화학 General Chemistry
034.020-005

2018 Spring Semester

Tue/Thr 9:30~10:45
Building 028-302

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Lecture 1-Outline

1) Atom Theories

2) Quantum Theories

3) Hydrogen Atom

4) Multi-electron Atoms

5) Periodic Table

1.0. Atom

: Smallest unit of matter that has the properties of a chemical element.

400 B.C.

"All matter is composed of indivisible small particles called atomos"

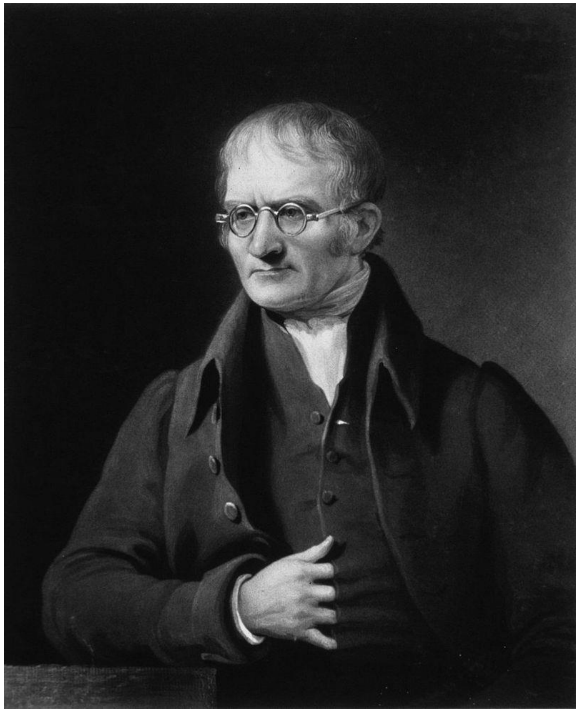
atomos = a (not) + tomos (cut)

in- divisible

- Dalton's Atomic Theory (1808)

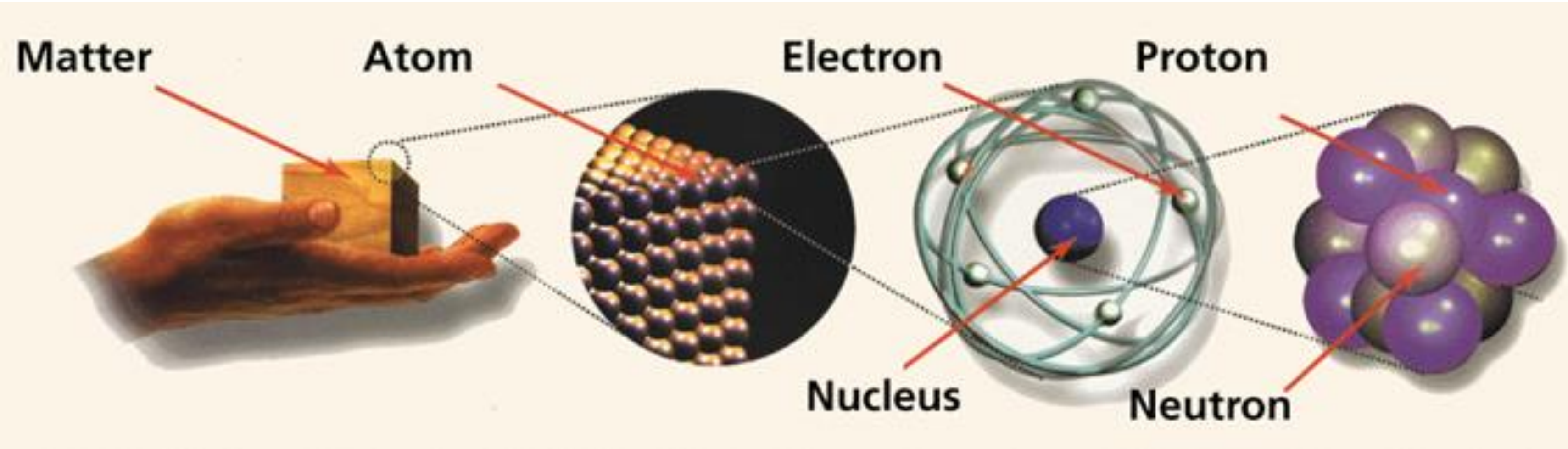
1) All matter is made of atoms. Atoms are indivisible and indestructible.
2) All atoms of a given element are identical in mass and properties.
3) Compounds are formed by a combination of two or more different kinds of atoms.
4) A chemical reaction is a rearrangement of atoms.

Today we know that 1) atoms can be destroyed via nuclear reactions but not by chemical reactions. Also, 2) there are isotopes, of which chemical properties are the same but their mass are different.

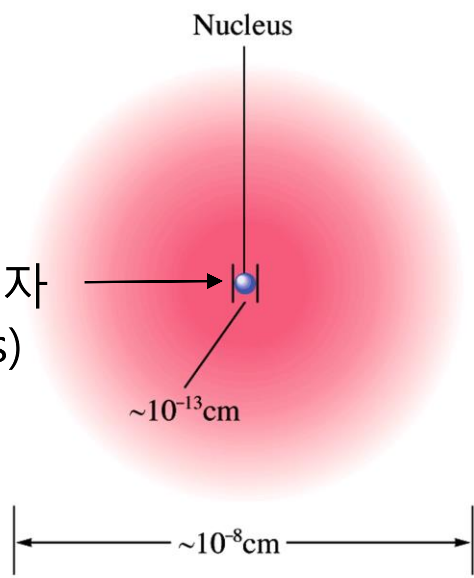


John Dalton
(1766 –1844)

Atom



- 양성자 (proton)
- 중성자 (neutron)
- <u>**전자 (electron)**</u>



1.1. Atom: Nuclear Model

J.J. Thomson
(1856 – 1940)

Nobel Prize
in Physics in 1906

R.A. Millikan
(1868 – 1953)

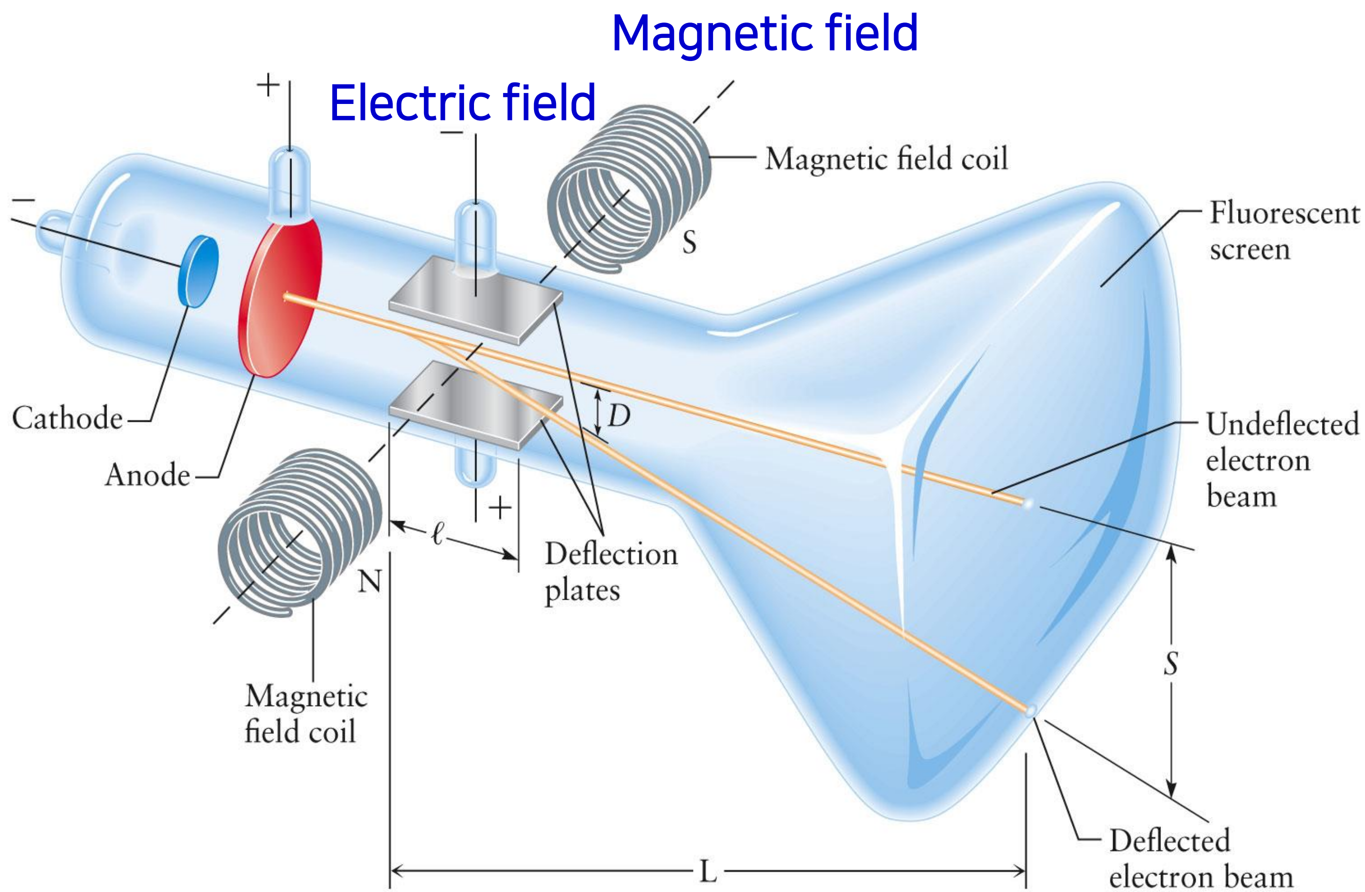
Nobel Prize
in Physics in 1923

Ernest Rutherford
(1871 – 1937)

