PH2103: Physics Laboratory II

(PH2203: Physics Laboratory III)

Instructors:

Bhavtosh Bansal,

Bheemalingam Chittari,

Partha Mitra

Rumi De

PH2103: Physics Laboratory II

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Optics
(Bhavtosh Bansal and Partha Mitra)

Modern Physics
(Bheemalingam Chittari and Rumi De)

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Experiments:

1. Electron Diffraction,

2. Photo Electric effect,

3. Velocity of Light,

4. Frank Hertz,

5. Stefan Boltzmann

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Lab Notes format for each experiment:

- Title:
- Aims(s):
- Working Principle/Formula:
- Experimental Setup/Schematic Diagrams:
- Data/Readings/Table/Plot:
- Analysis:
- Source of Errors:
- Conclusions:

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Source of Errors:

- Systematic Error ✓
  Instrument resolution,
- Environmental factors ✓
  Temperature, secondary source feed back, etc..
- Not sufficient readings ✓
  Fluctuations in readings/measurements, etc..

- Human Error ✗
- Faulty Instruments ✗

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1. Electron Diffraction,

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1. Electron Diffraction,

Particles have wave properties in addition to their familiar particle properties.

Louis de Broglie in 1924

$$\lambda = \frac{h}{P}$$

λ : (Wavelength), h : (Plank'sConstant) and P : (Momentum)

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Louis de Broglie in 1924

$$\lambda = \frac{h}{P}$$

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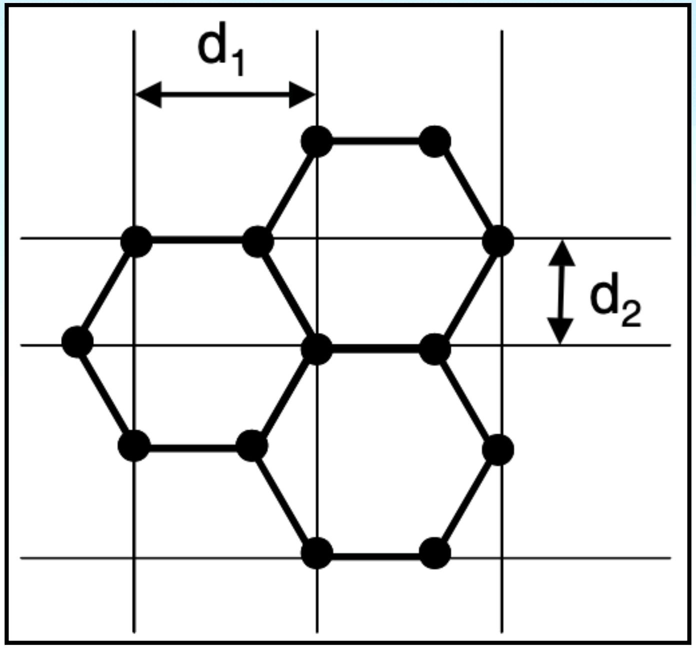
This particle wave nature is confirmed from the experimental observation on the diffraction of electrons in crystalline Nickel structure

Davisson and Germer in 1927

Modern Physics Lab

1. Electron Diffraction,

The regular arrangement of atoms in a single crystal can be understood as an array of lattice elements on parallel lattice planes.



Lattice plane spacings in graphite

Modern Physics Lab

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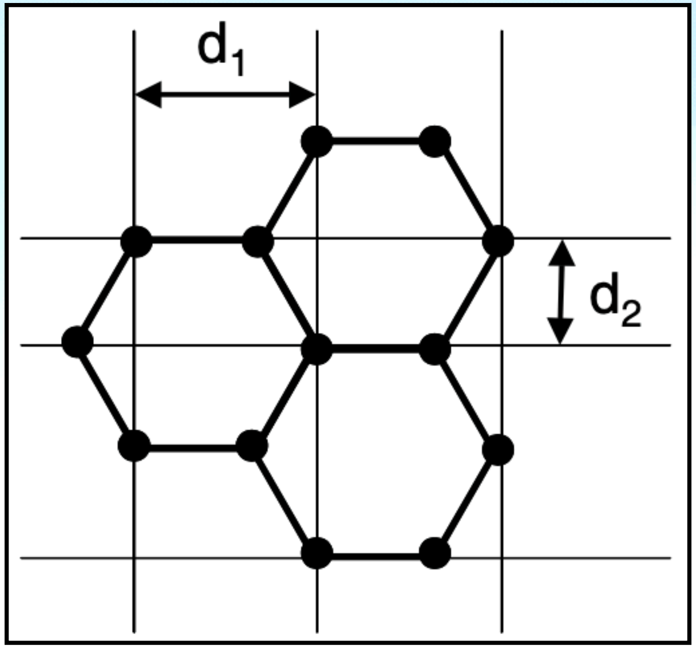

Lattice plane spacings in graphite

When we expose such a crystal lattice to *monochromatic x-rays* or *mono-energetic electrons*, and, additionally assuming that those have a wave nature, then each element in a lattice plane acts as a "scattering point", at which a spherical wave- let forms.

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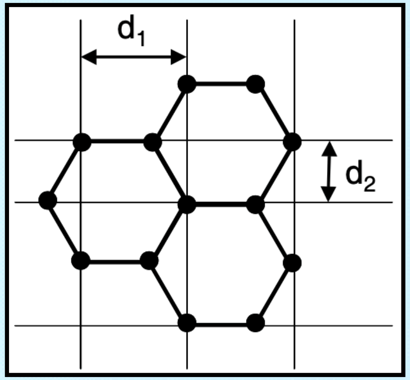
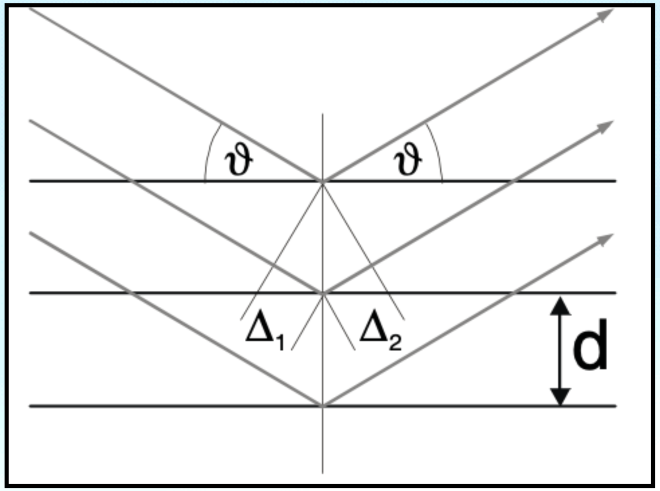
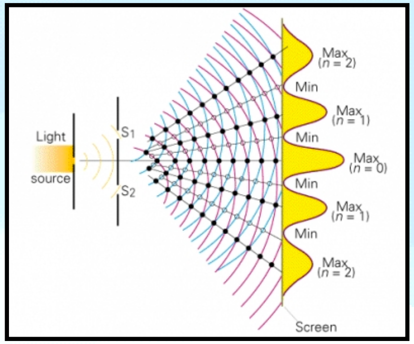
1. Electron Diffraction,







- These spherical wavelets create a “reflected” wave front. The wavelength λ remains unchanged with respect to the “incident” wave front, and the radiation directions which are perpendicular to the two wave fronts fulfil the condition “angle of incidence = angle of reflection”
- The constructive interference arises in the neighbouring rays reflected at individual lattice planes when their path differences $\Delta = \Delta_1 + \Delta_2 = 2d\sin\vartheta$

Bragg’s Condition:

$$n\lambda = 2d\sin\vartheta$$

$n = 1,2,3\ldots\ d =$ lattice plane spacing, $\vartheta =$ diffraction angle

H. W. and W. L. Bragg in 1913

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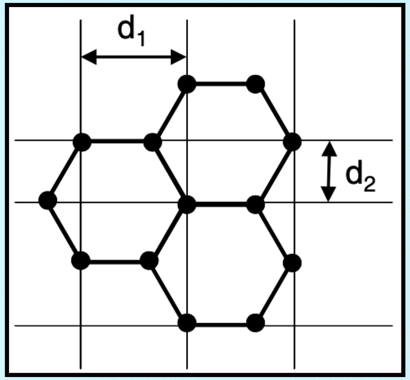
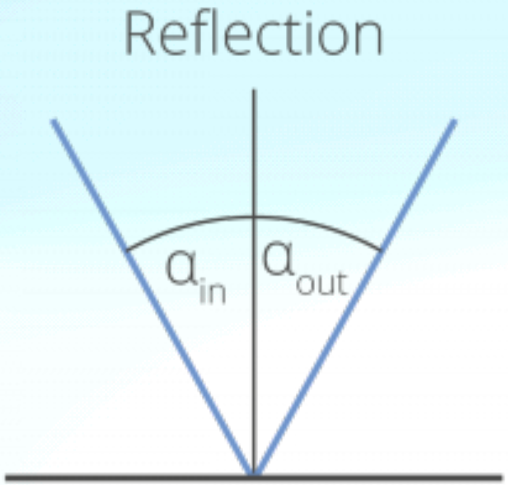


1. Electron Diffraction,

Diffraction is observed in two ways:



Davisson and Germer in 1927

https://www.gigahertz-optik.com/

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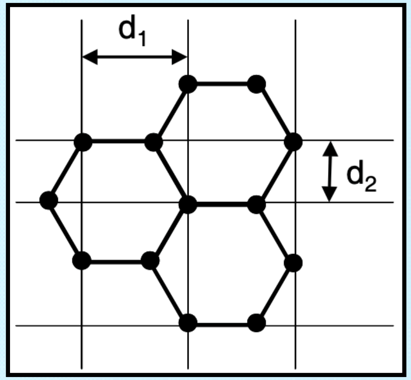

