CH 4: Roots of the Quantum Theory

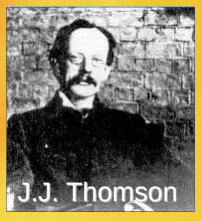
QUANTIZATION OF CHARGE AND MASS

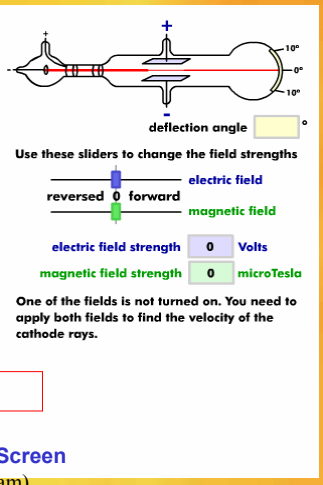
Dalton's atomic hypothesis,(1802) ➡
All elements were made up of a combination of different numbers of atoms and the atom is the smallest indivisible unit of matter

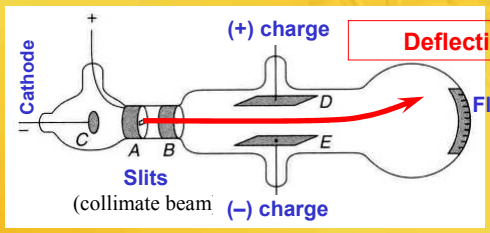
matter is quantized **which is the same property be attributed to electricity**

The work that led to the concept of quantization of charge was by Faraday in his famous work on electrolysis (1831~1837), in which he established the Faraday laws of electrolysis and the quantization of charge.

In 1897 J. J. Thomson discovered the electron and measured its e/m ratio.







Electron Beam e/m : Motion in E and B Fields

Circular Motion of electron in B field:

$$\boldsymbol{F}_E = e\boldsymbol{E}$$

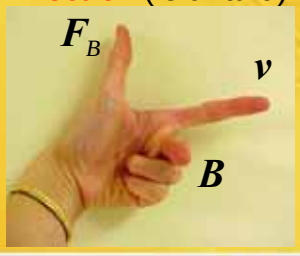
$$\frac{mv^2}{r}\ (or\ \boldsymbol{F}_{centrip}) = evB\ \ (or\ \boldsymbol{F}_B)$$

$$\boldsymbol{F}_B = e\boldsymbol{v} \times \boldsymbol{B}$$

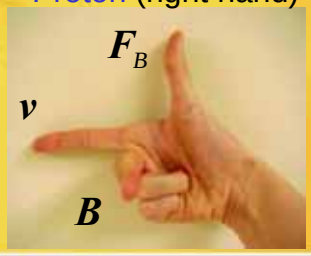
$$r = \frac{mv}{eB} \propto \frac{m}{e}$$

⇒ Larger *e/m* gives smaller *r*, or larger deflection.

Electron (left hand)



Proton (right hand)



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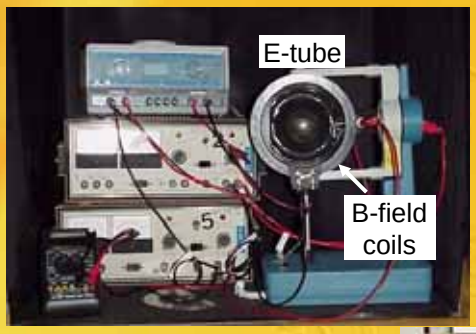
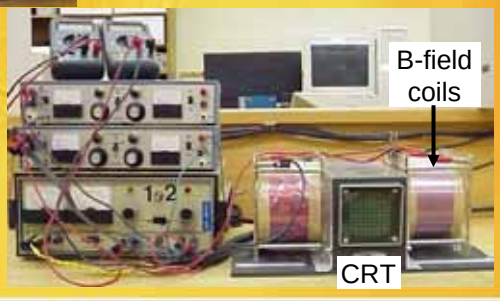
Electron Beam e/m: Modern Physics Lab



e/m with Electron Tube
(observe e-beam in gas tube)

Cathode Ray Tube
(study effects of E and B)



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Ionized Beam q/m: Mass Spectrometer

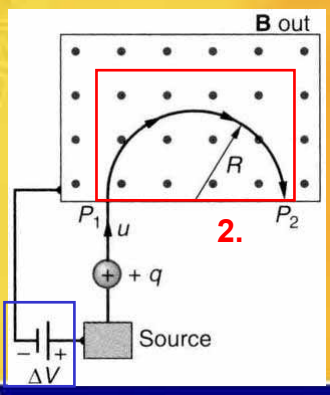
- Mass spectrometer measures q/m for unknown elements.