Nobel Prize
in Chemistry in 1908.
Also Known as a father
of nuclear physics

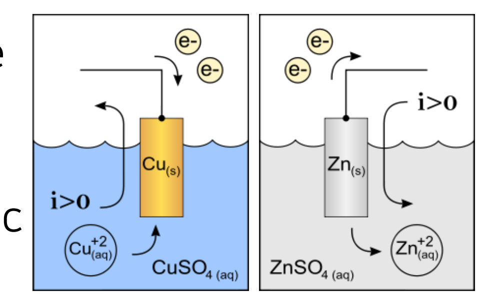
Cathode Ray Experiment by J.J. Thomson (1897)

- Crookes tube

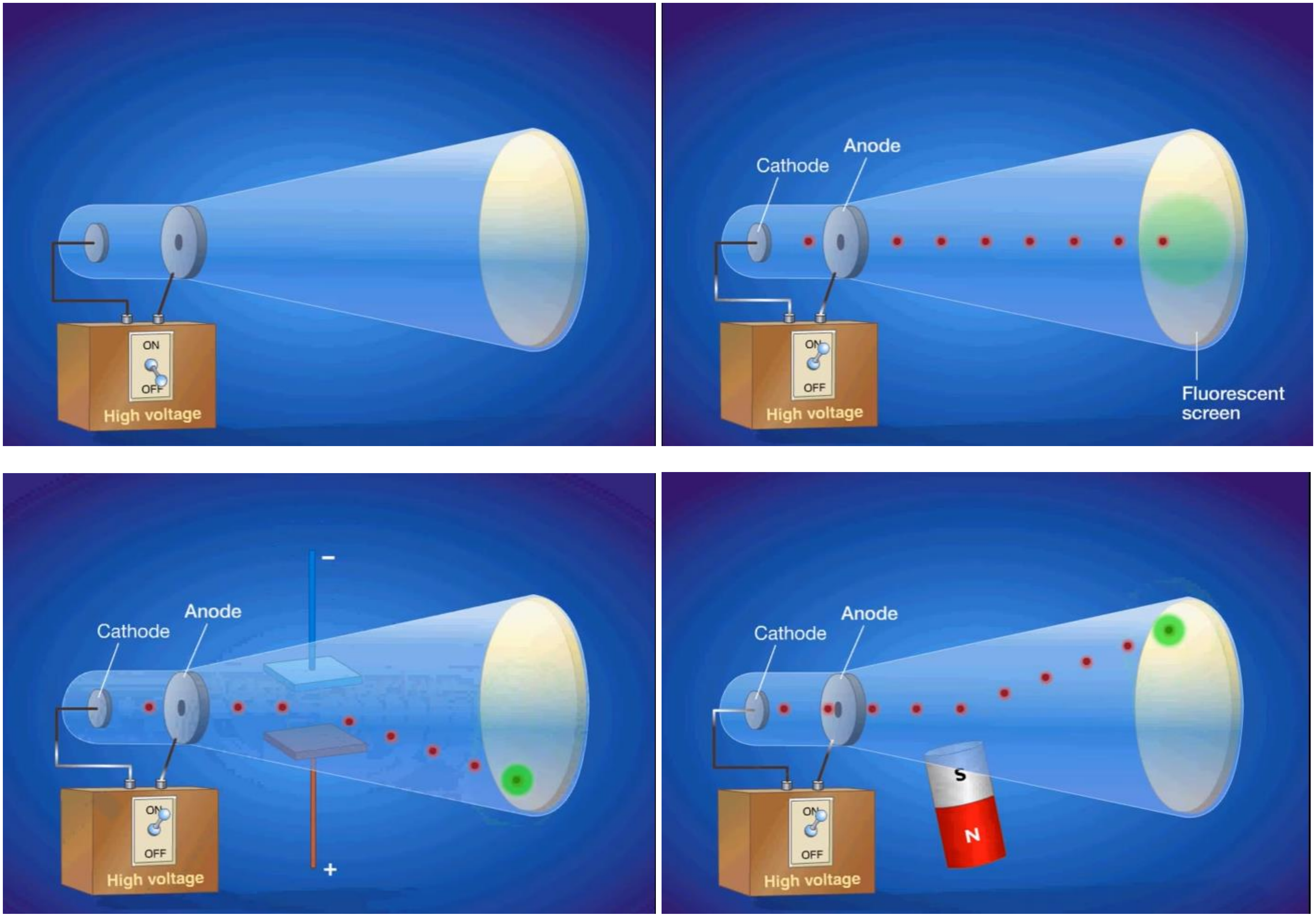


Cathode: Greek *kata-(down)+hodos(way):* way down for electrons or the electrode that positive electronic charges (cation) move into.

Anode: Greek *ana-(up)+hodos(way):* way up for electrons or the electrode that positive electronic charges (cation) flow away from.

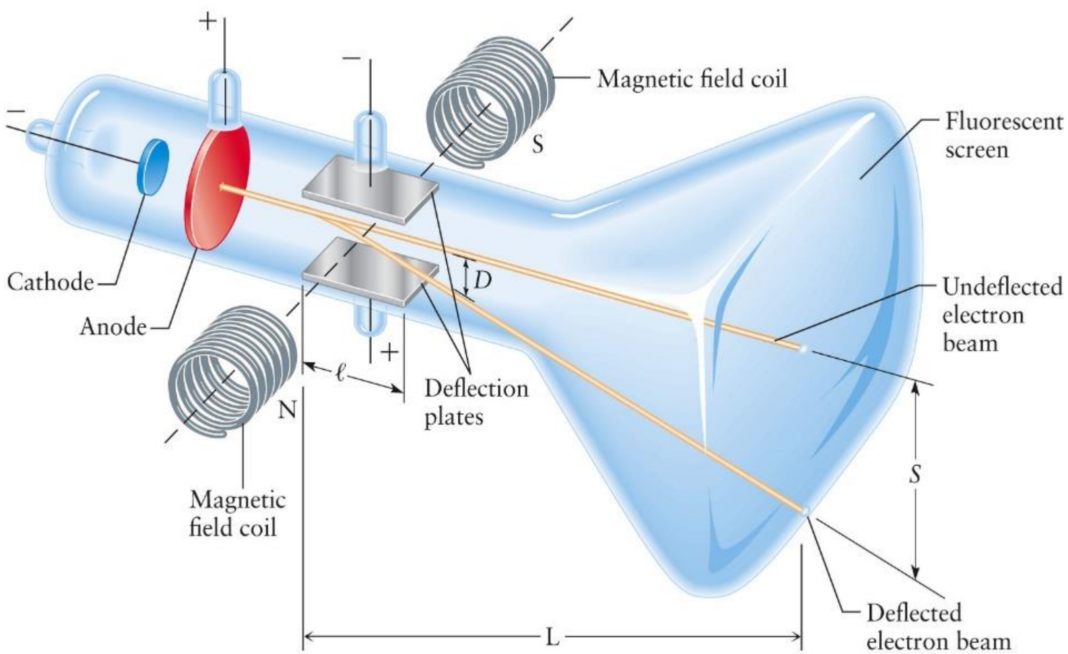


Cathode Ray Experiment by J.J. Thomson (1897)



Only if you are interested…

Cathode Ray Experiment by J.J. Thomson (1897)



1) Magnetic field = 0

$$F_E = eE$$
$$D = \tfrac{1}{2}at^2$$
$$F_E = m_e a = eE$$
$$a = (e/m_e)E$$
$$D = \tfrac{1}{2}(e/m_e)Et^2$$
$$= \tfrac{1}{2}(e/m_e)E(l/v)^2$$
$$S = (L/l)*D$$
$$= \tfrac{1}{2}(e/m_e)E(L/l)(l/v)^2$$

