Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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Chapter 12: Atoms

Chapter 12: Atoms

Introduction

Atoms are made up of the same amount of negative and positive charges. In Thomson's model, atoms were described as a spherical cloud of positive charges with embedded electrons. In Rutherford's model, one tiny nucleus bears most of the mass of the atom along with its positive charges and the electrons revolve around it.

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Introduction

Dalton’s Atomic Theory:

All elements are consisting of very small invisible particles, called atoms. Atoms of same element are exactly same, and atoms of different element are different.

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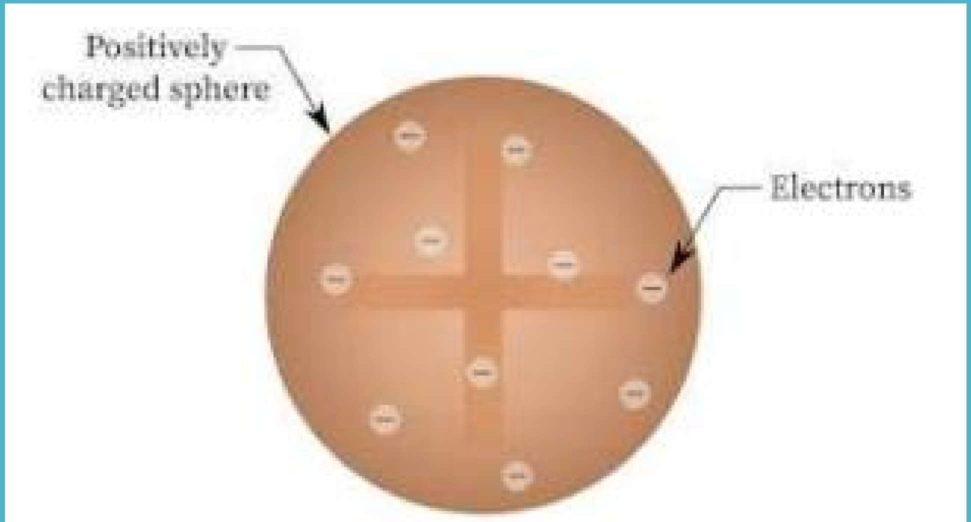
Thomson’s Atomic Model:

Every atom is uniformly positive charged sphere of radius of the order of 10-10 m, in which entire mass is uniformly distributed and negative charged electrons are embedded randomly.



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Thomson's Atomic Model:

Limitations of Thomson's Atomic Model:

- It could not explain the origin of spectral series of hydrogen and other atoms.
- It could not explain large angle scattering of α – particles.

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Alpha-Particle Scattering:

In 1911, Rutherford, along with his assistants, H. Geiger and E. Marsden, performed the Alpha Particle scattering experiment, which led to the birth of the ‘nuclear model of an atom’.

They took a thin gold foil having a thickness of 2.1×10-7 m and placed it in the center of a rotatable detector made of zinc sulfide and a microscope. Then, they directed a beam of 5.5MeV alpha particles emitted from a radioactive source at the foil. Lead bricks collimated these alpha particles as they passed through them.

