	2018		2019		2020	
	OD	D	OD	D	OD	D
α-particle scattering	–	1 Q (3 M)	–		–	
Rutherford atomic model	–	–	1 Q (3 M)		–	1 Q (2 M)
Bohr model, Energy levels, Hydrogen spectrum	–	1 Q (2 M) 1 Q (3 M)	2 Q (2 M)	3 Q (2 M) 1 Q (3 M)	1 Q (5 M) 1 Q (1 M)	1 Q (1 M) 2 Q (2 M) 1 Q (5 M)

Revision Notes

➢ There are roughly hundred types of atoms. (An atom is the identity of an element. 118 types of elements are known to us till date.)

➢ All atoms radiate different light spectra which shows these atoms are different and may be the smallest particles.

➢ With the discovery of electron by J. J. Thomson, it was evident that atoms have identical sub atomic particles and different light spectra of different atoms exists due to the motion of these particles.

➢ **Atomic models**

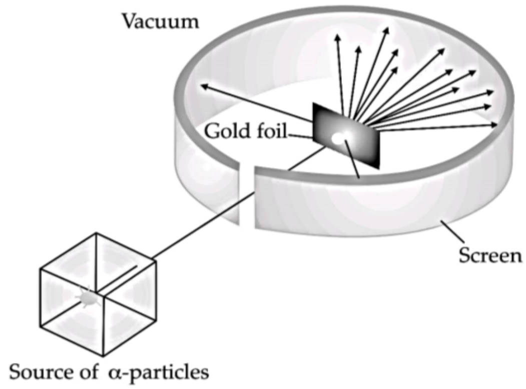
- As atom is electrically neutral, the discovery of electron led by J. J. Thomson established that it should also have positive charge. Hence, he proposed first model of atom- Plum-Pudding model.
- **Plum-Pudding model:** According to plum pudding model "the positive charge of the atom is uniformly distributed throughout the volume of the atom and the negatively charged electrons are embedded in it like seeds in a watermelon."
- But subsequent studies on atom showed the results very different to this atomic model.

Rutherford's atomic model:

- With the discovery of Avogadro number, the atomic size was understood to be quite big as compared to the sizes of atomic sub-particles.
- This led Rutherford to establish the second theoretical atomic model known as "nuclear model of the atom". It was inspired by planetary position around the Sun.
- According to this model "The entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus, with electrons revolving around the nucleus just as planets revolve around the Sun."
- Though, it was initially a theoretical model but it was a major step towards the modern atomic model.
- **Geiger** and **Marsden** experimentally proved Rutherford's atomic model.

Geiger and Marsden scattering experiment:

Experimental setup:



- Radioactive element ${}^{214}_{83}Bi$ was taken as α-particles generating source.
- Gold was taken as target metal. The selection of gold was based upon its two important characteristics:
  - Gold has the highest malleability. Gold foil that was used in experiment was almost transparent.
  - Gold is a heavy metal, hence it helped in discovery of nucleus.
- Lead bricks absorbed the α-particles which were not towards the direction of gold foil. They worked as collimator.
- The Detector was made from ZnS.

Experimental observations:

- When α-particles hit ZnS screen, it absorbs and glows. Hence, the number of α-particles can be counted by intensity variation.
- Most of the α-particles passed roughly in straight line (within 1°) without deviation. This showed that no force was acting upon most of α-particles.
- A very small number of α-particles were reflected. (1 out of 8000)

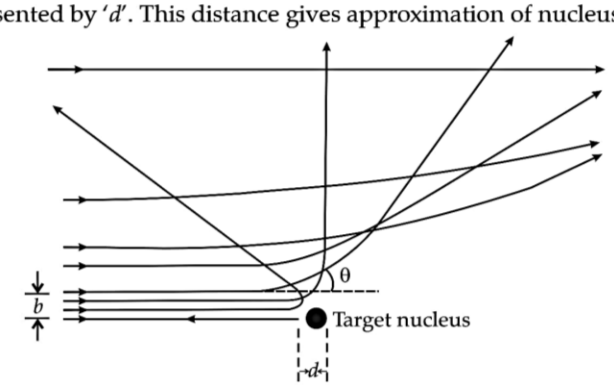
Conclusions:

- Most of the space in the atom is mostly empty (only 0.14% scatters more than 1°).
- Experiment suggests that all positively charged particles are together at one location at centre. It was called nucleus. So, nucleus has all the positive charges and the mass. Therefore, it has capability to reflect heavy positive α-particles.
- Size of nucleus calculated to be about 10^{-14} m. According to kinetic theory, size of one atom is of the order of 10^{-10} m.
- Force between α-particles and gold nucleus

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2eZe}{r^2}$$

Alpha-particle trajectory:

- **Impact parameter:** It is the perpendicular distance between direction of given α-particle and centre of nucleus. It is represented by 'b'.
- **Distance of closest approach:** It is the distance between centre of nucleus and the α-particle where it stops and reflects back. It is represented by 'd'. This distance gives approximation of nucleus size.



Electron Orbits

- We can calculate the energy of an electron and radius of its orbit based upon Rutherford model.
- The electrostatic force of attraction, F_e between the revolving electrons and the nucleus provides the requisite centripetal force (F_c) to keep them in their orbits.

$$F_e = F_c$$

For hydrogen atom,
$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$$

or,
$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

Electron has kinetic energy, $K = \frac{1}{2}mv^2$. Putting the value of mv^2 in the above equation

$$K = \frac{e^2}{8\pi\varepsilon_0 r}$$

And
$$v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$$

P.E. of an electron, $U = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}$ (negative sign shows that it is due to attractive force)

Total energy,
$$E = K + U$$
$$E = \frac{e^2}{\pi 8\varepsilon_0 r} + \left(-\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}\right)$$
$$= -\frac{e^2}{8\pi\varepsilon_0 r}$$

- Due to this negative energy, electron is bound to nucleus and revolves around it. This energy is known as binding energy of electron.
- From the equation, it is clear that if energy is zero, then radius is infinity. Practically, if we provide this amount of energy to this electron, it gets free.

Atomic Spectra:

- Each element has a characteristic spectrum of radiation, which it emits. There are two types of atomic spectra: Emission atomic spectra and absorption atomic spectra.
- **Emission atomic spectra:** Due to excitation of atom usually by electricity, light of particular wavelength emitted. Atomic spectra is known as emission spectra.
- **Absorption atomic Spectra:** If atoms are excited in presence of white light, it absorbs its emission spectral colour and black line will appear in the same place of that atoms' emission spectra. This type of spectra are known as absorption spectra.

Spectral series:

- The atom shows range of spectral lines. Hydrogen is the simplest atom and has simplest spectrum.
- The spacing between lines within certain sets of the hydrogen spectrum decreases in a regular way. Each of these sets is called a spectral series.
- **Balmer Series:** Balmer observed the first hydrogen spectral series in visible range of hydrogen spectrum. It is known as Balmer Series.

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

Longest wavelength = 6566.4 Å
Shortest wavelength = 3648 Å
where, R is Rydberg's constant . The value of R is 1.097×10^7 m^{-1}; $n = 3, 4, 5...$

$$\frac{1}{\lambda} = \frac{\nu}{c}$$

Hence,
$$\nu = Rc\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

TRICK.
for fast calculation of wavelength $\boxed{\frac{1}{R} = 912\,\text{Å}}$

Other series of spectra for hydrogen were as follows:

- **Lyman Series:** $\frac{1}{\lambda}=R\left(\frac{1}{1^2}-\frac{1}{n^2}\right)$; $n = 2, 3, 4, 5, ...$ This is in UV range.

  Longest wavelength = 1216 Å
  Shortest wavelength = 912 Å

- **Paschen Series:** $\frac{1}{\lambda}=R\left(\frac{1}{3^2}-\frac{1}{n^2}\right)$; $n = 4, 5, 6, ...$

  Longest wavelength = 18761.14 Å
  Shortest wavelength = 8208 Å

- **Brackett Series:** $\frac{1}{\lambda}=R\left(\frac{1}{4^2}-\frac{1}{n^2}\right)$; $n = 5, 6, ...$

  Longest wavelength = 40533.33 Å
  Shortest wavelength = 14592 Å

- **Pfund Series:** $\frac{1}{\lambda}=R\left(\frac{1}{5^2}-\frac{1}{n^2}\right)$; $n = 6, 7, 8 ....$

  Longest wavelength = 74618.1 Å
  Shortest wavelength = 22800 Å

- The Lyman series is in the ultraviolet while the Paschen, Brackett and Pfund series are in the infrared region.

