Tutorial

1. What inference can be drawn about the structure of an atom from Rutherford's experiment on scattering of α particles by a gold foil? List the processes/phenomena that could not be explained by classical physics.

2. In photoelectric effect phenomenon, how do the following parameters vary with increasing frequency of incident radiation: (a) Photocurrent and (b) Kinetic energy of photoelectrons.

3. What are the postulates of Bohr's theory for the structure of hydrogen atom? Which of them are consistent with the uncertainty principle? Rationalise.

4. Derive an expression for - (a) the radius of first Bohr orbit (b) energy of an electron in the first Bohr orbit. Calculate their respective values from known constants.

5. a) What total amount of energy (in Joules) would be required to shift all the electrons from the first Bohr orbit to the sixth orbit in one mole of hydrogen atoms? b) Through what distance would each electron have to move? c) If the electrons returned to their initial state, what would be the wavelength of emitted light?

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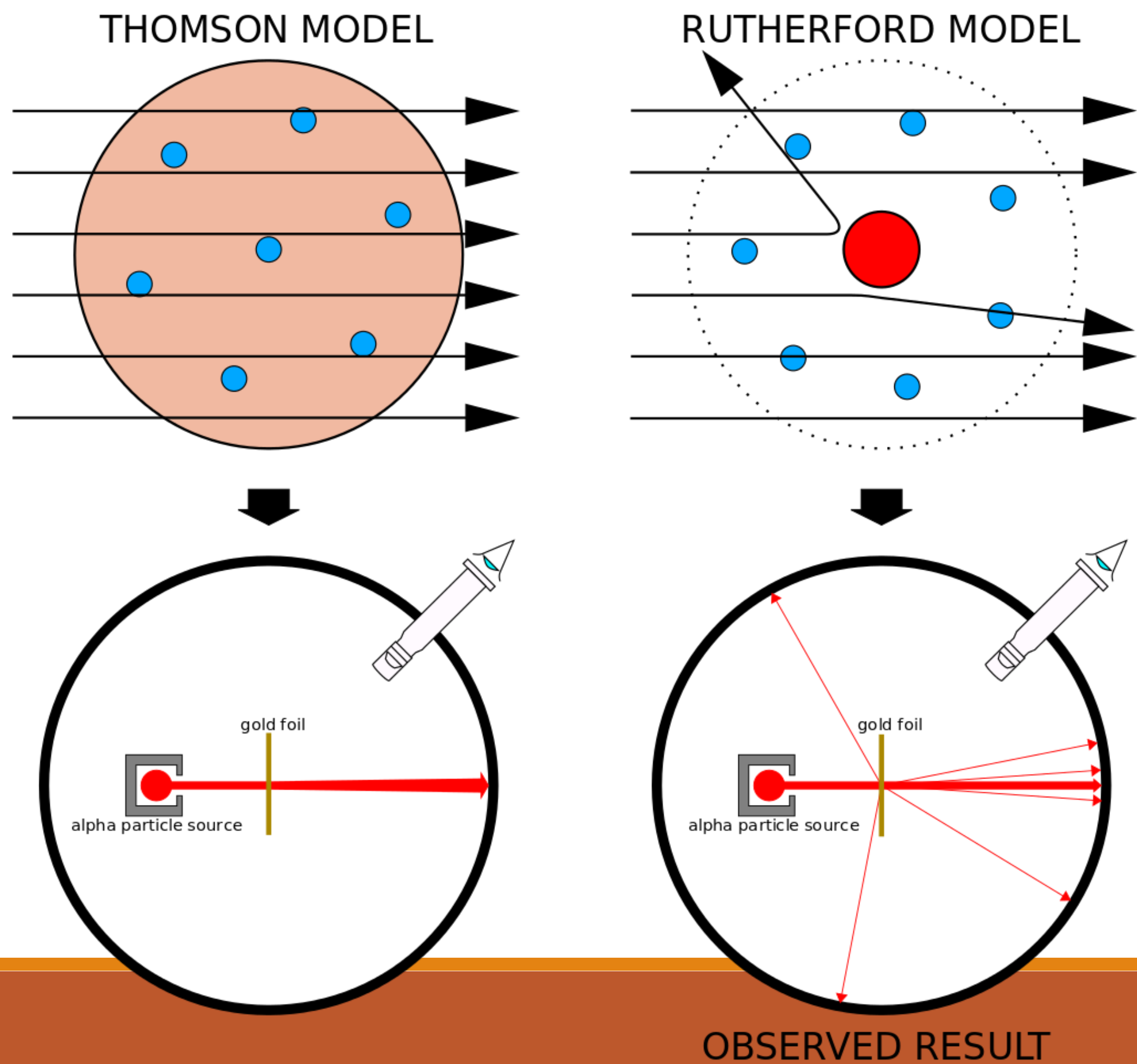

