Atomic structure

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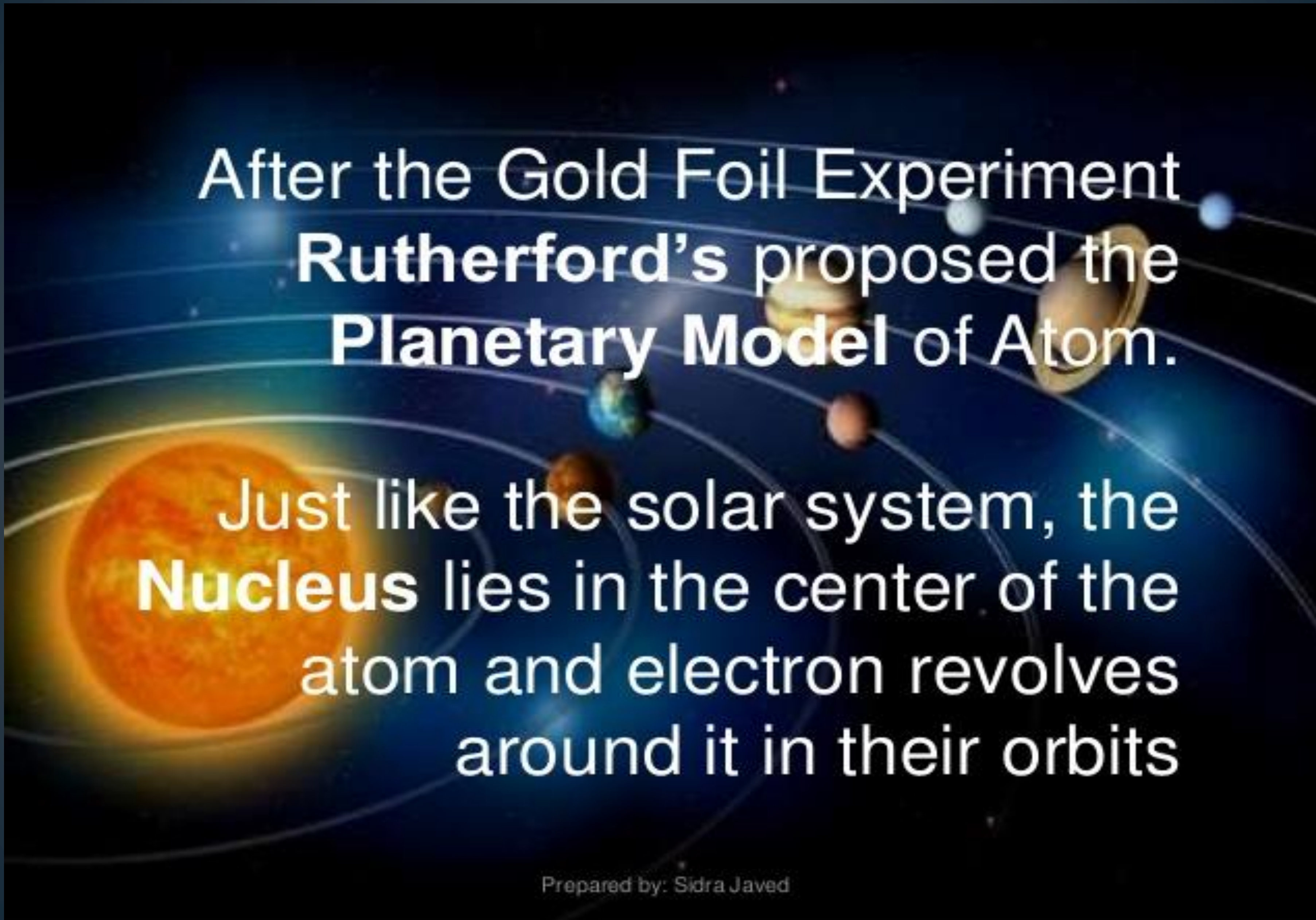
The Fundamental Particles

Particle	Charge (Coulomb)	Relative Charge	Mass (Kg)	Mass (a.m.u)	Found in:
Proton	+ 1.602 x 10^{-19}	+1	1.6727 x 10^{-27}	1.0073	Nucleus
Neutron	0	0	1.6750 x 10^{-27}	1.0087	Nucleus
Electron	-1.602 x 10^{-19}	-1	9.1095 x 10^{-31}	5.4858 x 10^{-4}	Outside Nucleus


