PHYS 111
1ST semester 1446

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Lecture 12 **B**

History and Models of the Atom

DEMOCRITUS

- ❑ Believed universe made of invisible units called atoms

- ❑ Named them Atoms

- ❑ 400 BC Aristotle said "He's a quack!!!"

- ❑ Took 2000 yrs. to be proved right!

JOHN DALTON (1766 – 1844)

Dalton's Atomic Theory

Wrote the first atomic theory

1. All elements are composed of tiny indivisible particles called atoms

2. Atoms of the same element are identical. Atoms of any one element are different from those of any other element.

3. Atoms of different elements combine in simple whole-number ratios to form chemical compounds

4. In chemical reactions, atoms are combined, separated, or rearranged – but never changed into atoms of another element.

Isotopes

❑ Dalton was wrong about all elements of the same type being identical

❑ Atoms of the same element *can* have different numbers of **neutrons.**

❑ Thus, different mass numbers.

❑ These are called **isotopes.**

FREDERICK SODDY

- **Frederick Soddy** (1877-1956) proposed the idea of isotopes in 1912 (note this was close to 30 years after Dalton's original idea)

- **Isotopes** are atoms of the **same element** having *different masses*, due to varying numbers of neutrons.

- Soddy won the Nobel Prize in Chemistry in 1921 for his work with isotopes and radioactive materials.

The "Billiard Ball" Model

❑ **Proposed by John Dalton in 1804**

❑ **This theory proposed that matter was composed of small, spherical particles**

❑ ***But* evidence was later gathered that matter was composed of even smaller bits**

New Evidence

❑ **During the 1900s evidence was discovered regarding charges:**

❑ **atoms have positive (Rutherford's contribution) and negative (Thomson's contribution) parts**

- **charges interact:**
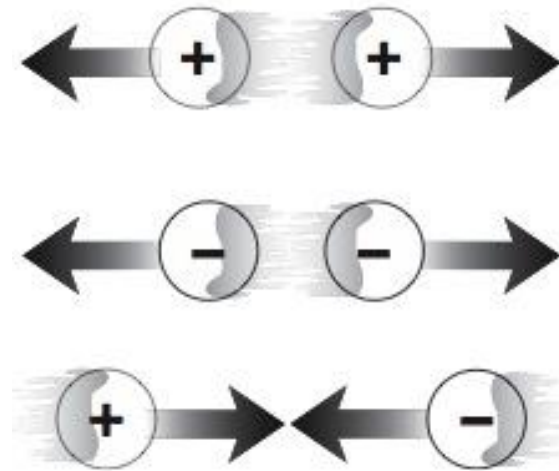
❑ **As a result, revisions to Dalton's model had to be made**

Thomson: "Plum Pudding" or "Chocolate Chip Cookie" Model

❑ **Using available data on the atom, J.J. Thomson came up with the idea of having charges embedded with Dalton's Billiard Balls**

❑ **Also used cathode ray experiment to discover the existence of the electron**

positive
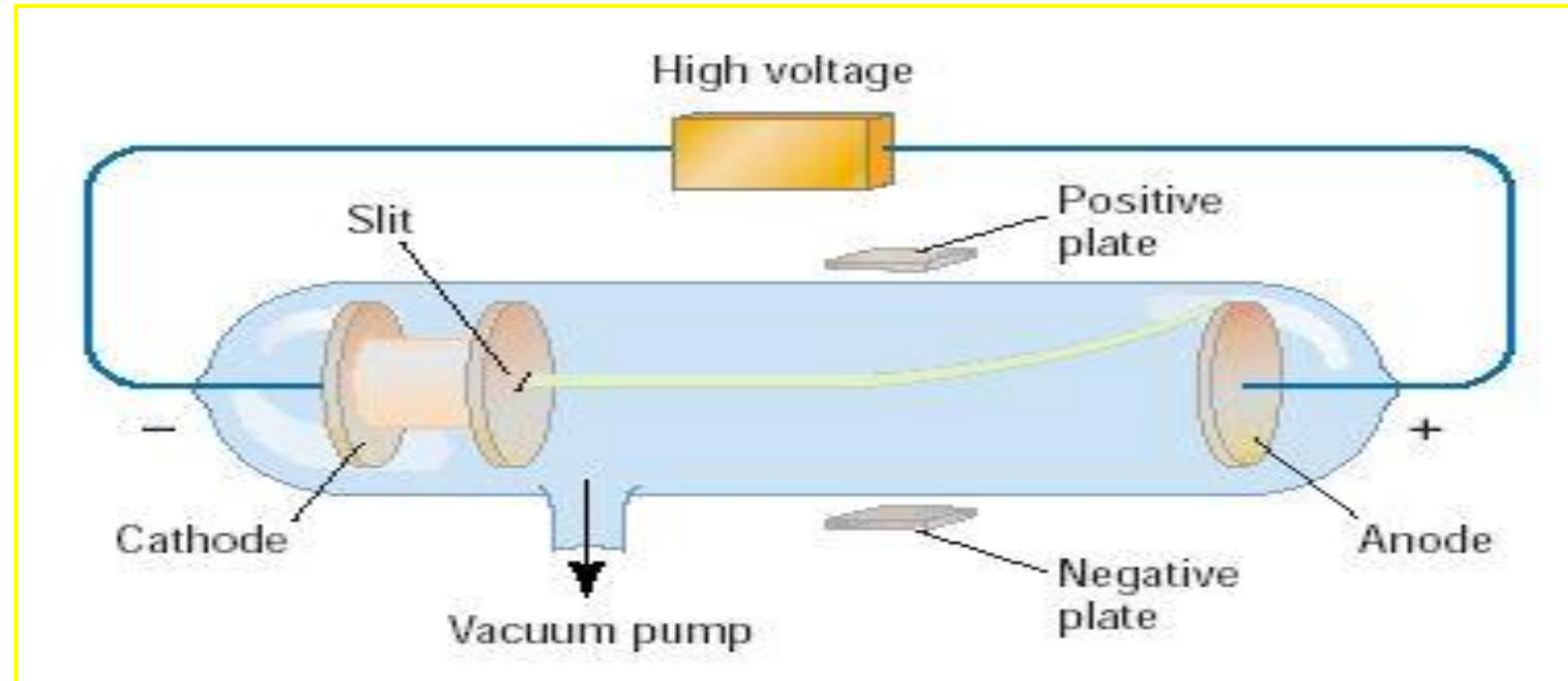(evenly distributed)
"dough"
part