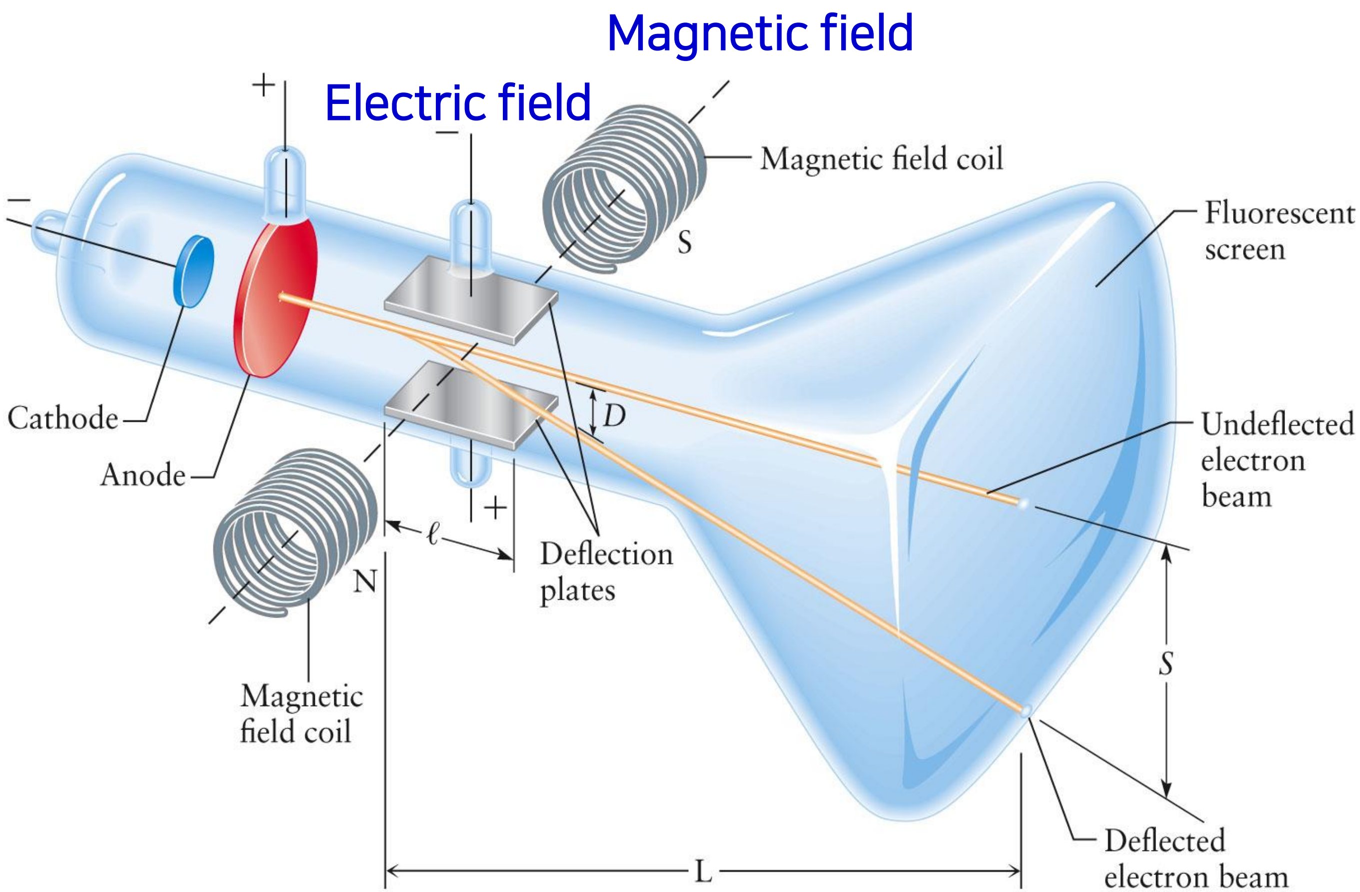
2) Magnetic field ≠ 0

$$F_B = evB$$
$$F_E = F_B$$
$$eE = evB$$
$$v = E/B$$

$$S = \tfrac{1}{2}(e/m_e)E(L/l)(l/v)^2$$
$$= \tfrac{1}{2}(e/m_e)E(Ll)(B/E)^2$$
$$e/m_e = 2SE/lLB^2$$

Cathode Ray Experiment by J.J. Thomson (1897)

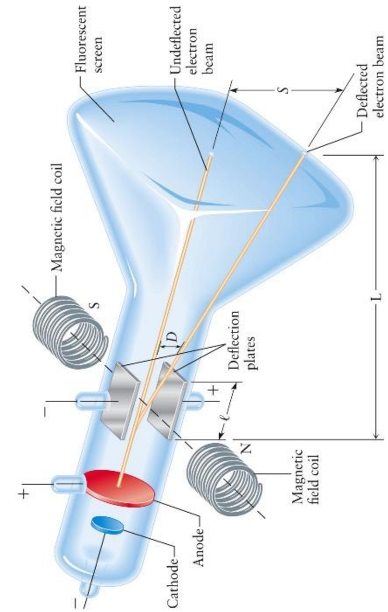
- Crookes tube

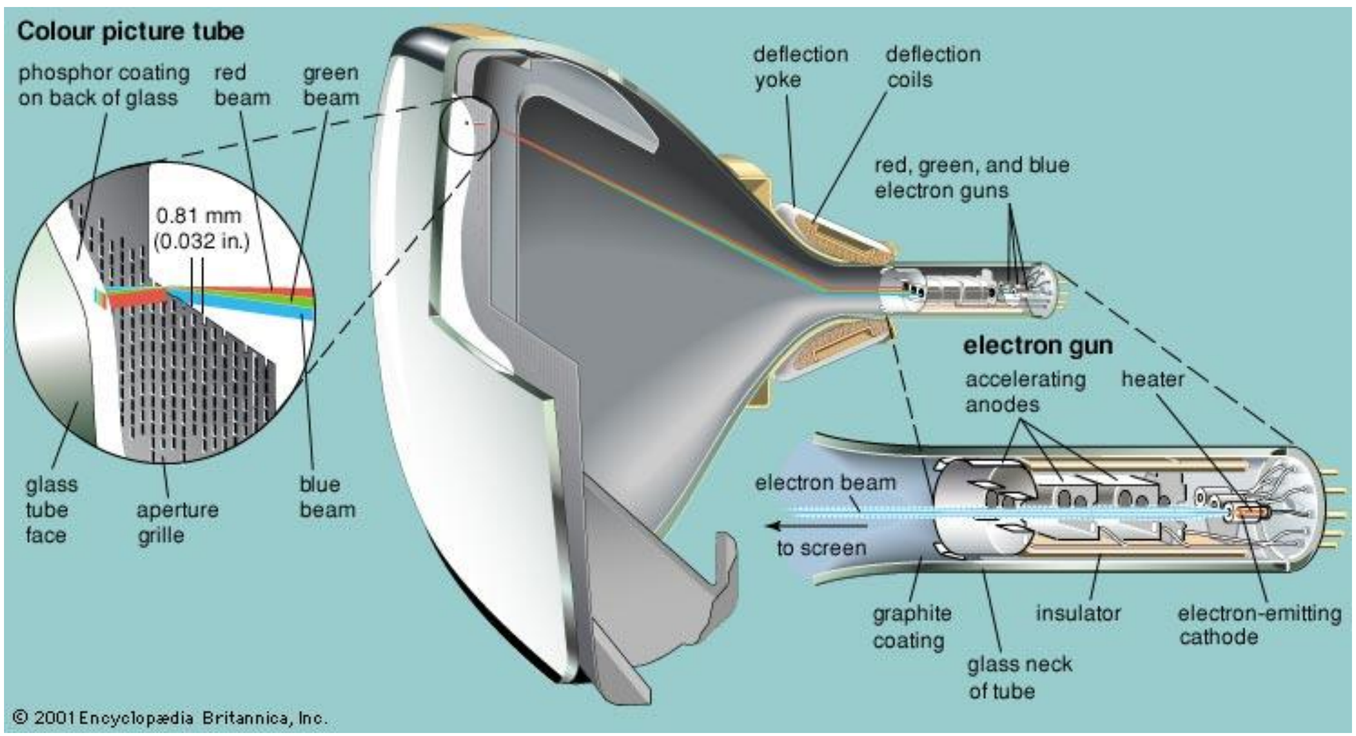


→ Atoms are actually composed of aggregates of

→ Electron is a subatomic particle with

→ Determined the


Fluorescent screen
Undeflected electron beam
Deflected electron beam
Magnetic field coil
Deflection plates
Magnetic field coil
Anode
Cathode
S
N
L
D


Colour picture tube
phosphor coating on back of glass
red beam
green beam
0.81 mm (0.032 in.)
glass tube face
aperture grille
blue beam
deflection yoke
deflection coils
red, green, and blue electron guns
electron gun
accelerating anodes
heater
electron beam
to screen
graphite coating
glass neck of tube
insulator
electron-emitting cathode
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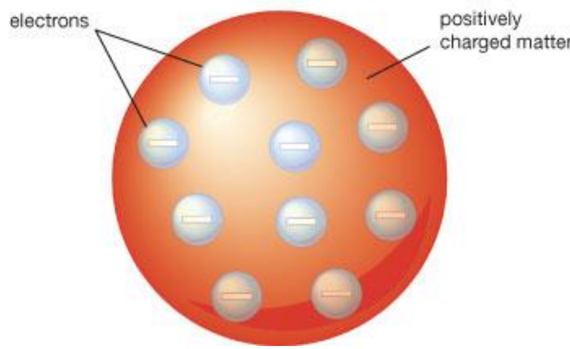
Cathode Ray Experiment by J.J. Thomson (1897)
Oil-drop Experiment by R.A. Millikan (1910)

J.J. Thomson (1897)