1. $\frac{1}{2}mv^2 = qV \Rightarrow v^2 = \frac{2qV}{m}$ Ions accelerated by E field.

2. $R = \frac{mv}{qB}$ Ion path curved by B field.

$$R^2 = \frac{m^2v^2}{q^2B^2} = \frac{m^2}{q^2B^2}\left(\frac{2qV}{m}\right)$$

$$\therefore \frac{q}{m} = \frac{2V}{B^2R^2}$$



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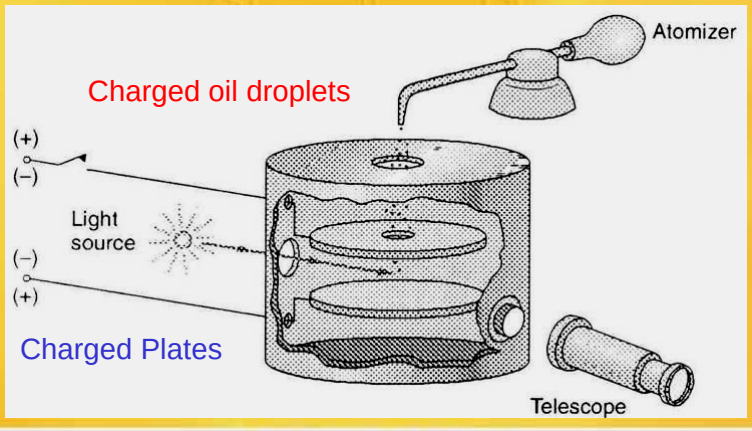
in 1909, R. A. Millikan measured the charge on the electron by means of the Millikan oil-drop method.
This confirmed the quantization of charge.



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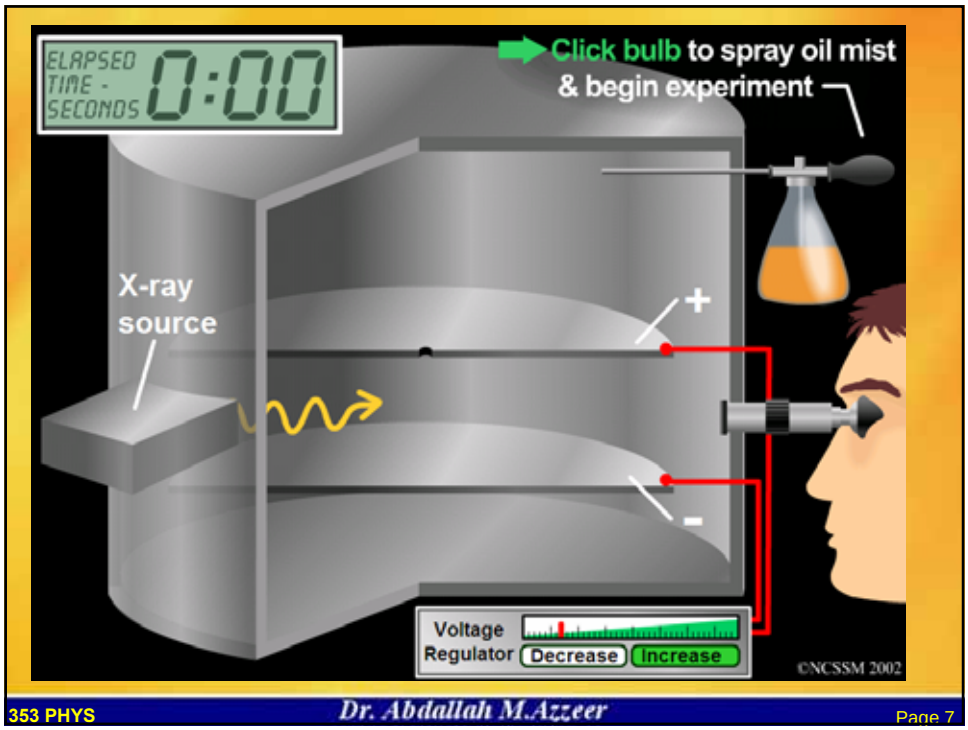


The conclusion from such experiments was that the charge *q* on any particle or body was an integral multiple of charge *e*,

$q = ne$, $n = 1,2,3,...,$

where *e* is the charge on the electron.

value is $e = (1.60210 \pm 0.00002) \times 10^{-19}$ **coul.**

Both charge and mass are quantized.