negative
"chocolate"
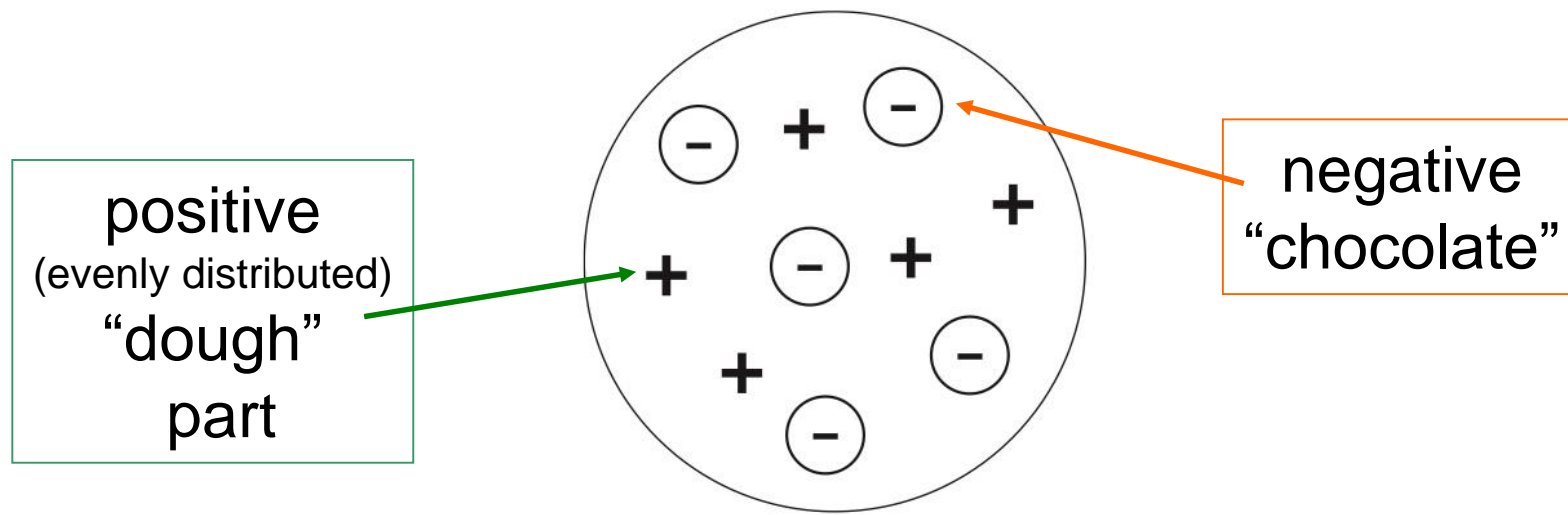
Note: this model kept Dalton's key ideas intact