Nobel Prize in Physics in 1906

Plum pudding model

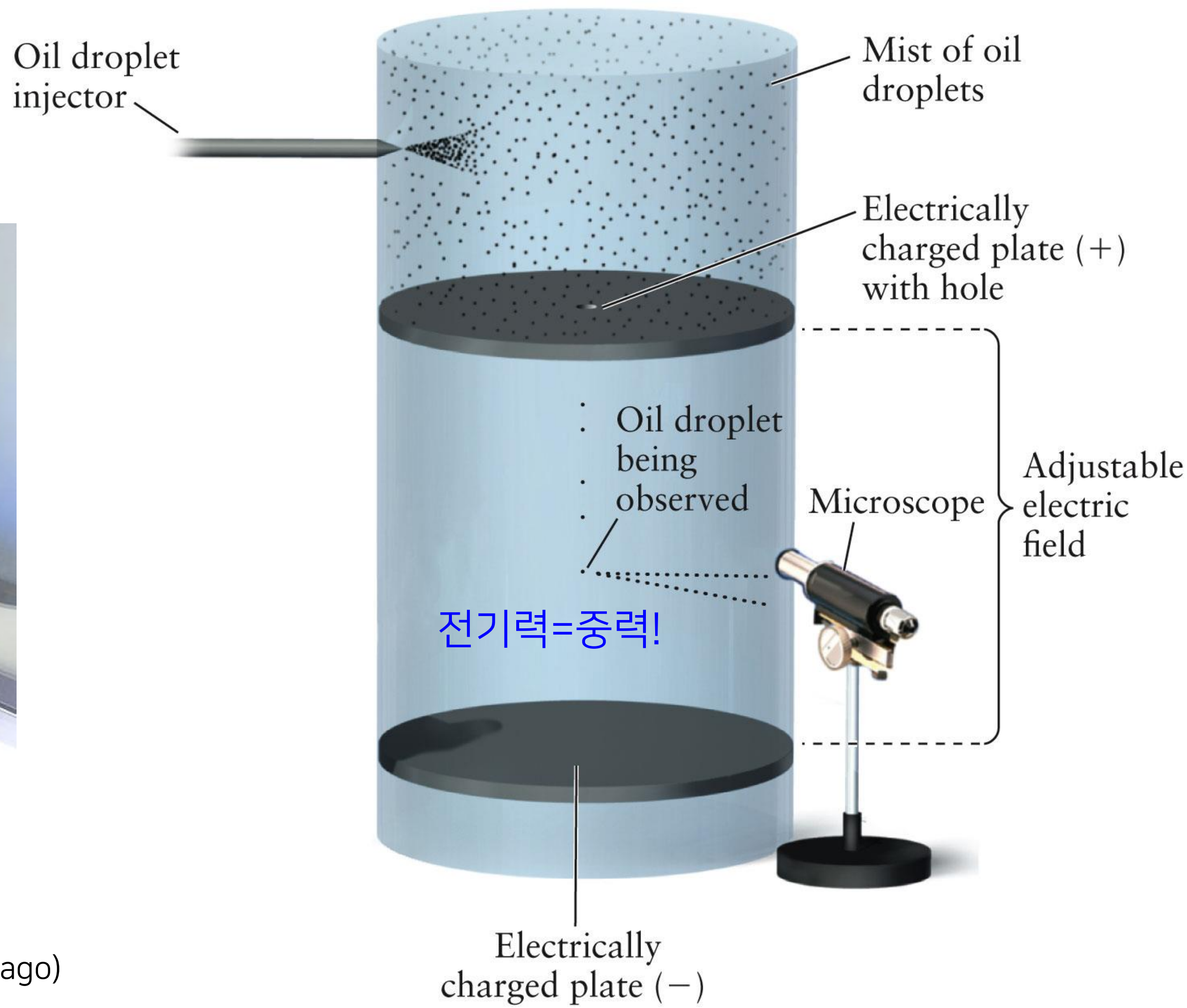


R.A. Millikan (1910)

Nobel Prize in Physics in1923

Oil-drop Experiment by R.A. Millikan (1910)

Museum of Science and Industry (Chicago)



Oil-drop Experiment by R.A. Millikan (1910)

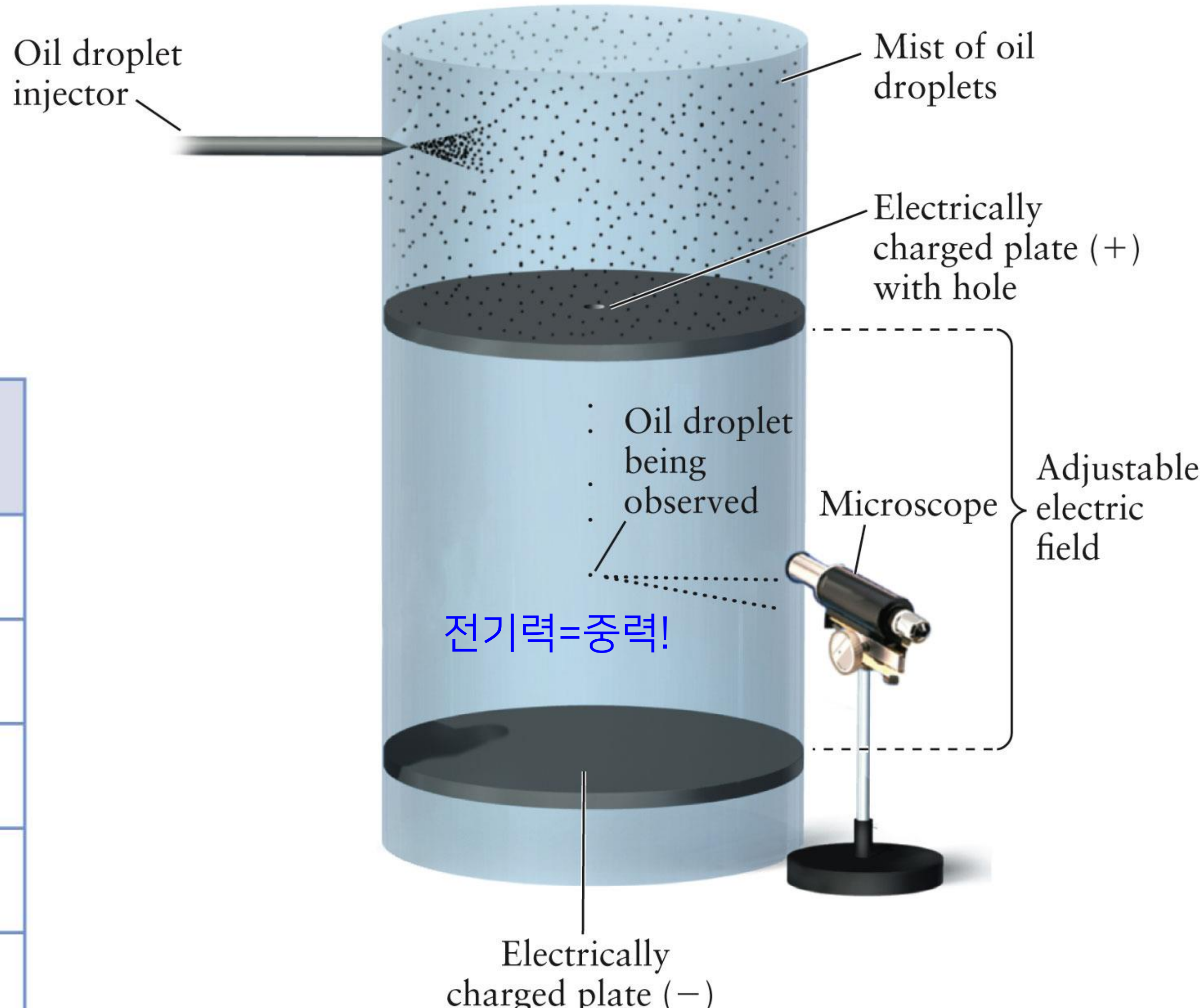
중력 = 전기력

$F = mg = qE$

$q = mg/E$

(electric field E, charge q)

Oil drop	Charge in coulombs (C)
A	4.8×10^{-19} C
B	3.2×10^{-19} C
C	6.4×10^{-19} C
D	1.6×10^{-19} C
E	4.8×10^{-19} C



Coulomb: SI unit of electric charge, 1C = 1 A X 1 s

Oil-drop Experiment by R.A. Millikan (1910)

Fundamental charge

$$e = 1.602 \times 10^{-19}\ C$$

From the Thomson's result (e/m_e),

$$m_e = 9.109 \times 10^{-31}\ kg$$

$q_e = 1.602176487 \times 10^{-19}$

Particle	Symbol	Charge*	Mass, kg
electron	e^-	-1	9.109×10^{-31}
proton	p	$+1$	1.673×10^{-27}
neutron	n	0	1.675×10^{-27}

Science

THE ISOLATION OF AN ION, A PRECISION MEASUREMENT OF ITS CHARGE, AND THE CORRECTION OF STOKES'S LAW

R. A. MILLIKAN

Published in 1910.

Science **32** (822), 436-448.
DOI: 10.1126/science.32.822.436

1) electric field = 0

a. Weight (mg) of oil drop is downward.

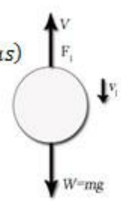
$= \rho V g$

$= \rho \frac{4}{3}\pi r^3 g \; (\rho = density \; and \; r = radius)$

b. Up thrust U of air is upward

$= \sigma v g$

$= \sigma \frac{4}{3}\pi r^3 g \; (\sigma = density \; of \; air \; and \; r = radius)$



viscous force $F_1 = 6\pi\eta r v_1$ (Stoke's law)

$$F_1 + U = W$$

$$or,\ 6\pi\eta r v_1 + \sigma \frac{4}{3}\pi r^3 g = \rho \frac{4}{3}\pi r^3 g$$

$$or,\ 6\pi\eta r v_1 = \frac{4}{3}\pi r^3 g(\rho - \sigma) \quad \text{......................... (i)}$$

$$or,\ r = \sqrt{\frac{9}{2}\frac{\eta v_1}{(\rho-\sigma)g}} \quad \text{............................... (ii)}$$

2) electric field ≠ 0

$$V + F_e = F_2 + W$$

$$or,\ \frac{4}{3}\pi r^3 \sigma g + qE = 6\pi\eta r v_2 + \frac{4}{3}\pi r^3 \rho g$$

$$or,\ qE = 6\pi\eta r v_2 + 6\pi\eta r v_1$$

$$or,\ q = \frac{6\pi\eta(v_1 + v_2) r}{E}$$

$$= \frac{6\pi\eta(v_1+v_2)}{V/d}\sqrt{\frac{9}{2}\frac{\eta v_1}{(\rho-\sigma)g}} \quad \text{..................................(iii)}$$

