ATOMIC STRUCTURE


Where No Man Has Gone Before

“If I have seen further, it is by standing on the shoulders of giants!”

- Isaac Newton

Democritus -- 400 B.C.

- **Student of Arostotle**
- **Basic particles make-up all matter**
- **The smallest, indivisible particles of matter are called atomos**

Robert Boyle

- First to study chemistry as a separate intellectual discipline
- First to carry out rigorous chemical exmperiments
- First to clearly define an element

Joseph Priestley - 1774

- Isolated the gas oxygen by heating mercury oxide (HgO)
- $2HgO \rightarrow 2Hg + O_2$
- Chemical formula
- Chemical equation

Law of Conservation of Mass

- **Mass is neither created nor destroyed in chemical reactions**

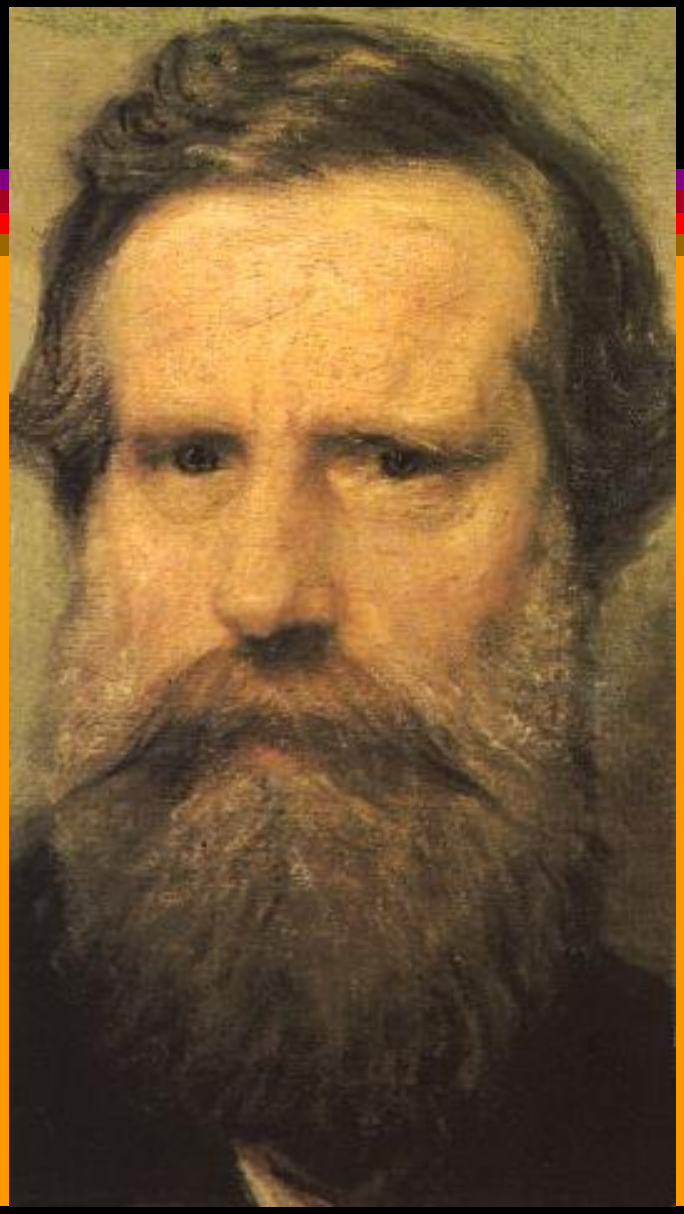
John Dalton -- 1807

- Studied chemical reactions which investigate the conservation of mass
- Developed Dalton's Atomic Theory

- All matter is composed of tiny, indivisible particles called atoms which cannot be created, destroyed, or interconverted
- Atoms of any particular element are identical; whereas, atoms of one element differ from atoms of other elements

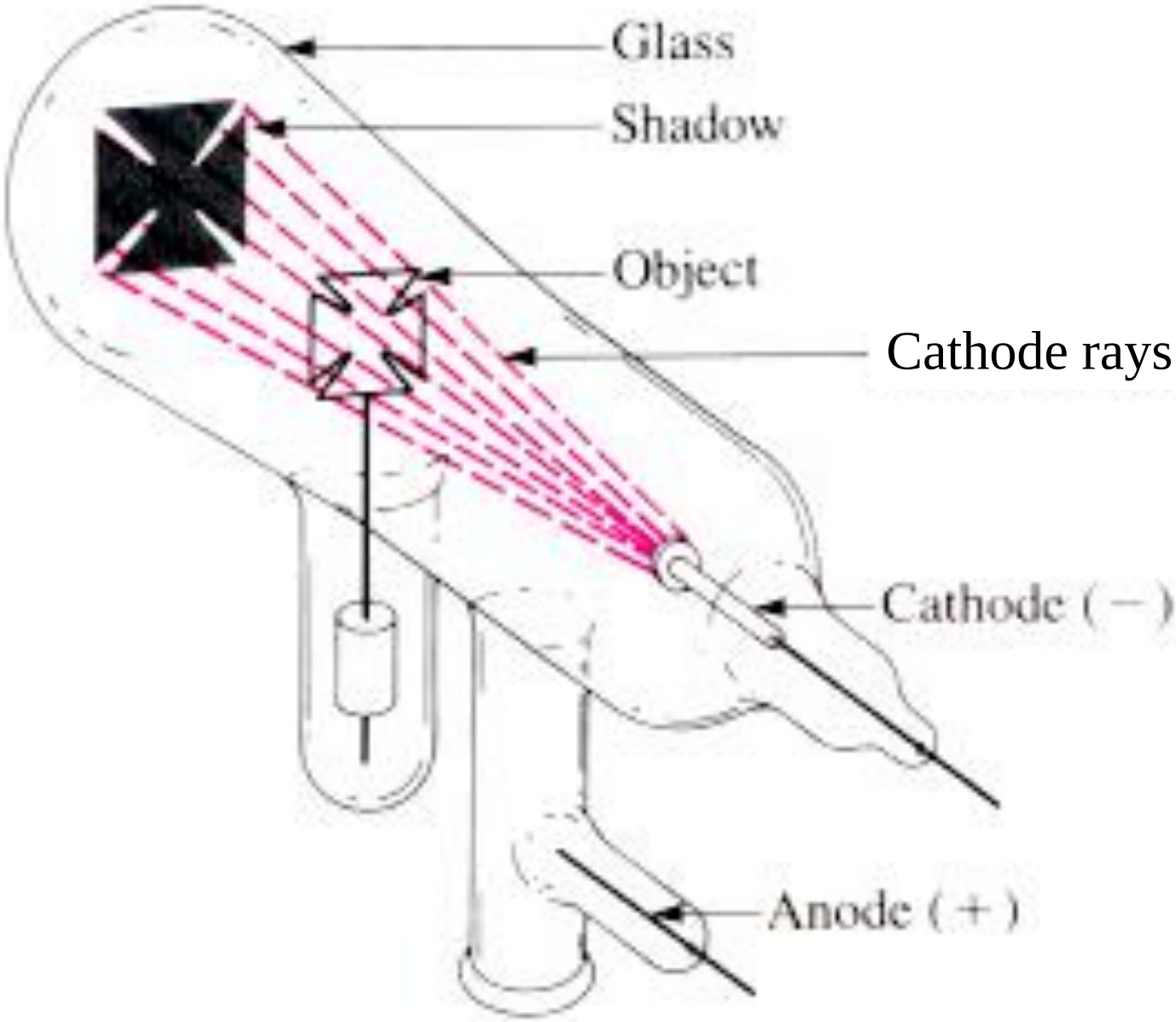
- **Chemical change is a union, separation, or rearrangement of atoms**
- **If the experimental conditions of a chemical reaction are changed, the combining ratio of one element with another element may also change**