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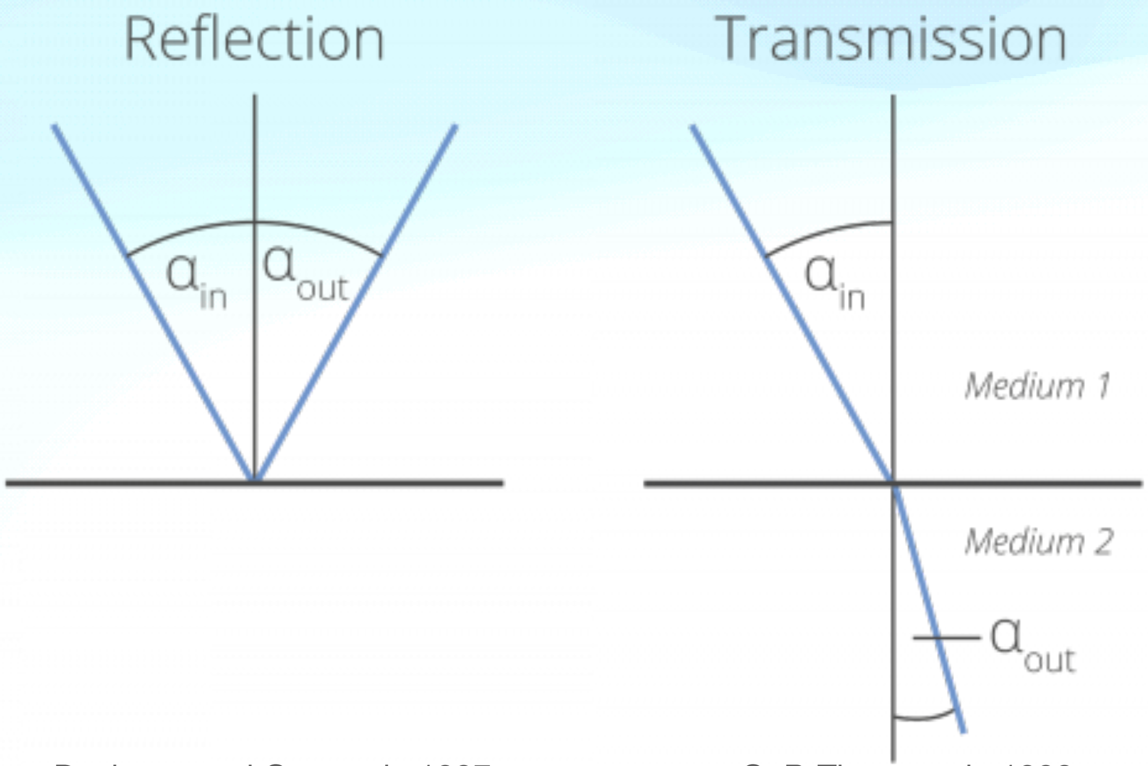

Davisson and Germer in 1927

G. P. Thomson in 1928

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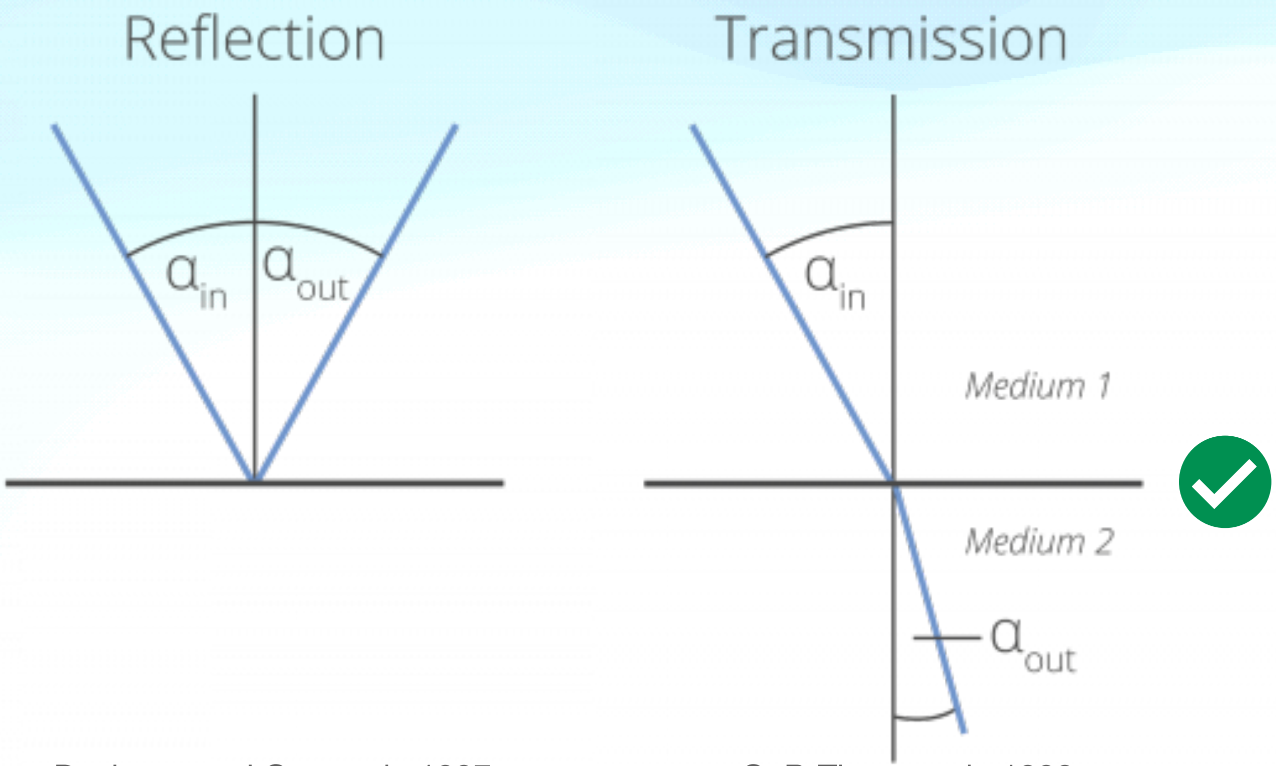

Davisson and Germer in 1927

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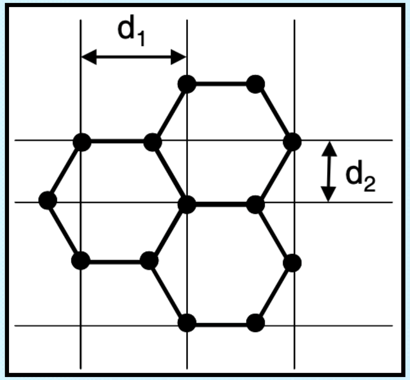

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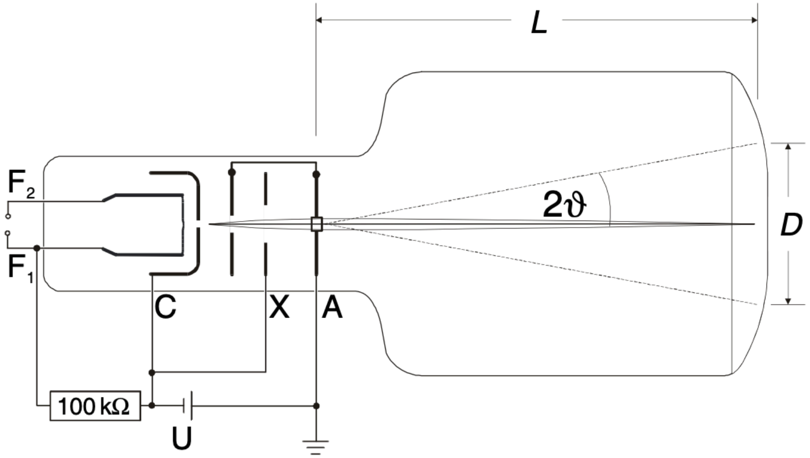

Fig. 4: Schematic sketch for determining the diffraction angle.
L = 13.5 cm (distance between graphite foil and screen),
D: diameter of a diffraction ring observed on the screen
ϑ: diffraction angle
For meaning of F_1, F_2, C, X and A see Fig. 5.