Thus knowing $\eta, v_1, v_2, \rho, \sigma, g, V, d$ value of q can be determined

FEATURES

www.iop.org/journals/physed

Doing it differently: attempts to improve Millikan's oil-drop experiment

Peter Heering[1,3] and Stephen Klassen[2]

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[2] The University of Winnipeg, 515 Portage Avenue, Winnipeg, MB, R3B 2E9, Canada

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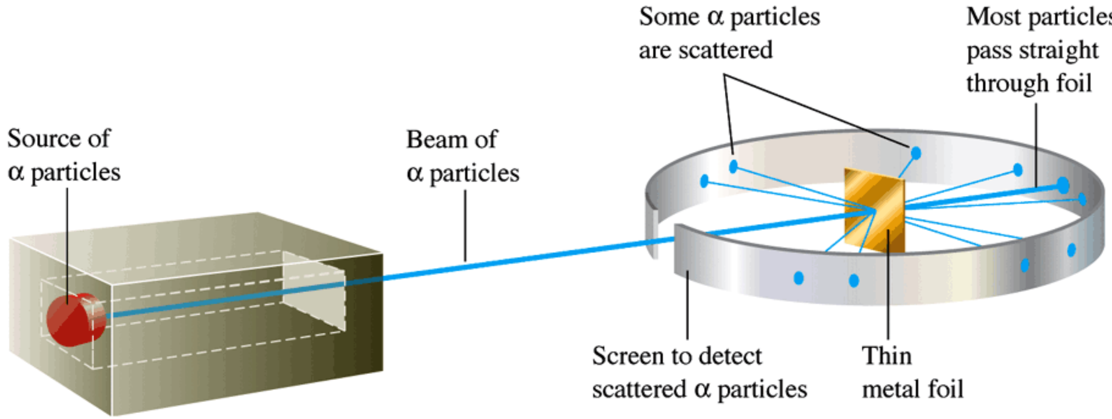
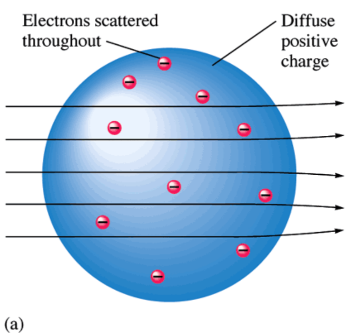
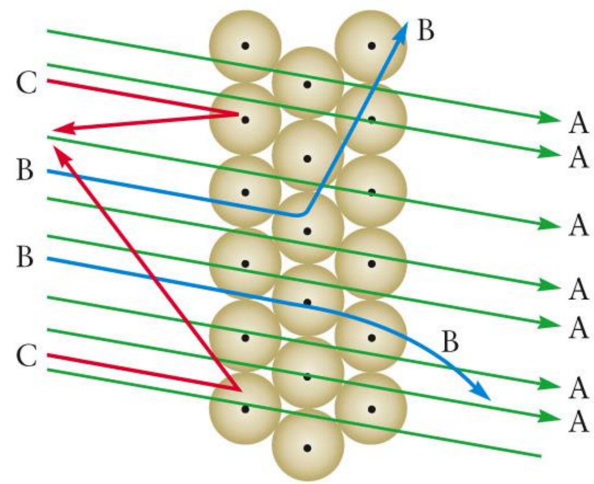
Rutherford's experiment on α-particle bombardment of metal foil.



<u>Alpha particle</u>:
2 proton
+2 neutron



(a) Expected result: Thomson's plum pudding model



"…. you fired a 15-inch canon at a piece of tissue paper and it came back… ."

Rutherford's model of atom: Nucleus, positively charged small particle (≤10^{-12} cm), possesses a net charge of + Ze, and Z electrons surrounding the nucleus out to a distance of about 10^{-8} cm

1.1. Atom: Nuclear Model

J.J. Thomson
(1856 – 1940)

- Electron is a subatomic particle with - charge.
- Determined e/m_e.

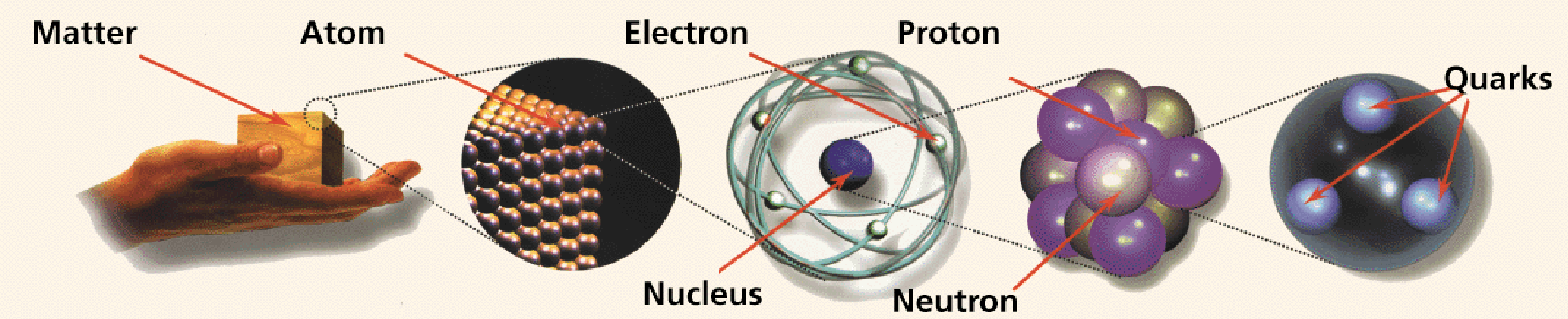
R.A. Millikan
(1868 – 1953)

-Measured q_e
-Can calculate the mass of electron

Ernest Rutherford
(1871 – 1937)

-New nucleus model

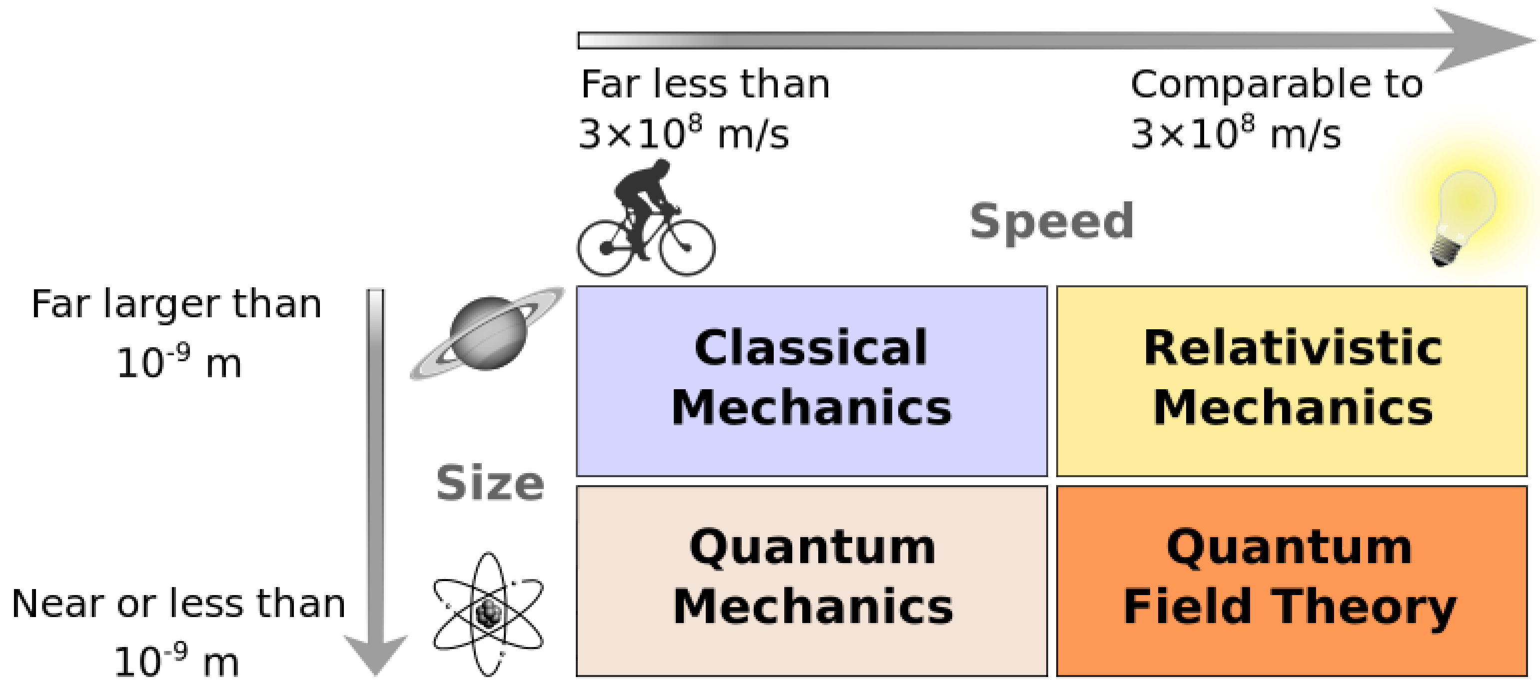
In modern physics….atoms can be divided into smaller elements such as quarks, leptons, hadrons…etc.