Discovery of the Electron
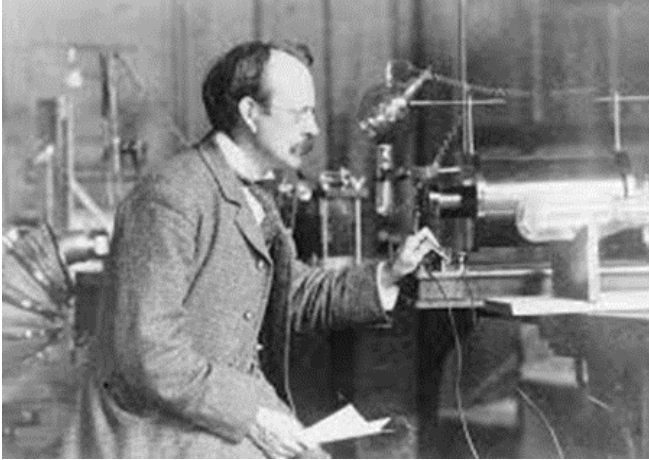
In 1897, J.J. Thomson used a *cathode ray tube* to deduce the presence of a negatively charged particle: the Electron

High voltage

Slit

Positive plate

−

Cathode

Vacuum pump

Negative plate

Anode

+

Conclusions from the Study of the Electron:

❑ **Cathode rays have identical properties regardless of the element used to produce them. All elements must contain identically charged electrons.**

❑ **Atoms are neutral, so there must be positive particles in the atom to balance the negative charge of the electrons**

■ **Electrons have so little mass that atoms must contain other particles that account for most of the mass**
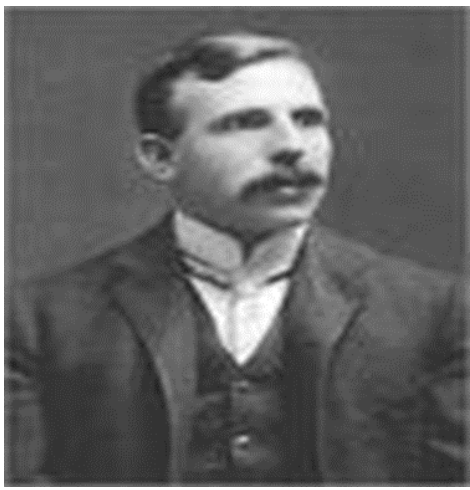
Mass of the Electron

Robert Millikan

Mass of the electron is 9.11×10^{-28} kg
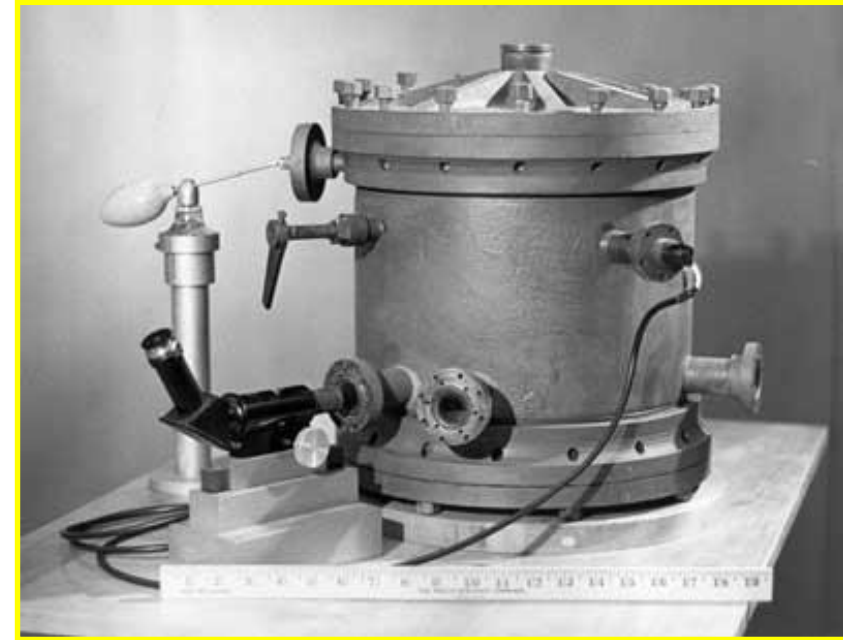
The oil drop apparatus