After the Gold Foil Experiment
Rutherford's proposed the
Planetary Model of Atom.
Just like the solar system, the
Nucleus lies in the center of the
atom and electron revolves
around it in their orbits
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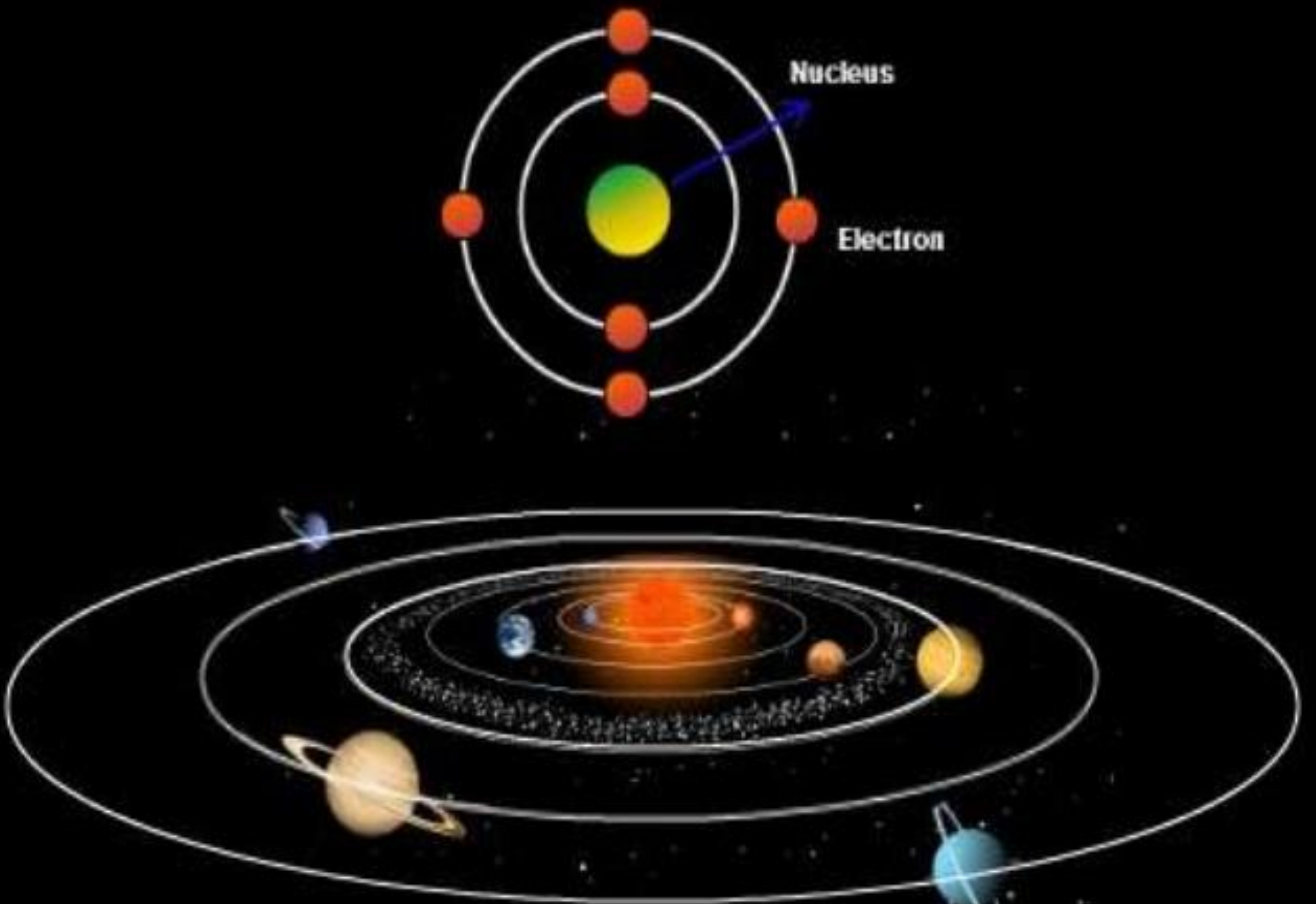