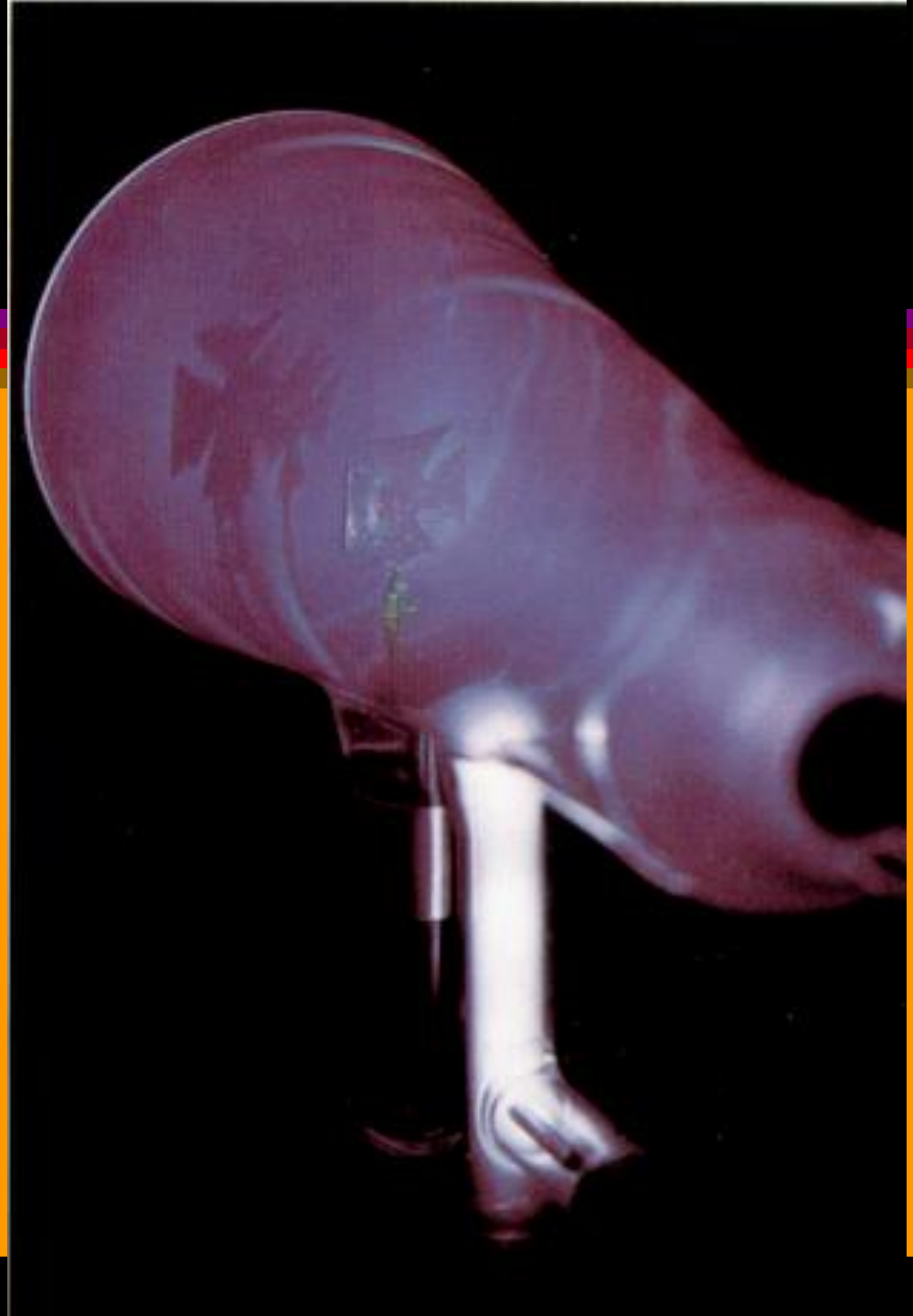
Sir William Crookes



Sir William Crookes 1879

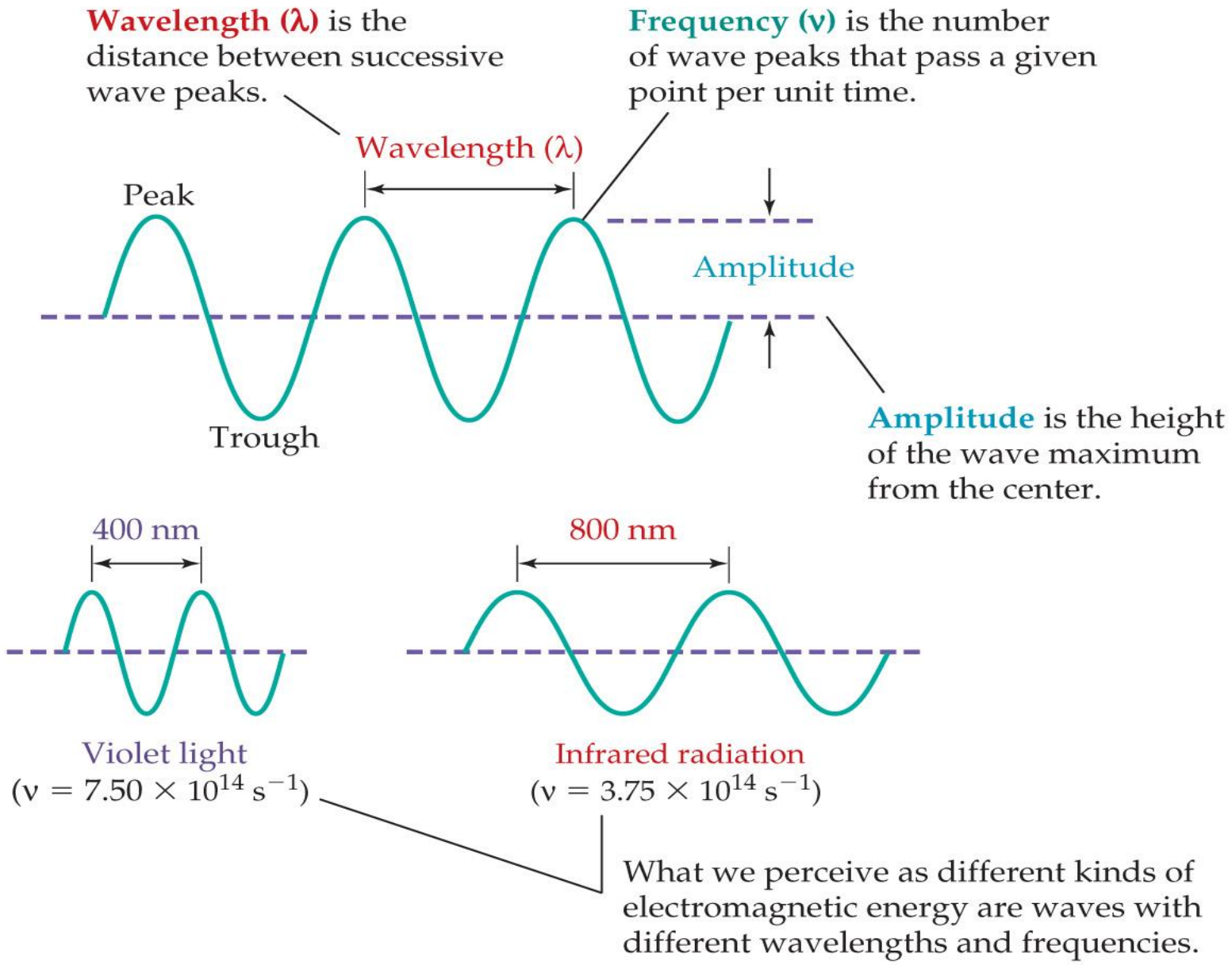
- Developed the cathode ray tube
- Discovered cathode rays
  - negatively charged particles

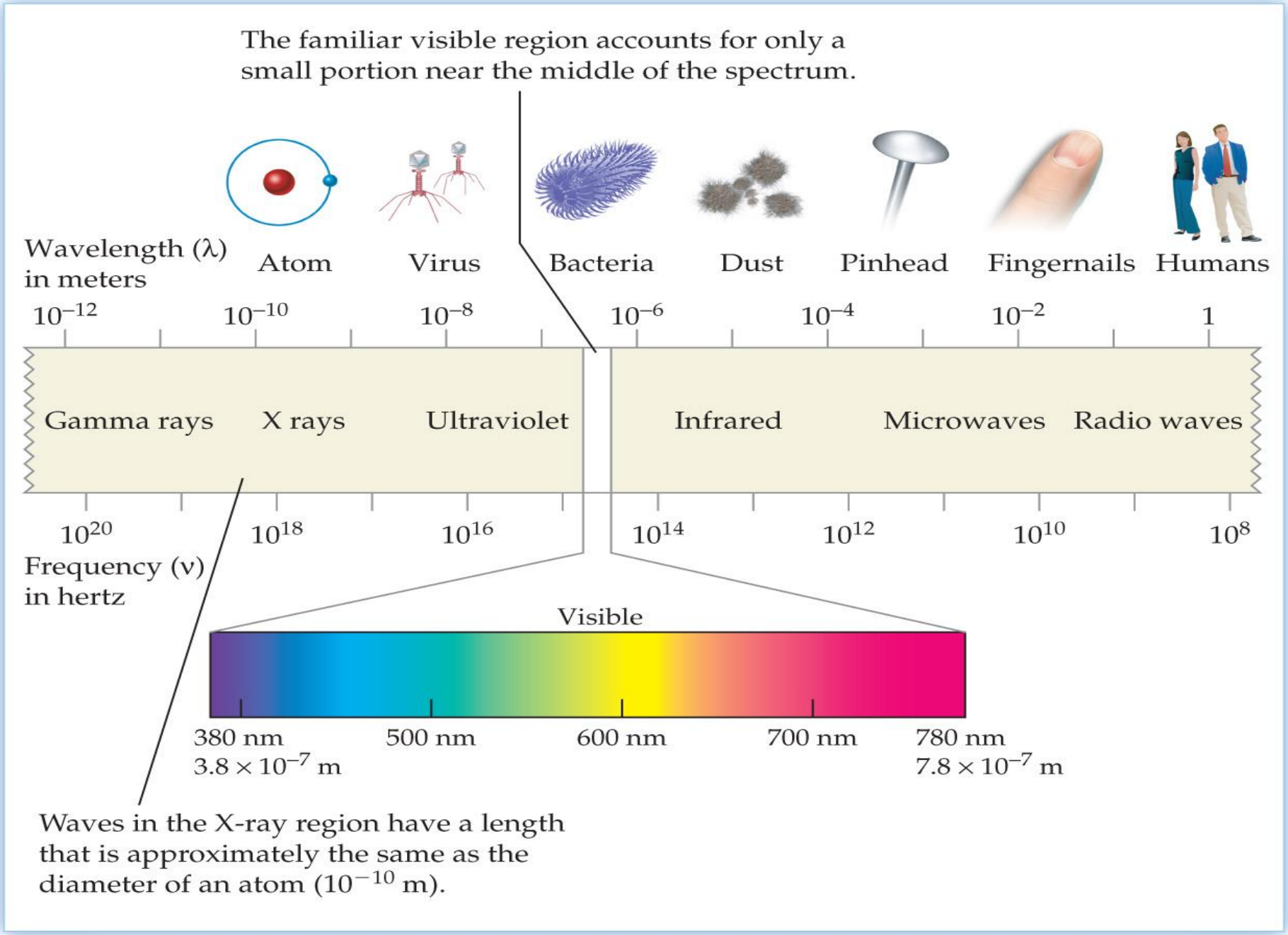

Glass
Shadow
Object
Cathode rays
Cathode (−)
Anode (+)

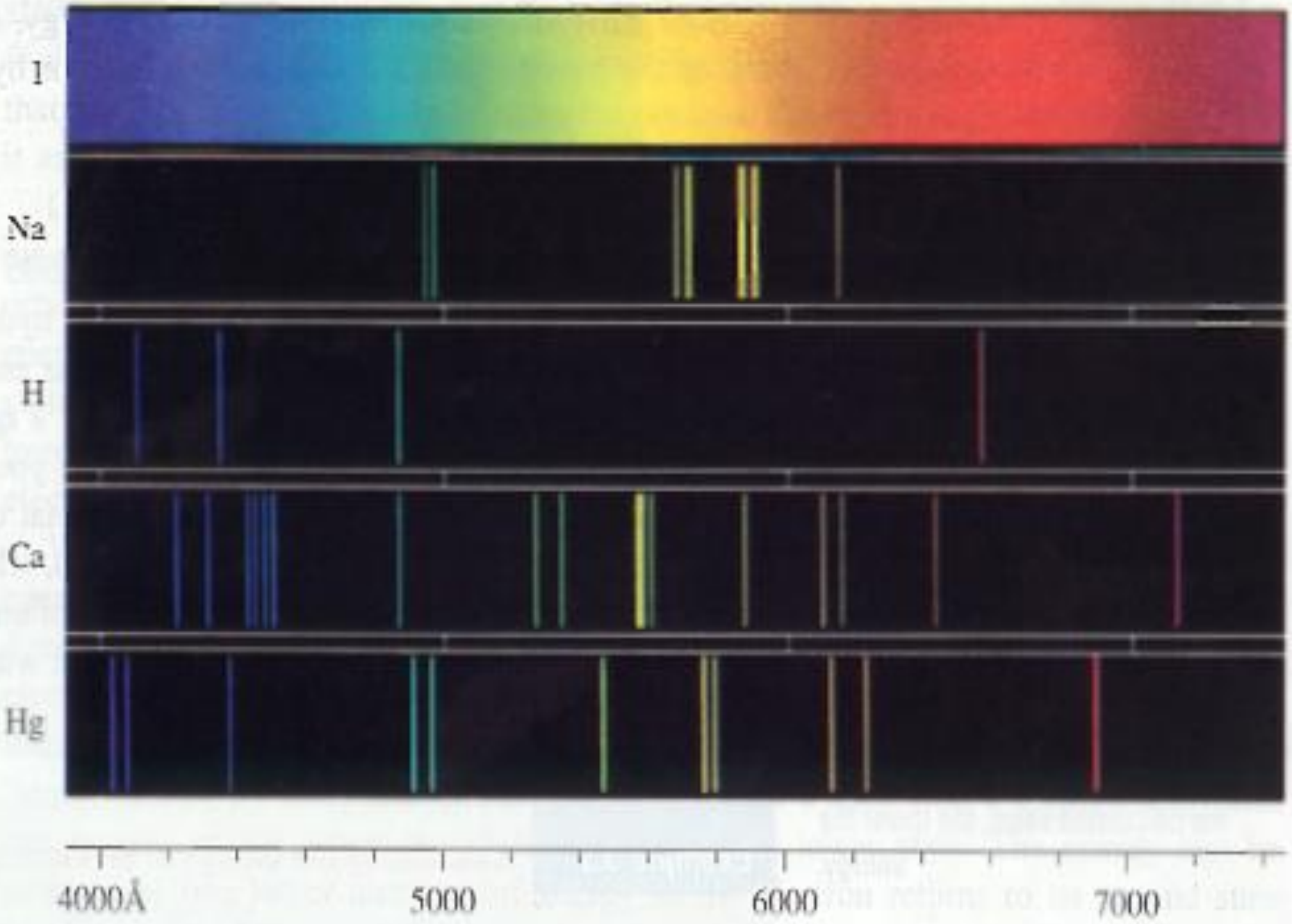


The Physics of Waves

- λ - (lamda) Represents wavelength of a wave
- ν - (nu) Represents the frequency of a wave
- $v=\lambda\nu$
- $E=h\nu$