1916 – Robert Millikan determines the mass of the electron: 1/1840 the mass of a hydrogen atom; has one unit of negative charge
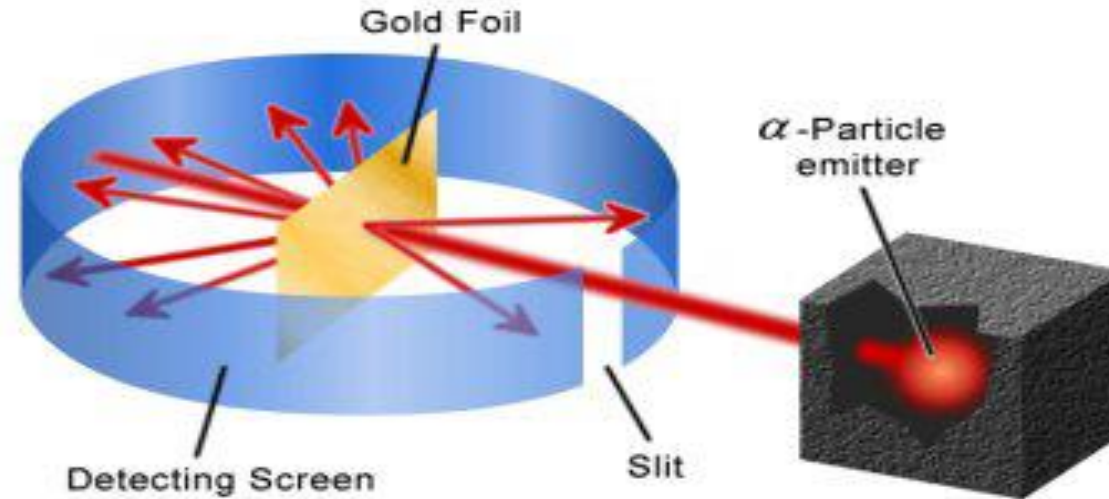
Nuclear Model

❑ **Ernest Rutherford discovered a huge flaw in the previous concept of the atom during his now famous gold foil experiment**

Discovered the Nucleus and the Positive Protons Surmised atoms are made of mostly empty space Didn't know about the Neutrons Famous Gold Foil Experiment
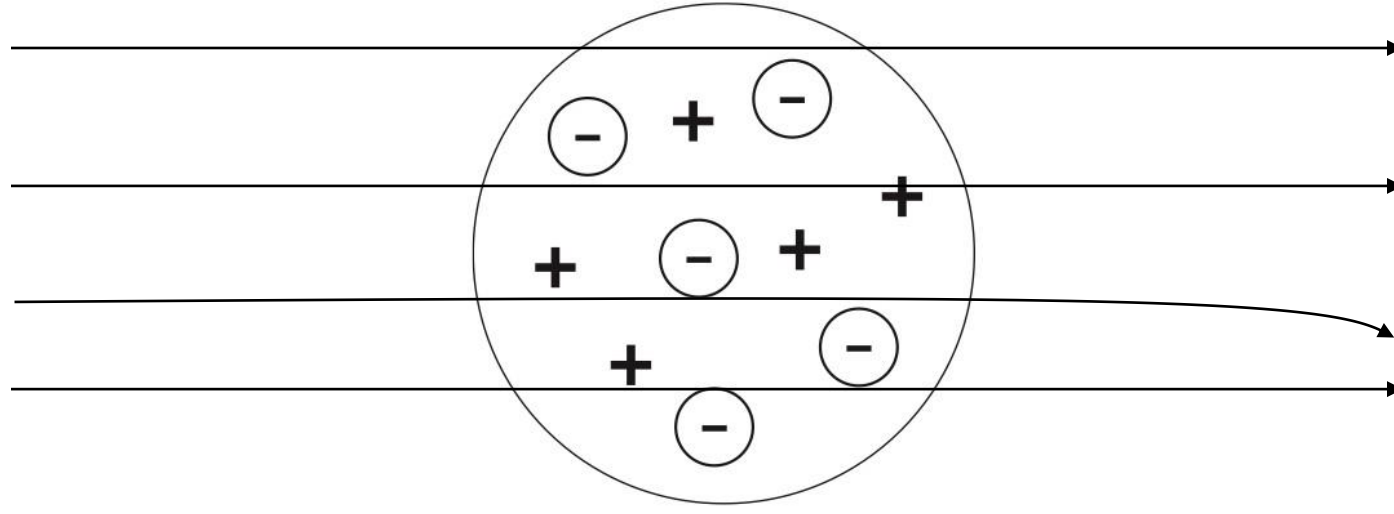
Gold Foil Experiment

- Particles shot through thin sheet of gold
- Most shots went straight through
- A small amount were deflected
- Hence… The atoms must be made of mostly empty space with a small dense nucleus

# Further explanation of Nuclear Model

- **If previous models were correct alpha particles would have passed straight through the gold**

Nuclear Model

- **Rutherford found that most (99%) of the alpha particles that he shot at the gold went straight through**