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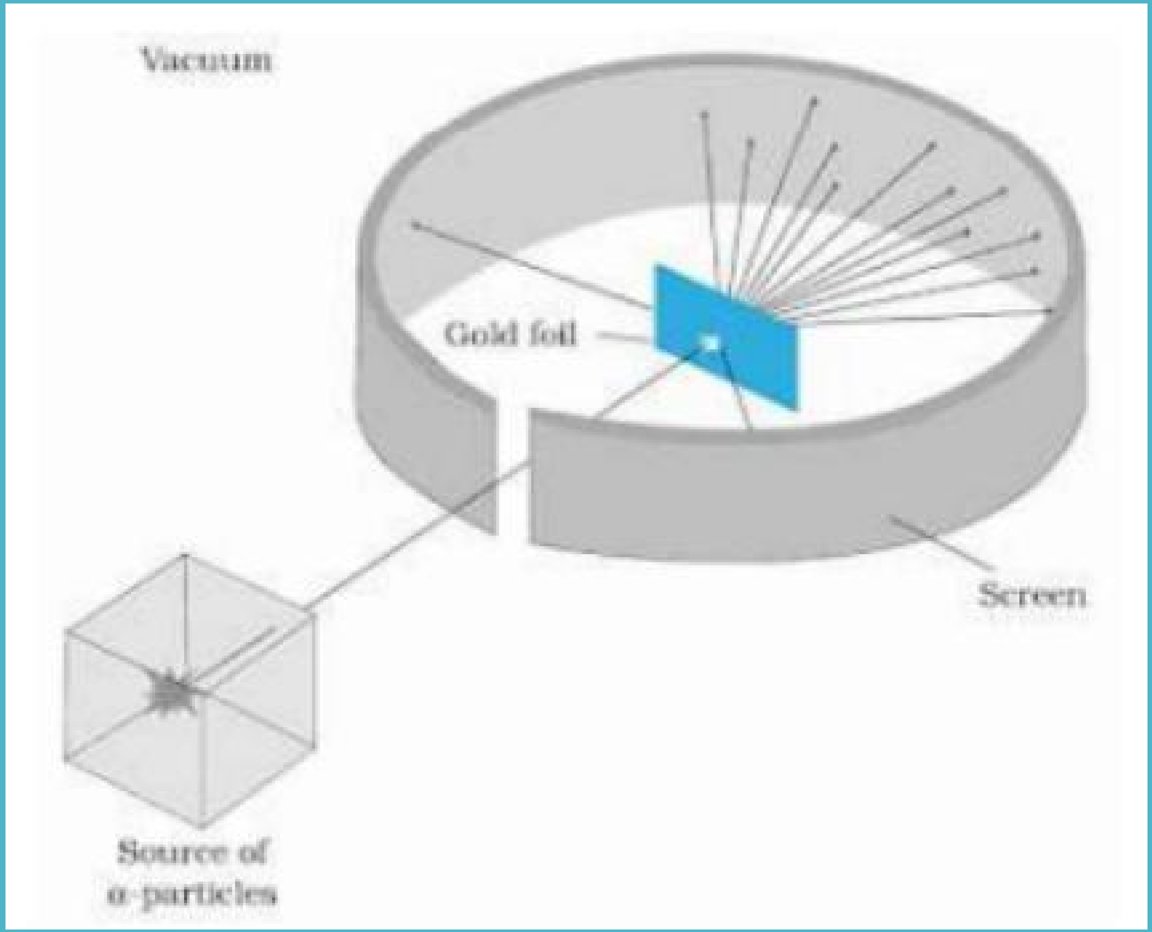
Alpha-Particle Scattering:



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Alpha-Particle Scattering:

After hitting the foil, the scattering of these alpha particles could be studied by the brief flashes on the screen. Rutherford and his team expected to learn more about the structure of the atom from the results of this experiment.

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Alpha-Particle Scattering:

Observations:

Here is what they found:

- 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 10.
- Around 1 in 8000 alpha particles deflected by more than 90o.

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Rutherford’s Nuclear Model:

In 1912, Rutherford proposed his nuclear model of the atom. It is also known as Rutherford's

planetary model of atom.

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Salient features of Rutherford's atom model are as follows:

- Every atom consists of a tiny central core, named nucleus, in which the entire positive charge and almost whole mass of the atom are concentrated. The size of nucleus is typically 10-4 times the size of an atom.
- Most of an atom is empty space.

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Salient features of Rutherford's atom model are as follows:

- In free space around the nucleus, electrons would be moving in orbits just as the planets do around the sun. The centripetal force needed for orbital motion of electrons is provided by electrostatic attractive forced experience by electron due to positively charged nucleus.

- An atom as a whole is electrically neutral. Thus, total positive charge of nucleus is exactly equal to total negative charge of all the electrons orbiting in an atom.