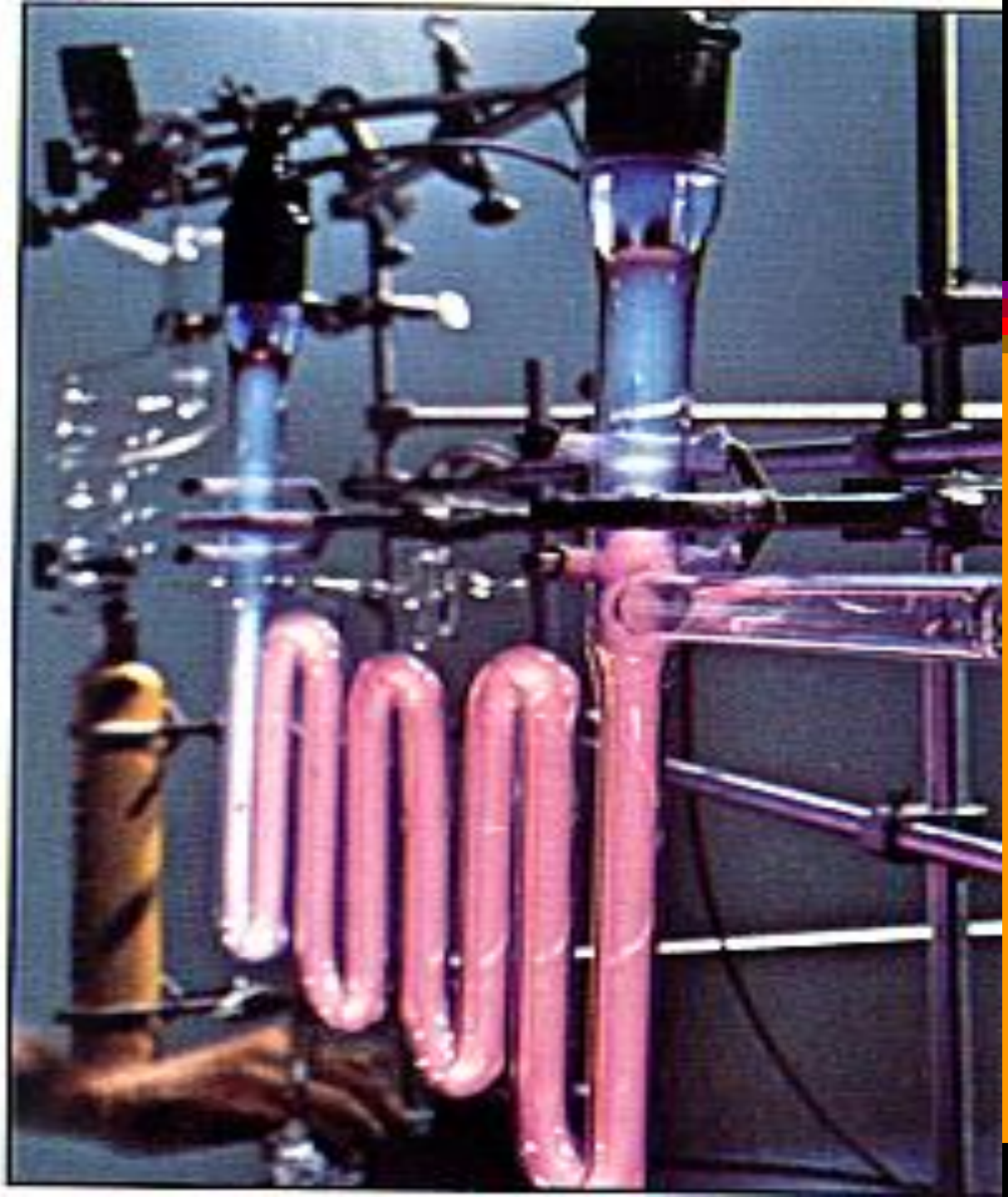





1
Na
H
Ca
Hg
4000Å
5000
6000
7000

J.J. Balmer -- 1885

- Swiss scientist
- Developed an equation to calculate the wavelength of lines in the hydrogen atom spectrum

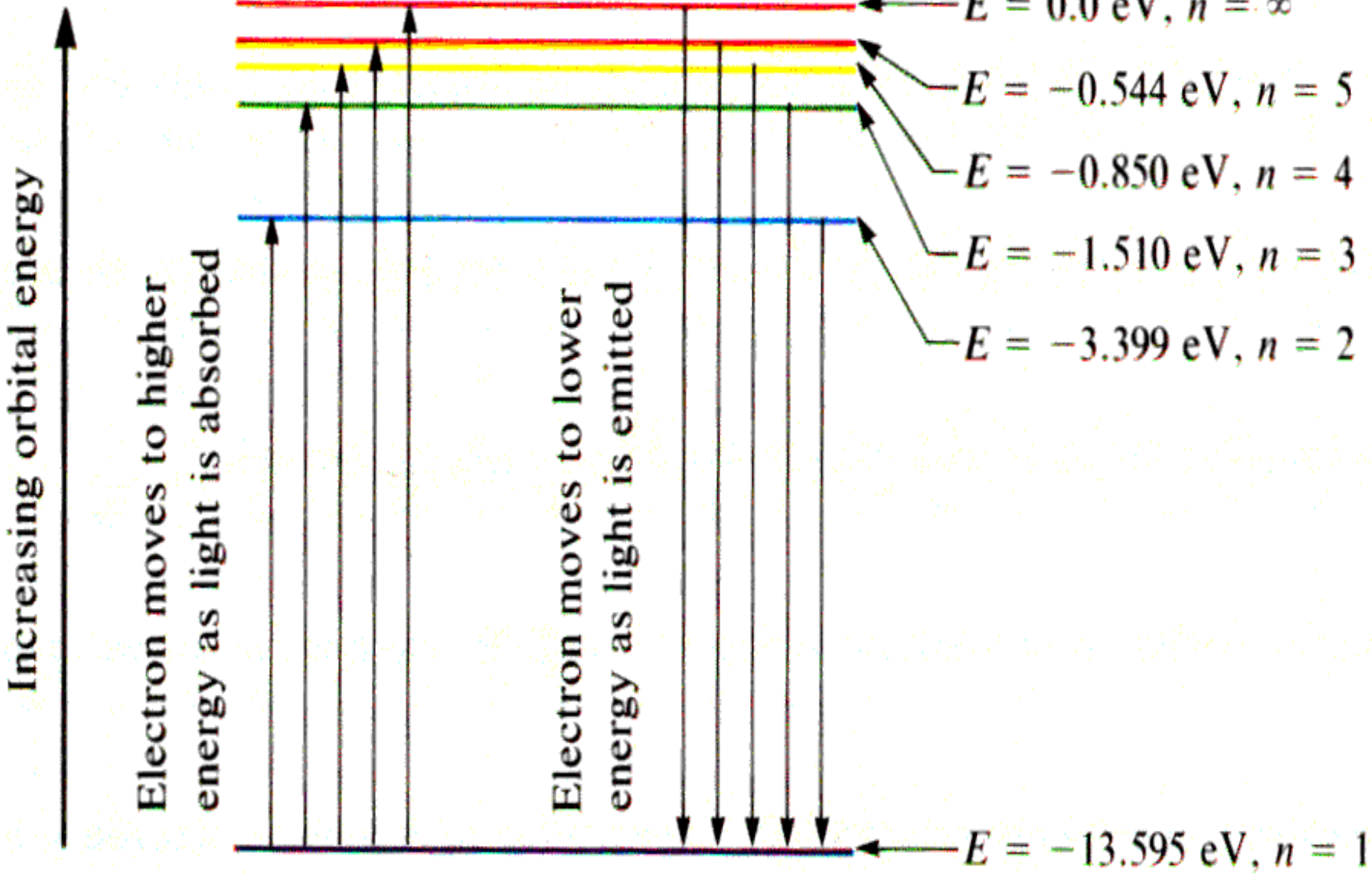


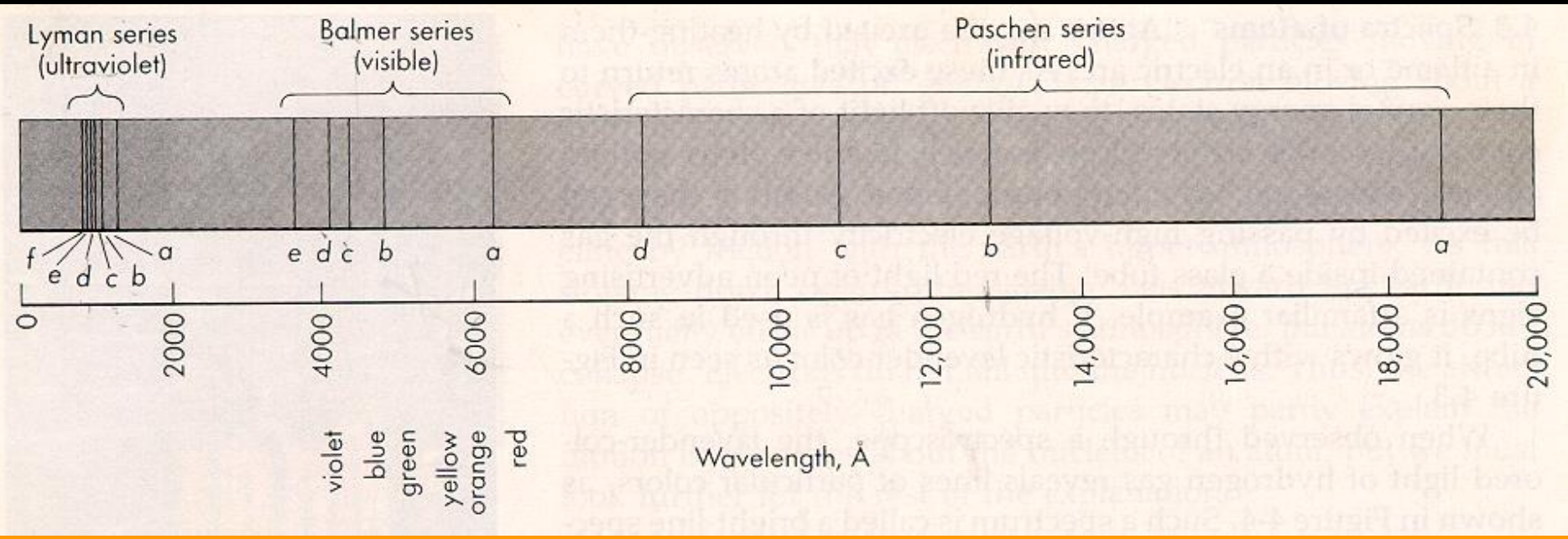
Eugen Goldstein -- 1886

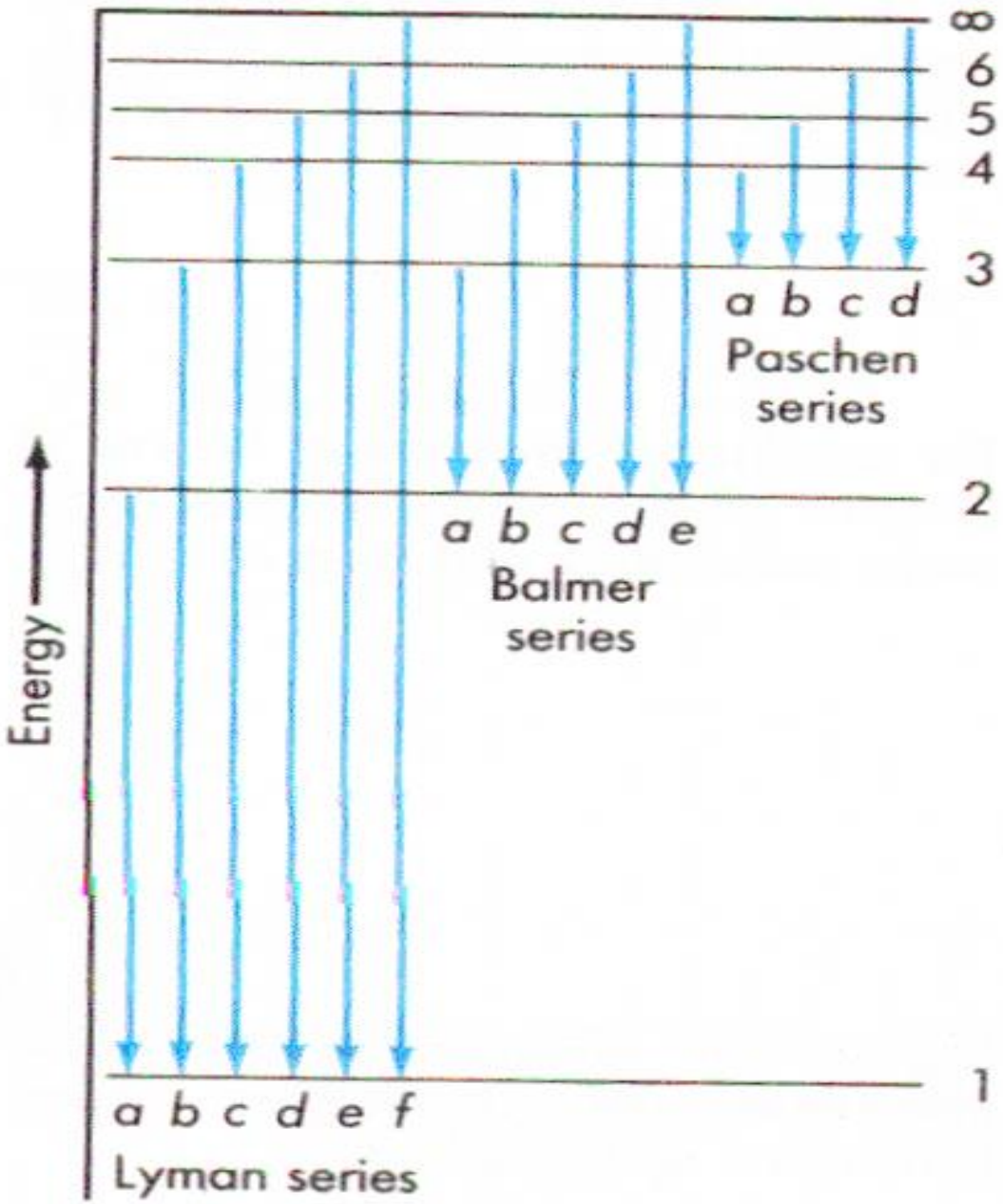
- Used a Crookes tube with holes in the cathode
- Observed another kind of ray which originated near the anode and passed through the holes in the cathode
- Canal rays