- **From these experiments Rutherford concluded that the atom had a dense positive core, with the rest composed of mostly empty space with the occasional negatively charged electron**
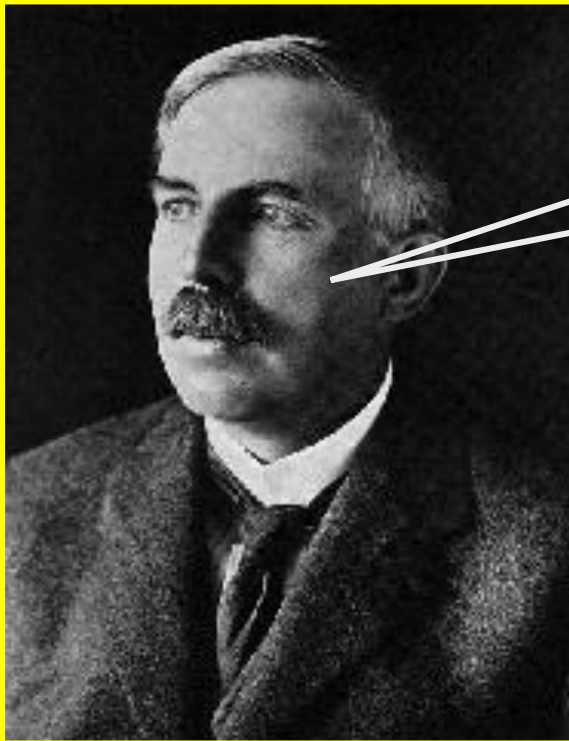
Note: this model completely changed the definition of atom
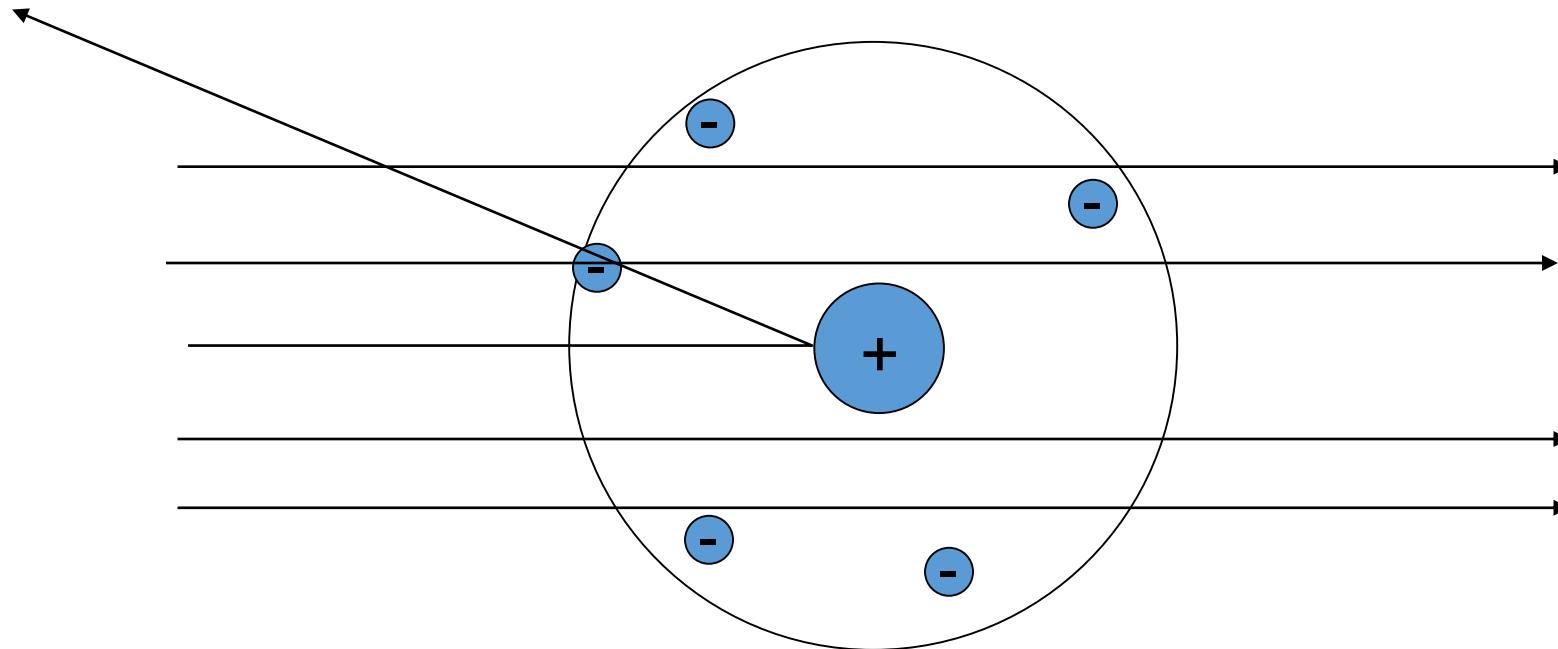
Rutherford's Findings

* Most of the particles passed right through
 * A few particles were deflected
* VERY FEW were greatly deflected