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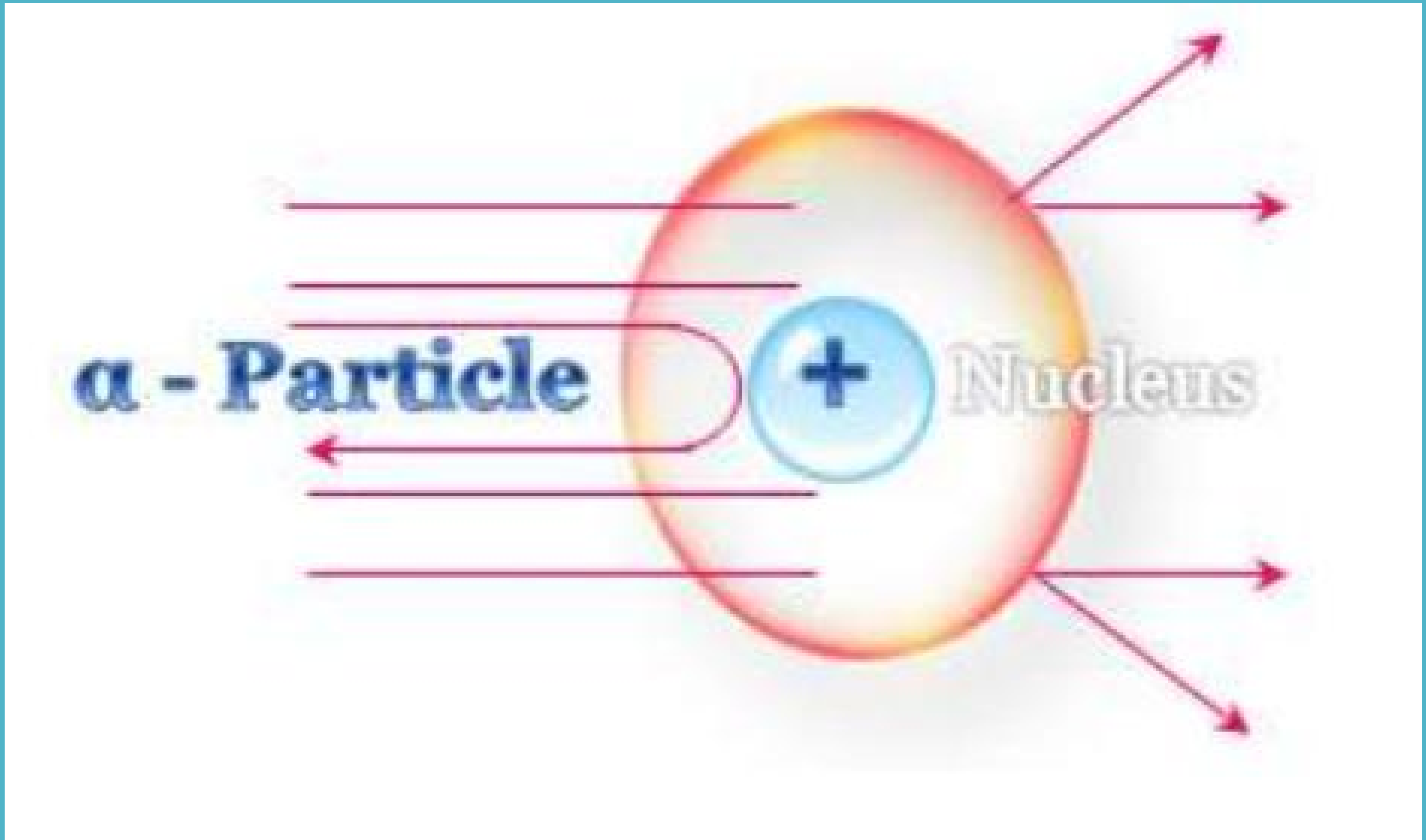
Salient features of Rutherford's atom model are as follows:



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Impact Parameter:

The perpendicular distance of the velocity vector of α-particle from the central line of the nucleus, when the particle is far away from the nucleus is called impact parameter.

Impact parameter $b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot(\frac{\theta}{2})}{E_k}$

where, Z = atomic number of the nucleus, Ek = kinetic energy of the c-particle and θ = angle of scattering.

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Bohr Model of the Hydrogen Atom:

It was Niels Bohr (1885-1962) who used the concept of quantized energy, and explained the model of a hydrogen atom in 1913. Bohr combined classical and early quantum concepts and proposed a theory in the form of three postulates.