Limitation of Rutherford model:

- **It could not explain the stability of the atom:** The electron orbiting around the nucleus radiates energy. As a result, the radius of the electron orbit should continuously decrease and ultimately the electron should fall into the nucleus.
- **It could not explain nature of energy spectrum:** According to the Rutherford's model, the electrons can revolve around the nucleus in all possible orbits. Hence, the atom should emit radiations of all possible wavelengths or in other words, it should have continuous spectrum. However, in practice, the atoms are found to have line spectrum or discrete spectrum.

Bohr's Model and Postulates:

- An electron can revolve in certain stable orbits without emission of radiant energy. These orbits are called stationary states of atom.
- Electron revolves around nucleus only in those orbits for which the angular momentum is the integral multiple of $\frac{h}{2\pi}$, where, h is Planck's constant.
- Hence angular momentum, $L=\frac{nh}{2\pi}$
- An electron may make a transition from one of its specified non-radiating orbit to another of lower energy. When it does so, a photon is radiated having energy equal to energy difference between initial and final state.

$$h\nu = E_i - E_f \quad \text{(where, } \nu \text{ is frequency)}$$

Angular momentum, $L = mv_n r_n$

According to Bohr's postulate, $L=\frac{nh}{2\pi}$

Hence,

$$mv_n r_n = \frac{nh}{2\pi}$$

$$mr_n = \frac{nh}{2\pi v_n}$$

For hydrogen atom, $v=\frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$

Combining these two equations, we get

$$v_n = \frac{1}{n}\cdot\frac{e^2}{4\pi\varepsilon_0}\frac{1}{(h/2\pi)}$$

This equation depicts that electron speed in n[th] orbit falls by a n factor.

$$r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)^2 \frac{4\pi\varepsilon_0}{e^2}$$

For innermost orbit $n = 1$; the value of r_1 is known as Bohr's radius a_0.

$$a_0 = \frac{h^2\varepsilon_0}{\pi m e^2}$$

If we put values of all constants, we get $a_0 = 5.29 \times 10^{-11}$ m ≈ 0.53 Å

It can also be observed that radii of n^{th} orbit increases by n^2 times.

By putting this value in total energy of an electron and convert the unit in eV, we get

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

Negative value shows that electron is bound to nucleus.

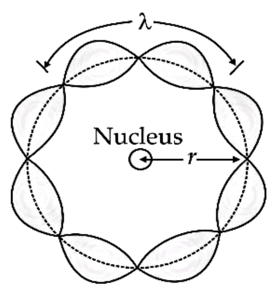
- The explanation of the hydrogen atom spectrum provided by Bohr's model was a brilliant achievement.

De-Broglie's explanation of Bohr's second postulate by quantization theory:

- According to Bohr's postulate, electron in hydrogen atom can revolve in certain orbit only in which its angular momentum, $L = n\frac{h}{2\pi}$. In these stationary orbits, electron does not radiate energy.
- De-Broglie proved it with the help of wave nature of electron.
- Travelling wave propagates energy but stationary wave does not propagates energy. In analogy to waves travelling on a string, particle waves can lead to standing waves under resonant conditions. Resonant condition is

$$l = n\lambda$$

where, l = perimeter of orbit.



Standing wave when $l = n\lambda$

For hydrogen atom, length of the innermost orbit is its perimeter. hence

$$2\pi a_0 = n\lambda \quad \text{...(i)}$$

According to de-Broglie's wavelength of electron,

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

Now equation (i) can be written as (taking $a_0 = r$)

$$2\pi r = n\frac{h}{p} \quad \text{...(ii)}$$

But $$p = mv$$

Hence, equation (ii) can be reduced as, $$2\pi r = n\frac{h}{mv}$$

$$mvr = \frac{nh}{2\pi}$$

$$L = \frac{nh}{2\pi}$$

This is Bohr's second postulate.

Limitation of Bohr's atomic model:

- Bohr's model is for hydrogenic atoms. It does not hold true for multi-electron model.

Know the Formulae

- **Radius of orbit,** $r = \dfrac{e^2}{4\pi\varepsilon_0 mv^2}$
- **Kinetic energy of electron in its orbit,** $K = \dfrac{e^2}{4\pi\varepsilon_0 r}$
- **PE of an electron;** $U = -\dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{e^2}{r}$
- **Velocity of electron in its orbit;** $v = \dfrac{e}{\sqrt{4\pi\varepsilon_0 mr}}$
- **Total energy of an electron in an orbit;** $E = -\dfrac{e^2}{8\pi\varepsilon_0 r}$

Spectral series

- **Balmer Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{2^2} - \dfrac{1}{n^2}\right)$, n = 3, 4, 5..... This is in Visible range.
- **Lyman Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{1^2} - \dfrac{1}{n^2}\right)$; n = 2, 3, 4, 5, ...This is in UV range.
- **Paschen Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{3^2} - \dfrac{1}{n^2}\right)$; n = 4, 5, 6
- **Brackett Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{4^2} - \dfrac{1}{n^2}\right)$; n = 5, 6, 7...
- **Pfund Series:** $\dfrac{1}{\lambda} = R\left(\dfrac{1}{5^2} - \dfrac{1}{n^2}\right)$; n = 6, 7, 8....

These series are in infrared region.

- **Relation between speed, total energy of an electron and its radius with respect to orbital number *n*:**

$$v_n = \frac{1}{n}\frac{e^2}{4\pi\varepsilon_0}\frac{1}{(h/2\pi)}$$

$$r_n = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)\frac{4\pi\varepsilon_0}{e^2}$$

Bohr radius, $a_0 = \dfrac{h^2\varepsilon_0}{\pi me^2} = 0.53\ \text{Å}$

Energy for nth orbiting electron, $E_n = \dfrac{-13.6}{n^2}\text{eV}$

How is it done on the GREENBOARD?

Q. 1. **A photon emitted during the de-excitation of electron from a state n to the first excited state in a hydrogen atom, irradiates a metallic cathode of work function 2 eV, in a photo cell, with a stopping potential of 0.55 V. Obtain the value of the quantum number of the state *n*. [O.D. I, II, 2019]**

Solution:

Step I. Given: Work function $(\omega_0) = 2$ eV

Stopping potential $V_0 = 0.55$ V

Stopping potential energy $= eV_0 = 0.55$ eV $= KE_{max}$

Apply Einstein's photoelectric Equation

$$KE_{max} = h\upsilon - \omega_0$$

or, $$eV_0 = h\upsilon - \omega_0$$

or, $$h\upsilon = 0.55 \text{ eV} + 2.0 \text{ eV}$$

$$h\upsilon = 2.55 \text{ eV}$$

Since, $$h\upsilon \text{ (in eV)} = \frac{12375}{\lambda(\text{Å})}$$

So, $$\lambda = \frac{12375}{2.55} \text{ Å}$$

$$\approx 4853 \text{ Å}$$

Again, $$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

[Since, it is excited to first excited state, So $n_f = 2$ and $n_i = n$]

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

$$\frac{912\text{Å}}{4853\text{Å}} = \frac{1}{4} - \frac{1}{n^2} \quad \left[\because \frac{1}{R} = 912 \text{ Å}\right]$$

or, $$\frac{1}{n^2} = 0.25 - 0.188 = 0.062$$

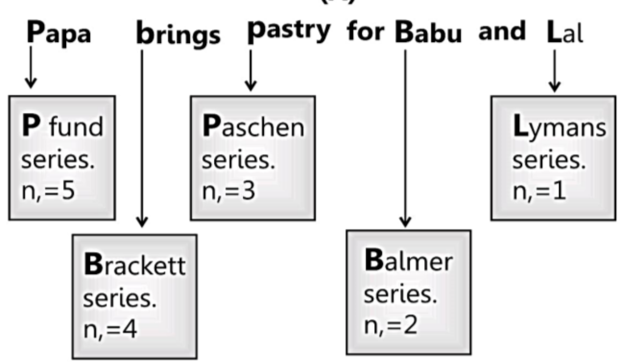
or, $$n \approx 4.02$$

$$n = 4$$

Mnemonics

Hydrogen Spectra:

(A)



Hydrogen Spectra:
(B)

1 is Unimportant, 2 is very important, rest are important.