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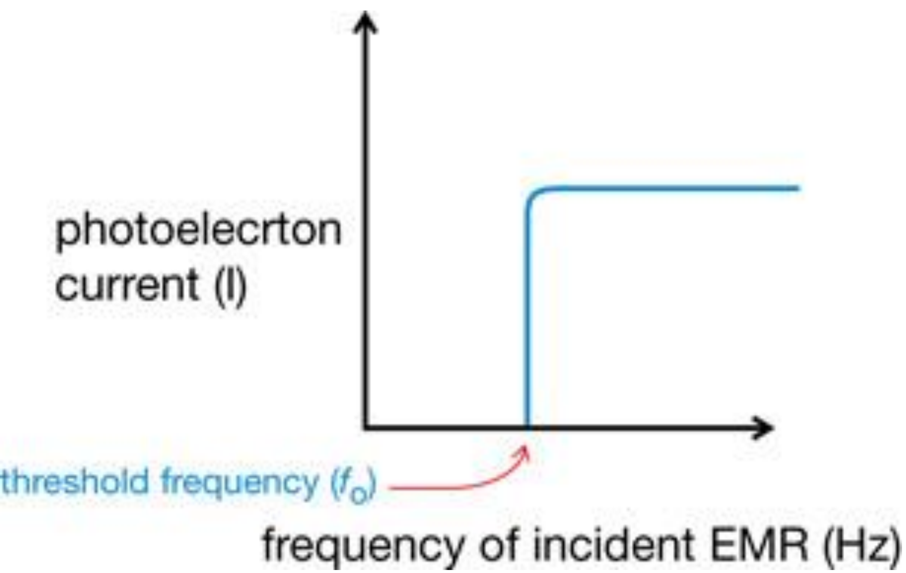