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Bohr Model of the Hydrogen Atom:

These postulates are:

- Postulate I: An electron in an atom could revolve in certain stable orbits without emitting radiant energy. Each atom has certain definite stable orbits. Electrons can exist in these orbits. Each possible orbit has definite total energy. These stable orbits are called the stationary states of the atom.

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Bohr Model of the Hydrogen Atom:

- **Postulate II: An electron can revolve around the nucleus in an atom only in those stable orbits whose angular momentum is the integral multiple of $\frac{h}{2\pi}$**

  (where h is Planck's constant). Therefore, angular momentum (L) of the orbiting electron is quantised.

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Bohr Model of the Hydrogen Atom:

- Postulate III: An electron can make a transition from its stable orbit to another lower stable orbit. While doing so, a photon is emitted whose energy is equal to the energy difference between the initial and final states. Therefore, the energy of photon is given by, $h\upsilon = E_i - E_f$

where Ei and Ef are the energies of the initial and final states.

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Bohr Model of the Hydrogen Atom:

Failure of Bohr’s Model:

- This model is applicable only to hydrogen-like atoms and fails in case of higher atoms.
- It could not explain the fine structure of the spectral lines in the spectrum of hydrogen atom.

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Bohr Model of the Hydrogen Atom:

Ground State and Excited States:

The lowest energy level of an atom is called the "ground state" and higher levels are called "excited states". The H-atom has lowest energy in the state for the principal quantum number n = 1. and all other states (i.e, for n = 2, 3, 4…) are excited states. Thus E2, E3, E4 …are called the first, the second, the third …excited states respectively.

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Hydrogen Spectrum Series:

Each element emits a spectrum of radiation, which is characteristic of the element itself. The spectrum consists of a set of isolated parallel lines and is called the line spectrum.

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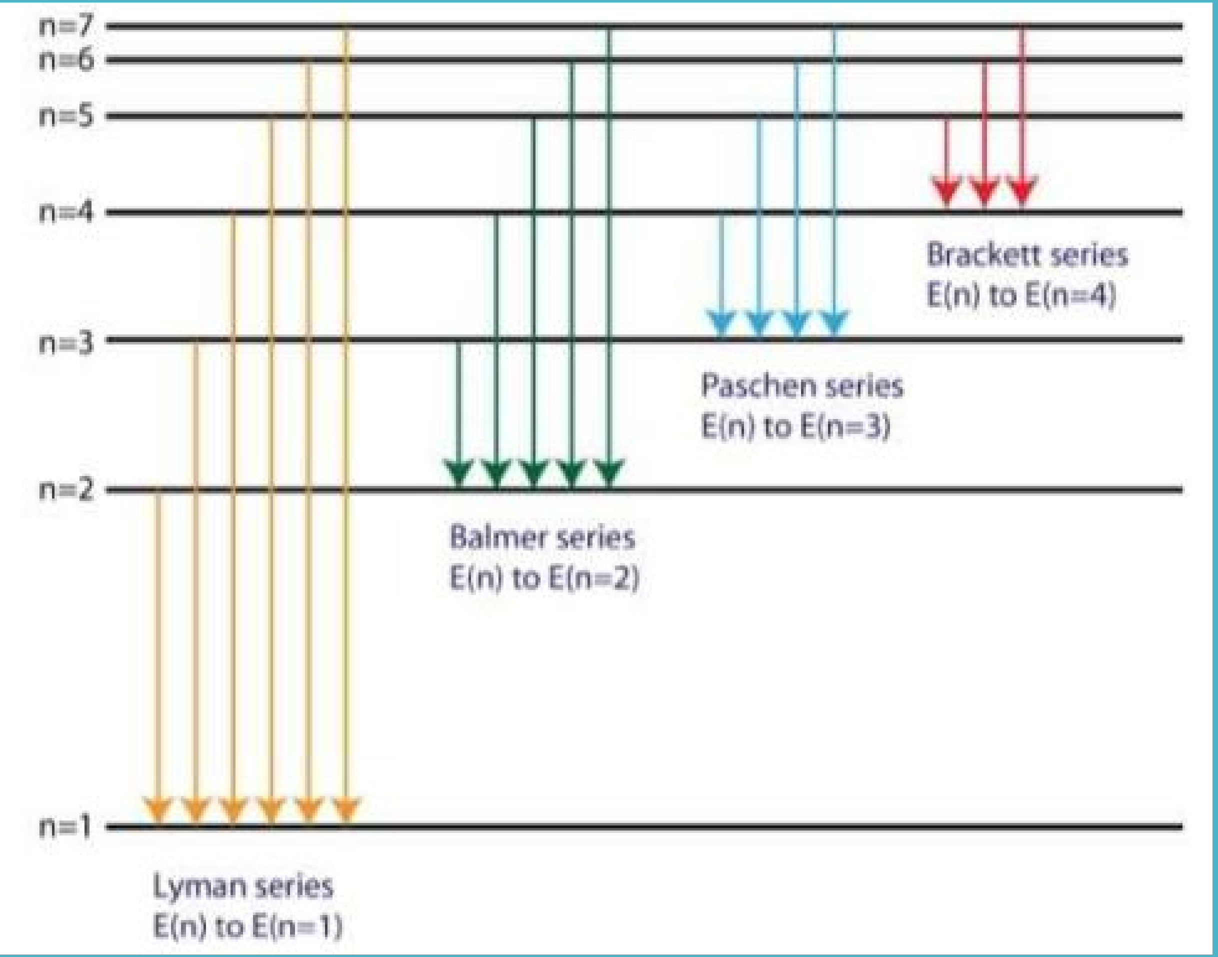
Hydrogen Spectrum Series:



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Hydrogen Spectrum Series:

There are four visible spectral lines corresponded to transitions from higher energy levels down to the second energy level (n = 2). This is called the Balmer series. Transitions ending in the ground state (n = 1) are called the Lyman series, but the energies released are so large that the spectral lines are all in the ultraviolet region of the spectrum. The transitions called the Paschen series and the Brackett series both result in spectral lines in the infrared region because the energies are too small.

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Hydrogen Spectrum Series:

Wave Model:

It is based on wave mechanics. Quantum numbers are the numbers required to completely specify the state of the electrons.

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Hydrogen Spectrum Series:

In the presence of strong magnetic field, the four-quantum number are:

- Principal quantum number (n) can have value 1,2, … ∞
- Orbital angular momentum quantum number l can have value 0,1, 2, …, (n – 1).

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Hydrogen Spectrum Series:

De Broglie's Hypothesis:

This states that the wavelength of electrons is $\lambda = \frac{h}{mv}$

and the whole number of wavelengths is equal to the orbits circumference the main orbit corresponding to the circular standing waves.

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Hydrogen Spectrum Series:

Binding Energy:

Binding energy of a system is defined as the minimum energy needed to separate its constituents to large distances. This may also be defined as the energy released when its constituents are brought from infinity to form the system. The binding energy of H-atom in ground state is 13.6 eV which is the same as its ionization energy.

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Hydrogen Spectrum Series:

Ionization Energy and Ionization Potential:

The minimum energy needed to ionize an atom is called "ionization energy". The potential difference through which an electron should be accelerated to acquire this much energy is called "ionization potential". Hence, ionization energy of H-atom in ground state is 13.6 eV and ionization potential is 13.6 V.

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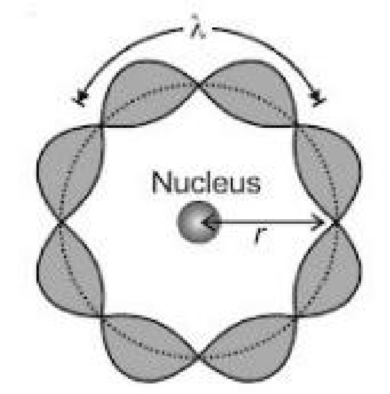
Hydrogen Spectrum Series:

de-Broglie's Explanation of Bohr's Second Postulate:

de-Broglie explained second postulate of Bohr's atomic model by assuming an electron to a particle wave. Therefore, it should form standing waves under resonance condition.