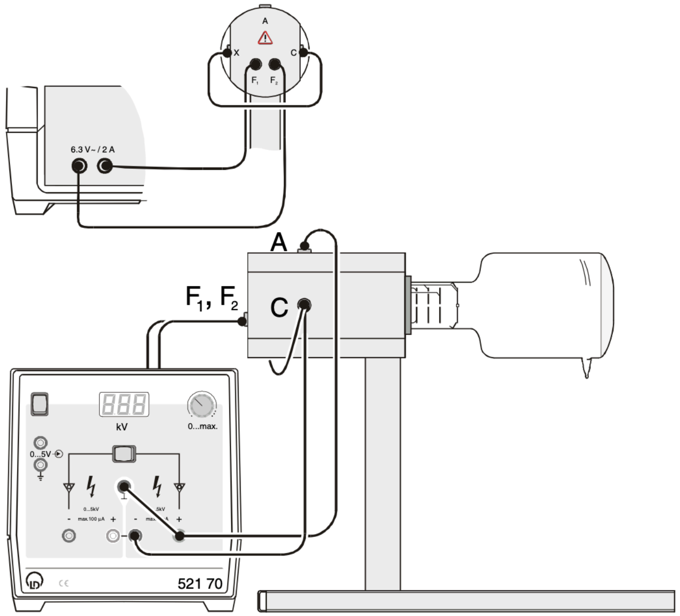

Fig. 5: Experimental setup (wiring diagram) for observing the electron diffraction on graphite. Pin connection:
F_1, F_2: sockets for cathode heating
C: cathode cap
X: focusing electrode
A: anode (with polycrystalline graphite foil see Fig. 4)

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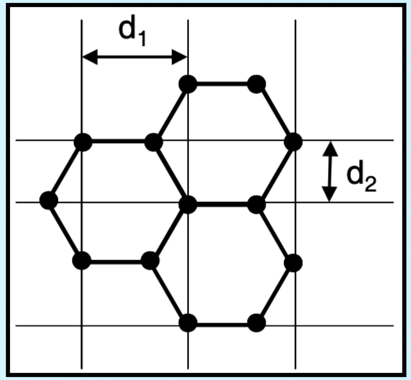
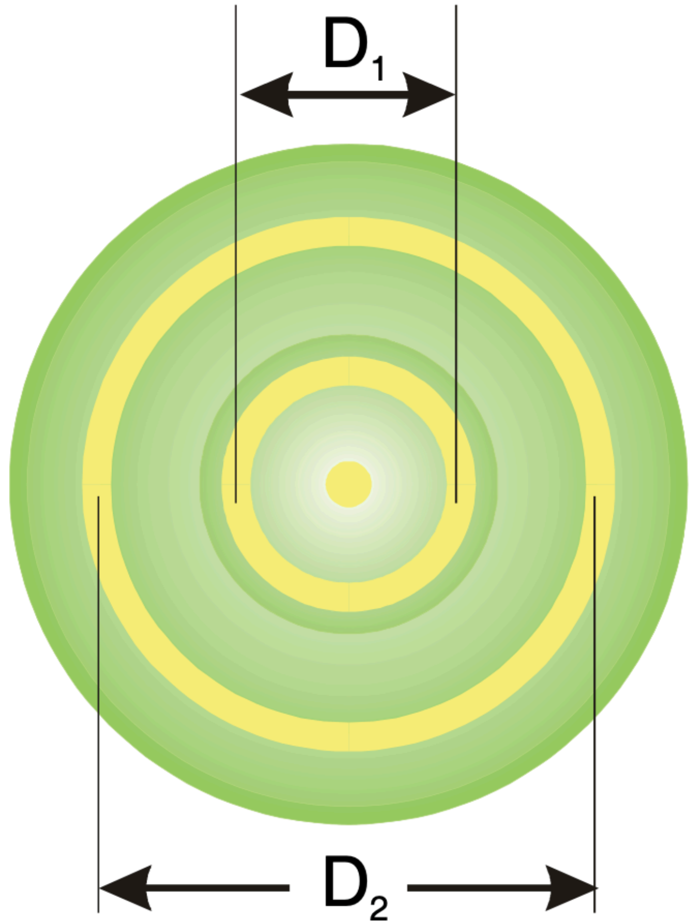


1. Electron Diffraction,

- The electrons emitted by the hot cathode a small beam is singled out through a pin diagram.
- After passing through a focusing electron-optical system the electrons are incident as sharply limited monochromatic beam on a polycrystalline graphite foil.
- The atoms of the graphite with different space lattice which acts as a diffracting grating for the electrons.
- On the fluorescent screen appears a diffraction pattern of two concentric rings which are centred around the indiffracted electron beam
-



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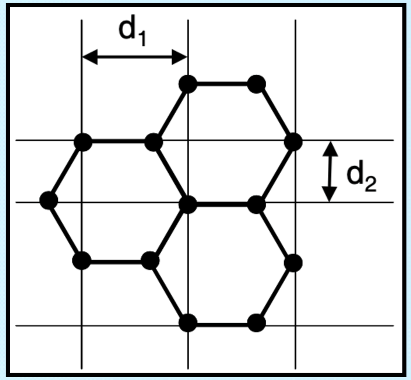
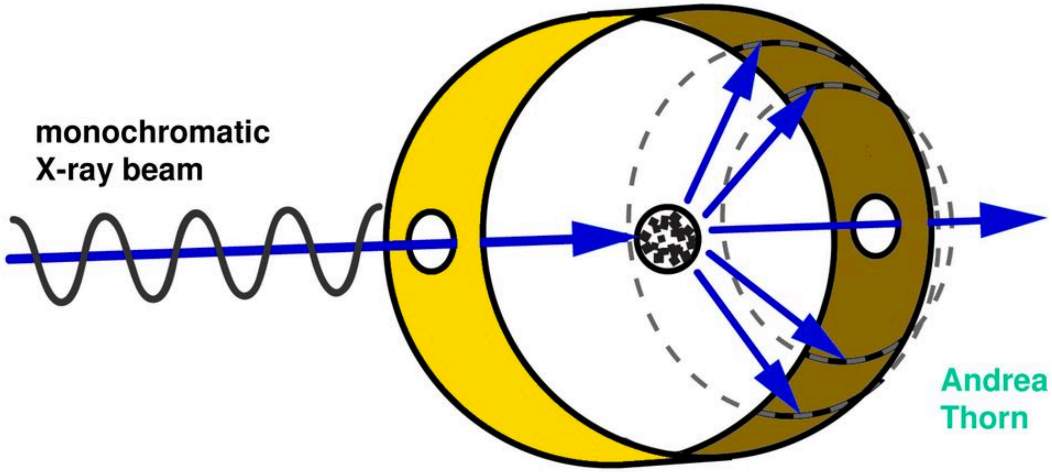
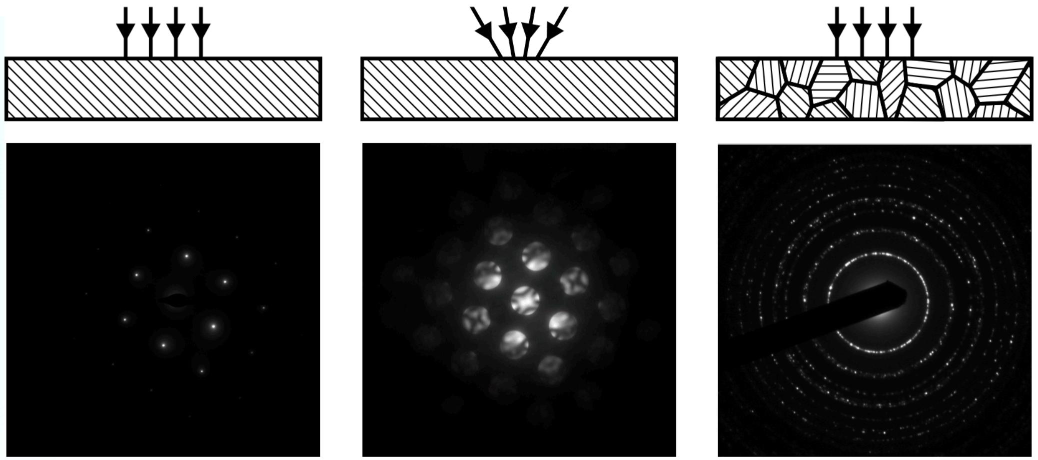
1. Electron Diffraction,

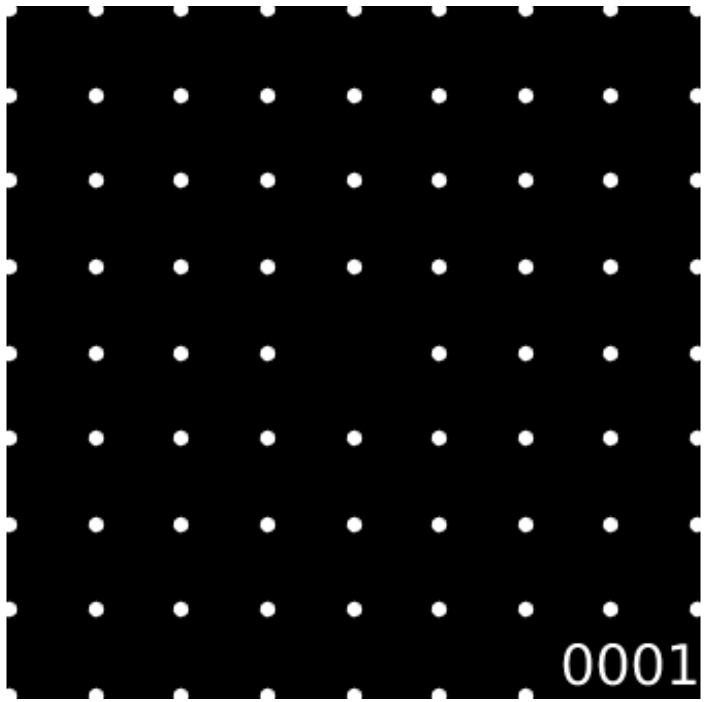


The Debye-Scherrer method (Göttingen, 1915)



Since the microcrystals are in all possibe orientations, the diffraction pattern consists of concentric cones with diffraction angles 2θ. These can be recorded with a cylindrical film or area detector. The intensities are measured as a function of θ.