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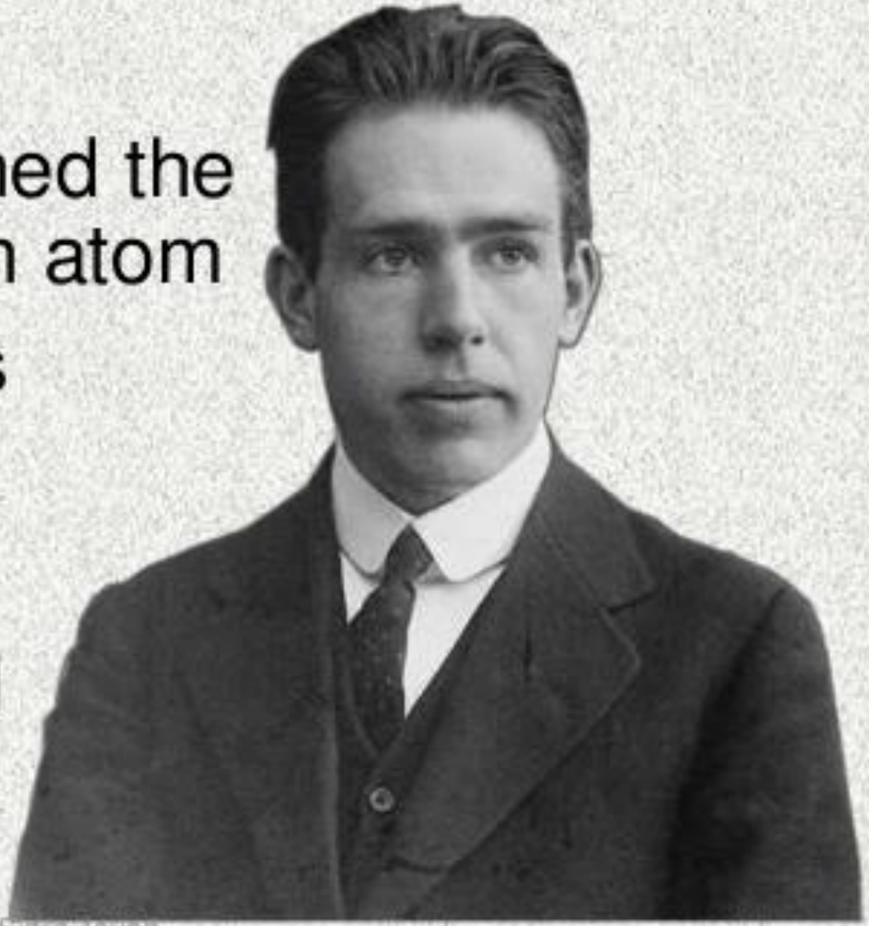
Neil Bohr, a Danish Physicist studied in Rutherford Laboratory since 1912.

He successfully explained the spectrum of hydrogen atom and presented Bohr's Atomic model.