QUANTIZATION OF RADIATION

- Lorentz transformation equations apply equally to mechanics and to electromagnetism.
- This indicates a close unity between the two
- Above, we saw that the charge is quantized, also, the mass of any mechanical system-atoms, molecules, etc.-is also quantized,
- Maxwell's confirmed the wave nature of light by development of equations for the electromagnetic field and verified by Hertz in 1887, proving that light consists of electromagnetic waves.
- wave theory of light (or of electromagnetic radiation) was stay until early in 20th century .

Early in the twentieth century, many scientists made experimental observations connected with electromagnetic radiation *which* could *not* be explained by the wave theory of light. These experiments concerned the following phenomena.

1)Blackbody radiation spectrum

2)Photoelectric effect

3)X-ray spectra

4)Compton scattering

5)Optical line spectra

Thus the wave theory of light could explain interference, diffraction, and polarization, but not experiments (1) to (3).

In order to explain the **blackbody radiation spectrum,**

Max Planck in 1901 introduced the quantum hypothesis, which was eventually used in explaining all the experimental facts from (1) to (5).

Planck's hypothesis ;(original form).

If a physical system executes a simple harmonic motion in one dimension with frequency ν, it can take only those energy values E which are given by the relation

$$E = nh\nu = \frac{nhc}{\lambda} \quad , \quad n = 1, 2, 3, \ldots .$$

Where *h* is a constant called *Planck's constant.*

Thus Planck implied that the system can exist only in certain discrete energy states given by $E=nh\nu$.

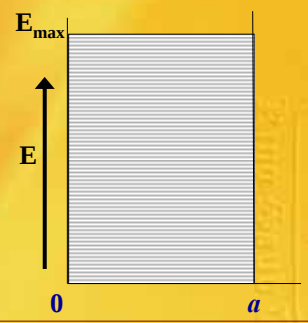
Such states (E) are called *quantum states,*

n is called the *quantum number.*

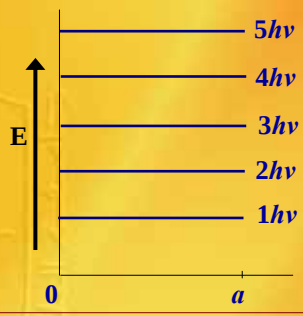
the oscillators emit or absorb energy in bundles of size hν,

i.e., the radiation emitted or absorbed is also quantized.

The value of *h* is found to be 6.625×10^{-34} joule-sec.



CLASSICAL THEORY
energy can take any value (continuous range) between 0 and E_{max}



Planck's quantum hypothesis, *E* can take only discrete energy values

Figure shows the distinction between the classical theory and the Planck quantization hypothesis as applied to the harmonic oscillator.

Example

A radio station operates on a frequency of 98 MHz and radiates a power of 200 kW. How many quanta of energy are emitted per second?

ν=98 MHz , P=200 kW , n=? per sec.

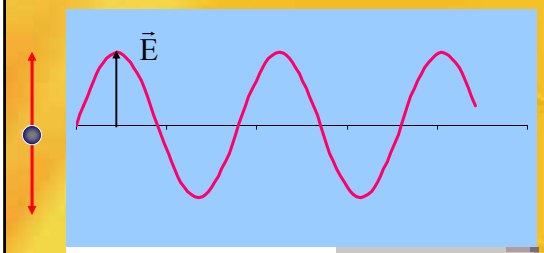
E=nhν

Power=energy/time

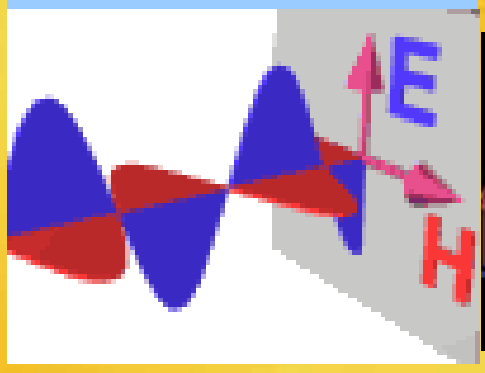
P=nhν/t

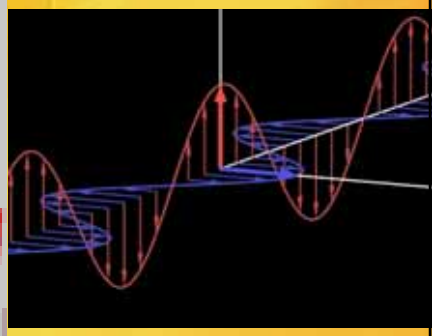
$$\frac{n}{t} = \frac{P}{h\nu} = \frac{200\times10^{3}\ \text{J/s}}{(6.625\times10^{-34}\ \text{J.s})(98\times10^{6}\ \text{s}^{-1})} = 3.08\times10^{30}\ \text{quanta/sec}$$