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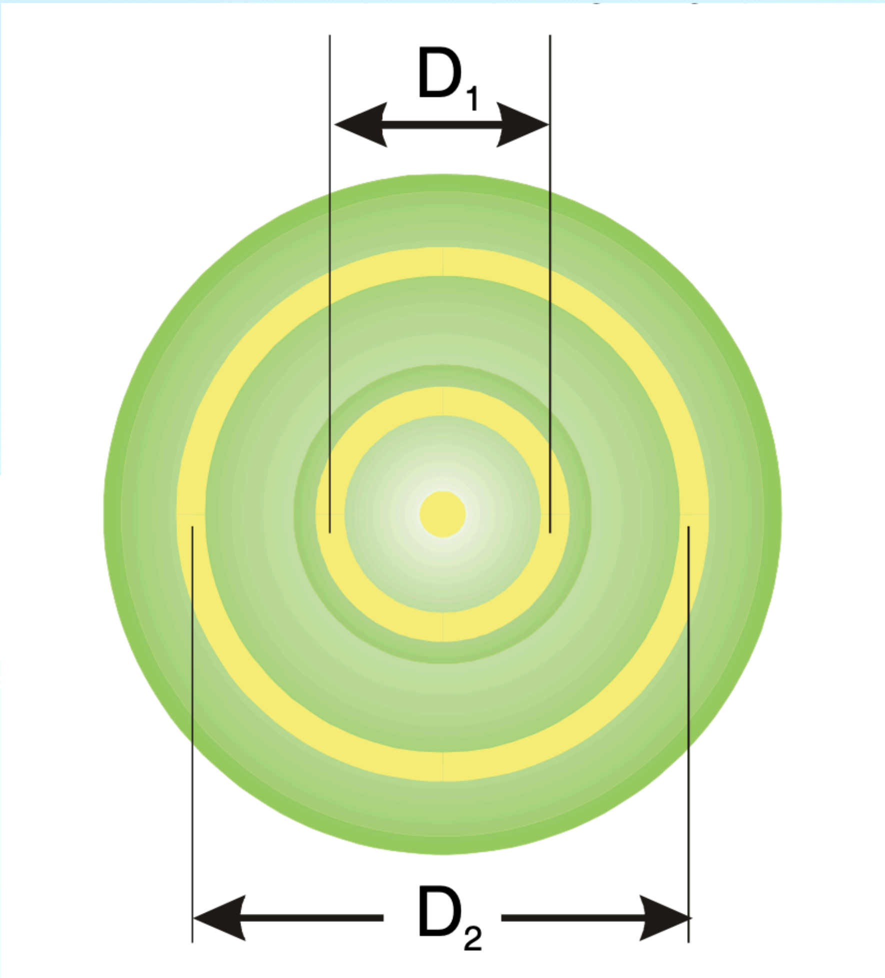

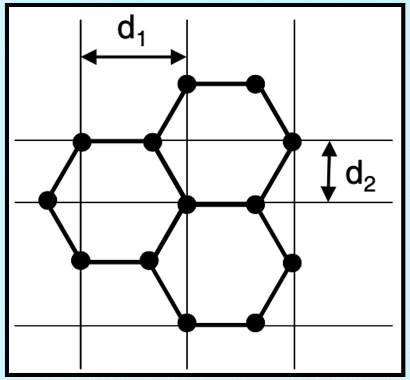

$$\lambda = \frac{h}{P}$$

- The diameter of the concentric rings changes with the wavelength λ and thus with the accelerating voltage U

$$\mathrm{e\,.\,U} = \frac{1}{2}mv^2 = \frac{1}{2m}(mv)^2 = \frac{1}{2m}P^2$$

$$P = \sqrt{\mathrm{2m\,.\,e\,.\,U}}$$

$$\lambda = \frac{h}{\sqrt{\mathrm{2m\,.\,e\,.\,U}}}$$

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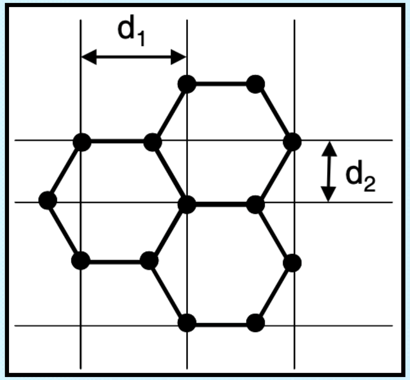

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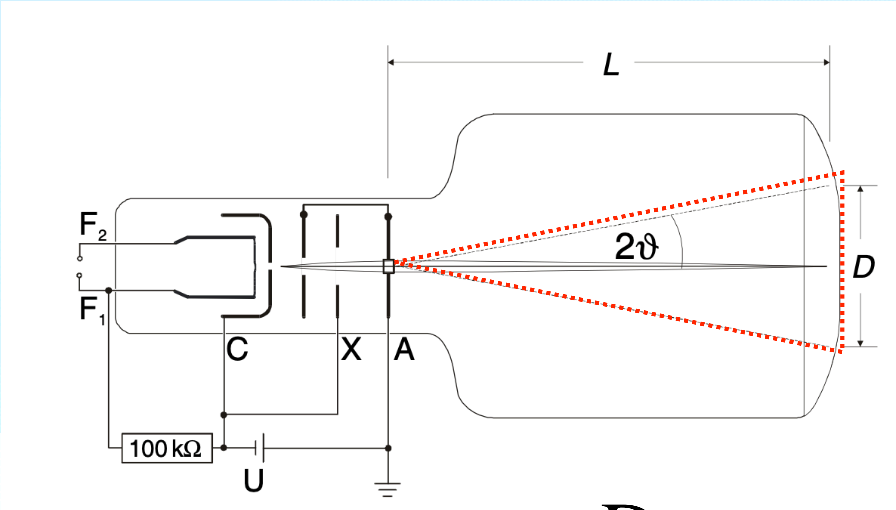

$$\tan\ (2\vartheta) = \frac{\mathrm{D}}{2\mathrm{L}}$$

$$\frac{\sin 2\vartheta}{\cos 2\vartheta} = \frac{\mathrm{D}}{2\mathrm{L}}$$

$$2\ \sin\vartheta \sim \frac{\mathrm{D}}{2\mathrm{L}}\ \text{for}\ \vartheta \to 0$$

$$n\lambda = 2d\sin\vartheta$$

$$n\lambda = d \times 2\ \ \sin\vartheta$$

$$\lambda = d \times \frac{D}{2L};\ \ n = 1$$

And We have,

$$\lambda = \frac{h}{\sqrt{2\mathrm{m}\,.\,\mathrm{e}\,.\,\mathrm{U}}}$$

Now we have relation between D vs U:

$$\mathrm{D} = \frac{2.\mathrm{L}\,.\,\mathrm{h}}{\mathrm{d}\sqrt{2\mathrm{m}\,.\,\mathrm{e}\,.\,\mathrm{U}}}$$

L = 13.5 cm

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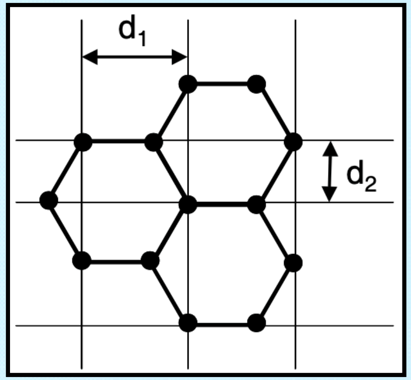
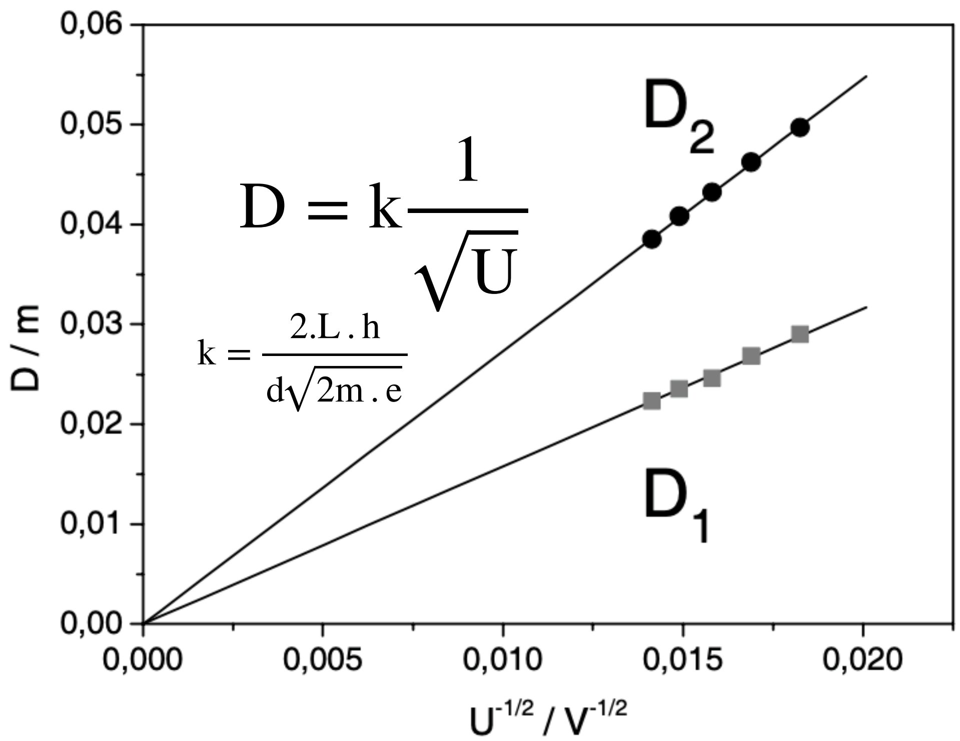
1. Electron Diffraction,