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Hydrogen Spectrum Series:

According to de-Broglie, for an electron moving in nth circular orbit of radius r, $2\pi = n\lambda \; n = 1, 2, 3 \ldots$

i.e., circumference of orbit should be integral multiple of de-Broglie wavelength of electron

moving in nth orbit. As we know that de-Broglie wavelength,

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

$$2\pi r = \frac{nh}{mv}$$

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

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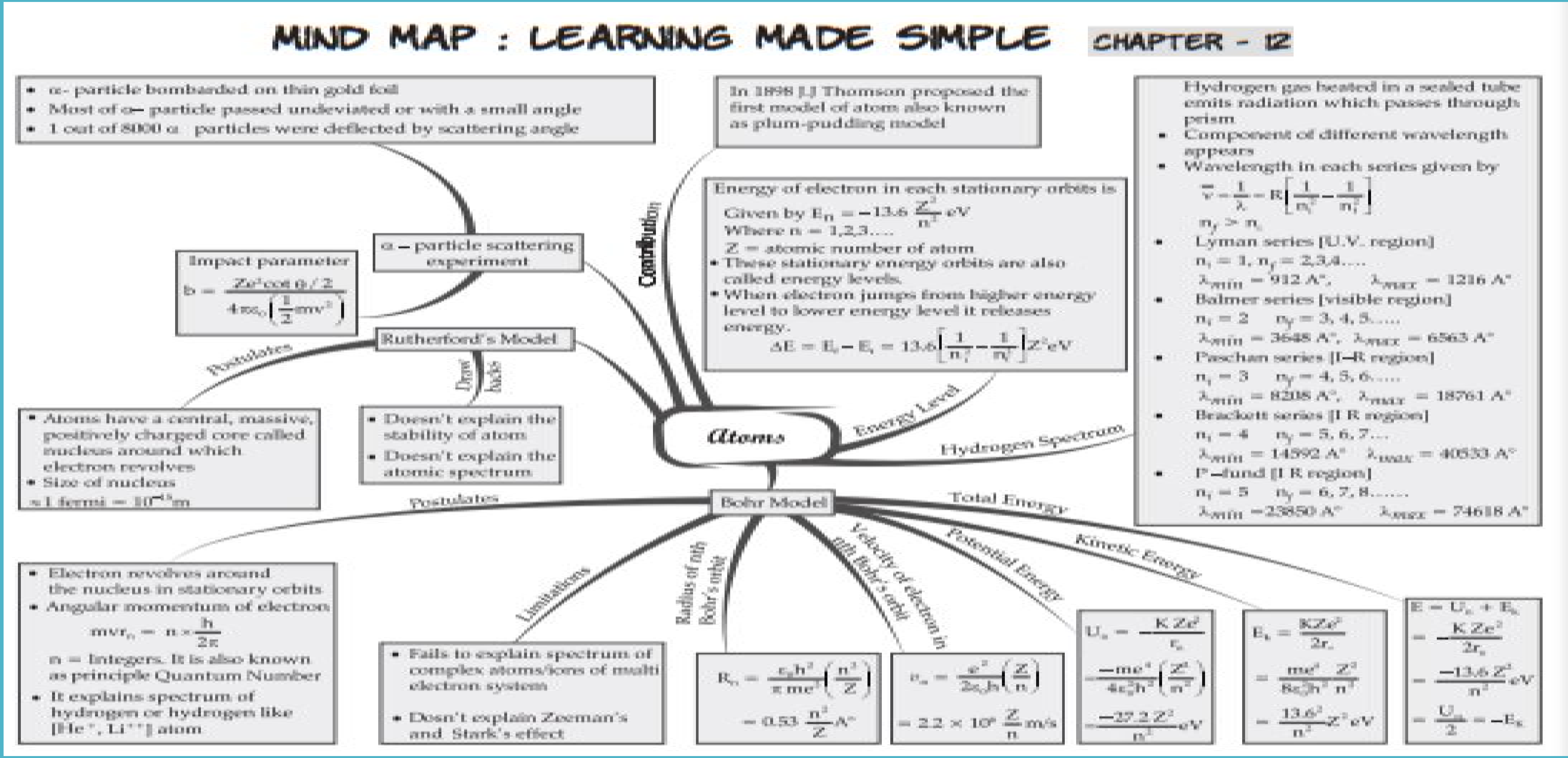

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