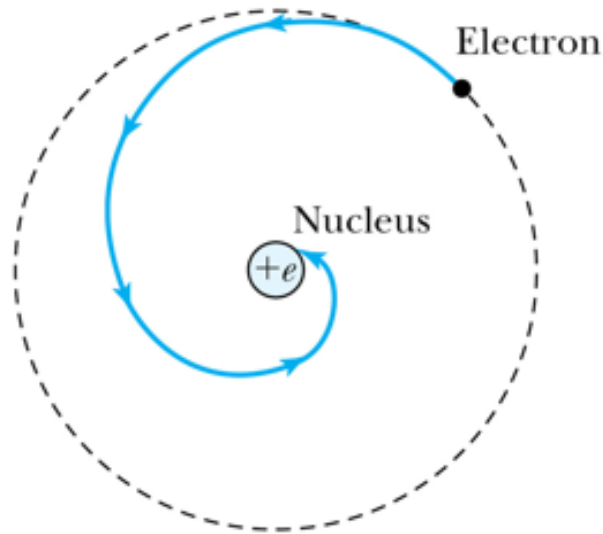"Like howitzer shells bouncing off of tissue paper!"

Conclusions:

#1 The nucleus is small
#2 The nucleus is dense
#3 The nucleus is positively charged

The Planetary Model is Doomed

- From classical E&M theory, an accelerated electric charge radiates energy (electromagnetic radiation) which means total energy must decrease. ⟶ *Radius r must decrease!!*
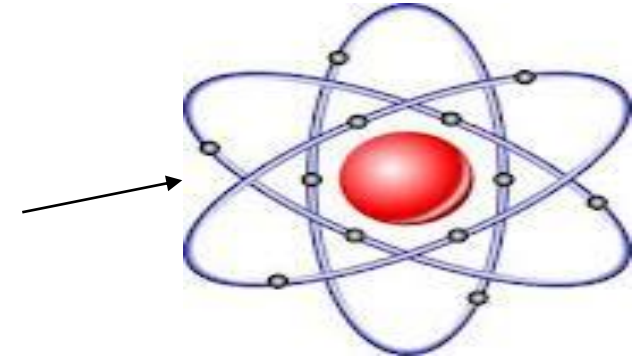

Electron crashes into the nucleus!?

Niels Bohr

- Discovered that electrons exist in several distinct layers or levels
- "Jimmy Neutron Model"
- Travel around nucleus like planets travel around sun
- Electrons Orbit
- Electrons can jump between levels with energy being added/released

The Bohr Model of the Hydrogen Atom

Bohr's general assumptions:

1) **"Stationary states" (orbiting electrons do not radiate energy) exist in atoms.**

2) $E = E_1 - E_2 = hf$

3) **Classical laws of physics do not apply to transitions between stationary states.**

4) **The mean kinetic energy of the electron-nucleus system is $K = n\, hf_{orb} / 2$, where f_{orb} is the frequency of rotation.**

Bohr Radius

- The diameter of the hydrogen atom for stationary states is

$$r_n = \frac{4\pi\varepsilon_0 n^2 \hbar^2}{me^2} \equiv n^2 a_0$$
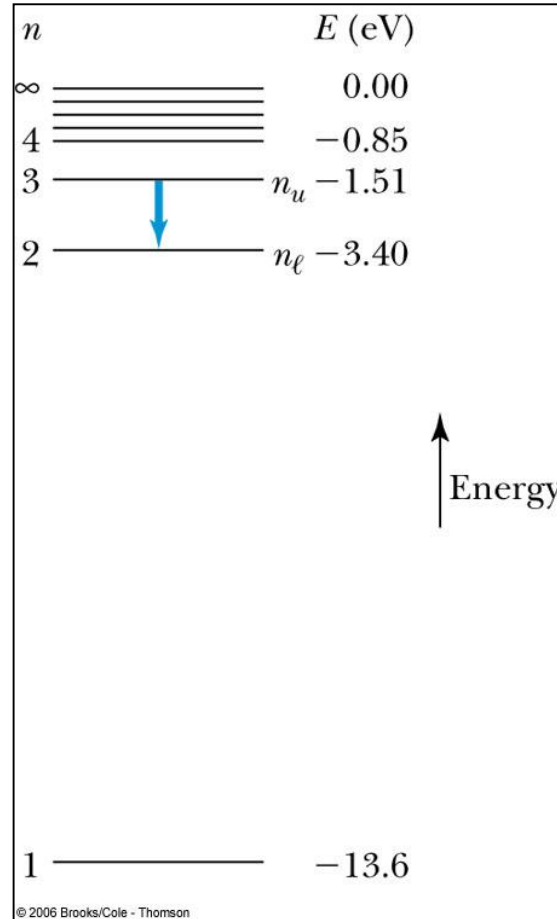
Where the **Bohr radius** is given by

$$a_0 = \frac{4\pi\varepsilon_0 \hbar^2}{me^2} = \frac{(1.055\times10^{-34} \text{ J}\cdot\text{s})^2}{\left(8.99\times10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(9.11\times10^{-31} \text{ kg})(1.6\times10^{-16} \text{ C})^2} = 0.53\times10^{-10} \text{ m}$$

- The smallest diameter of the hydrogen atom is

$$2r_1 = 2a_0 \approx 10^{-10}\text{m}$$

- $n = 1$ gives its lowest energy state (called the "ground" state)

The Hydrogen Atom

- The energies of the stationary states

$$E_n = -\frac{e^2}{8\pi\varepsilon_0 r_n} = -\frac{e^2}{8\pi\varepsilon_0 a_0 n^2} \equiv -\frac{E_0}{n^2}$$

where E_0 = 13.6 eV.