a) Determination of wavelength of the electrons

b) Verification of the de Broglie's equation

c) Determination of lattice plane spacings of graphite



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2. Photo Electric effect,

2. Photo Electric effect,

Most of the metals under influence of radiation, emit electrons

Albert Einstein in 1905

- That the emission process depends strongly on frequency of radiation.
- For each metal there exists a critical frequency such that light of lower frequency is unable to liberate electrons, while light of higher frequency always does.
- The emission of electron occurs within a very short time interval after arrival of the radiation and member of electrons is strictly proportional to the intensity of this radiation.
- These facts are strong evident that the energy of the radiation is quantised:

$$E = h\nu$$

$$h : \text{Plank's constant},\ \nu : \text{Frequency}$$

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2. Photo Electric effect,

- Energy of the bound electrons in metal is:

$$E = e\,.\,\phi \qquad \phi : \text{work function}$$

Then for the emission of the electrons,

$$h\nu > e\,.\,\phi$$

With the additional velocity of the electrons,

$$h\nu = \frac{1}{2}mv^2 + e\,.\,\phi$$

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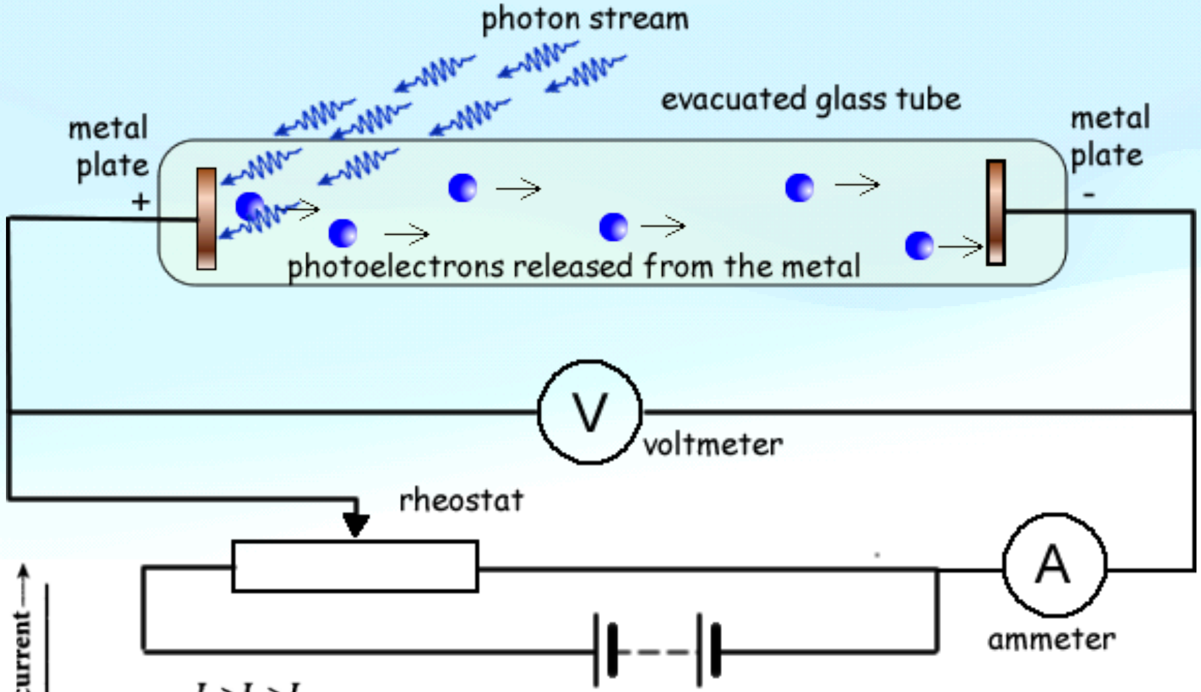
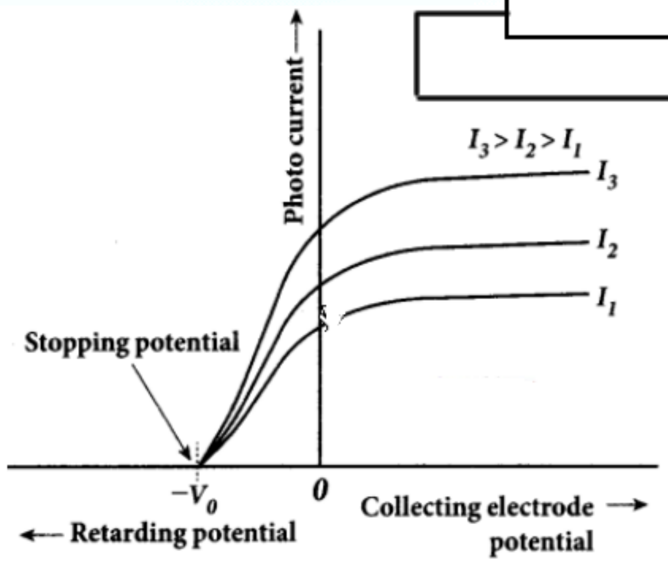
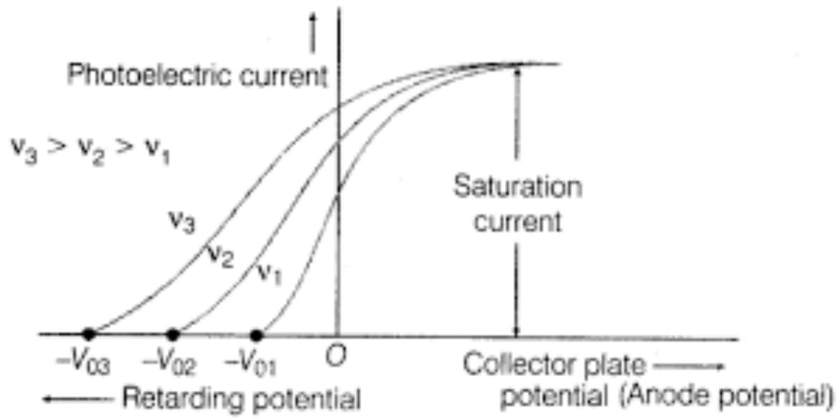
2. Photo Electric effect,





Variation of photocurrent with potential difference



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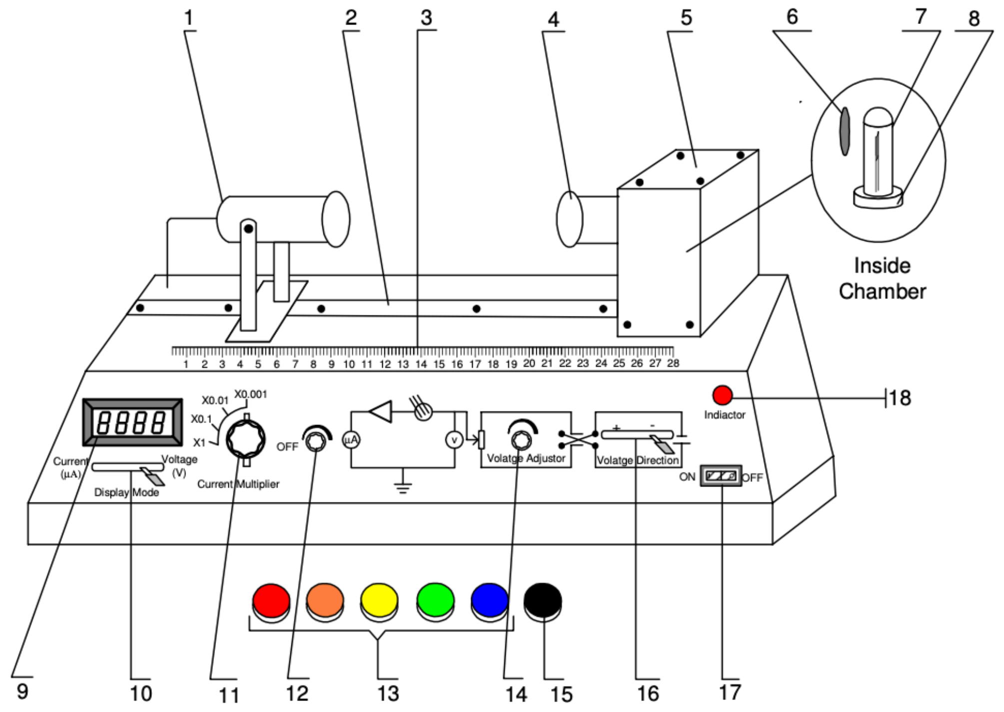
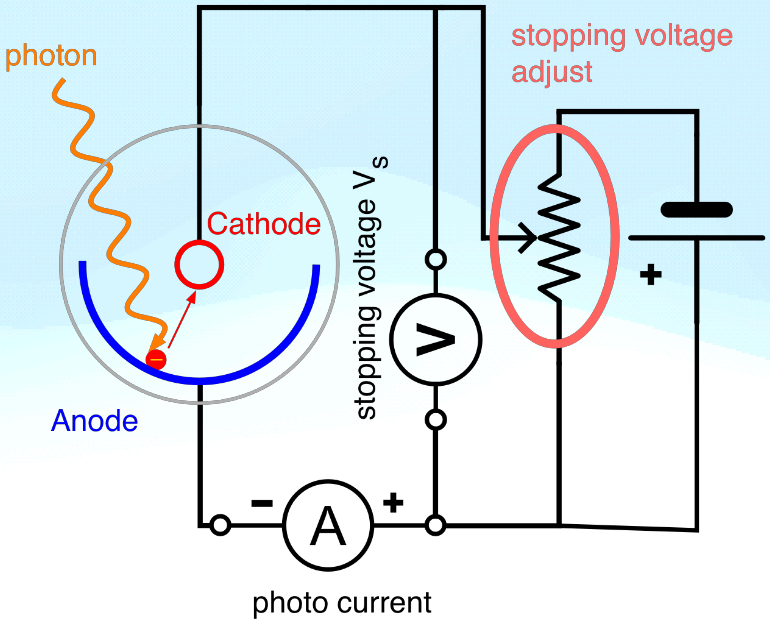
2. Photo Electric effect,



1-Light source, 2-Guide, 3-Scale, 4-Drawtube, 5-Cover, 6-Focus lens, 7-Vacuum Phototube, 8-Base for holding the Phototube, 9-Digital Meter, 10-Display mode switch, 11-Current multiplier, 12-Light intensity switch, 13-Filter set, 14-Accelerate voltage adjustor, 15-Lens cover, 16-Voltage direction switch, 17-Power switch, 18-Power indicator.