J.R. Rydberg -- 1890

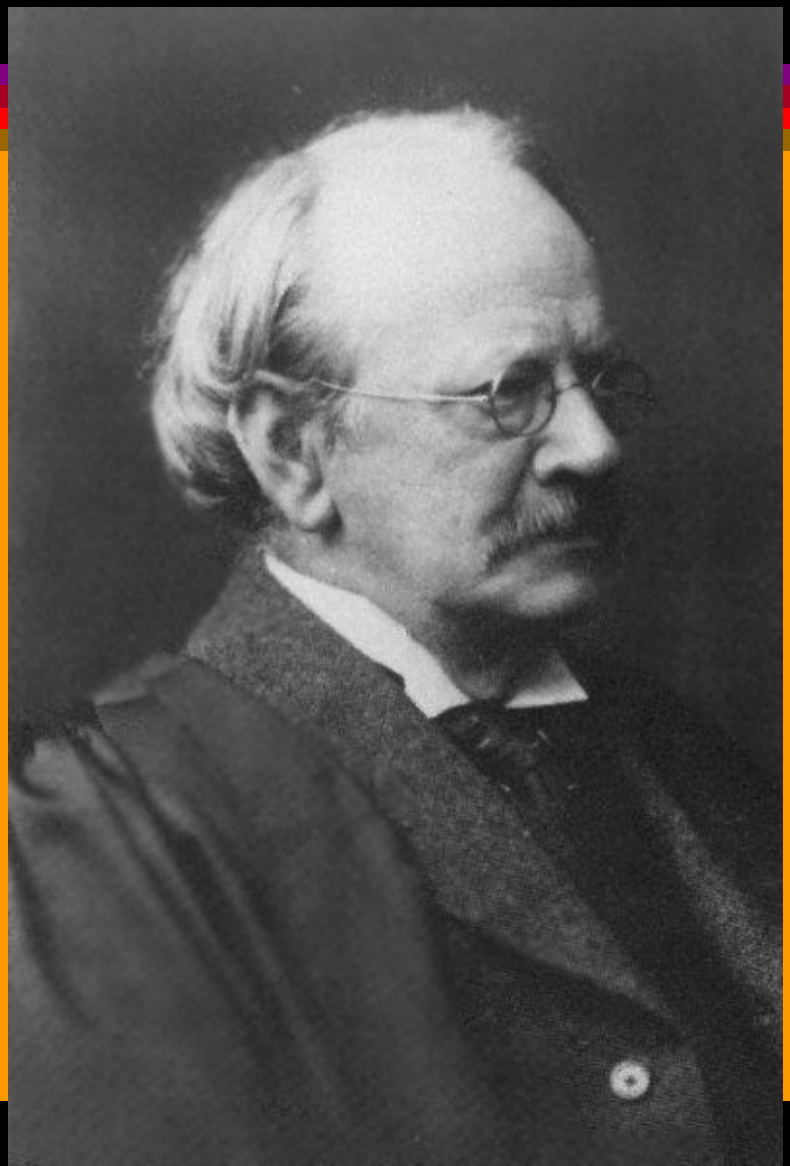
- German
- Developed an equation based on Balmer's work, which describes the energies associated with various energy levels in the hydrogen atom
- $E=h\nu=2.179 \times 10^{-18} J(1/n_1^2 - 1/n_2^2)$


Increasing orbital energy
Electron moves to higher energy as light is absorbed
Electron moves to lower energy as light is emitted
E = 0.0 eV, n = ∞
E = −0.544 eV, n = 5
E = −0.850 eV, n = 4
E = −1.510 eV, n = 3
E = −3.399 eV, n = 2
E = −13.595 eV, n = 1


Lyman series
(ultraviolet)
Balmer series
(visible)
Paschen series
(infrared)
f e d c b a
e d c b a
d c b a
0
2000
4000
6000
8000
10,000
12,000
14,000
16,000
18,000
20,000
violet
blue
green
yellow
orange
red
Wavelength, Å

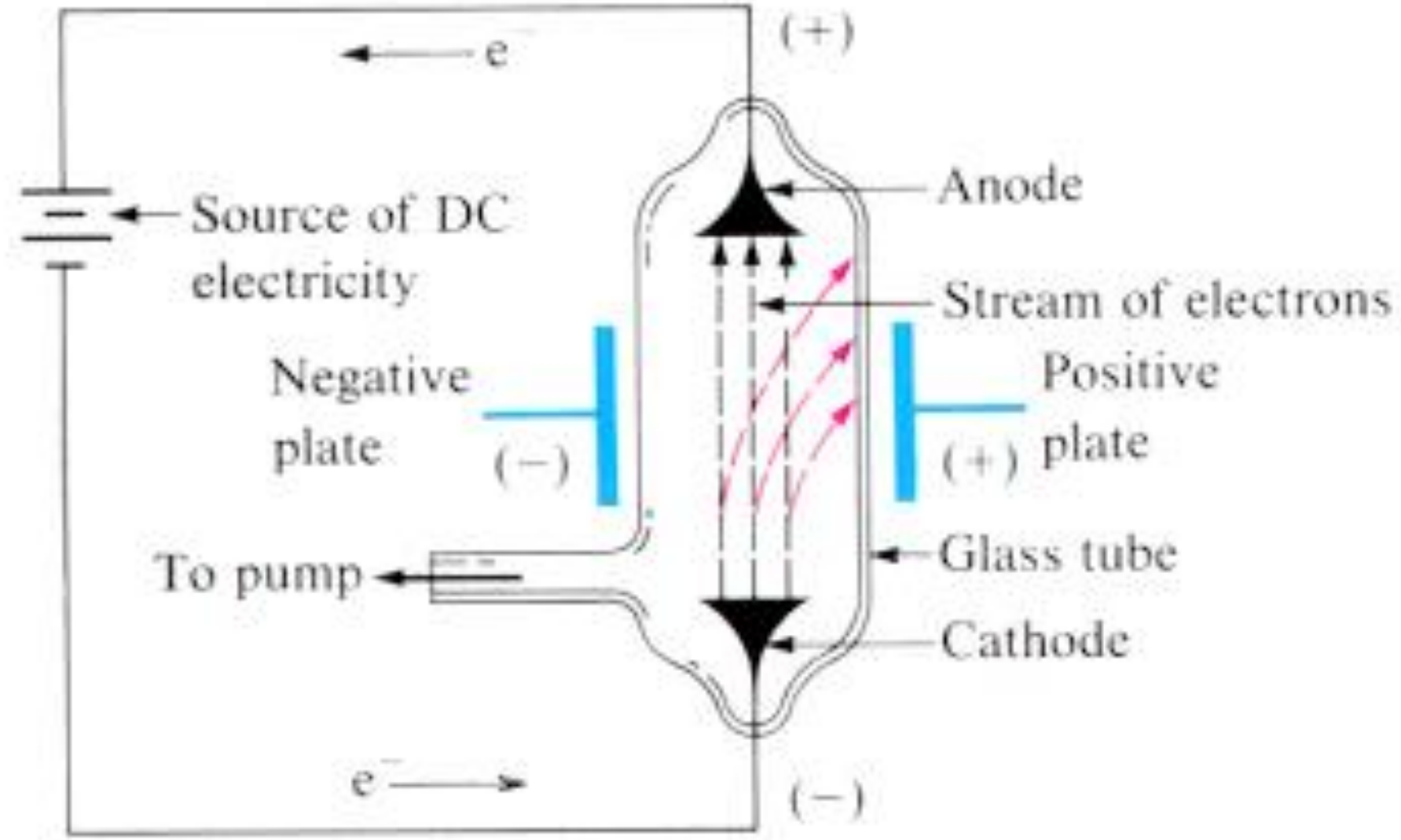

Energy
∞
6
5
4
3
2
1
a b c d
Paschen series
a b c d e
Balmer series
a b c d e f
Lyman series

J.J. Thomson

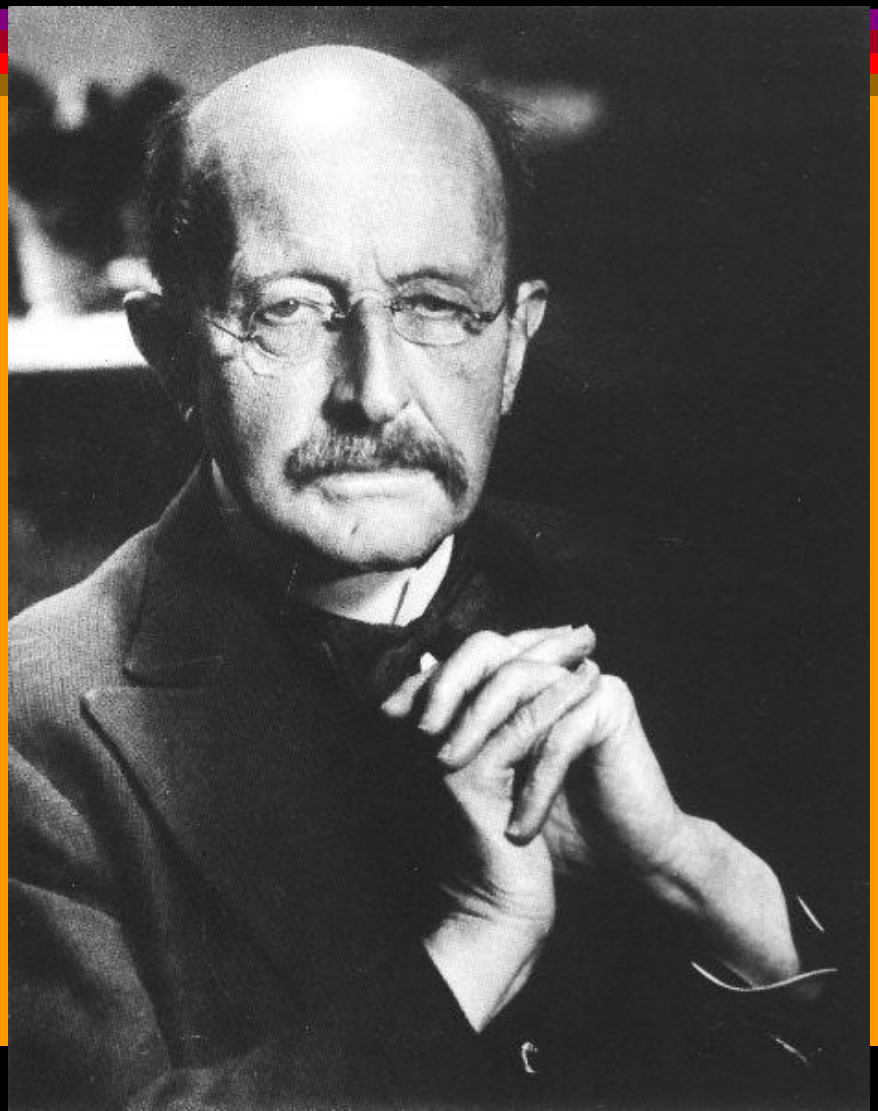


J.J. Thomson -- 1897

- English physicist
- Measured the deflection of cathode ray particles in both a magnetic and an electric field
- Determined the charge (e) to mass (m) ratio and found them to be identical for all particles regardless of the metal used as an electrode or the type of gas within the tube


e⁻
(+)
Source of DC electricity
Anode
Stream of electrons
Negative plate
(−)
Positive plate
(+)
To pump
Glass tube
Cathode
e⁻
(−)