- $n_1=1$ (i.e. Lyman series) UV range
- $n_1=2$ (i.e. Balmer series) Visible range
- $n_1=3, 4, 5$ (i.e. Paschen, Brackett and pfund series) IR range

Objective Type Questions

(1 mark each)

[A] Very Short Answer Type Questions

Q. 1. Which series of atomic spectrum of Hydrogen lies in infrared region?
R **[CBSE O.D. SET 1, 2020 Modified]**

Ans. Paschen series. **1**

Q. 2. What will be the ionisation potential if the first excitation potential of a given atom is 10.2 V? A

Ans. The minimum energy needed to ionized an atom is called ionisation energy. The potential difference through which an electron should be accelerated to acquire energy is called ionisation potential.

$$(E_2)_H-(E_1)_H=10.2\ \text{eV}$$

or $$\frac{(E_1)_H}{4}-(E_1)_H=10.2\ \text{eV}$$

$\therefore\ (E_1)_H=-13.6$ eV Hence, ionisation potential energy is $(E_\infty)_H-(E_1)_H=13.6$ eV

$\therefore$ Ionisation potential = 13.6 eV. **1**

Q. 3. What will be the radius of a Hydrogen atom when it is in first excited state? U

Ans. The radius is given by

$$r_2=r_1\,(2)^2$$
$$=4r_1$$

Q. 4. What is the maximum number of spectral lines emitted by a hydrogen atom when it is in the third excited state ? U

Ans. If n is the quantum number of highest energy level, then the total number of possible spectral lines emitted is

$$N=\frac{n(n-1)}{2}$$

Here, third excited state means fourth energy level, *i.e.*, $n=4$

$$\therefore\quad N=\frac{4(4-1)}{2}=6$$ **1**

Q. 5. Name the experiment responsible for the discovery of atomic nucleus. R

Ans. Rutherford's Alpha Scattering Experiment. **1**

Q. 6. Most of the mass of an atom is with the positive charge. In case of hydrogen atom, what fraction of the atomic mass is with the positive charge? U

Ans. A hydrogen atom contains one proton (+ve charge) and one electron (–ve charge). As the mass of a proton is 1836 times that of an electron, so 1836/1837 part of the atomic mass is associated with the positive charge. **1**

Q. 7. Out of the three radiations of the wavelength 8000 Angstrom, 5000 Angstrom and 1000 Angstrom, which one corresponds to Lyman series of Hydrogen spectrum. A

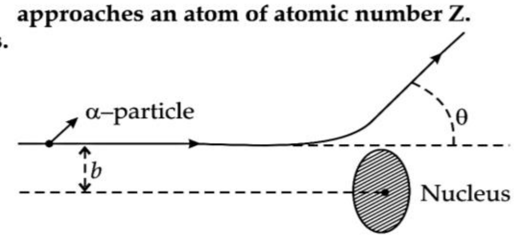
Ans. 1000 Angstrom; because it belongs to ultraviolet radiations in the electromagnetic spectrum. **1**

Q. 8. What are the drawbacks of Thomson's model of atom. R

Ans. Thomson's model of the atom could not explain the origin of spectral lines in the form of series as in case of hydrogen atom. It could not account for the scattering of alpha particles through large angles as in case of Rutherford's experiment. **1**

Q. 9. Show the trajectory of the alpha particle when it approaches an atom of atomic number Z. U

Ans.



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[B] ASSERTION REASON TYPE QUESTIONS

For the following questions, two statements are given one labelled as **Assertion (A)** and the other labelled as **Reason (R):** Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

Q. 1. Assertion (A): Bohr postulated that the electrons in stationary orbits around the nucleus do not radiate.

Reason (R): According to classical Physics, all moving electrons radiate.

Ans. (b) **1**

Explanation: Bohr postulated that electrons in stationary orbits around the nucleus do not radiate. This is true.

According to classical Physics, the moving electrons radiate only when they jump from a higher energy orbit to the lower energy orbit. So, the reason is false.

Q. 2. Assertion (A): According to Rutherford, atomic model the path of electron is parabolic.

Reason (R): According to classical Physics, an accelerated particle always follow parabolic path.

Ans. (d) **1**

Explanation: According to Rutherford "The entire positive charge and most of the mass of the atom is concentrated in a small volume called the nucleus, with electrons revolving around the nucleus just as planets revolve around the Sun."

So the assertion is false.

According to classical Physics, the moving electrons radiate only when they jump from a higher energy orbit to the lower energy orbit. So, the reason is also false.

Q. 3. Assertion (A): In the α-particle scattering experiment, most of the α-particles pass undeviated.

Reason (R): Most of the space in the atom is empty.

Ans. (a) **1**

Explanation: Most of the α-particles pass roughly in a straight line (within 1^0) without deviation. This shows that no force is acting on them. So assertion is true.

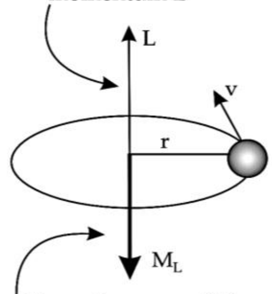
Most of the space in the atom is empty. Only 0.14% of α-particles are scattered more than 1°.

Short Answer Type Questions-I **(2 marks each)**

Q. 1. Use Bohr's model of hydrogen atom to obtain the relationship between the angular momentum and the magnetic moment of revolving electron.

A [CBSE DEL SET 1, 2020]

Ans. In Bohr model of Hydrogen atom, electron is modeled as a point negative charge rotating in a circular orbit about a fixed axis about a nucleus.



Let us consider

r = Radius of the orbit

v = Velocity

e = Charge of electron

m = Mass of electron **1**

$$\text{Time period (T)} = \frac{\text{circumference}}{\text{velocity}} = 2\pi r/v$$

$$\text{Current(i)} = \frac{-e}{T} = \frac{-e}{\frac{2\pi r}{v}} = \frac{-ev}{2\pi r}$$

The magnetic moment due to a current loop enclosing an area A is given by:

$$M_L = iA = \frac{-ev}{2\pi r}\times A = \frac{-ev}{2\pi r}\times \pi r^2 = \frac{-erv}{2} = \frac{-merv}{2m}$$

L = Angular momentum = mvr

So, $M_L = \frac{-e}{2m}L$ **1**

Q. 2. Write the shortcomings of Rutherford atomic model. Explain how these were overcome by the postulates of Bohr's atomic model.

U [CBSE DEL SET 3, 2020]

Ans. Shortcomings of Rutherford atomic model: Rutherford proposed planetary model of atom in which electrons revolve round the nucleus.

An electron revolving round the nucleus has an acceleration directed towards the nucleus.

Such accelerated electron must radiate electromagnetic radiation.

But, if an revolving electron radiates energy, the total energy of the system must decrease. In such situation, the electron must come closer to the nucleus and hit the nucleus. Also, the radiation spectrum of emitted electromagnetic waves should be continuous.

However, this does not happen in an atom. Atom is not unstable and the spectrum is not continuous. Rutherford atomic model cannot explain these two observations. These are the shortcomings of Rutherford Atomic Model. **1**

To overcome this discrepancy, Neils Bohr put forward three postulates combining classical Physics and Planck's quantum hypothesis.

Bohr's 1st postulate provides stability to the atomic model.

Bohr's 2nd postulate provides justification that electrons may revolve in stationary orbit.

Bohr's 3rd postulate provides the explanation of line spectrum. 1

Q. 3. State Bohr's quantization condition of angular momentum. Calculate the shortest wavelength of the Bracket series and state to which part of the electromagnetic spectrum does it belong.