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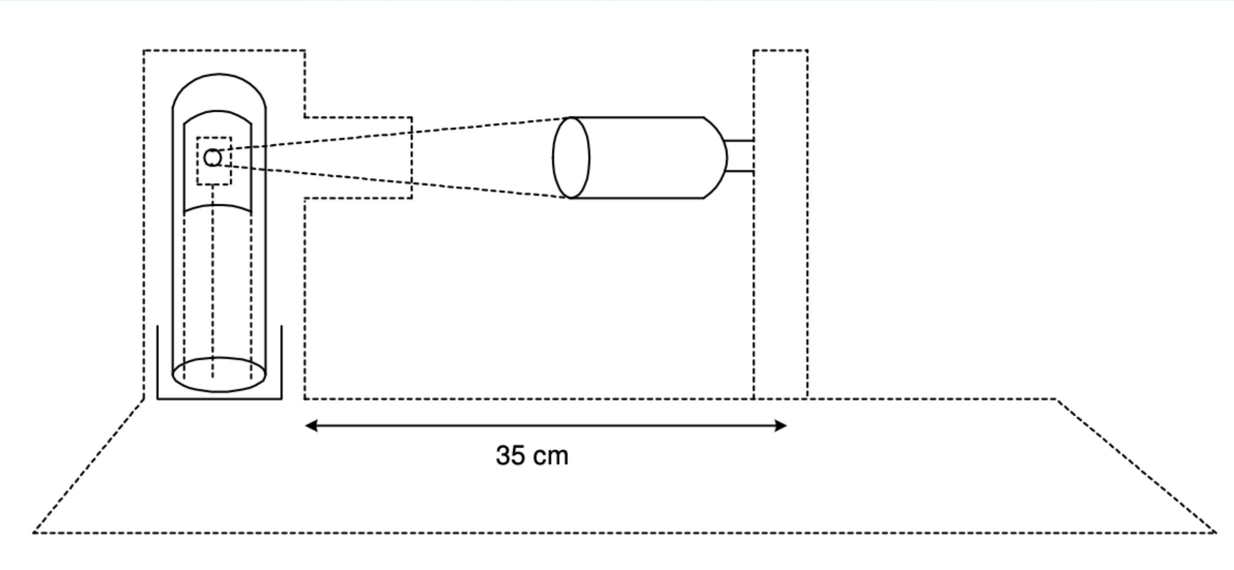

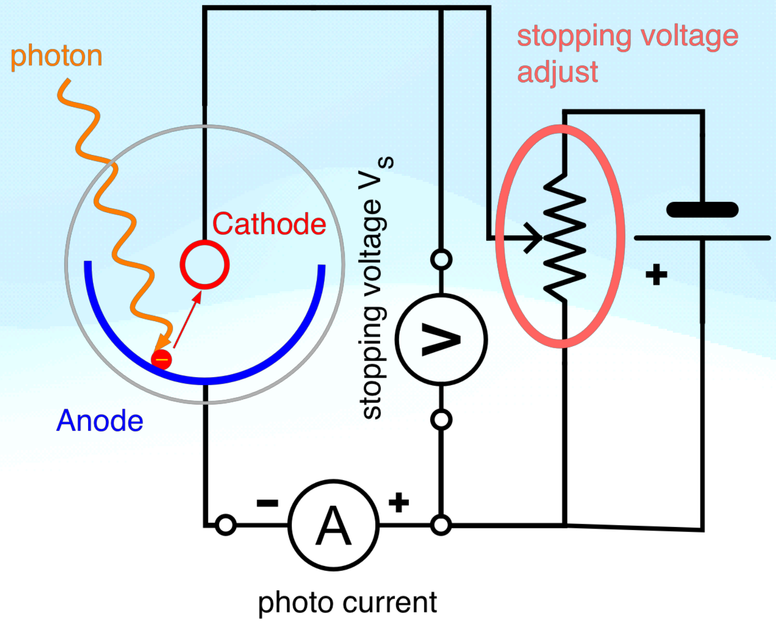

- The light source is used to shine light on a photodiode to generate a photo current.
- We stop the photocurrent by applying a potential with retarding potential technique
- The potential required to stop the photocurrent is called as stopping potential (V_s), and the kinetic energy of the electrons is defined as $E_e = \frac{1}{2}mv^2 = eV_s$

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2. Photo Electric effect,

$$E_e = \frac{1}{2}mv^2 = eV_s$$

Then,

$$h\nu = eV_s + e\,.\,\phi$$

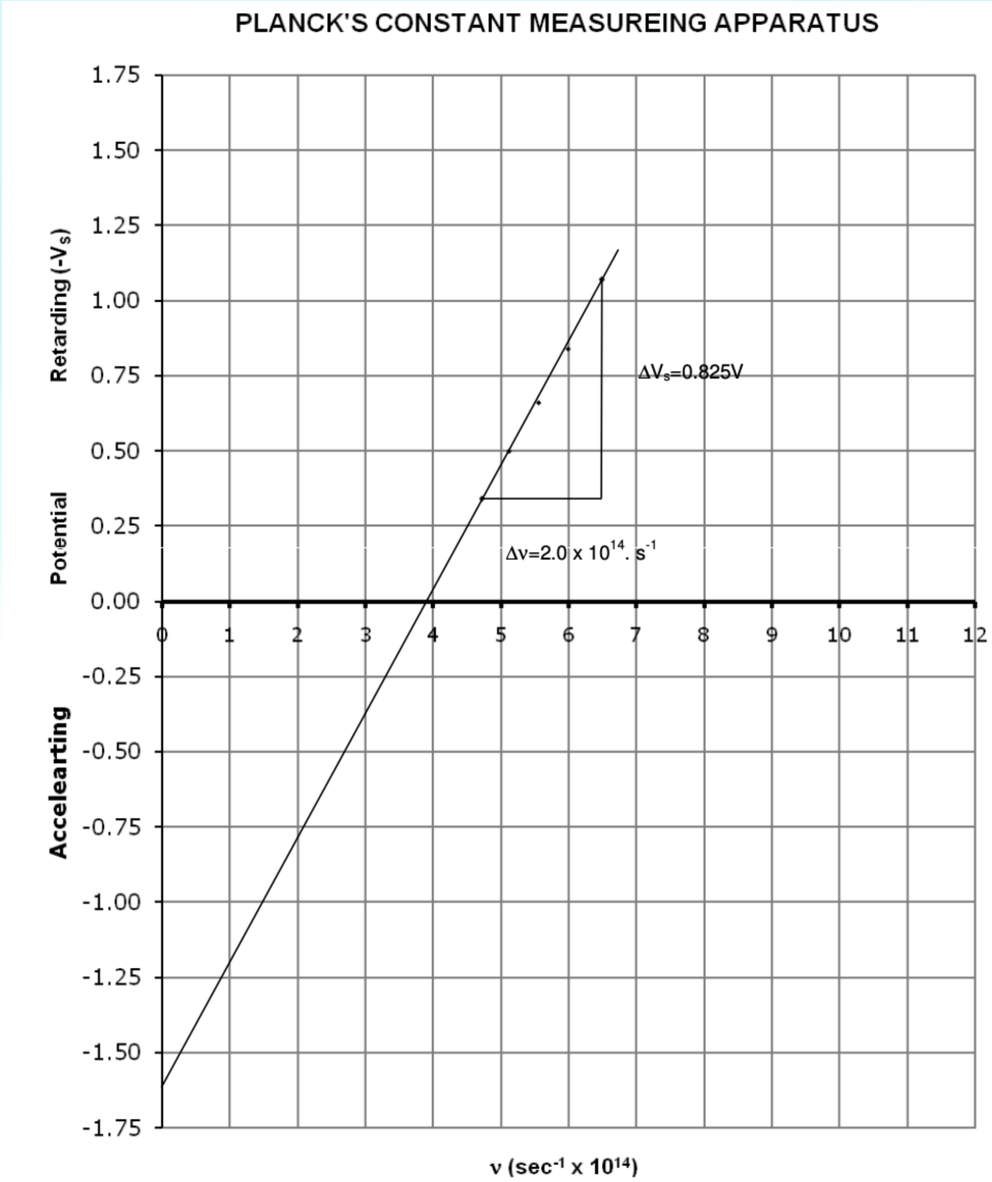
$$V_s = \frac{h}{e}\nu - \phi$$

$$V_s = -\phi \text{ for } \nu = 0$$

- **Determination of Planck's Constant**

Form the slope of the equation:

$$V_s = \frac{h}{e}\nu - \phi$$



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3. Velocity of Light,

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3. Velocity of Light,

A periodic light is an electromagnetic signal which intensity is dependent on time, and change its phase by distance.