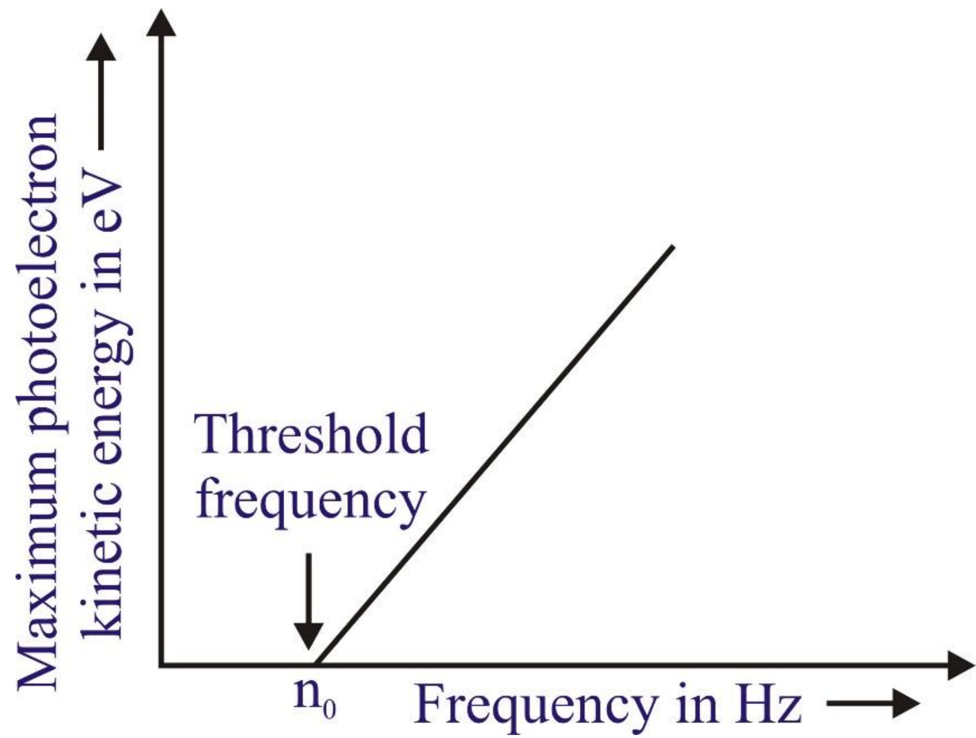

3. What are the postulates of Bohr's theory for the structure of hydrogen atom? Which of them are consistent with the uncertainty principle? Rationalise.

Limitations of Bohr's theory:

(i) It does not explain the spectra of atoms having more than one electron.

(ii) Bohr's atomic model failed to account for the effect of magnetic field (Zeeman effect) or electric field (Stark effect) on the spectra of atoms or ions.

It was observed that when the source of a spectrum is placed in a strong magnetic or electric field, each spectral line further splits into a number of lines. This observation could not be explained on the basis of Bohr's model.

(iii) De Broglie suggested that electrons like light have dual character. It has particle and wave character. Bohr treated the electron only as particle.

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(iv) Another objection to Bohr's theory came from Heisenberg's Uncertainty Principle.

According to this principle "It is impossible to determine simultaneously the exact position and momentum of a small moving particle like an electron".
The postulate of Bohr, that electrons revolve in well-defined orbits around the nucleus with well-defined velocities is thus not tenable.

4. Derive an expression for - (a) the radius of first Bohr orbit (b) energy of an electron in the first Bohr orbit. Calculate their respective values from known constants.

For an hydrogen atom

- Combining $\lambda = \frac{h}{mv}$ and 2πr=nλ → $\boldsymbol{m_e vr = \frac{nh}{2\pi}}$

Angular momentum is quantized and integral multiples of $\frac{h}{2\pi}$ *or* ħ

- Centrifugal force ($\frac{m_e v^2}{r}$) is equal to coulombic force

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

- Put $v = \frac{nh}{2\pi m_e r}$ in $\frac{e^2}{4\pi\varepsilon_0 r^2} = \frac{m_e v^2}{r}$ to obtain $\boldsymbol{r = \frac{4\pi\varepsilon_0 \hbar^2 n^2}{m_e e^2}}$
- Calculate the smallest radius (when n=1) is $r=a_0=52.92$ pm

4. Derive an expression for - (a) the radius of first Bohr orbit (b) energy of an electron in the first Bohr orbit. Calculate their respective values from known constants.

For an hydrogen atom

- Potential energy from Coulomb's law $\mathbf{V(r)} = -\frac{e^2}{4\pi\varepsilon_0 r}$. The "–" sign indicate attractive interaction.
- Total energy $\mathbf{E=KE+PE}=\frac{1}{2}m_e v^2 - \frac{e^2}{4\pi\varepsilon_0 r}$
- $(m_e v^2$ from $\frac{e^2}{4\pi\varepsilon_0 r^2}=\frac{m_e v^2}{r})$; $\mathbf{E}=\frac{1}{2}\left(\frac{e^2}{4\pi\varepsilon_0 r}\right) - \frac{e^2}{4\pi\varepsilon_0 r} = -\frac{e^2}{8\pi\varepsilon_0 r}$
- Use $r=\frac{4\pi\varepsilon_0 \hbar^2 n^2}{m_e e^2}$; $E_n = -\frac{e^2}{8\pi\varepsilon_0 r} = \frac{m_e e^4}{8\varepsilon_0^2 h^2 n^2}$; n=1, 2, 3,…….