2.3 BLACKBODY RADIATION إشعاع الجسم الأسود



- عبارة عن إشعاع كهرومغناطيسي
- مصدرة شحنات متذبذبة





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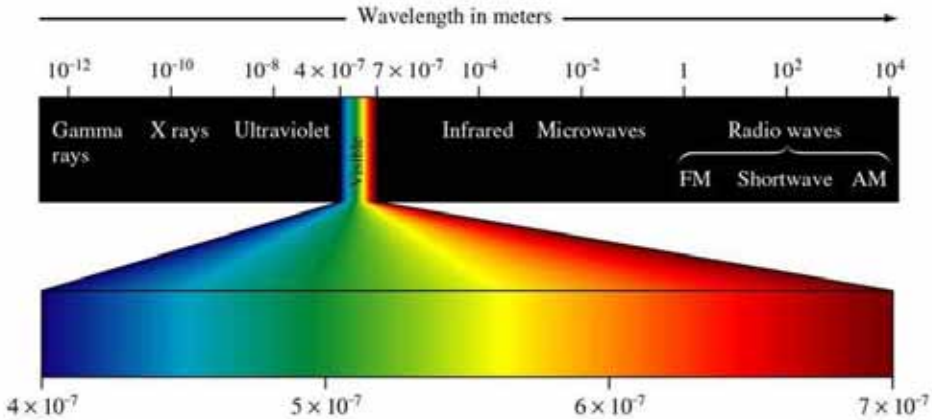

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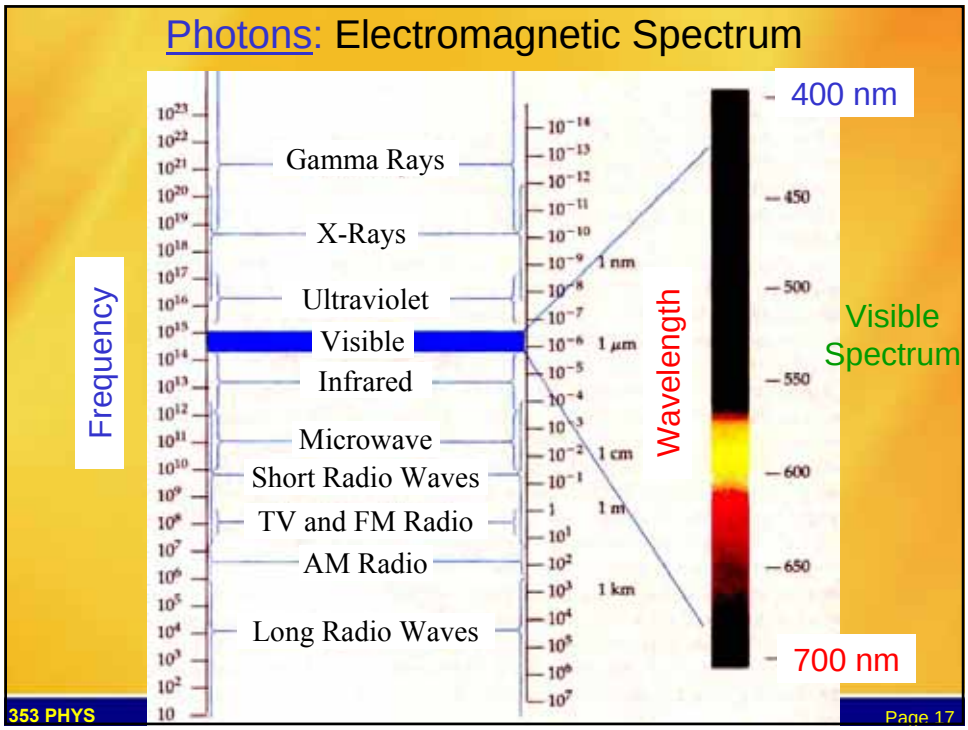
Photons: Electromagnetic Spectrum
Frequency
Gamma Rays
X-Rays
Ultraviolet
Visible
Infrared
Microwave
Short Radio Waves
TV and FM Radio
AM Radio
Long Radio Waves
Wavelength
1 nm
1 μm
1 cm
1 m
1 km
400 nm
450
500
550
600
650
700 nm
Visible Spectrum
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