$$I = I_0 + \Delta I_0 \,.\, \cos(2\pi \,.\, \nu \,.\, t)$$

We can write simply as alternative signal

$$U = a \,.\, \cos(2\pi \,.\, \nu \,.\, t)$$

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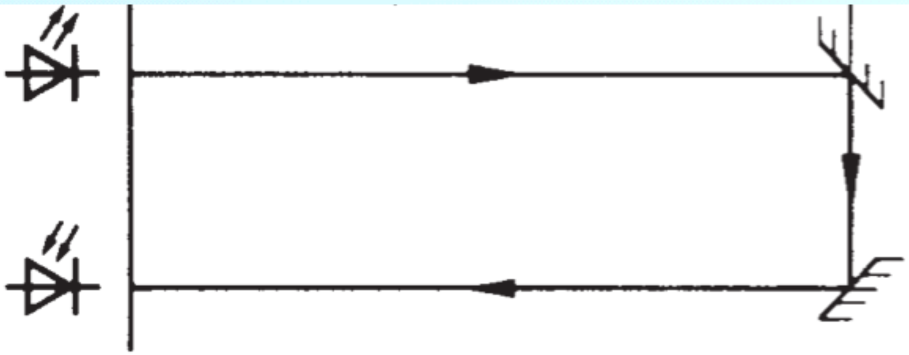
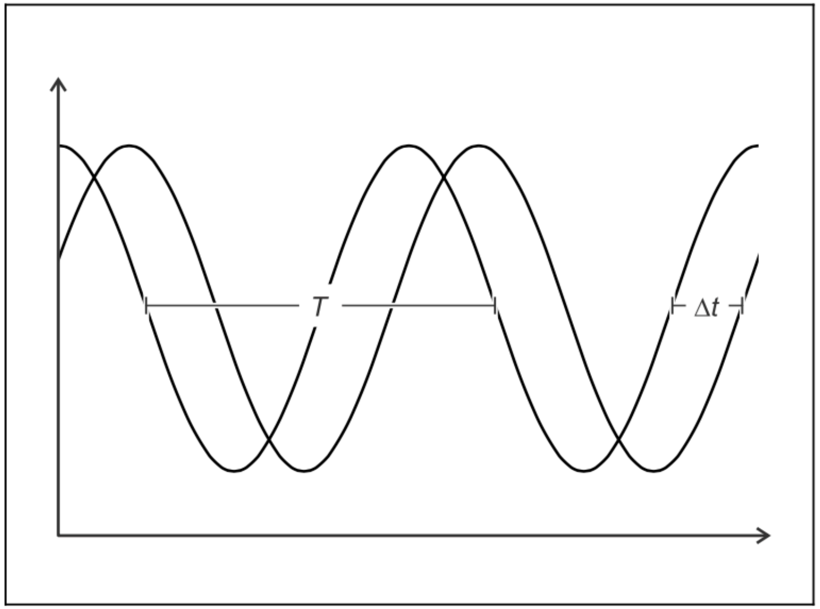
3. Velocity of Light,

It will show a phase difference at the receiver as

$$U = a \,.\, \cos(2\pi \,.\, \nu \,.\, t - \Delta\phi)$$





Lets make a path difference for a known phase difference by measuring the phase at the receiver

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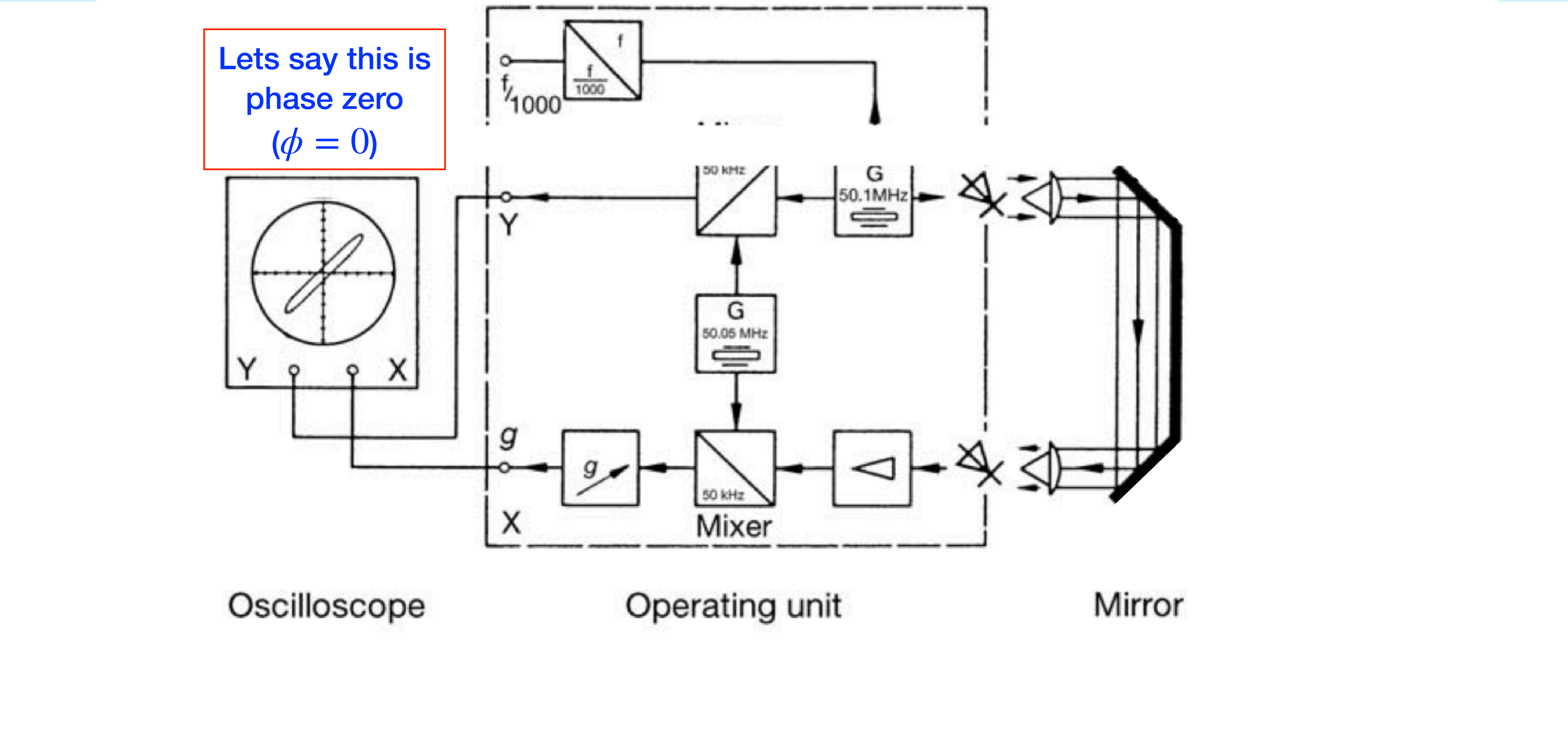
3. Velocity of Light,



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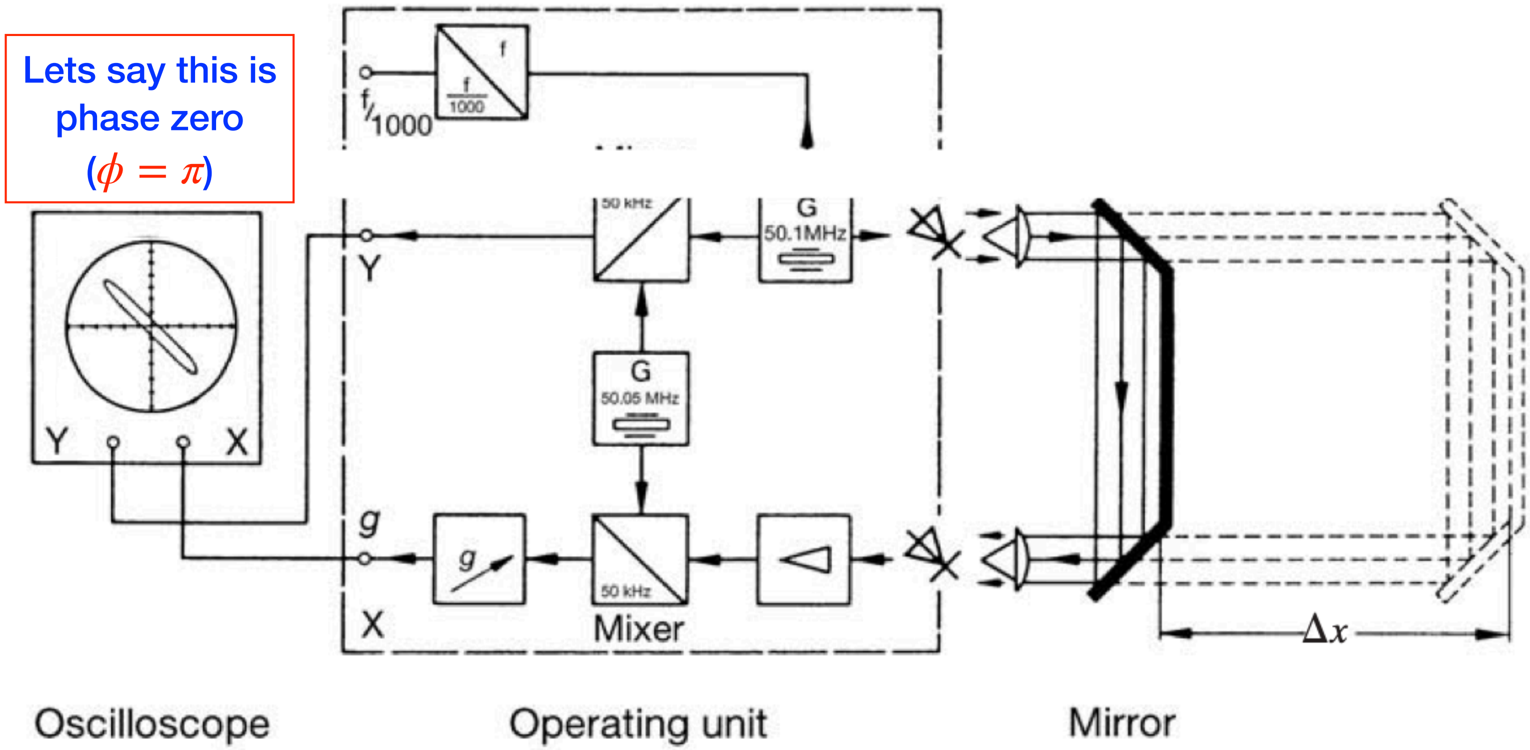