  - Emission of light occurs when the atom is in an excited state and decays to a lower energy state ($n_u \rightarrow n_\ell$).
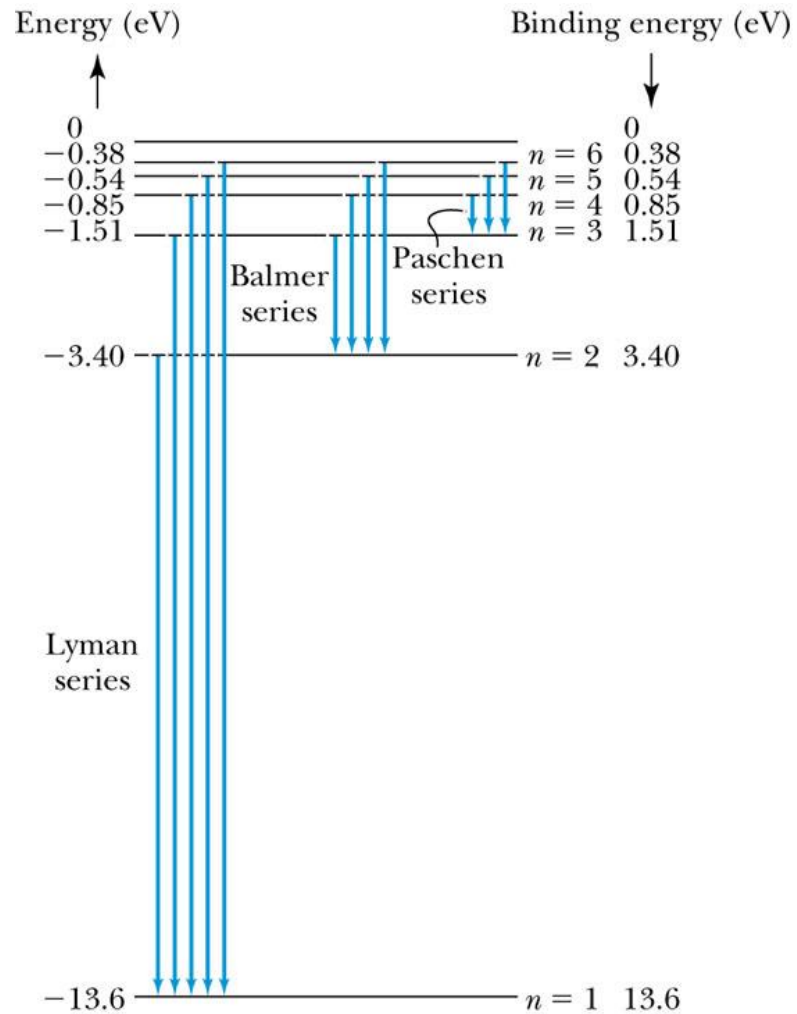
$$hf = E_u - E_\ell$$

where f is the frequency of a photon.

$$\frac{1}{\lambda} = \frac{f}{c} = \frac{E_u - E_\ell}{hc} = R_\infty \left(\frac{1}{n_\ell^2} - \frac{1}{n_u^2} \right)$$

R_∞ is the **Rydberg constant**.

Transitions in the Hydrogen Atom

Energy (eV)

0
−0.38
−0.54
−0.85
−1.51

Balmer series

Paschen series

−3.40

Lyman series

−13.6

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Binding energy (eV)

0
$n = 6$ 0.38
$n = 5$ 0.54
$n = 4$ 0.85
$n = 3$ 1.51

$n = 2$ 3.40

$n = 1$ 13.6

Lyman series

The atom will remain in the excited state for a short time before emitting a photon and returning to a lower stationary state. All hydrogen atoms exist in n = 1 (invisible).