		LEPTONS		QUARKS	
Matter Particles All ordinary particles belong to this group	FIRST FAMILY	**Electron** Responsible for electricity and chemical reactions; it has a charge of –1	**Electron neutrino** Particle with no electric charge, and possibly no mass; billions fly through your body every second	**Up** Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	**Down** Has an electric charge of minus one-third; protons contain one, neutrons contain two
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators.	SECOND FAMILY	**Muon** A heavier relative of the electron; it lives for two-millionths of a second	**Muon neutrino** Created along with muons when some particles decay	**Charm** A heavier relative of the up; found in 1974	**Strange** A heavier relative of the down; found in 1974
	THIRD FAMILY	**Tau** heavier still; it is extremely unstable. It was discovered in 1975	**Tau neutrino** Not yet discovered but believed to exist	**Top** Heavier still; found in 1995	**Bottom** Heavier still; measuring bottom quarks is an important test of electroweak theory

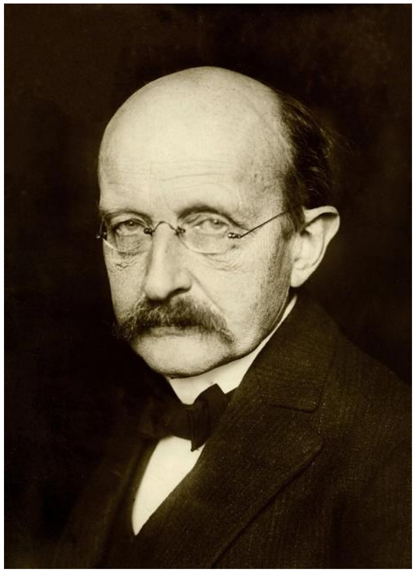
But atoms are indivisible <u>in chemical reactions</u>, therefore atoms are the smallest unit of matter that has the properties of a chemical element.

Modern Physics that Relates to Chemistry



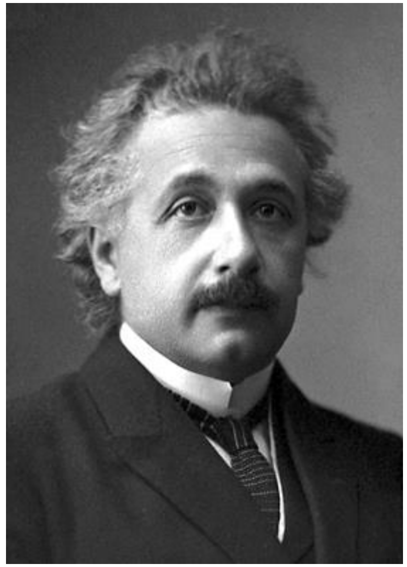
The movement of electrons (small and fast) can't be explained by the classical mechanics!

developed in the early 20th century and onwards, or branches greatly influenced by early 20th century physics



Max Planck
(1858 –1947)

Nobel Prize in Physics in 1918



Albert Einstein
(1879 -1955)

Nobel Prize in Physics in 1921

Niels Bohr
(1885 –1962)

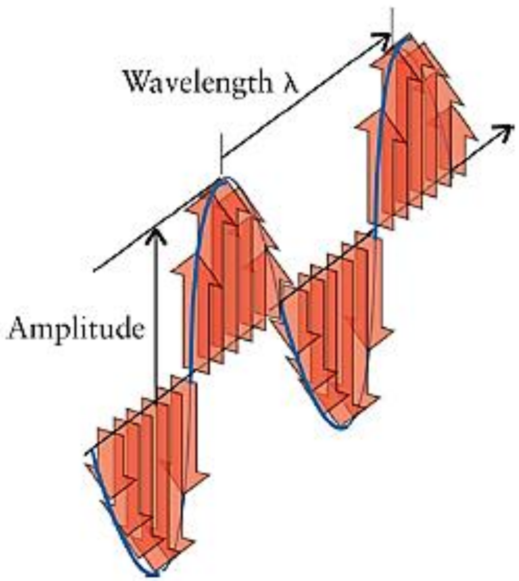
Nobel Prize in Physics in 1922

Studied with Thomson/Rutherford

Erwin Schrödinger
(1887–1961)

Nobel Prize in Physics in 1933

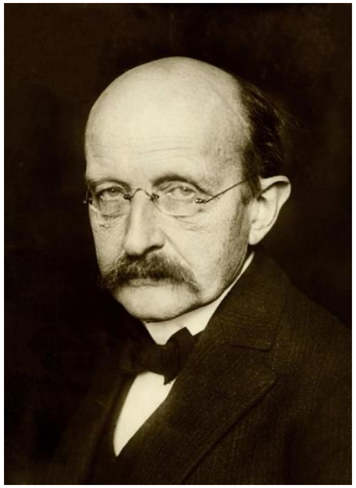
1.2. The Characteristics of Electromagnetic Radiation



Light = electromagnetic wave 전자기복사선

ν = frequency (s^{-1} = Hertz = Hz)
λ = wavelength (m)
c = speed of light = 2.9979×10^8 m/s

wavenumber ($\tilde{\nu}$)= 1/ λ (m^{-1})



Max Planck
(1858 –1947)

3 primary characteristics

1 : distance between two peaks in a wave (λ).

2. : number of cycles per second that pass a given point in space (v).

3. = frequency (s^{-1}) x wavelength (m) = m/s

Greek alphabet

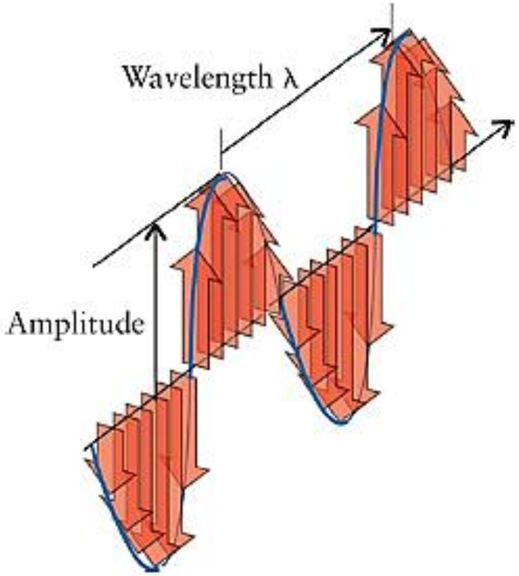
V: frequency: number of occurrences of a repeating event per unit time

Letter	Name	Sound	
		Ancient[5]	Modern[6]
Α α	alpha, άλφα	[a] [aː]	[a]
Β β	beta, βήτα	[b]	[v]
Γ γ	gamma, γάμμα	[g], [ŋ][7]	[ɣ] ~ [ʝ], [ŋ][8] ~ [ɲ][9]
Δ δ	delta, δέλτα	[d]	[ð]
Ε ε	epsilon, έψιλον	[e]	[e]
Ζ ζ	zeta, ζήτα	[zd]A	[z]
Η η	eta, ήτα	[ɛː]	[i]
Θ θ	theta, θήτα	[tʰ]	[θ]
Ι ι	iota, ιώτα	[i] [iː]	[i], [ʝ],[10] [ɲ][11]
Κ κ	kappa, κάππα	[k]	[k] ~ [c]
Λ λ	lambda, λάμδα	[l]	[l]
Μ μ	mu, μυ	[m]	[m]

Letter	Name	Sound	
		Ancient[5]	Modern[6]
Ν ν	nu, νυ	[n]	[n]
Ξ ξ	xi, ξι	[ks]	[ks]
Ο ο	omicron, όμικρον	[o]	[o]
Π π	pi, πι	[p]	[p]
Ρ ρ	rho, ρώ	[r]	[r]
Σ σ/ς[13]	sigma, σίγμα	[s]	[s] ~ [z]
Τ τ	tau, ταυ	[t]	[t]
Υ υ	upsilon, ύψιλον	[y] [yː]	[i]
Φ φ	phi, φι	[pʰ]	[f]
Χ χ	chi, χι	[kʰ]	[x] ~ [ç]
Ψ ψ	psi, ψι	[ps]	[ps]
Ω ω	omega, ωμέγα	[ɔː]	[o]

wavelength

1.2. The Characteristics of Electromagnetic Radiation



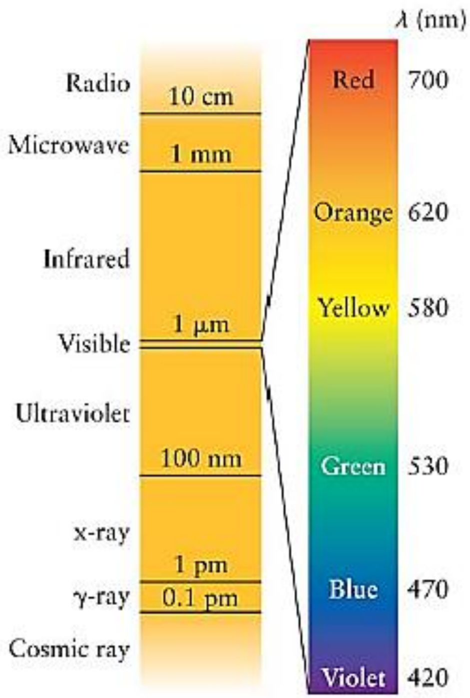
Light = Electromagnetic Wave

$E = h\nu = hc/\lambda$ (h=Planck constant)

wavelength × frequency = speed of light

$\lambda\,\nu \quad = \quad c$

$$c = 2.9979 \times 10^8\, m \cdot s^{-1} \approx 3.0 \times 10^8\, m \cdot s^{-1}$$