The extended path light path is $\Delta l = 2.\Delta x$

For the phase difference ($\Delta\phi = \pi$) the time required is $\Delta t = 1/2f$, f is modulation fequency

$$\boxed{\text{The velocity of light is } C = \frac{\Delta l}{\Delta t} = 4f\,.\,\Delta x}$$

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3. Velocity of Light, Determination of Refractive index:

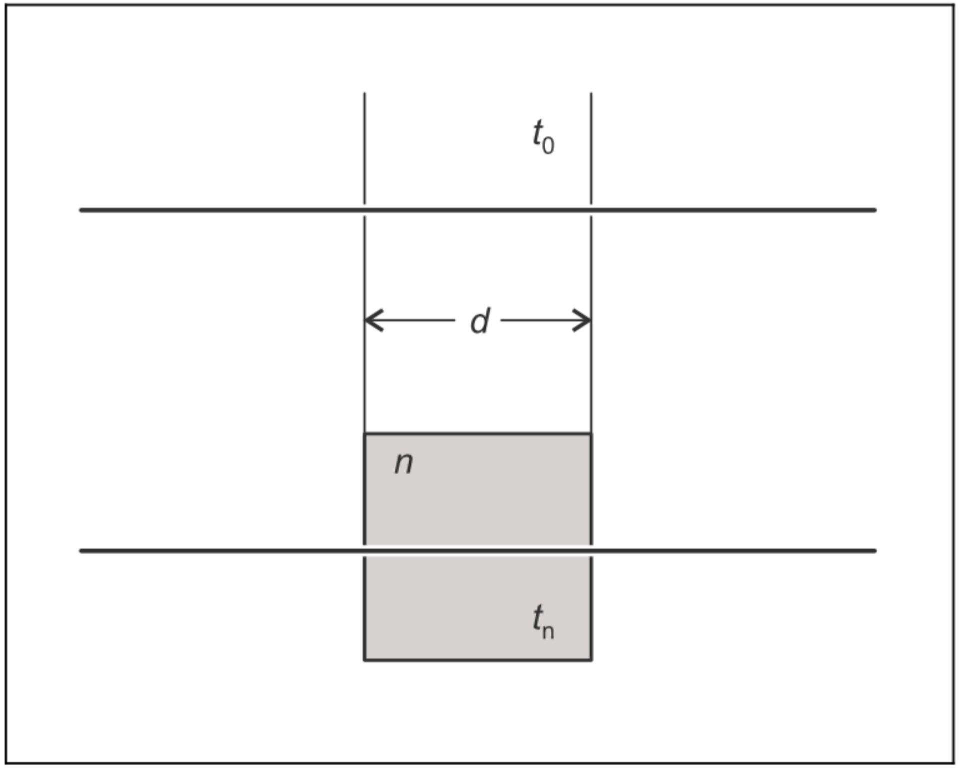

Fig. 1 In a medium with the refractive index *n* light propagates at a lower velocity than in vacuum. This leads to a change in the propagation time *t* of light along a path of length *d*.

Velocity of light in medium is:

$$C_M = \frac{C}{n}$$

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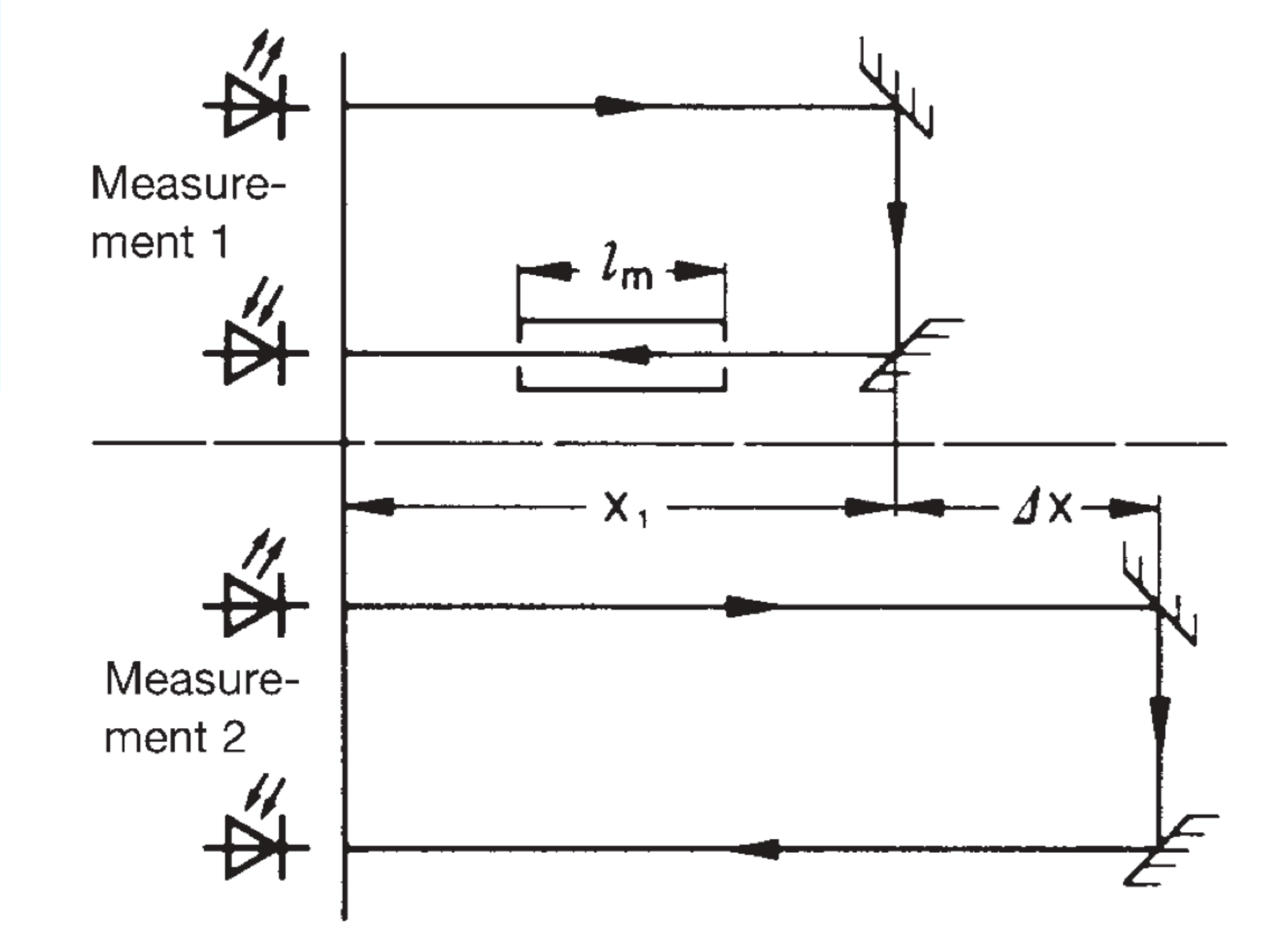
3. Velocity of Light, Determination of Refractive index:



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3. Velocity of Light, Determination of Refractive index:

Refractive index of the medium is:

$$n = \frac{\mathrm{C}}{\mathrm{C_M}} = \frac{2.\Delta x}{l_m} + 1 + \frac{k\,.\,C}{f\,.\,l_m}$$

$$\frac{k\,.\,C}{f\,.\,l_m} \sim 6.k, \text{ for 1m water medium}$$

$$\frac{k\,.\,C}{f\,.\,l_m} \sim 20.k, \text{ for 30cm resin medium}$$

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For 4. Frank Hertz and 5. Stefan Boltzmann,
Look to Prof. Rumi De's notes

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Todo list in each experiments:

1. Electron Diffraction (Estimate the Planck's Constant)
   - 5 Different voltage between 3kV to 5kV
   - For each voltage at least 6 readings of diameter of each ring

2. Velocity of Light (Find the speed of light and refractive index of medium)
   - At least 6 Readings of c in air
   - 6 readings in medium

3. Photo Electric effect (Estimate the Planck's Constant)
   - For each value of frequency, at least 5 readings averages.
   - Two graphs of stopping potential vs frequency at two different intensities, either by varying distance or bulb current.

4. Frank Hertz (Determination of Ar gas first excited state)
   - At least two (three preferable) sets of readings by varying Extraction voltage and retardation voltage

5. Stefan Boltzmann (Verify the Stefan Boltzmann Law)
   - Room temperature Resistance of bulb at 6 to 8 different current
   - V vs I
   - At least 6 to 8 reading in bulb glowing condition.

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Marks divison (Total 100 Marks)

1. Lab notes (25 Marks),
   - Each experiment carried 5M
2. Midsem VIVA (25 Marks)
   - After minimum three experiments done by all sub-groups
3. Endsem Practical and VIVA (50 Marks),

All the best