5. a) What total amount of energy (in Joules) would be required to shift all the electrons from the first Bohr orbit to the sixth orbit in one mole of hydrogen atoms? b) Through what distance would each electron have to move? c) If the electrons returned to their initial state, what would be the wavelength of emitted light?

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Tutorial

6. An alpha (α) particle and a free electron, each initially at rest, combine to form He^{+} ion in its ground state, with the emission of a photon. Estimate the energy of this photon.

For an He^{+}atom

- Potential energy from Coulomb's law **V(r)=** $-\frac{2e^2}{4\pi\varepsilon_0 r}$. The "–" sign indicate attractive interaction.
- Total energy **E=KE +PE=**$\frac{1}{2}m_e v^2 - \frac{2e^2}{4\pi\varepsilon_0 r}$
- ($m_e v^2$ from $\frac{2e^2}{4\pi\varepsilon_0 r^2}=\frac{m_e v^2}{r}$); **E=**$\frac{1}{2}\left(\frac{2e^2}{4\pi\varepsilon_0 r}\right) - \frac{2e^2}{4\pi\varepsilon_0 r} = -\frac{2e^2}{8\pi\varepsilon_0 r}$
- Use $r=\frac{4\pi\varepsilon_0 \hbar^2 n^2}{2m_e e^2}$; $E_n=-\frac{2e^2}{8\pi\varepsilon_0 r}=\frac{2m_e e^4}{8\varepsilon_0^2 h^2 n^2}$; n=1, 2, 3,…….

Tutorial

6. An alpha (α) particle and a free electron, each initially at rest, combine to form He^{+} ion in its ground state, with the emission of a photon. Estimate the energy of this photon.

- $\frac{1}{\lambda} = \frac{2m_e e^4}{8\varepsilon_0^2 ch^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$= $2R_\infty(\frac{1}{n_1^2} - \frac{1}{n_2^2})$ in cm^{-1}
- $n_2=\infty$, $n_1=1$. $\frac{1}{\lambda} = 2R_\infty$ cm^{-1}

Tutorial

7. At 115° K, atoms of vapourised sodium (at wt 23) have a rms velocity of about 700 ms^{-1}. What is the de Broglie wavelength of sodium atoms at this velocity?

8.a) With what speed must an electron travel in order to have a de Broglie wavelength of 0.1 nm? b) Through what potential difference must the electron be accelerated to give it this velocity?

9. What is the de Broglie wavelength for (a) rifle bullet of mass 1.0 g and velocity 300 ms^{-1}, (b) 70 kg person running at a speed of 10 ms^{-1}.

7, 8(a), 9

De Broglie wavelength **$\lambda = h/p$;**

p= **mv**= momentum

λ=wavelength

8(b) $mv^2/2 = e\Delta V$

Tutorial

10. A small communication satellite weighs 1470 g and is traveling at a velocity of 7500 cm/s. If the uncertainty in its velocity (Δv) is 10 cm/s. what uncertainty will be associated in locating the satellite?

11. a) If the position of speck of dust mass 1 micro gram is known within 10^{-3} mm, what is the indeterminacy in its momentum and velocity?
(b) If an electron in a hydrogen atom is confined to a region of size 53 picometer (pm) from the nucleus, what is the indeterminacy in its momentum and velocity?

De Broglie wavelength

$\lambda = h/p$;

Uncertainty Principle

Position and Momentum: $\Delta x * \Delta p \geq \hbar/2$.

Time and Energy: $\Delta t * \Delta E \geq \hbar/2$

Tutorial

12) Analogous to The Schrödinger equation H ψ = E ψ (which is a basis for molecular structure and spectroscopy), other operator equations are written as Operator * function = number * function. The number is called an eigenvalue and the function, the eigenfunction. Suggest eigenfunctions and eigenvalues for operators d/dx, d^2/dx^2, $\partial^2/\partial y^2 + \partial^2/\partial z^2 + \partial^2/\partial x^2$, $(h / 2 \pi i) \partial / \partial\varphi$, $\int dx$. All molecular energy levels are the solutions of appropriate Schrödinger or other operator equations.