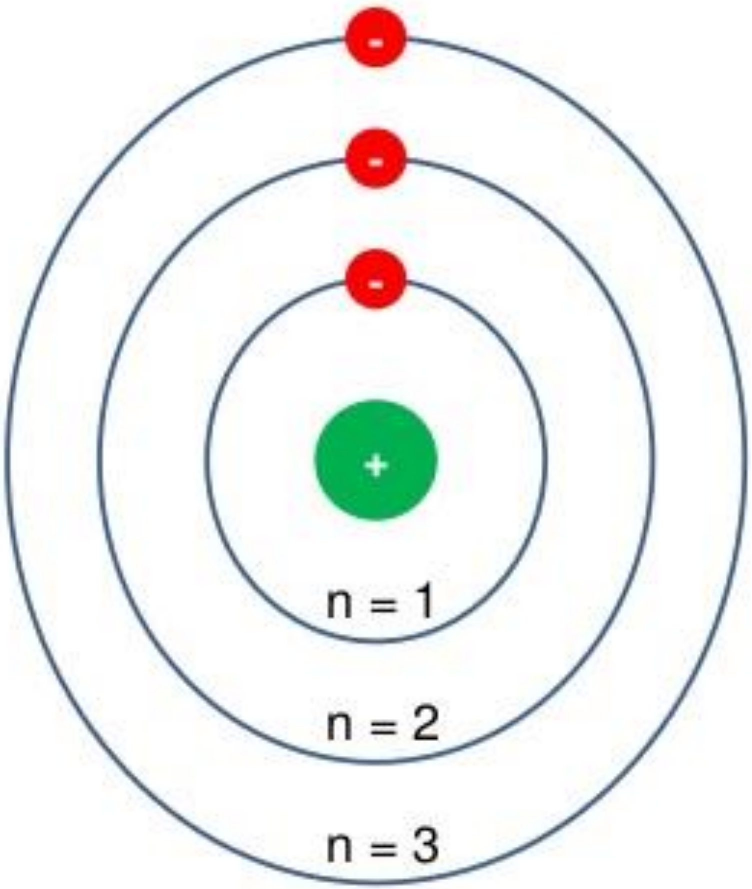
He was awarded Nobel Prize in 1922



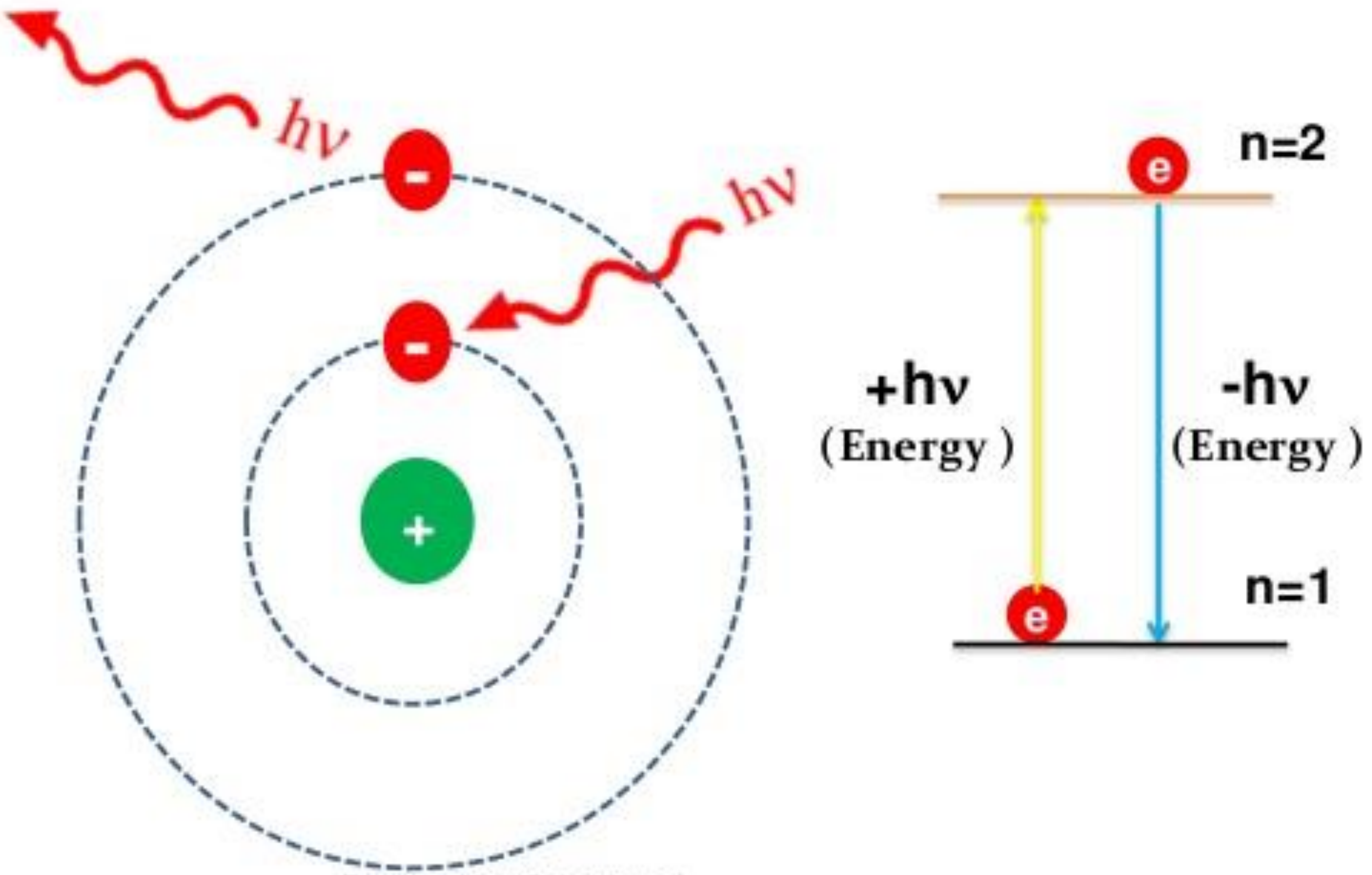
Bohr’s Model of Atom

1- Electrons revolves around the nucleus in definite energy levels called orbits or shells in an atom without radiating energy.