R & A **[CBSE DEL SET 1, 2019]**

Ans. Statement of Bohr's quantization condition ½
Calculation of shortest wavelength 1
Identification of part of electromagnetic spectrum ½

Electron revolves around the nucleus only in those orbits for which the angular momentum is some integral of $h/2\pi$. (where h is Planck's constant) ½

Also give full credit if a student write mathematically $mvr = \frac{nh}{2\pi}$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$ ½

For Brackett Series,
Shortest wavelength is for the transition of electrons from $n_i = \infty$ to $n_f = 4$

$$\frac{1}{\lambda} = R\left(\frac{1}{4^2}\right) = \frac{R}{16}$$

$$\lambda = \frac{16}{R}\text{m}$$

= 1458.5 nm on substitution of value of R 1

[Note: Don't deduct any mark for this part, when a student does not substitute the value of R, to calculate the numerical value of λ]

Infrared region. **[CBSE Marking Scheme, 2019]**

Q. 4. A hydrogen atom in the ground state is excited by an electron beam of 12.5 eV energy. Find out the maximum number of lines emitted by the atom from its excited state. R **[CBSE OD SET 1, 2019]**

Ans. Calculation of energy in excited state ½
Formula ½
Finding out the maximum number of lines. 1

Energy in ground state, $E_1 = -13.6$ eV
Energy supplied = 12.5 eV
Energy in excited state, $-13.6 + 12.5 = -1.1\ eV$ ½

But, $$E_n = \frac{-13.6}{n^2} = -1.1$$ ½

$$n = 3$$ ½

Maximum number of lines = 3 ½

[CBSE Marking Scheme, 2019]

Q. 5. Calculate the orbital period of the electron in the first excited state of hydrogen atom.

A **[Delhi 1, 2019]**

Ans. Statement of the Formula for r_n ½
Statement of the formula for v_n ½
Obtaining formula for T_n ½
Getting expression for T_2 ($n = 2$) ½

Radius, $r_n = \frac{h^2\varepsilon_0}{\pi me^2}n^2$ ½

velocity, $v_n = \frac{2\pi e^2}{4\pi\varepsilon_0 h}\frac{1}{n}$ ½

Time period, $T_n = \frac{2\pi r_n}{v_n} = \frac{4\varepsilon_0^2 h^3 n^3}{me^4}$

For first excited state of hydrogen atom $n=2$ ½

$$T_2 = \frac{32\ \varepsilon_0^2 h^3}{me^4}$$

On calculation we get $T_2 \approx 1.22 \times 10^{-15}$ s. ½

[**Note:** Do not deduct the last ½ mark if a student does not calculate the numerical value of [T_2]]

Alternatively,

$r_n = (0.53n^2)\ \text{Å} = 0.53 \times 10^{-10} n^2$ ½

$v_n = \left(\frac{c}{137n}\right)$ ½

$$T_n = \frac{2\pi(0.53)}{\left(\frac{c}{137n}\right)} \times 10^{-10} n^2$$

$$= \frac{2\pi(0.53)}{c} \times 10^{-10} n^3 \times 137 s$$

$$= \frac{2 \times 3.14 \times 0.53 \times 10^{-10} \times 8 \times 137}{3 \times 10^8} s$$ ½

$$= 1215.97 \times 10^{-18} = (1.22 \times 10^{-15}) s$$ ½

Alternatively,

If the student writes directly $T_n \propto n^3$

T_2 = 8 times of orbital period of the electron in the ground state (award one mark only)

[CBSE Marking Scheme, 2019]

Q. 6. Calculate the ratio of the frequencies of the radiation emitted due to transition of the electron in a hydrogen atom from its (i) second permitted energy level to the first level and (ii) highest permitted energy level to the second permitted level. A&E **[Comptt. I, II, III, 2018]**

Ans. Formulae ½
(i) Frequency of first case ½
(ii) Frequency of second case ½
Ratio ½

We have,

$$h\nu = E_f - E_i$$
$$= \frac{E_0}{n_f^2} - \frac{E_0}{n_i^2}$$ ½

(i) $$h\nu_1 = E_0\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = E_0 \times \frac{3}{4}$$ ½

(ii) $$h\nu_2 = E_0\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = E_0 \times \frac{1}{4}$$ ½

$$\therefore \quad \frac{\nu_1}{\nu_2} = 3$$ ½

[CBSE Marking Scheme, 2018]

Q. 7. The ground state energy of hydrogen atom is – 13.6 eV. If an electron makes a transition from an energy level – 1.51 eV to – 3.4 eV, calculate the wavelength of the spectral line emitted and the series of hydrogen spectrum to which it belongs.
A [OD I, II, III, 2017]

Ans. Energy difference = 3.4 eV – 1.51 eV
= 1.89 eV = 3.024×10^{-19} J ½

Energy $= \frac{hc}{\lambda} = 3.024 \times 10^{-19}$ J ½

Wavelength $= 6.47 \times 10^{-7}$ m ½

The given series is Balmer series. ½

[CBSE Marking Scheme, 2017]

Detailed Answer:

Energy difference $= E_f - E_i$
= 3.4 eV – 1.51 eV
= 1.89 eV

Since, $\lambda = \frac{12375(\text{in Å})}{E(\text{in eV})}$ ½

$= \frac{12375}{1.89\,\text{eV}}$ Å

= 6547 Å 1

As this spectrum is in visible range. This radiation lies in Balmer series. ½

Q. 8. Write two important limitations of Rutherford's nuclear model of the atom. R [Delhi, I, II, III, 2017]

Ans. (i) According to Rutherford's model, electron orbiting around the nucleus, continuously radiates energy due to the acceleration; hence the atom will not remain stable. 1

(ii) As electron spirals inwards; its angular velocity and frequency change continuously; therefore it will emit a continuous spectrum. 1

[CBSE Marking Scheme, 2017]

Q. 9. Define the distance of closest approach. An α-particle of kinetic energy '*K*' is bombarded on a thin gold foil. The distance of the closest approach is '*r*'. What will be the distance of closest approach for an α- particle of double the kinetic energy ?
U [Delhi I, 2017]

Ans. It is the distance of charged particle from the centre of the nucleus, at which the whole of the initial kinetic energy of the (far off) charged particle gets converted into the electric potential energy of the system. 1

Distance of closest approach (r_c) is given by

$$r_c = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{K}$$ ½

'K' is doubled,

$\therefore r_c$ becomes $\frac{r}{2}$ ½

[**Alternatively:** If a candidate writes directly $\frac{r}{2}$ without mentioning formula, award the 1 mark for this part.] **[CBSE Marking Scheme, 2017]**

Q. 10. The short wavelength limit for the Lyman series of the hydrogen spectrum is 913·4 Å. Calculate the short wavelength limit for Balmer series of the hydrogen spectrum. A [CBSE OD SET 2, 2017]

Ans. **Formula** ½
Calculation 1½

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^{\,2}} - \frac{1}{n_2^{\,2}}\right)$$ ½

$\therefore$ For Balmer Series: $(\lambda_B)_{short} = 4/R$ ½

and For Lyman Series: $(\lambda_L)_{short} = 1/R$ ½

$\therefore \lambda_B = 913.4 \times 4$ Å = 3653.6 Å ½

[CBSE Marking Scheme, 2017]

Q. 11. Calculate the de-Broglie wavelength of the electron orbiting in the *n* = 2 state of hydrogen atom. A [CBSE O.D. SET 1, 2016]

Ans. Formulae of kinetic energy and de-Broglie a wavelength ½ + ½
Calculation and Result ½ + ½
Kinetic energy for the second state- ½

$$E_k = \frac{13.6eV}{n^2} = \frac{13.6eV}{4} = 3.4 \times 1.6 \times 10^{-19}\,\text{J}$$

de-Broglies wavelength, λ

$$= \frac{h}{\sqrt{2mE_k}}$$ ½

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$ ½

= 0.067 nm ½

[CBSE Marking Scheme, 2016]

Q. 12. Calculate the shortest wavelength of the spectral lines emitted in Balmer series.
[Given Rydberg constant, R = 10^7 m^{-1}]
A [CBSE O.D. SET-I 2016]

Ans. Formula 1
Calculation and Result ½+½

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

For shortest wavelength, $n = a$ ½

Therefore, $\frac{1}{\lambda} = \frac{R}{4} = \Rightarrow 1 = \frac{4}{R} = 4 \times 10^{-7}$ m ½

[CBSE Marking Scheme, 2016]

Q. 13. In the ground state of hydrogen atom, its Bohr radius is given as 5.3×10^{-11} m. The atom is excited such that the radius becomes 21.2×10^{-11} m. Find (i) the value of the principal quantum number and (ii) the total energy of the atom in this excited state. A [OD South, 2016]

Ans. (i) $r = r_0 n^2$ ½
$21.2 \times 10^{-11} = 5.3 \times 10^{-11}\,n^2$
$\Rightarrow n = 2$ ½

(ii) $E = \frac{-13.6\,\text{eV}}{n^2}$ ½

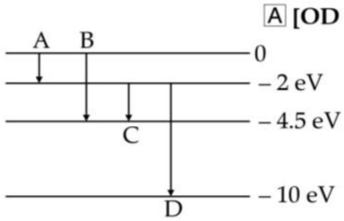
$= \frac{-13.6\,\text{eV}}{2^2} = -3.4\,\text{eV}$ ½

[Award ½ mark if the student just writes $E = E_1/4$]

[CBSE Marking Scheme, 2016]

Q. 14. The energy levels of a hypothetical atom are given below. Which of the shown transitions will result in the emission of photon of wavelength 275 nm ?