Max Planck



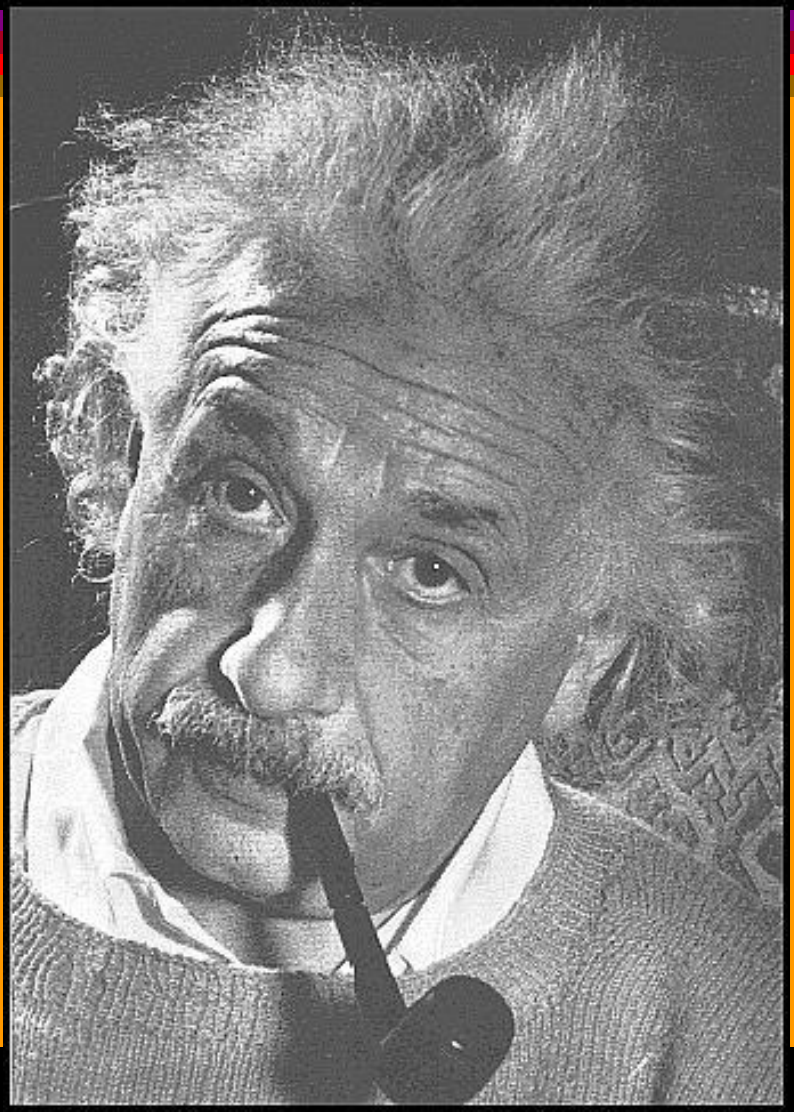
Max Planck -- 1900

- German physicist
- Proposed a quantum theory that described the light emitted from a hot object as composed of discrete unit called quanta or photons
- $E=h\nu$

J.J. Thomson -- 1904

- Proposed a model of the atom with electrons embedded in a sea of positive charges
- Called the “plum-pudding model”

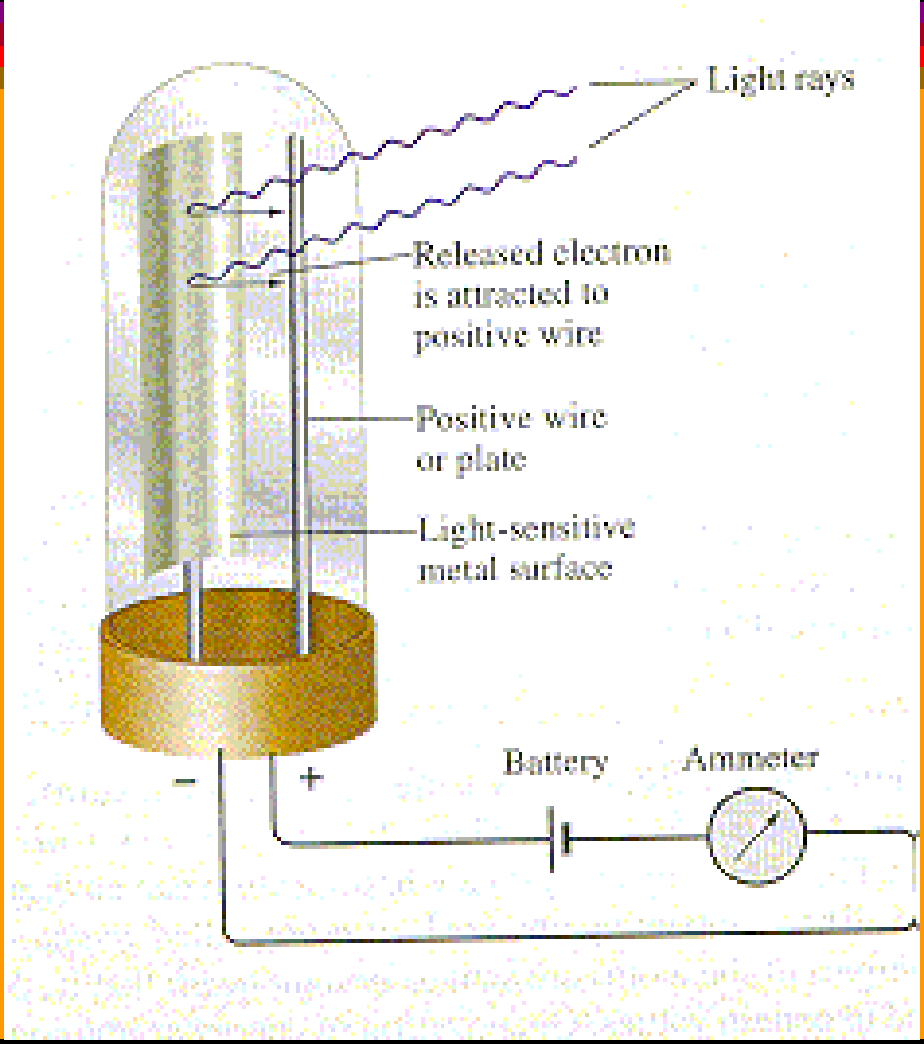
Albert Einstein



Albert Einstein -- 1905

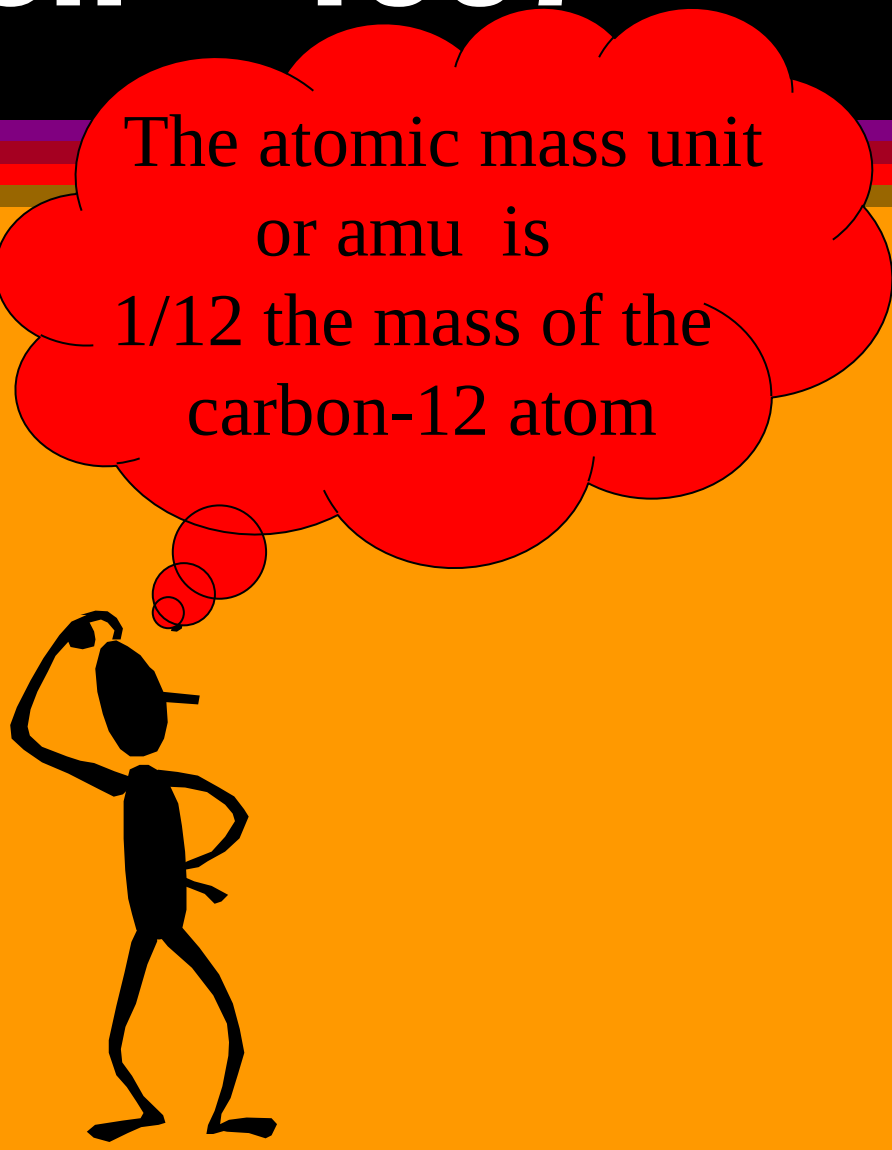
- Published an explanation of the photoelectric effect
  - today the photoelectric effect has resulted in such technology as automatic doors
- Electrons are emitted from metals when these metals are exposed to light of the proper frequency
- $E=h\nu=hc/\lambda$

The Photoelectric Effect



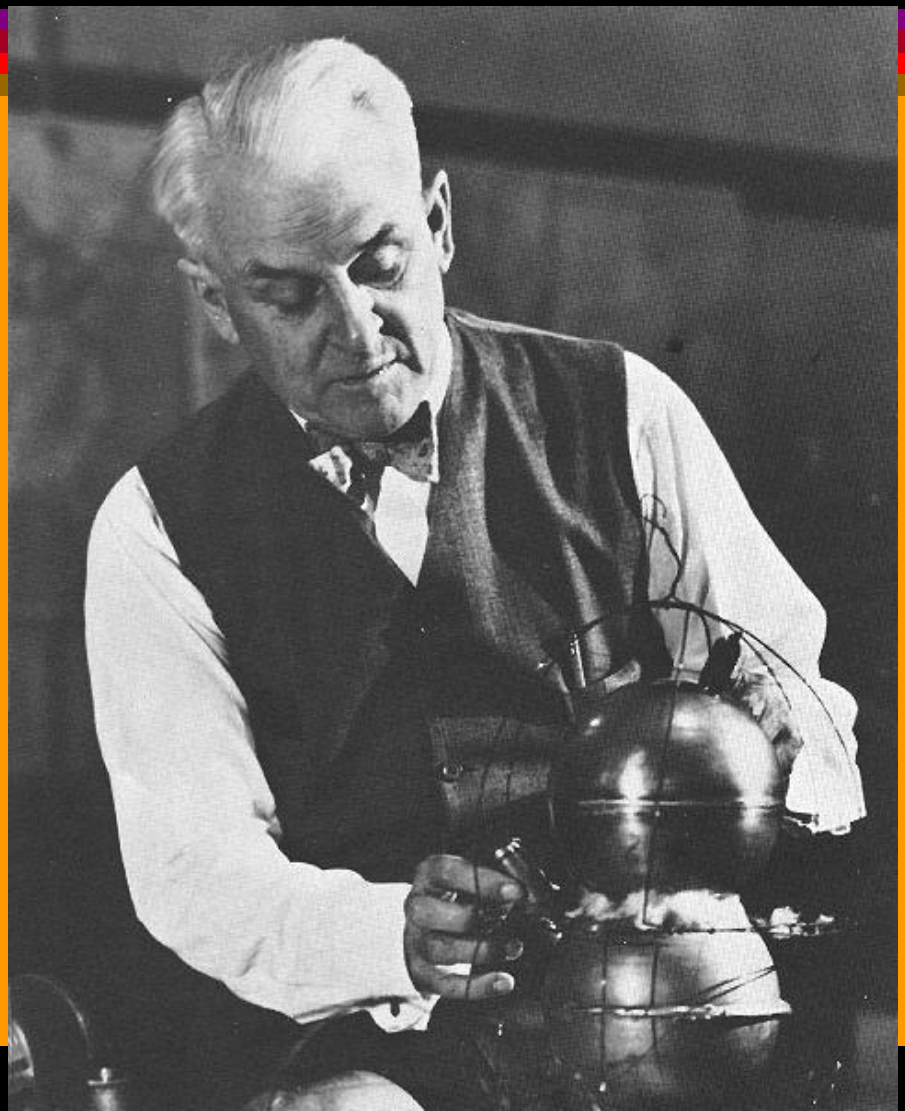
J.J. Thomson -- 1907

- **Determined that Goldstein's rays are positively charged particles called protons**
- **The mass was determined to be**
  - **1.0073 amu**
  - **1.673 X 10^{-27} Kg**