2- As long as an electron remain in a shell it never gains or losses energy.



3- The gain or loss of energy occurs within orbits only due to jumping of electrons from one energy level to another energy level.



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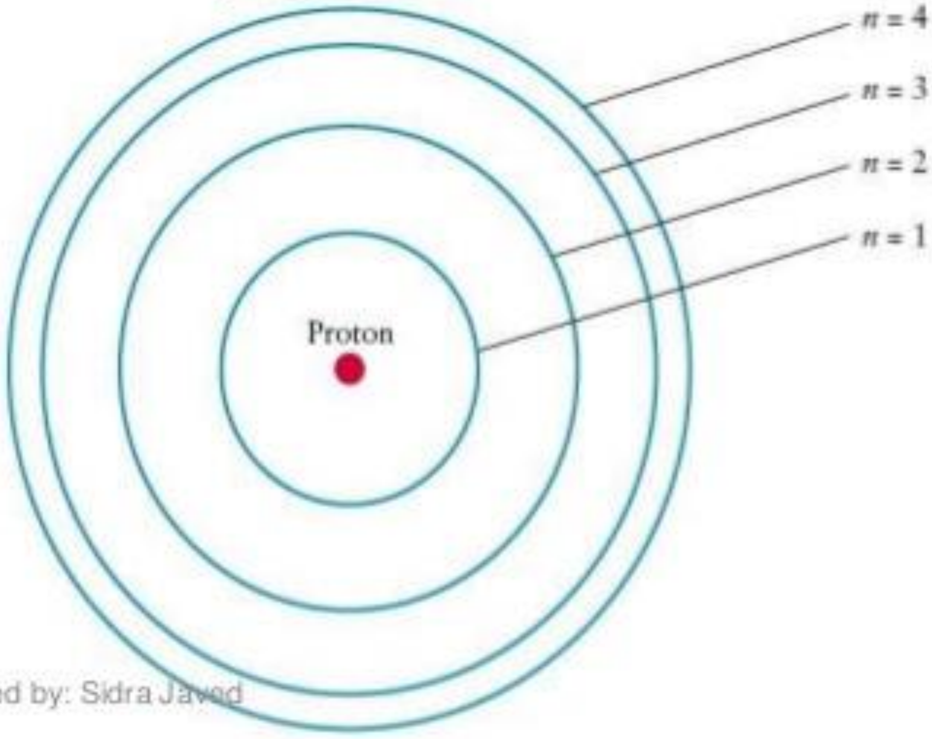
4- The angular momentum (mvr) of an electron is equal to $nh/2\pi$.

The angular momentum of an orbit depends upon its quantum number (n) and it is integral multiple of the factor $h/2\pi$

i.e. $mvr = nh/2\pi$

Where,

n = 1, 2, 3, 4,....



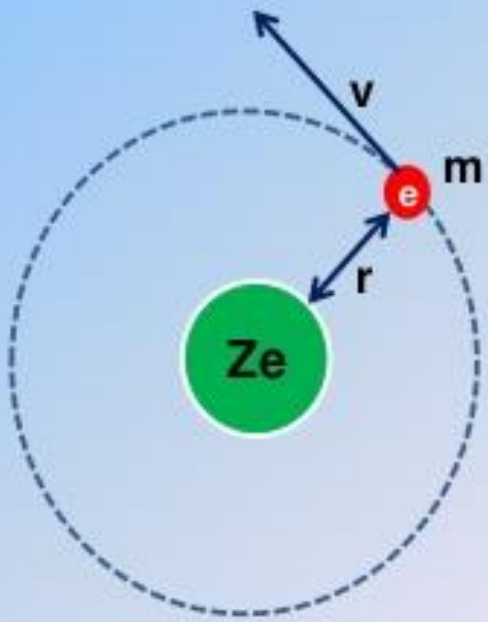
Applications Of Bohr's Atomic Model

- Derivation of Radius of an Orbit of an atom
- Derivation of Energy of an Orbit
- Derivation of Wave Number ($\bar{u}$)

Derivation of Radius of an Orbit of an Atom

Consider an atom having an electron e^- moving around the nucleus having charge Ze where Z is the atomic number.