A [OD South, 2016]



Ans. (i) Energy of photon $= \frac{hc}{\lambda}$ ½

$= \frac{6.64 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9} \times 1.6 \times 10^{-18}}$ eV

$= 4.5$ eV ½+½

(ii) The corresponding transition is B ½

[CBSE Marking Scheme, 2016]

Detailed Answer:

Energy of a photon corresponding to wavelength λ,

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

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9}}\ \text{J} \quad ½$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9} \times 1.6 \times 10^{-19}}\ \text{eV}$$

$$= \frac{6.6 \times 3 \times 10^{2}}{275 \times 1.6}$$

$$= 4.5\ \text{eV} \quad 1$$

(ii) The calculated energy of the photon matches with the transition B. ½

Q. 15. Show that the radius of the orbit in hydrogen atom varies as n^2, where n is the principal quantum number of the atom. **U [Delhi I, II, III, 2015]**

Ans. $\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r^2} = \frac{mv^2}{r}$ ½

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

$$mv^2r = \frac{e^2}{4\pi\varepsilon_0} \quad \text{...(i) ½}$$

According to the Bohr's postulate,

$$mvr = \frac{nh}{2\pi}$$

$$m^2v^2r^2 = \frac{n^2h^2}{4\pi^2} \quad ½$$

Putting the value of mv^2r from eqn. (i)

$$\frac{e^2}{4\pi\varepsilon_0}mr = \frac{n^2h^2}{4\pi^2}$$

$$r = \left(\frac{n^2}{m}\right)\left(\frac{h}{2\pi}\right)\frac{4\pi\varepsilon_0}{e^2}$$

The above equation shows that r is directly proportional to n^2 ½

[CBSE Marking Scheme, 2015]

Commonly Made Error

- Some students were unable to recall the correct equation.

i.e., $mvr = \frac{nh}{2\pi}$ and $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r^2}$

Answering Tip

- The students should carefully revise the relationships between the different variables in case of Bohr's postulates.

Short Answer Type Questions-II

(3 marks each)

Q. 1. Derive an expression for the frequency of radiation emitted when a hydrogen atom de -excites from level n to level $(n - 1)$. Also show that for large values of n, this frequency equals to classical frequency of revolution of an electron.

A [SQP 2020-21]

Ans. Derivation of frequency of radiation emitted when a hydrogen atom de-excites from level n to level $(n-1)$.

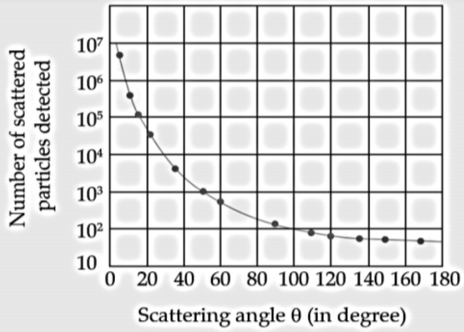
$$\nu = \frac{me^4(2n-1)}{(4\pi)^2\left(\frac{h}{2\pi}\right)^3 n^2(n-1)^2} \quad 2$$

Comparing for large values of n, with classical frequency $\nu = \frac{v}{2\pi r}$ 1

Detailed Answer:

The frequency of emitted radiation when a hydrogen atom de-excites from level n to level $(n-1) = \nu$

$$\nu = \frac{me^2}{(4\pi)^2\varepsilon_0^2(h/2\pi)^2}\left[\frac{1}{(n-1)^2} - \frac{1}{n^2}\right]$$

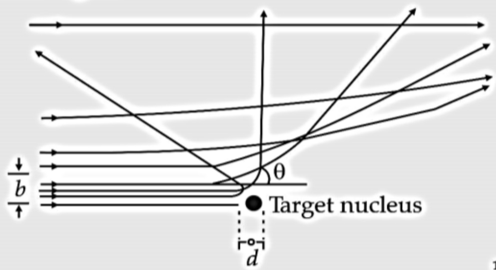


½

The data shows that large number of α-particles do not suffer large scattering but small number suffer greater scattering. It is concluded that ½

(i) most of the space in the atom is empty. ½

(ii) massive positively charged nucleus occupies small region. ½

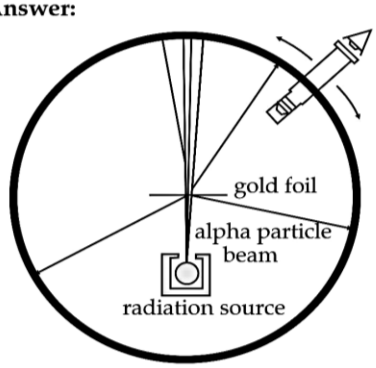


½

From the picture, it is clear that small impact parameter suffers large scattering, thus it shows the upper limit to the size of nucleus. ½

[CBSE Marking Scheme, 2019]

Detailed Answer:



Observation:

- Most of the alpha particles passed through the foil without suffering any collisions.
- Around 0.14% of the incident alpha particles scattered by more than 1°.
- Around 1 in 8000 alpha particles deflected by more than 90°.

Conclusion:

(1) Since most of the Alpha particles passed through the foil without undergoing any deflection, there must be sufficient empty space within the atom.

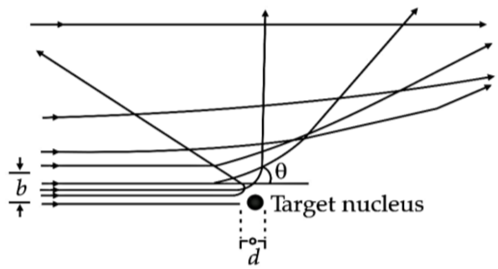
(2) Since few alpha particles were deflected through small angles and alpha particles were positively charged particles, so they could be deflected only by some positive body present within the atom. Those alpha particles deflected which passed very close to this positive body.

(3) Since some alpha particles were deflected back and alpha particles are heavy particles, so they could be deflected back only when they strike some heavier body inside the atom.

(4) Since the number of alpha particles deflected back is very-very small, this shows that the heavy body present in an atom must be occupying a small volume.

The small heavy positively charged body present within the atom was called nucleus.

The trajectory, traced by the a-particles in the Coulomb field of target nucleus, has the form as shown below.



The size of the nucleus was estimated by observing the distance (d) of closest approach, of the α-particles. This distance is given by:

$$d = \frac{1}{4\pi\varepsilon_0}\frac{2eZe}{K}$$

where, K = kinetic energy of the a-particles when they are far away from the target nuclei.

Since, the value of 'd' can easily be calculated or determine when the value of Z is more. Hence, it is more useful for the upper limit on the size of nucleus. 3

Q. 4. (a) How is the stability of hydrogen atom in Bohr model explained by de-Broglie's hypothesis ?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to n = 4 level. When it gets de-excited, find the maximum number of lines which are emitted by the atom. Identify the series to which these lines belong. Which of them has the shortest wavelength ?