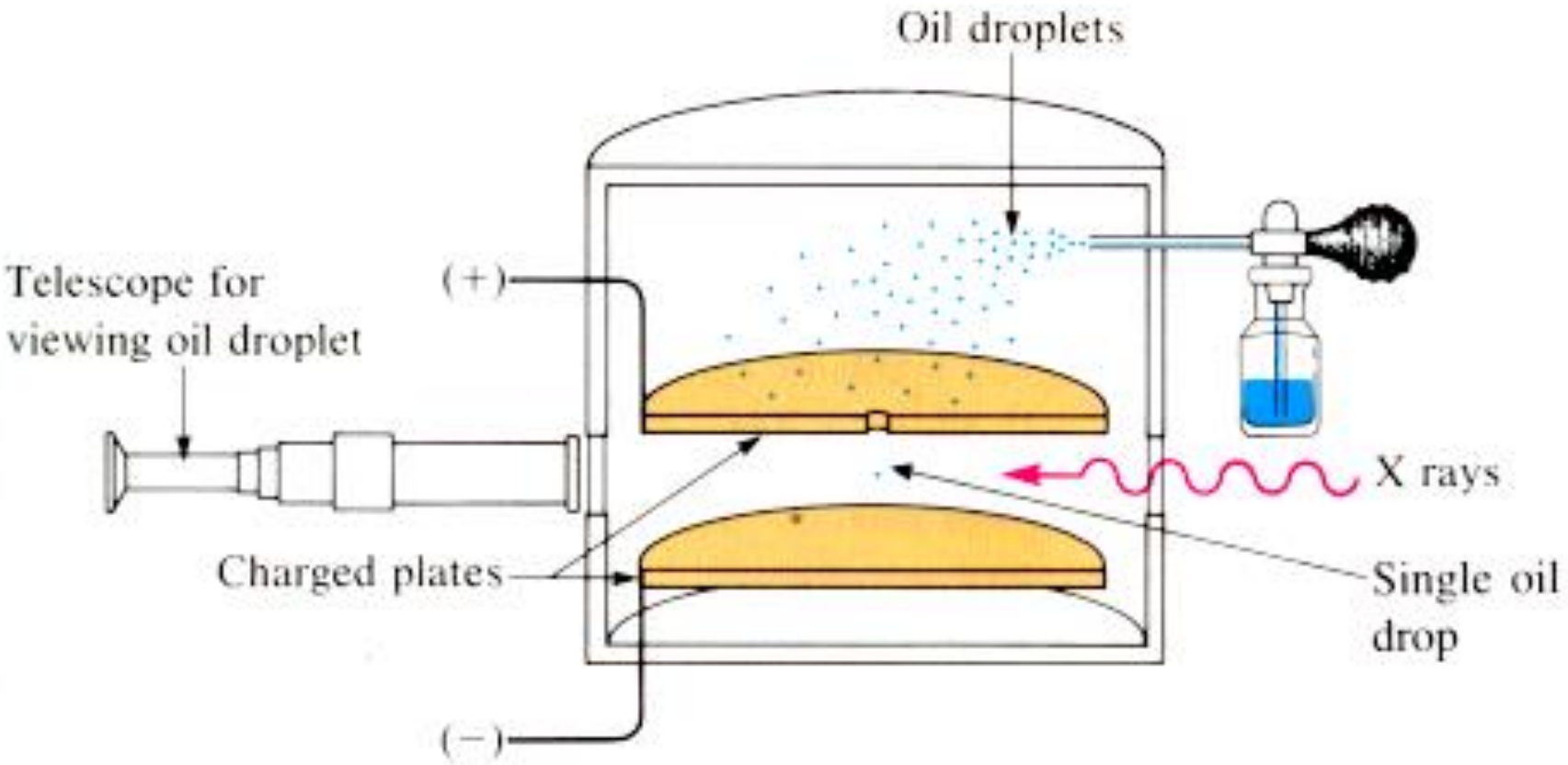
1 amu is
1.660×10^{-27} Kg

Robert Millikan

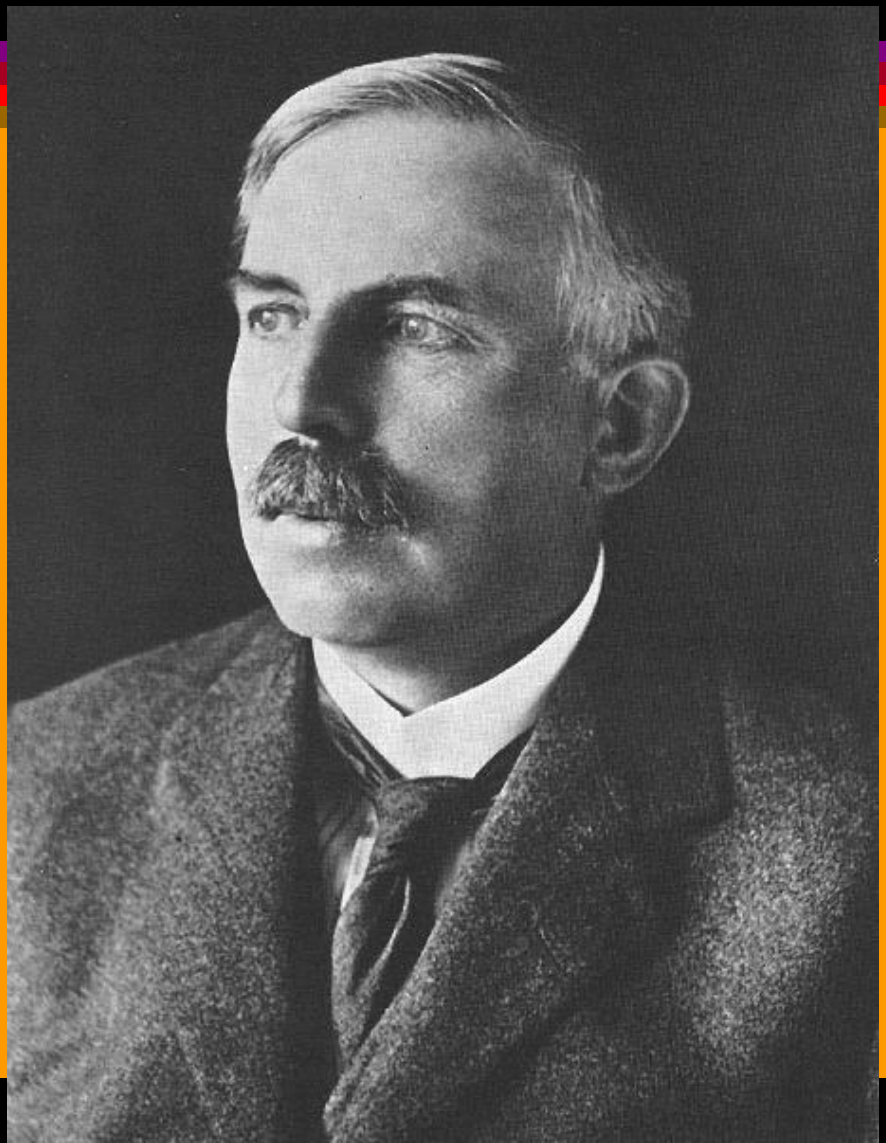


Robert Millikan -- 1909

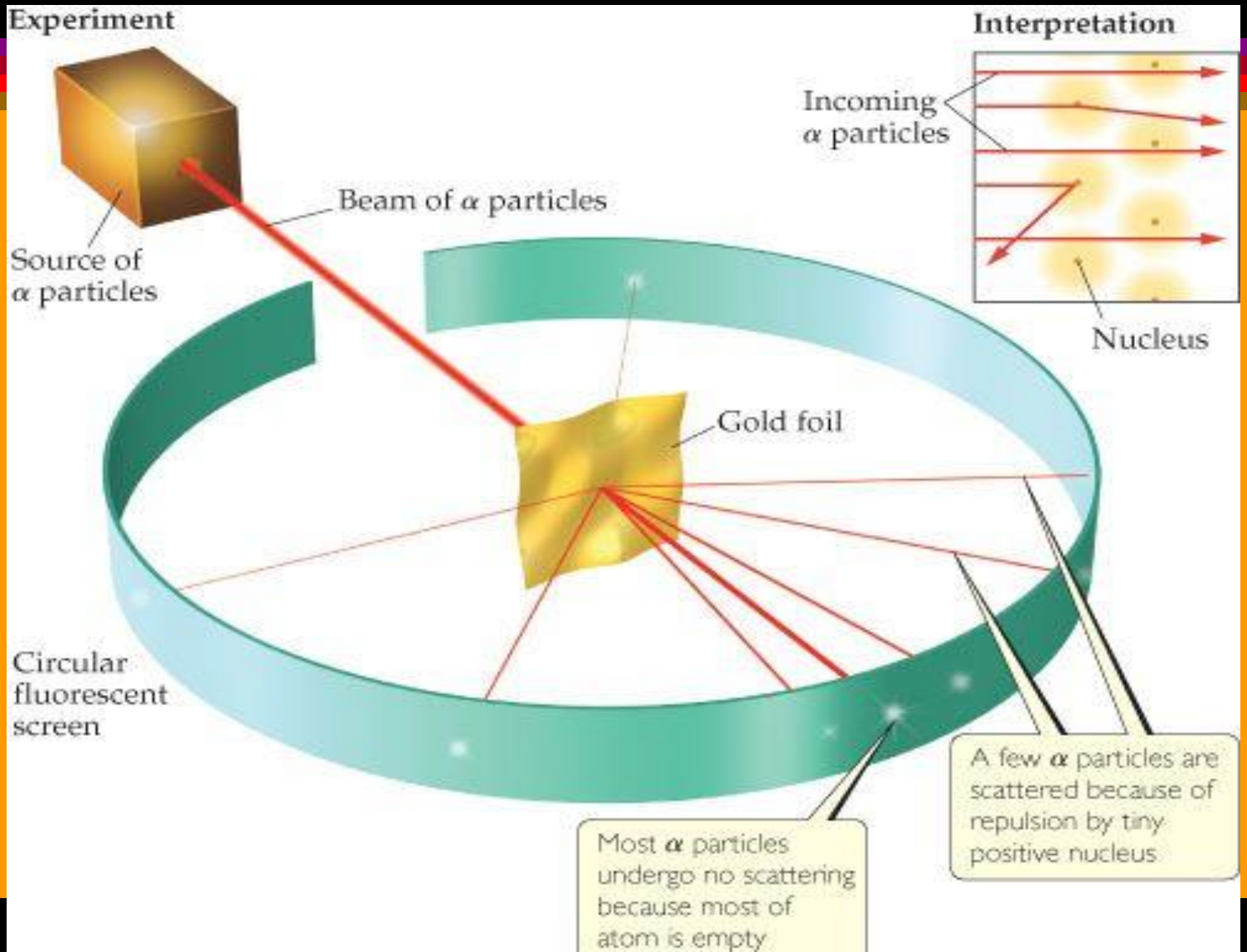
- Millikan Experiment
- Determined the charge of the electron
- From the value of e/m, he found the mass to be 1/1837 of the mass of a hydrogen atom
  - 0.00055 amu
  - 9.11 X 10^{-31} Kg