Let m be the mass, r the radius of the orbit and v, the velocity of the revolving electron.



According to Coloumb's law, the electrostatic force of attraction b/w nucleus and electron :

$$F_c = \frac{q_1 q_2}{4\pi\varepsilon_o r^2} = \frac{Ze.e}{4\pi\varepsilon_o r^2}$$

$$= \frac{Ze^2}{4\pi\varepsilon_o r^2}$$

Where ε_o is the vacuum permittivity constant (ε_o= 8.84 x 10^{-12} C^2/J.m)

Centrifugal force acting on the electron = $\frac{mv^2}{r}$

The two forces are equal and balance each other

$$\frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_o r^2}$$

$$mv^2 = \frac{Ze^2}{4\pi\varepsilon_o r} \ldots\ldots\ldots\ldots(1)$$

$$r = \frac{Ze^2}{4\pi\varepsilon_o mv^2} \ldots\ldots\ldots\ldots(2)$$

According to Bohr's postulate:

$$mvr = \frac{nh}{2\pi} \ldots\ldots\ldots\ldots\ldots(3)$$

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

$$v^2 = \frac{n^2h^2}{4\pi^2m^2r^2} \ldots\ldots\ldots(4)$$

Put value in eq(2).

$$r = \frac{Ze^2}{4\pi\varepsilon_\circ m} \times \frac{4\pi^2 m^2 r^2}{n^2 h^2}$$

$$\frac{1}{1} = \frac{Ze^2 \pi m r}{\varepsilon_\circ n^2 h^2}$$

$$Ze^2 \pi m r = \varepsilon_\circ n^2 h^2$$

$$r = \frac{\varepsilon_\circ n^2 h^2}{Ze^2 \pi m} \ldots\ldots\ldots\ldots\ldots(5)$$

For Hydrogen atom, Z = 1

$$r = \frac{\varepsilon_\circ n^2 h^2}{Ze^2 \pi m}$$

$$r = \frac{\varepsilon_\circ n^2 h^2}{(1)e^2 \pi m}$$

$$r = \frac{\varepsilon_\circ n^2 h^2}{\pi m e^2} \quad \ldots\ldots\ldots\ldots (6)$$

$$r = n^2 a^o$$

Where a^o is a constant quantity,

$$a^o = \frac{\varepsilon_\circ h^2}{e^2 \pi m}$$

$$a^o = 0.529 x 10^{-10} m$$

$$a^o = 0.529 \overset{o}{\mathrm{A}}$$

$$r = n^2 . a^o$$

Derivation of Energy of an Electron in an Orbit

The energy of an electron in an orbit is the sum of its potential and kinetic energy

$$E_T = K.E + P.E$$

$$E_T = \frac{1}{2}mv^2 + \left(-\frac{Ze^2}{4\pi\varepsilon_o r}\right) \ldots\ldots(7)$$

$$E_T = \frac{1}{2}mv^2 - \frac{Ze^2}{4\pi\varepsilon_o r}$$

From eq(1) $$mv^2 = \frac{Ze^2}{4\pi\varepsilon^{\circ} r}$$

Putting value in eq (7)

$$E_T = \frac{Ze^2}{2.4\pi\varepsilon^{\circ} r} - \frac{Ze^2}{4\pi\varepsilon^{\circ} r}$$

$$E_n = \frac{Ze^2}{8\pi\varepsilon_{\circ} r} - \frac{Ze^2}{4\pi\varepsilon_{\circ} r}$$

$$E_n = \frac{Ze^2}{4\pi\varepsilon_{\circ} r}\left(\frac{1}{2} - 1\right)$$

$$E_n = \frac{-Ze^2}{8\pi\varepsilon_{\circ} r} \ldots\ldots\ldots\ldots\ldots(8)$$