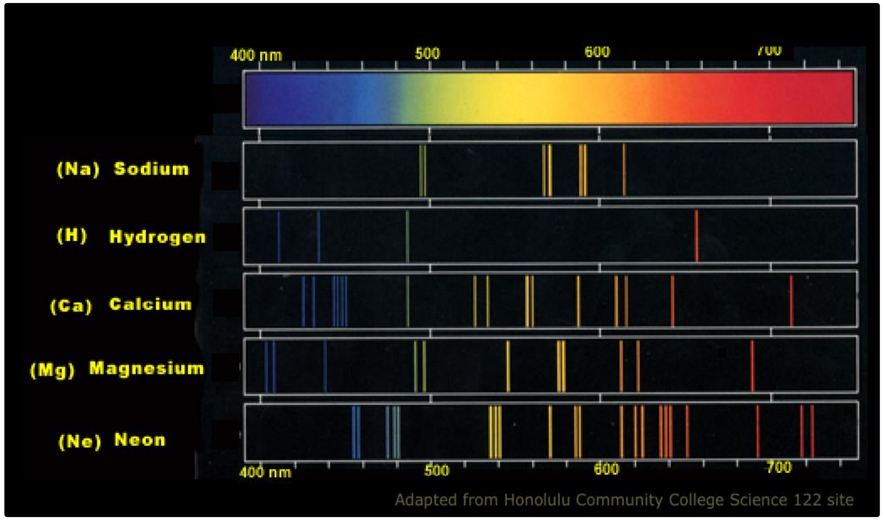


TYPE OF RADIATION	RELATIVE WAVELENGTH	TYPICAL WAVELENGTH (meters)	ENERGY CARRIED PER WAVE OR PHOTON
	Wavelength		Increasing
AM radio waves		100	
Television waves		1	
Microwaves		10^{-3}	
Infrared waves		10^{-6}	
Visible light		5×10^{-7}	
Ultraviolet waves		10^{-7}	
X rays		10^{-9}	

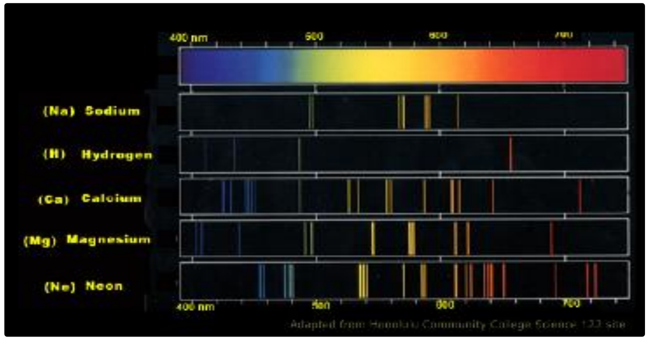
Spectroscopy = spectro- + scopy

spectrum instrument for viewing

: the study of the interaction between matter and <u>electromagnetic radiation</u>.



1.3. Atomic Spectra



H_2 + electrical energy → H + H^*
H^* → $H^{(*)}$ + $h\nu$ (spectral lines): discrete energy level

Johann Rydberg's general equation

$$\boxed{\nu = \mathcal{R}\left\{\frac{1}{n_1^2} - \frac{1}{n_2^2}\right\}} \quad n_1 = 1, 2, \ldots, \quad n_2 = n_1 + 1, n_1 + 2, \ldots$$

R (Rydberg constant) = 3.29×10^{15} Hz

an empirical constant

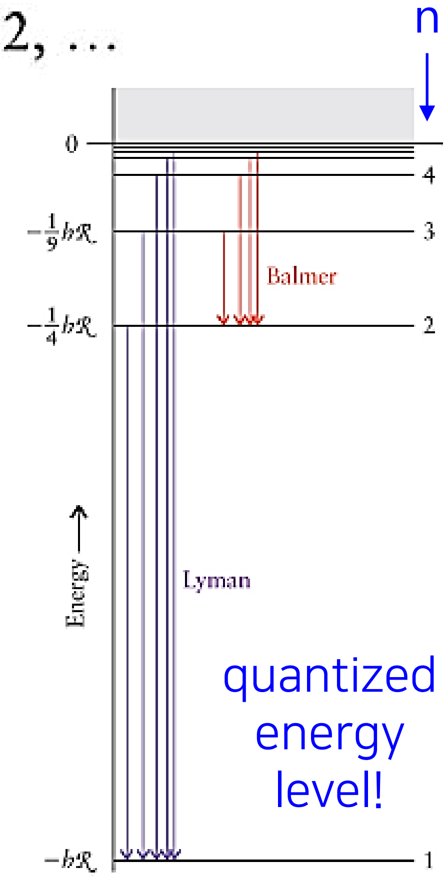
n_1 = 1 (Lyman series), ultraviolet region

n_1 = 2 (Balmer series), visible region

n_1 = 3 (Paschen series), infrared region

For instance, n_1 = 2 and n_2 = 3,

$$\nu = \mathcal{R}\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = \frac{5}{36}\mathcal{R} \qquad \lambda = 6.57\times10^{-7}\ \text{m}$$

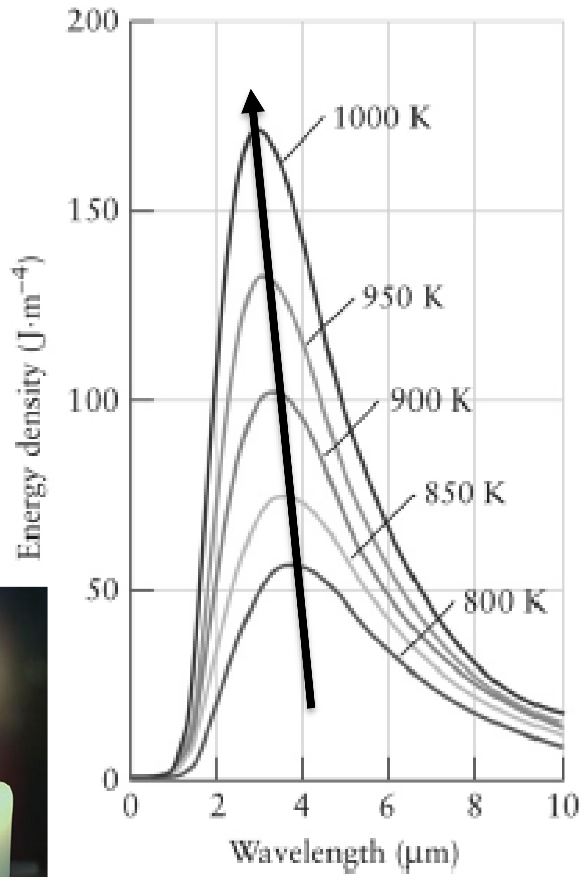


1.4. Radiation, Quantum/Quanta, and Photons

Blackbody Radiation (흑체복사)

Any heated object emit radiation.

The spectra of heat objects show characteristic spectra, irrespective of its original color. Can't be explained by the classical electromagnetic theory.



<u>Stefan-Boltzmann law:</u>

Total intensity = constant X T^4

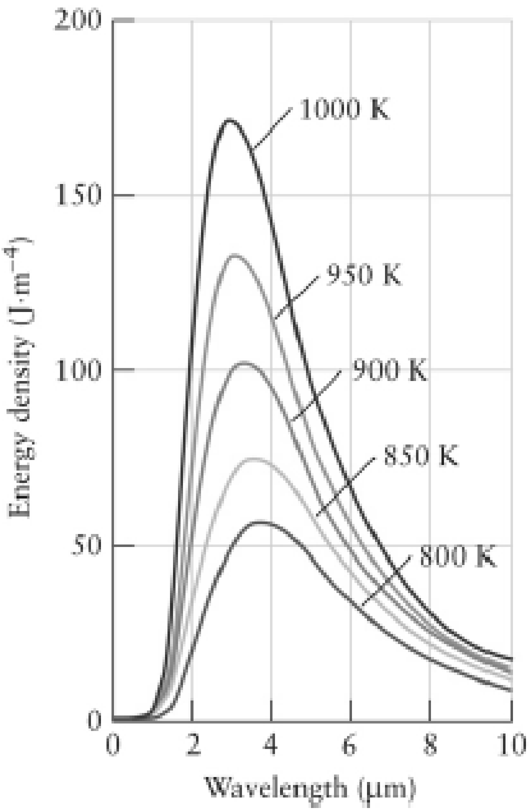
(constant = 5.67 X 10^{-8} W m^{-2} K^{-4})

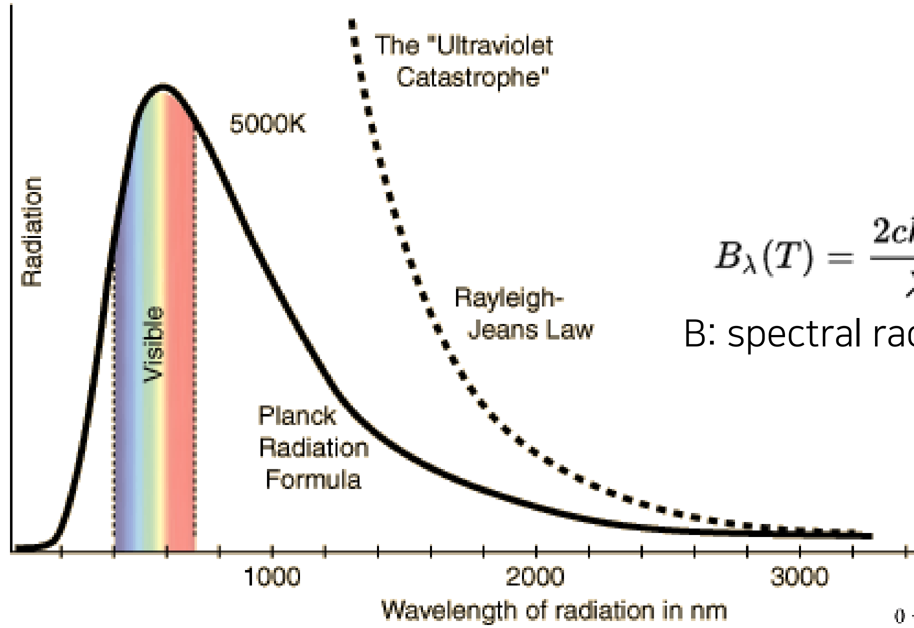
<u>Wien's law:</u>

$T \lambda_{max}$ = constant = 2.9 K mm

With the spectrum of the radiation, we can estimate the temperature of the object such as stove, sun, star, and etc.