U & A [CBSE O.D. SET 2, 2019]

Ans. (a) Explanation 2

(b) Identification of Series ½

(c) Identification of shortest wavelength ½

(a) Explanation: The quantised electron orbits and energy state are due to wave nature of the electron and only resonant standing waves can persist. 2

According to de Broglie Hypothesis,

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

$$= \frac{nh}{mv}$$

$$mvr = \left(\frac{nh}{2\pi}\right)$$

(b) Lyman series: ½

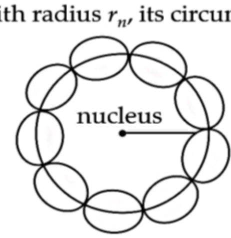
transition from $n = 4$ to $n = 1$ will have shortest wavelength. ½

[CBSE Marking Scheme, 2019]

Detailed Answer:

(a) Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. The second postulates is: Electron revolves around the nucleus only in those orbits for which angular momentum in integral multiple of $\frac{h}{2\pi}$.

de-Broglie had proposed that material particle such as electrons also have a wave nature. He argued that the electron in its circular orbit, as proposed by Bohr, must be seen as a particle wave. Drawing an analogy with waves travelling on the string, particle waves too can lead to formation of standing waves. In a string, standing waves are formed, when the total distance travelled by a wave back and forth is one wavelength, two wavelength or integral multiple of wavelengths. Other waves interfere with themselves after reflection and their amplitude falls to zero. For an electron moving in n^{th} orbit with radius r_n, its circumference is $2\pi r_n$.



$\therefore \quad 2\pi r_n = n\lambda, n = 1, 2, 3$

From de-Broglie's hypothesis,

Wavelength of the election (λ) is given as,

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

For n^{th} orbit, $\lambda = \frac{h}{mv_n}$

$$\therefore \quad 2\pi r_n = \frac{nh}{mv_n} \text{ or } mv_n r_n = \frac{nh}{2\pi}$$

This is the second postulate of Bohr that gives the discrete orbits and energy levels in hydrogen atom. Thus de-Broglie explained the postulate of quantisation angular momentum. **2**

(b) For ground state $n = 1$, For de-excitation from $n = 4$ to $n = 1$, we get spectral lines constituting Lyman series whose wavelength is given by the formula,

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

Here R = Rydberg constant number $n = 2, 3, 4$

$$\therefore \frac{1}{\lambda_2} = R\left(1 - \frac{1}{4}\right) = \frac{3R}{4} \Rightarrow \lambda_2 = \frac{4}{3R}$$

$$\frac{1}{\lambda_3} = R\left(\frac{1}{1^2} - \frac{1}{3^2}\right) = R\left(1 - \frac{1}{9}\right)$$

$$\Rightarrow \quad \lambda_3 = \frac{9}{8R}$$

$$\frac{1}{\lambda_4} = R\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = R\left(1 - \frac{1}{16}\right)$$

$$\Rightarrow \quad \lambda_4 = \frac{16}{15R} \quad \left[\text{Here, } \frac{1}{R} = 912 \text{Å}\right]$$

There would be maximum three lines emitted by the atom.

λ_4 has the shortest wavelength. **1**

Q. 5. (a) State Bohr's postulate to define stable orbits in hydrogen atom. How does de Broglie's hypothesis explain the stability of these orbits?

(b) A hydrogen atom initially in the ground state absorbs a photon which excites it to the $n = 4$ level. Estimate the frequency of the photon.

R & U [CBSE, 2018]

Ans. (a) Statement of Bohr's postulate **1**

Explanation in terms of de Broglie hypothesis **½**

(b) Finding the energy in the $n = 4$ level **1**

Estimating the frequency of the photon **½**

(a) Bohr's postulate, for stable orbits, states

"The electron, in an atom, revolves around the nucleus only in those orbits for which its angular momentum is an integral multiple of $\frac{h}{2\pi}$ (h = Planck's constant)." ½

[Also accept $mvr = n.\frac{h}{2\pi}$ (n =1,2,3,…….)]

As per de Broglie's hypothesis $\lambda = \frac{h}{p} = \frac{h}{mv}$

For a stable orbit, we must have circumference of the orbit = $n\lambda$ (n =1,2,3,…….)

$\therefore \quad 2\pi r = n.mv$

or $\quad mvr = \frac{nh}{2\pi}$ ½

Thus de –Broglie showed that formation of stationary pattern for integral 'n' gives rise to stability of the atom.

This is nothing but the Bohr's postulate. ½

(b) Energy in the $n = 4$ level $= \frac{-E_0}{4^2} = -\frac{E_0}{16}$ ½

$\therefore$ Energy required to take the electron from the ground state, to the $n = 4$ level

$$= \left(-\frac{E_0}{16}\right) - (-E_0)$$

$$= \frac{-1+16}{16}E_0 = \frac{15}{16}E_0$$

$$= \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19} \text{ J} \quad ½$$

Let the frequency of the photon be v, we have

$$h\nu = \frac{15}{16} \times 13.6 \times 1.6 \times 10^{-19}$$

$$\therefore \quad \nu = \frac{15 \times 13.6 \times 1.6 \times 10^{-19}}{16 \times 6.63 \times 10^{-34}} \text{Hz} \quad ½$$

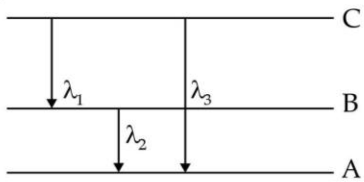
$$\simeq 3.1 \times 10^{15} \text{ Hz}$$

(Also accept 3×10^{15} Hz)

[CBSE Marking Scheme, 2018]

Q. 6. (i) State Bohr's quantization condition for defining stationary orbits. How does de Broglie hypothesis explain the stationary orbits?

(ii) Find the relation between the three wavelengths λ_1, λ_2 and λ_3 from the energy level diagram shown below.



Ans. (i) Statement of Bohr's quantization condition ½
de- Broglie explanation of stationary orbits 1

(ii) Relation between $\lambda_1, \lambda_2\, \lambda_3$ 1½

(i) Only those orbits are stable for which the angular momentum, of revolving electron, is an integral multiple of $\frac{h}{2\pi}$.

Alternatively

$L = \frac{nh}{2\pi}$ *i.e.* angular momentum of orbiting electron is quantized.] ½

According to de-Broglie hypothesis

Linear momentum $(p) = \frac{h}{\lambda}$

And for circular orbit, $L = r_n p$ where 'r_n' is the radius of quantized orbits.

$$= \frac{rh}{\lambda}$$

Also $$L = \frac{nh}{2\pi}$$

$$\therefore \quad \frac{rh}{\lambda} = \frac{nh}{2\pi}$$

$$\Rightarrow \quad 2\pi r_n = n\lambda$$

$\therefore$ Circumference of permitted orbits are integral multiples of the wave-length λ. ½

(ii) $$E_C - E_B = \frac{hc}{\lambda_1} \quad \text{...(i) ½}$$

$$E_B - E_A = \frac{hc}{\lambda_2} \quad \text{...(ii) ½}$$

$$E_C - E_A = \frac{hc}{\lambda_3} \quad \text{...(iii) ½}$$

Adding (i) & (ii)

$$E_C - E_A = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} \quad \text{...(iv)}$$

Using equation (iii) and (iv)

$$\frac{hc}{\lambda_3} = \frac{hc}{\lambda_1} + \frac{hc}{\lambda_2}$$

$$\Rightarrow \quad \frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} \quad ½$$

[CBSE Marking Scheme, 2016]

Q. 7. Find the ratio between the wavelengths of the 'most energetic' spectral lines in the Balmer and Paschen series of the hydrogen spectrum.

A [Delhi Comptt., 2016]

Ans. Spectral lines in Balmer series,

$$\frac{1}{\lambda_B} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad ½$$

For 'most energetic' wavelength; λ_B should be minimum. Hence $\frac{1}{\lambda_B}$ should be maximum. For this

case $n = \infty$.

$$\frac{1}{\lambda_B} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$$\frac{1}{\lambda_B} = \frac{R}{2^2} \Rightarrow \lambda_B = \frac{4}{R} \quad ½$$

Spectral lines in Paschen series

$$\frac{1}{\lambda_P} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \quad ½$$

Similarly we can prove that for 'most energetic' wavelength ; λ_P

$$n = \infty$$

$$\frac{1}{\lambda_P} = R\left(\frac{1}{3^2} - \frac{1}{\infty}\right)$$

Hence, $$\frac{1}{\lambda_P} = \frac{R}{3^2} \Rightarrow \lambda_P = \frac{9}{R} \quad ½$$

Hence the ratio

$$\lambda_B : \lambda_P = 4 : 9 \quad 1$$

Commonly Made Error

- Many students couldn't understand or relate the fact that for 'most energetic' spectral lines, they had to put $n = \infty$ in different series.