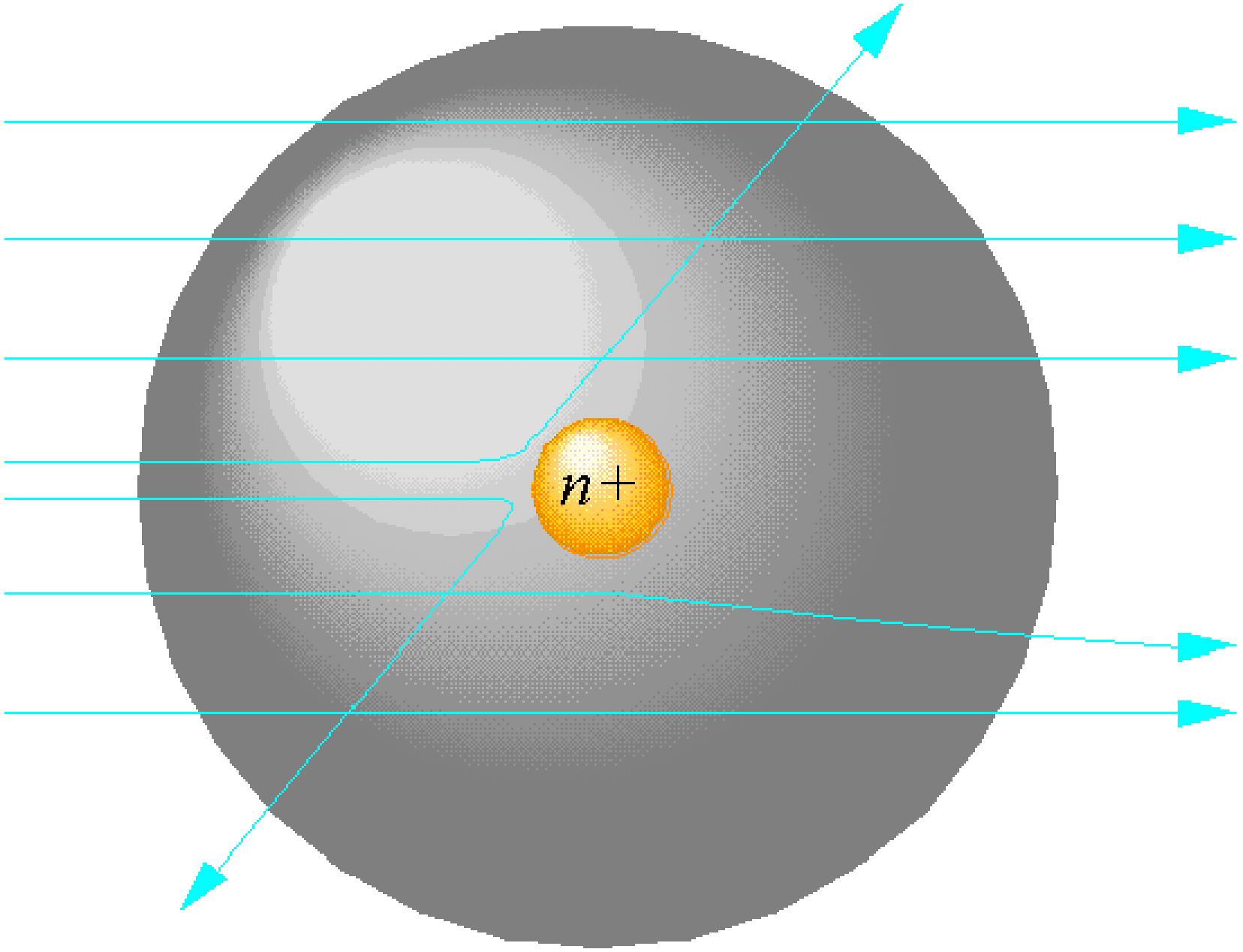

Oil droplets
Telescope for
viewing oil droplet
(+)
X rays
Charged plates
Single oil
drop
(−)

Ernest Rutherford



1909 -- Rutherford Experiment

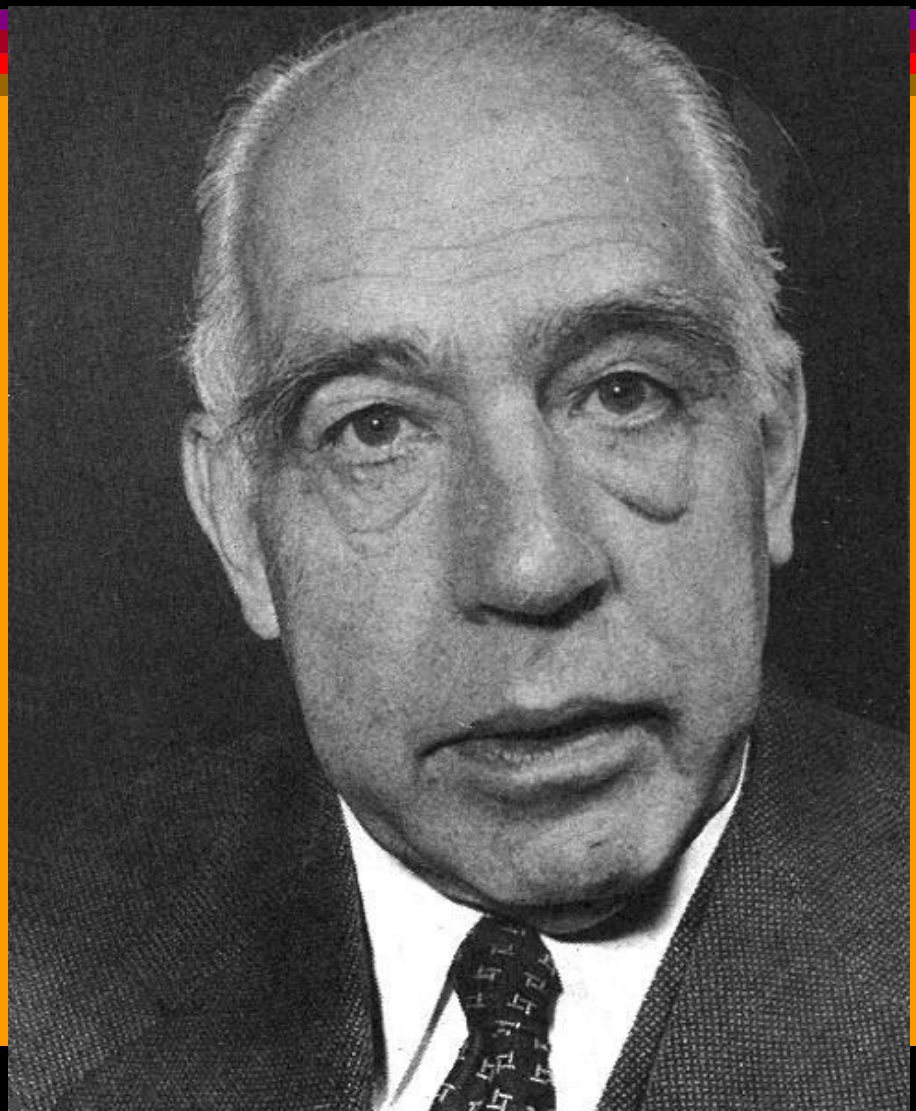



n+

Ernest Rutherford -- 1911

- Published his 1909 work in 1911
- Projected a beam of α particles onto a very thin gold foil
- From experimental results, Rutherford concluded:
  - the volume occupied by an atom is largely empty space
  - each atom contains a massive, positively charged nucleus
  - electrons move about the nucleus giving the atom its volume

Niels Bohr -- 1913



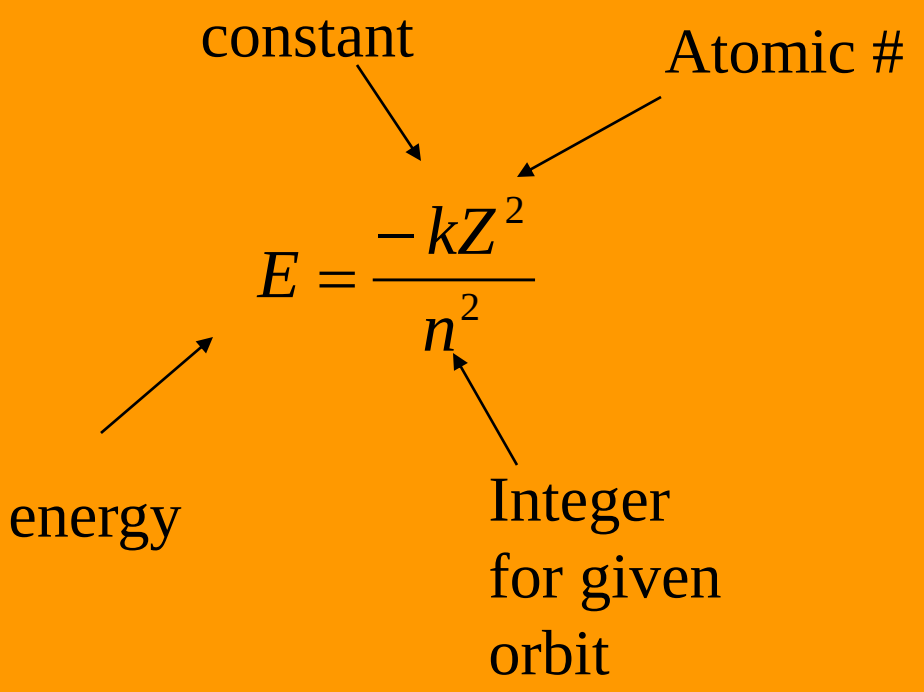
Niels Bohr -- 1913

- Proposed that the electron's energy is quantized
- Developed the Bohr model of the atom
  - Often called the planetary model

- The electron of hydrogen moves about the nucleus in a circular orbit
- The centrifugal force due to this motion counterbalances the electrostatic attraction between the nucleus and the electron

- **The energy of the electron is restricted to certain values, each corresponding to an orbit with a different radius**