Now putting the value of *r* from eq(5) into eq(8),

$$E_n = \frac{-Ze^2}{8\pi\varepsilon_o} \times \frac{Ze^2\pi m}{\varepsilon_o n^2 h^2}$$

$$E_n = \frac{-Z^2 e^4 m}{8\varepsilon_o^2 n^2 h^2} \quad \ldots\ldots\ldots(9)$$

For Hydrogen atom; Z=1

$$E_n = \frac{-me^4}{8\varepsilon_o^2 n^2 h^2}$$

$$E_n = -\frac{me^4}{8\varepsilon_o^2 h^2}\left[\frac{1}{n^2}\right]$$

But $\frac{me^4}{8\varepsilon_o^2 h^2} = -2.178 \times 10^{-18}\,\mathrm{J}$

$$E_n = -2.178 \times 10^{-18}\left(\frac{1}{n^2}\right)\mathrm{J}\ldots\ldots\ldots(10)$$

$$E_n = -\frac{k}{n^2}$$

$$\text{where}\, k = 2.178 \times 10^{-18}$$

The negative sign indicated Decrease in energy of the electron.

For 1 mol of electron, multiply by Avogadro's No.

$$E_n = -\left(\frac{k}{n^2}\right) \times 6.02 \times 10^{23} \text{ J/mol}$$

$$E_n = -\left(\frac{k}{n^2}\right) \times \frac{6.02 \times 10^{23}}{1000} \text{ KJ/mol}$$

$$E_n = 1313.315\left(\frac{1}{n^2}\right) \text{KJ/mol}$$

This energy is associated with 1.008 gram-atoms of hydrogen.

Derivation of Wave number

$$\nu = c\bar{\upsilon}\ldots\ldots\ldots\ldots(14)$$

Where c is the velocity of Light

Putting value of ν from eq(13) into eq(14)

$$\bar{\upsilon}c = \frac{me^4}{8\varepsilon_o^2 h^3}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$$\bar{\upsilon} = \frac{me^4}{8\varepsilon_o^2 h^3 c}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)\ldots\ldots\ldots\ldots(15)$$

Putting values of constants, we get a factor called Rydberg's Constant, R.

$$\frac{me^4}{8\varepsilon_o^2 h^3 c} = R = 1.09678 \times 10^7\,\mathrm{m}^{-1}$$

$$\therefore \bar{\upsilon} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \ldots\ldots\ldots\ldots(16)$$

Defects of Bohr's Atomic Model

1- According to Bohr, the radiation results when an electron jumps from one energy orbit to another energy orbit, but he did not explained how this radiation occurs.

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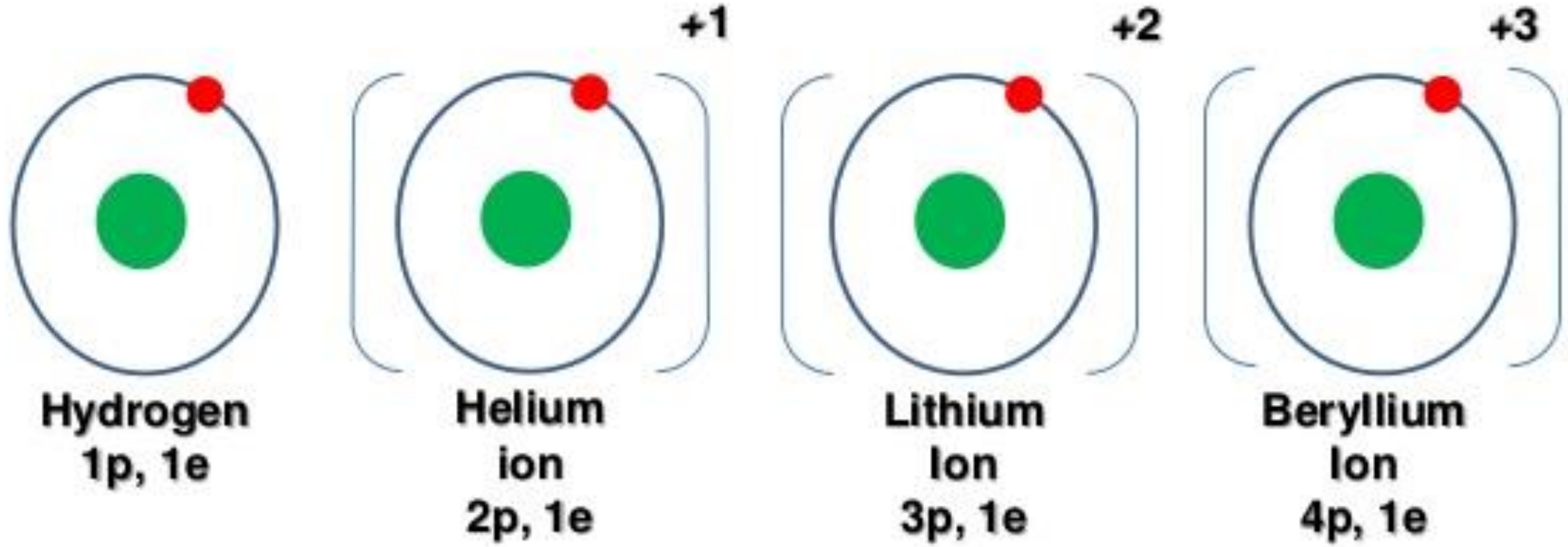
2- Bohr's theory explained the existence of various lines in H-spectrum, but it predicted that only a series of lines exist. Later on it was realized that the spectral lines that had been thought to be a single line was actually a collection of several lines very close to each other.