Balmer series

When sunlight passes through the atmosphere, hydrogen atoms in water vapor absorb the wavelengths (visible).
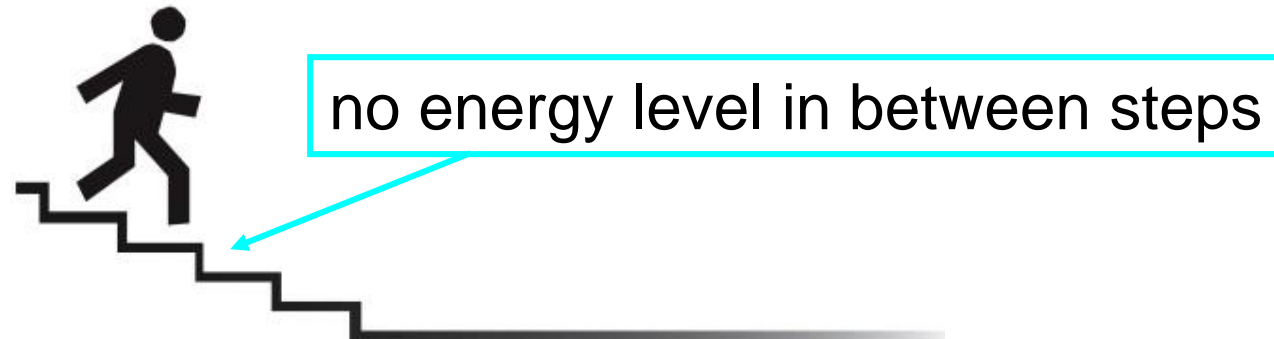
Bohr Model

- **Niels Bohr** proposed that electrons revolve around the central positive nucleus (like planets in the solar system)

negative electrons

3 positive protons
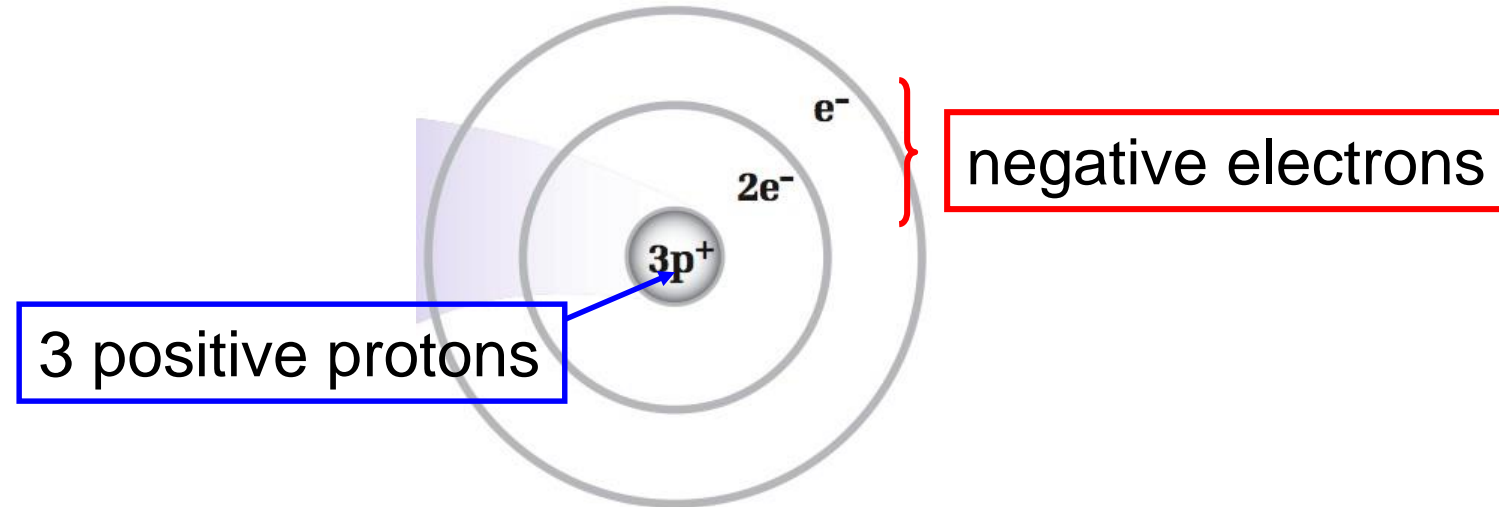
Bohr Model

- Bohr also suggested that the electrons can only revolve in certain orbits, or at certain energy levels (ie, the energy levels are *quantized)*

no energy level in between steps

Stair steps are *quantized*. They only have certain places where a person may stand.

HEISENBERG AND SCHRODINGER

- **Found that Electrons live in fuzzy regions or "clouds" not distinct orbits**
- **Improved on Bohr's findings**
- **Electron location can not be predicted**
- **Quantum Mechanical Model**

Quantum Mechanical Model

- ### The *current* understanding of the atom is based on Quantum Mechanics

- ### This model sees the electrons not as individual particles, but as behaving like a cloud - the electron can be "anywhere" in a certain energy level

- ## Most things we do can be explained using Dalton's and/or Bohr's model

- ## The Quantum Mechanical model, although most accurate, is complex even at a university level (conceptually and mathematically)

Quantum Mechanical Model

electrons can be found anywhere in these "shells"

1e⁻

2e⁻

3p⁺

nucleus

note: *the electrons are still quantized* no electrons can be found here