- **Quantum number**

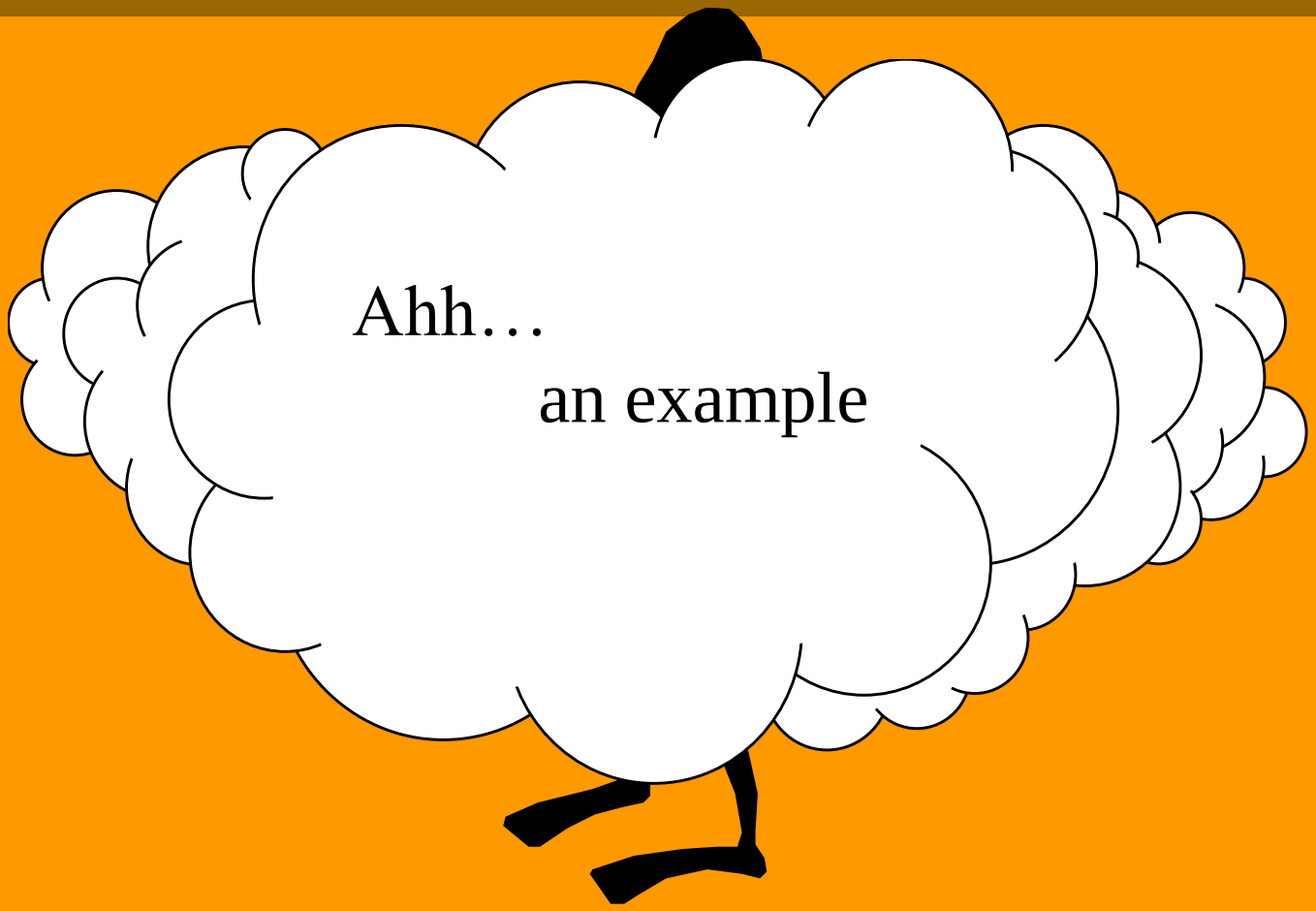


Integer characteristic of an orbit

Radius of hydrogen atom

$$R_{orbit} = \frac{n^2 a_o}{Z}$$

Atomic #


Ahh…
an example

- If a spark promotes the electron in a hydrogen atom into an orbit with n=3, what is the calculated energy, in joules, of the electron?

First…Which equation is needed?

$$E = \frac{-kZ^2}{n^2}$$

Second…What is given?

- **Hydrogen atom**
- **n=3**

Third…How do I set the problem up?

$$E = \frac{-\left(2.179 \times 10^{-18}\ \text{J}\right)(1)^2}{(3)^2} = -2.421 \times 10^{-19}\ \text{J}$$

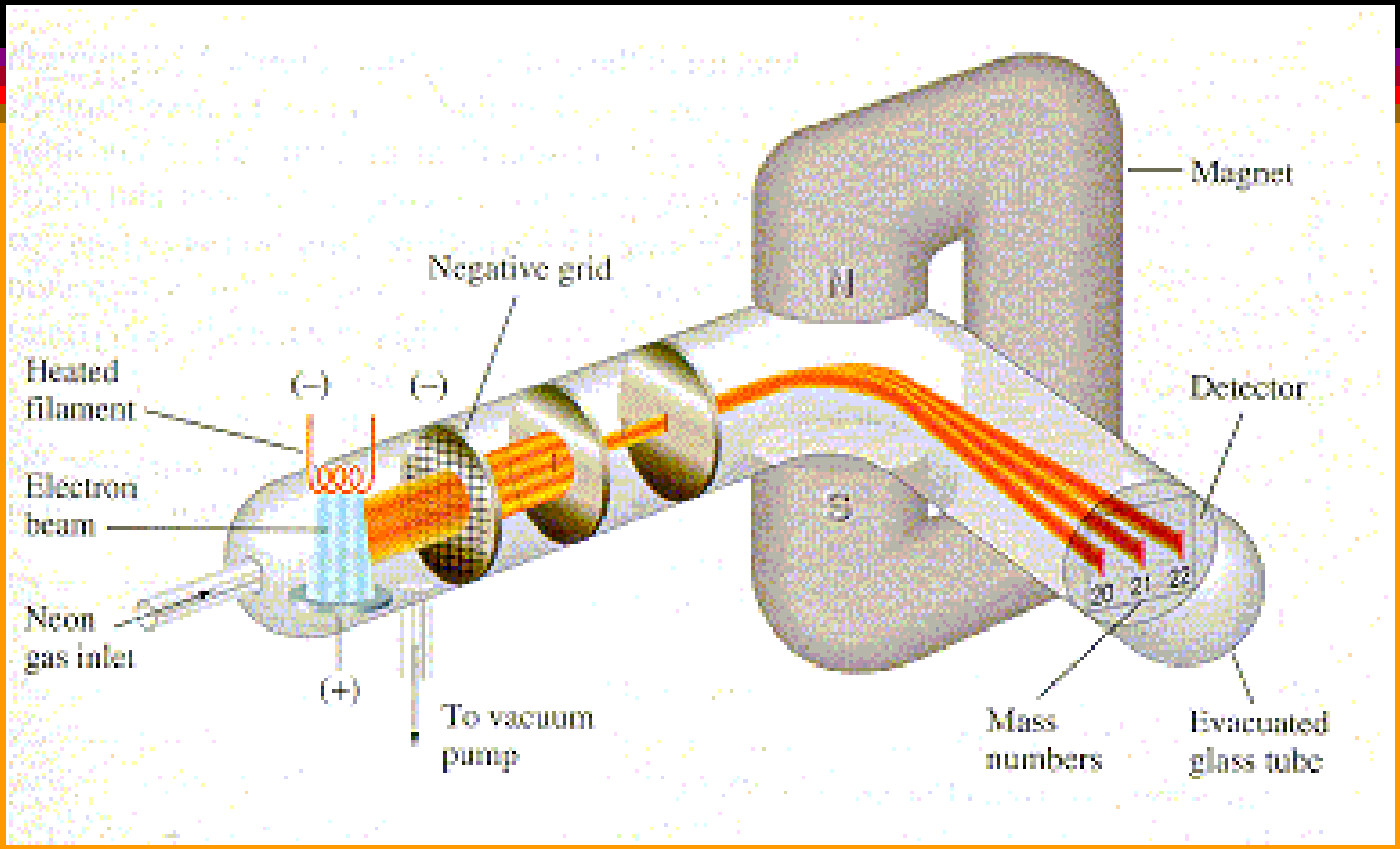
Henry Moseley -- 1913

- English physicist
- Killed during World War I
- Used X-rays striking an element to determine the number of protons (atomic number) in the nucleus
- X-rays produced by various elements were measured
- The X-ray energies were dependent on the atomic number of each element

F.W. Aston -- 1913-14

- **Developed the mass spectrometer**
  - **Gaseous substance are bombarded by high-energy electrons, thus knocking off electrons so as to produce positively charged ions**
  - **Ions are directed through a magnetic or electrical field, which deflects their paths depending on their mass/charge ratio**

Mass Spectrometer



- Atoms of the same element have differing masses
- Identified the isotopes of various elements

Masson, Harkins, & Rutherford 1920

- **Orme Masson (Australian)**
- **William Harkins (American)**
- **Ernest Rutherford (New Zealander)**

Independently postulate the existence of an uncharged particle with the same mass as the proton (neutron).

Failures with the Bohr model lead to a need for a new atomic model

- Electrostatic attraction of positive nucleus and negative electrons.
- Centrifugal force holding the nucleus and electrons apart.

VS

Electrons behave as a wave as well as a particle.

Bohr's Model Provides Insight into Atom's Behavior

- Energies of electrons (energy levels) are quantized.
- Quantum numbers describe such electron properties as energy and location.
- An electron's energy changes with distance from the nucleus.
- Spectral lines of the elements are due to quantized electronic energies.

Nucleons

The total of all nuclear particles. Includes both protons & neutrons.

Atomic Mass

The mass in atomic mass units of an element

Molecular Mass

The mass in atomic mass units of a molecule

Formula Mass

or

Empirical Mass

The mass in

atomic mass units

of an ionic compound

NaCl

Na - 23.0 X 1 = 23.0

Cl - 35.5 X 1 = 35.5

58.5 amu

CO_2

C - 12 X 1 = 12

O - 16 X 2 = 32

----

44 amu

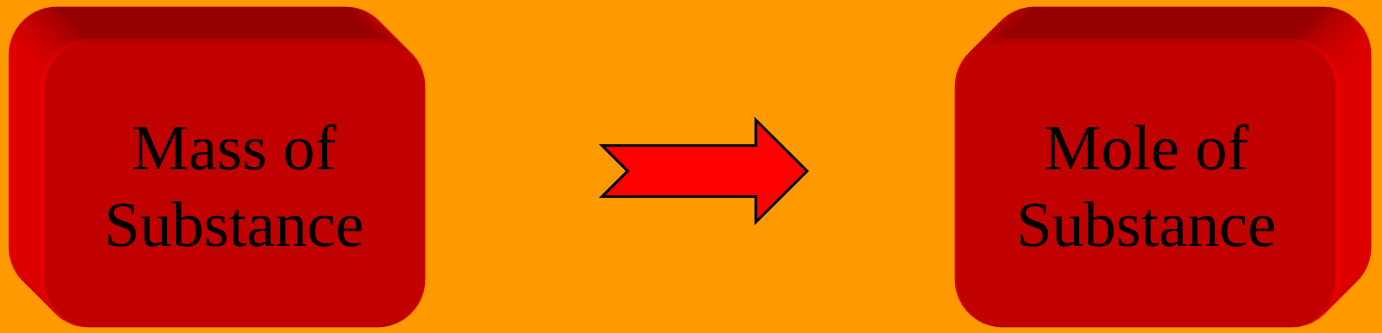
Moles

- The quantity of matter containing Avogadro's number of particles
- 6.022 X 10^{23} particles
- Particles may include:
  - subatomic particles
  - ions
  - atoms
  - molecules

Molar Mass

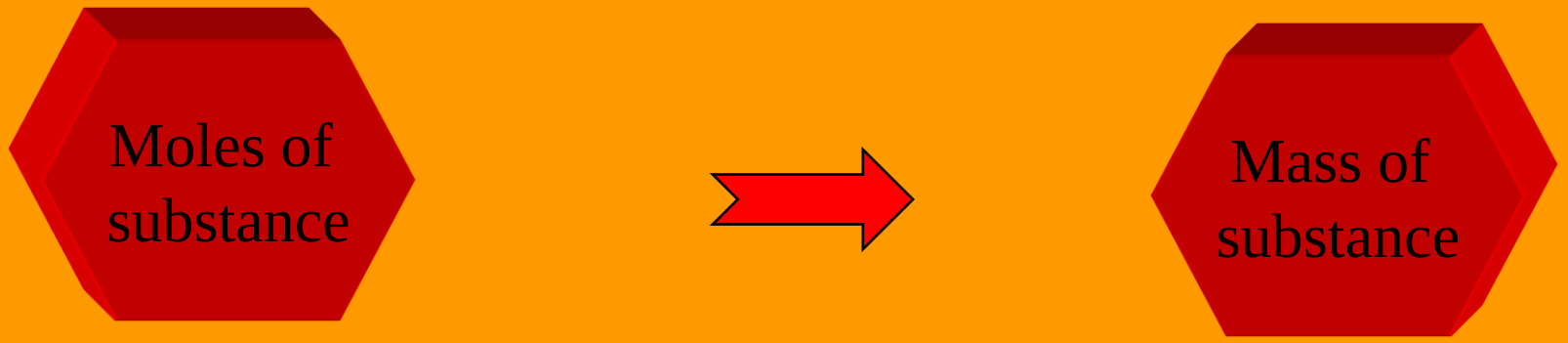
The mass of
one mole of a substance
in
grams

Calculating moles from grams



Divide grams by molar mass

Calculating grams from moles



Multiply moles by molar mass

Nuclear Chemistry

- **Nuclear equation: Elemental symbols represent only the *nuclei* of atoms.**
- **The subscript represents only the number of nuclear charges (protons or atomic number).**

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}e$$

Alpha (α) Radiation

Helium nuclei

$$^{4}_{2}He$$

Beta (β) Radiation

electron

$${}^{0}_{-1}e$$

Gamma (γ) Radiation

Electromagnetic radiation

Positron Emission

A proton changes into a neutron plus an ejected positron.

Electron Capture

The nucleus captures one of the surrounding electrons in an atom, thereby converting a proton into a neutron.