Answering Tip

- The formula for the number of spectral lines should be understood carefully.

Q. 8. Using Bohr's postulates, derive the expression for the orbital period of the electron moving in the nth orbit of hydrogen atom.
R [Foreign, I, II, III, 2017]

Ans. $mvr = \dfrac{nh}{2\pi}$ ....Bohr postulate ½

Also, $\dfrac{mv^2}{r} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{r^2}$ ½

$\Rightarrow mv^2 r = \dfrac{e^2}{4\pi\varepsilon_0}$ ½

$\Rightarrow v = \dfrac{e^2}{4\pi\varepsilon_0}\times\dfrac{2\pi}{nh} = \dfrac{e^2}{2\varepsilon_0 nh}$ ½

$T = \dfrac{2\pi r}{v} = \dfrac{2\pi mvr}{mv^2}$ ½

$= \dfrac{2\pi\left(\dfrac{nh}{2\pi}\right)}{m\left(\dfrac{e^2}{2\varepsilon_0 nh}\right)^2}$

$= \dfrac{4n^3h^3\varepsilon_0^2}{me^4}$ ½

(Also accept if the student calculates T by obtaining expressions for both v and r.)

[CBSE Marking Scheme, 2017]

Long Answer Type Questions (5 marks each)

Q. 1. (a) State the postulates of Bohr's model of hydrogen atom and derive the expression for Bohr radius.
(b) Find the ratio of the longest and the shortest wavelengths amongst the spectral lines of Balmer series in the spectrum of hydrogen atom.
R [CBSE OD SET 1, 2020]

Ans. (a) Postulates of Bohr Model of Hydrogen atom:

Postulate – I: The electrons revolve in a circular orbit around the nucleus. The electrostatic force of attraction between the positively charged nucleus and negatively charged electrons provide necessary centripetal force for circular motion. ½

Postulate – II: The electrons can revolve only in certain selected orbits in which angular momentum of electrons is equal to the integral multiple $\dfrac{h}{2\pi}$, where h is Planck's constant. These orbits are known as stationary or permissible orbits. The electrons do not radiate energy while revolving in theses orbits. ½

Postulate – III: When an electrons jumps from higher energy orbit to lower energy orbit, energy is radiated in the form of a quantum or photon of energy hv, which is equal to the difference of the energies of the electron in the two orbits. ½

Expression for Bohr radius:

Let us consider

m = Mass of an electron

r = Radius of the circular orbit in which the electron is revolving

v = Speed of electron

$-e$ = Charge of electron ½

From 1st postulate

Centripetal force = Electrostatic force

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$\therefore \quad v^2 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{mr}$ .... (i)

From 2nd postulate

$$mvr = \frac{nh}{2\pi}$$

or, $v = \dfrac{nh}{2\pi mr}$

or, $v^2 = \dfrac{n^2h^2}{4\pi^2m^2r^2}$ .... (ii) ½

Comparing eqns (i) and (ii),

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{mr} = \frac{n^2h^2}{4\pi^2m^2r^2}$$

or, $\dfrac{1}{4\pi\varepsilon_0}\dfrac{e^2}{mr} = \dfrac{n^2h^2}{4\pi^2m^2r^2}$

$\therefore$ Bohr radius, $r = \dfrac{\varepsilon_0 n^2h^2}{\pi me^2}$ ½

(b) Shortest wavelength in Balmer series:

$$\frac{1}{\lambda_S} = R\left(\frac{1}{2^2} - \frac{1}{\infty}\right)$$

$\therefore \quad \lambda_S = \dfrac{4}{R}$ **1**

Longest wavelength in Balmer series:

$\therefore \quad \dfrac{1}{\lambda_L} = R\left(\dfrac{1}{2^2} - \dfrac{1}{3^2}\right)$

$\therefore \quad \lambda_L = \dfrac{36}{5R}$

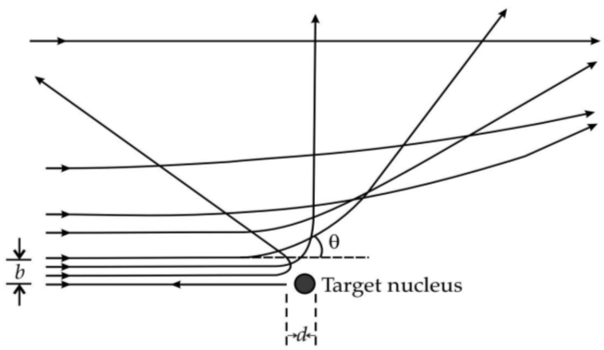
So, $\dfrac{\lambda_L}{\lambda_S} = \dfrac{\frac{36}{5R}}{\frac{4}{R}} = \dfrac{9}{5}$ **1**

Q. 2. (i) In Rutherford scattering experiment, draw the trajectory traced by α-particles in the coulomb field of target nucleus and explain how this led to estimate the size of the nucleus.

(ii) Describe briefly how wave nature of moving electrons was established experimentally.

(iii) Estimate the ratio of de-Broglie wavelengths associated with deuterons and α-particles when they are accelerated from rest through the same accelerating potential *V*. U **[OD I, II, III, 2015]**

Ans. (i) The trajectory, traced by the α-particles in the Coulomb field of target nucleus, has the form as shown below:



1

The size of the nucleus was estimated by observing the distance (d) of closest approach, of the α-particles. This distance is given by:

$$d = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2eZe}{K}$$

where, K = kinetic energy of the α-particles when they are far away from the target nuclei. 1

(ii) The wave nature of moving electrons was established through the Davisson-Germer experiment. ½

In this experiment, it was observed that a beam of electrons, when scattered by a nickel target, showed 'maxima' in certain directions; (like the 'maxima' observed in interference/diffraction experiments with light.) ½

(iii)

$$\lambda = \frac{h}{p} \quad ½$$

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

$$\lambda = \frac{h}{\sqrt{2mqV}} \quad ½$$

Hence, $$\frac{\lambda_d}{\lambda_\alpha} = \sqrt{\frac{m_a q_\alpha}{m_d q_d}}$$

(accelerated potential is same for both particles)

$$\frac{\lambda_d}{\lambda_\alpha} = \sqrt{\frac{4\times 2}{2\times 1}} = 2 \quad 1$$

Q. 3. (i) Using Bohr's postulates, derive the expression for the total energy of the electron in the stationary states of the hydrogen atom.

(ii) Using Rydberg formula, calculate the wavelengths of the spectral lines of the first member of the Lyman series and of the Balmer series. [Foreign 2014]

Ans. (i)

$$mvr = \frac{nh}{2\pi} \quad ½$$

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$r = \frac{e^2}{4\pi\varepsilon_0 mv^2}$$

$$r = \frac{e^2}{4\pi\varepsilon_0 m\left(\frac{nh}{2\pi mr}\right)^2} \quad ½$$

$$\Rightarrow \quad r = \frac{\varepsilon_0 n^2h^2}{\pi me^2} \quad ½$$

Potential energy, $U = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{r}$

$$= -\frac{me^4}{4\varepsilon_0^2 n^2h^2} \quad ½$$

$$\text{K.E.} = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{nh}{2\pi mr}\right)^2 \quad ½$$

$$= \frac{n^2h^2\pi^2m^2e^4}{8\pi^2 m\varepsilon_0^2 n^4h^4} \quad ½$$

$$\text{K.E.} = \frac{me^4}{8\varepsilon_0^2 n^2h^2} \quad ½$$

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

$$= -\frac{me^4}{8\varepsilon_0^2 n^2h^2} \quad ½$$

(ii) **Rydberg's formula:** For first member of Lyman series,

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

$$\lambda = \frac{4}{3R} = \frac{4}{3}\times 912\,\text{Å} \quad ½$$

$$= 1216\,\text{Å}$$

For first member of Balmer Series.