Blackbody Radiation : Ultraviolet catastrophe





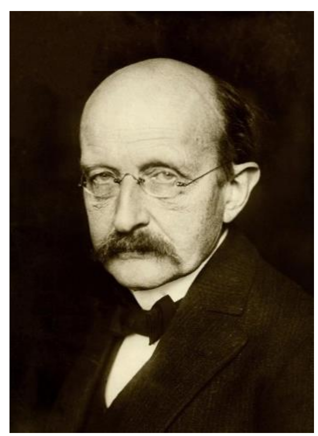
$$B_\lambda(T) = \frac{2ck_B T}{\lambda^4}$$

B: spectral radiance

Quantization of Electromagnetic Wave

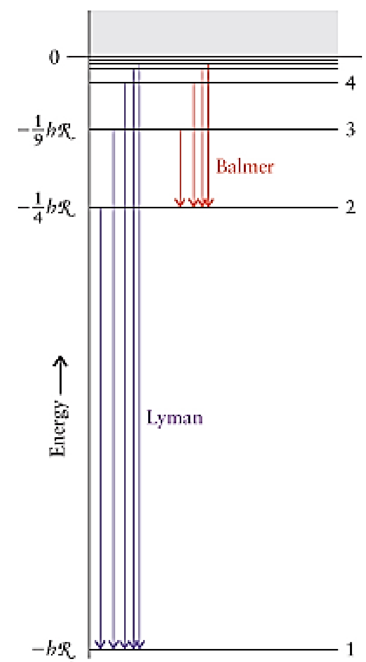
E = hv

h = 6.626 × 10^{-34} J·s
(Plank constant)

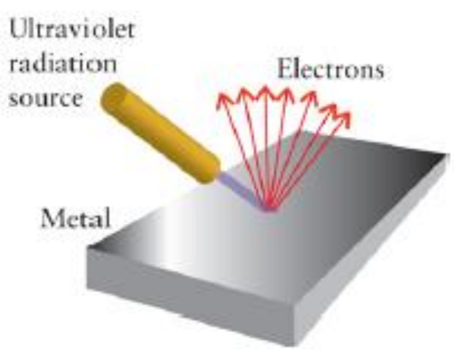


Max Planck
(1858 –1947)

quantized energy level!



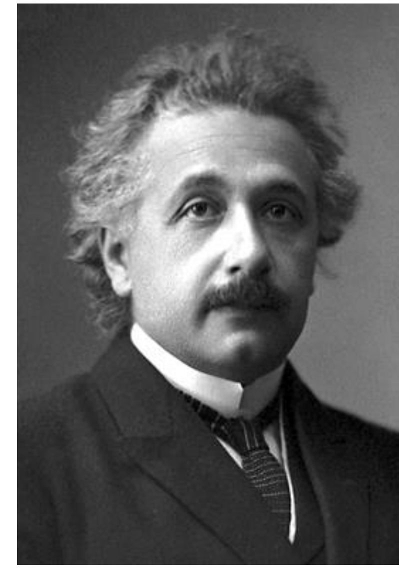
Photoelectric effect   Photon: a particle with packets of energy!!!



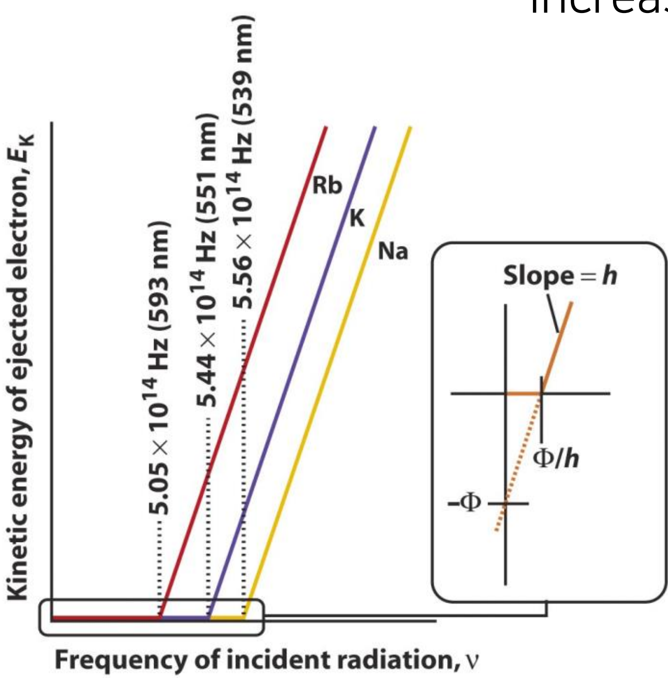
Experimental results

1. No electron is ejected when the frequency is below a particular threshold value: $\nu < \nu_0$
2. Electrons are immediately ejected even if the intensity is low.

3. The kinetic energy of e- linearly increases with the frequency of radiation.



Nobel Prize in Physics in 1921



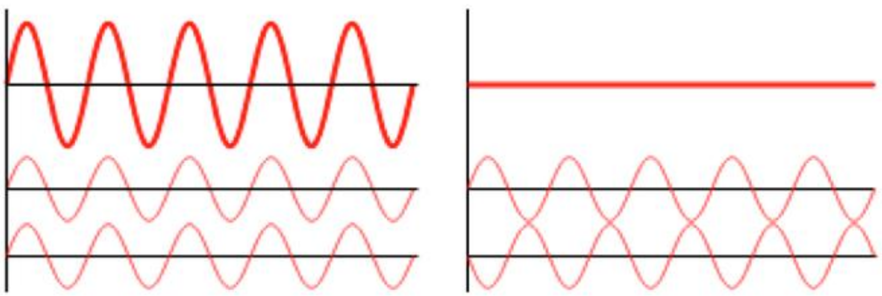
$$\underbrace{\frac{1}{2}m_e v^2}_{\text{Kinetic energy of ejected electron}} = \underbrace{h\nu}_{\text{Energy supplied by photon}} - \underbrace{\Phi}_{\text{Energy required to eject photon}}$$

work function

1.5. The Wave-Particle Duality

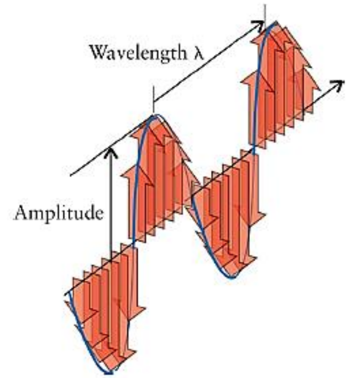
-Photoelectic effect → particle

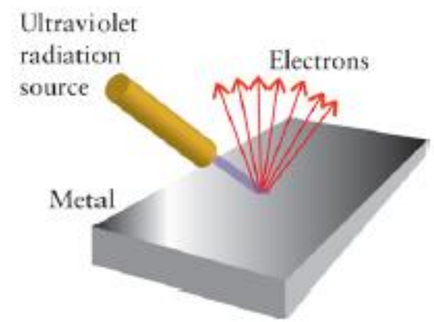
-Diffraction and interference → wave



Constructive interference
Phase difference of 2nπ*(period)

Destructive interference
Phase difference of nπ*(period)

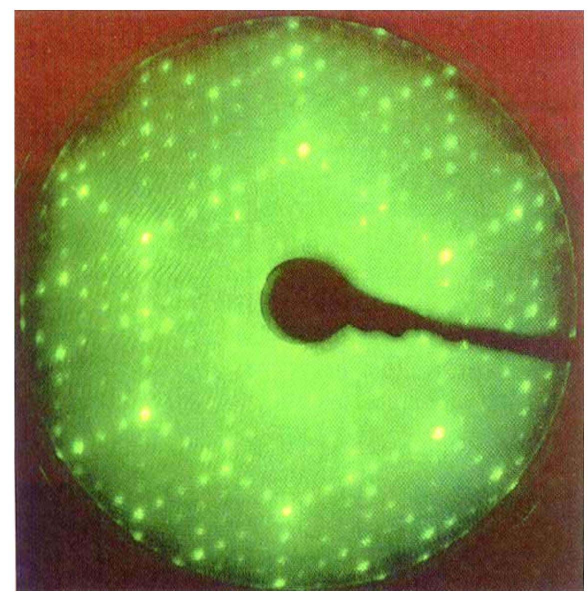




de Broglie's material wave

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

p = linear momentum= mv



Diffraction pattern of
electron-wave by a silicon crystal

1.6. The Uncertainty Principle

Heisenberg uncertainty principle (1927)

$$\Delta p \, \Delta x \geq \frac{h}{4\pi}$$

선운동량　　　위치

* Schrödinger's cat

https://www.youtube.com/watch?v=pNTMYNj2Ulk

Werner Heisenberg
1901 –1976
Nobel Prize in Physics (1932) for the creation of quantum mechanics