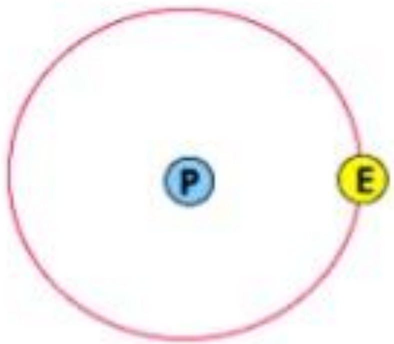
3- Bohr's theory successfully explained the observed spectra for H – atom and similar ions (He^{+1} , Li^{+2} , Be^{+3} etc) but it can not explained the spectra for poly electron atoms.

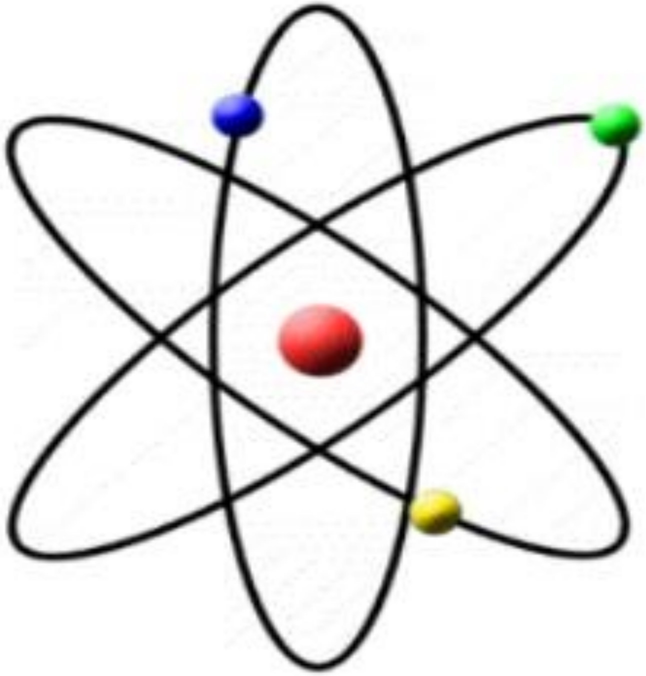


4- If a substance which gives line emission spectrum is placed in a magnetic field, the lines of the spectrum get split up into a number of closely spaced lines. This phenomenon is known as **Zeeman effect.** Bohr's theory has no explanation for this effect.

5- If a substance which gives line emission spectrum is placed in an external electric field, the lines of the spectrum get split up into a number of closely spaced lines. This phenomenon is known as **Stark effect.** Bohr's theory has no explanation for this effect as well.

6- Bohr suggested circular orbits of electron around the nucleus of H – atom but later it was proved that the motion of electron is not in a single plane, but takes place in three dimensional space.





7- Bohr's assumes that an electron in an atom is located at a definite distance from the nucleus and is revolving round it with definite velocity i.e. it has a fixed momentum.

This idea is not in agreement with **Heisenberg's uncertainty principle** which states that it is impossible to determine the exact position and momentum of a particle simultaneously with certainty.


The End
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