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

$$\lambda = \frac{36}{5R}$$

$$= \frac{36}{5}\times 912\,\text{Å}$$

$$= 6566.4\,\text{Å} \quad ½$$

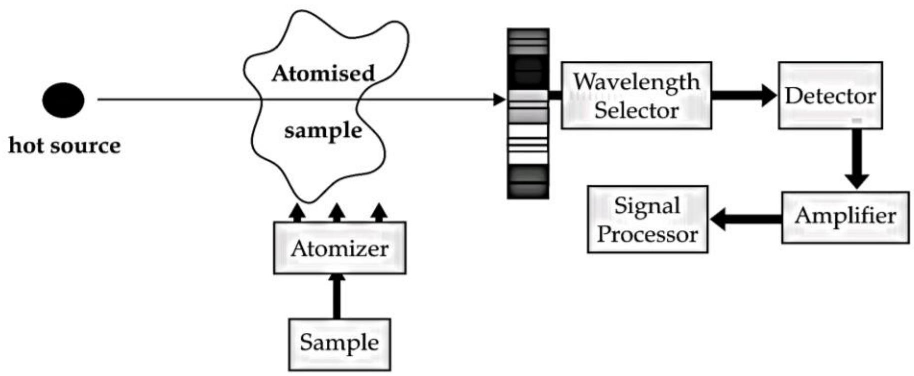
[CBSE Marking Scheme, 2014]

Visual Case-based Questions (1×4=4 marks)

Attempt any 4 sub parts from each question. Each question carries 1 mark.

Q. 1. ATOMIC ABSORPTION SPECTROMETER: The atomic absorption (AA) spectrometer is used to analyze metals at very low concentrations, typically in the parts per million (ppm) or parts per billion (ppb) ranges. A liquid sample containing dissolved material whose concentration is to be measured is aspirated into a thin, wide AA flame, or is introduced into a small carbon furnace which is heated to a high temperature.

Absorption spectrum



Basic Principle of AAS is the measurement of absorption of radiation by free atoms. The total amount of absorption depends on the number of free atoms present and the degree to which the free atoms absorb the radiation. At the high temperature of the AA flame, the sample is broken down into atoms using an atomizer and it is the concentration of these atoms that is measured.

Sample in the form of solution is used. It is broken up into a fine mist with the help of an atomizer.

When the mist reaches the flame, the intense heat breaks up the sample into its individual atoms.

When a photon coming out from the hot source hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, then the electron in the lower energy level absorb the photon and jumps up to the higher energy level. If the photon energy does not correspond to the difference between two energy levels then the photon will not be absorbed (it may be scattered away).

Hence in the spectrum, the wavelength corresponding to the absorbed photons is observed as black lines as shown in the following spectrum of Hydrogen. The dark lines correspond to the frequencies of light those have been absorbed by the sample element.

Using this process, a source of photons (generally a white light) of various energies is used to obtain the absorption spectra of different materials and to identify them.

(i) What is the basic principle of Atomic Absorption Spectrophotometer?

(a) Emission of photons when excited electron of an atom comes back to lower energy level.

(b) Absorption of photons when electrons at lower energy level jumps to a higher energy level.

(c) Emission of electrons from an atom at a very high temperature

(d) Emission of electron when energetic photons bombard an atom

Ans. (b) **1**

Explanation: Basic Principle of AAS is the measurement of absorption of radiation by free atoms. When a photon hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, the electron in the lower energy level absorb the photon and jumps up to the higher energy level.

(ii) What happens when a photon hits an atom and the energy of the photon is not equal to the gap between two electron energy levels of the atom?

(a) The photon is absorbed and the electron moves to an intermediate energy level.

(b) The photon is absorbed and the electron gets scattered

(c) The photon is not absorbed. It gets scattered.

(d) None of the above

Ans. (c) **1**

Explanation: When a photon hits an atom and the energy of the photon is equal to the gap between two electron energy levels of the atom, the electron in the lower energy level absorb the photon and jumps up to the higher energy level. If the photon energy does not correspond to the difference between two energy levels then the photon will not be absorbed (it may be scattered away).

(iii) How the corresponding wavelength of the absorbed photon is represented in the absorption spectrum?

(a) By a black line

(b) By a white line

(c) By a black line in the lower wavelength range and by a white line in the higher wavelength range

(d) By a white line in the lower wavelength range and by a black line in the higher wavelength range

Ans. (a) **1**

Explanation: In the spectrum the wavelength corresponding to the absorbed photons is observed as black lines.

(iv) What should be the concentration of metal for analysis using Atomic Absorption Spectrometer?

(a) Very High concentration

(b) Very Low concentration

(c) Medium concentration

(d) Any concentration

Ans. (b) **1**

Explanation: The atomic absorption (AA) spectrometer is used to analyze metals at very low concentrations, typically in the parts per million (ppm) or parts per billion (ppb) ranges.

(v) How the sample for analysis is driven to atomic state in AAS?

(a) At a very high temperature, the sample is driven to its gaseous state

(b) using an atomizer and then intense heating.

(c) By rotating the solution of the sample at a very high speed.

(d) None of the above

Ans. (b) **1**

Explanation: Sample in the form of solution is used. It is broken up into a fine mist with the help of an atomizer. When the mist reaches the flame, the intense heat breaks up the sample into its individual atoms.

Q. 2. SPECTRUM ANALYSIS AND ASTRONOMY: Each element in the periodic table can appear in gaseous form and produce its own spectrum unique to that element. Hydrogen will not look like Helium, which will not look like carbon which will not look like iron... and soon.

Astrophysicists can identify what kinds of materials are present in stars from the analysis of star's spectra. This type of study is called astronomical spectroscopy.

The science of spectroscopy is quite sophisticated. From spectrum lines analysis astrophysicists can determine not only the element, but the temperature and density of that element in the star. The spectral line also can tell us about any magnetic field of the star.

The width of the line can tell us how fast the material is moving. We can learn about winds in stars from this. The shifting of spectral lines shift back and forth indicates that the star may be orbiting another star.

The following table shows a rough guide for the relationship between the temperature of a star and the electromagnetic spectrum.

Temperature (Kelvin)	Predominant Radiation	Astronomical Examples
600 K	Infrared	Planets, warm dust
6,000 K	Optical	The photosphere of Sun and other stars
60,000 K	UV	The photosphere of very hot stars
600,000 K	Soft X-rays	The corona of the Sun
6,000,000 K	X-rays	The coronae of active stars

If the spectrum of a star is red or blue shifted, then it can be used to infer its velocity along the line of sight. Edwin Hubble observed that more distant galaxies tended to have more red shifted spectra. This establishes the theory of expansion of the universe.

(i) What is astronomical spectroscopy?

(a) Study of spectrum of star light and to identify its distance from earth.

(b) Study spectrum of star light and to identify what kinds of elements are present in stars.

(c) Both (a) and (b)

(d) None of the above

Ans. (b) **1**

Explanation: Astrophysicists can identify what kinds of materials are present in stars from the analysis of star's spectra. This type of study is called astronomical spectroscopy.

(ii) From the spectrum analysis the following information of a star can be obtained.

(a) Elements present, temperature

(b) magnetic field, density, mass

(c) distance of the star

(d) Both (a) and (b)

Ans. (d) **1**

Explanation: From spectrum lines analysis astrophysicists can determine not only the element, but the temperature and density of that element in the star. The spectral line also can tell us about any magnetic field of the star.

(iii) The lines in a star's spectrum is found to shift back and forth. What conclusion may be drawn from this observation?

(a) the star may be orbiting another star

(b) There may be a storm in the star

(c) The star may be rotating at a very high speed

(d) None of the above

Ans. (a) **1**

Explanation: The shifting of spectral lines shift back and forth indicates that the star may be orbiting another star.

(iv) What may be the approximate temperature if soft X-rays are found predominantly in the spectrum?

(a) 60000 C **(b)** 600000 C

(c) 60000K **(d)** 600000 K

Ans. (d) **1**

Explanation: From the table we find that predominant presence of soft X-rays in the spectrum indicated that the temperature is 600000K.

(v) Which nature of spectrum establishes the theory of the expanding universe?

(a) Red-shift of spectrum

(b) Blue-shift of spectrum

(c) Back and forth movement of spectral lines

(d) None of the above

Ans. (a) **1**

Explanation: If the spectrum of a star is red or blue shifted, then it can be used to infer its velocity along the line of sight. Edwin Hubble observed that more distant galaxies tended to have more red-shifted spectra. This establishes the theory of expansion of the universe.

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