PH2203: Physics Laboratory IV

(PH2103: Physics Laboratory III)

Instructors:

Arindam Kundagrami,
Ayan Banerjee,
Bheemalingam Chittari,
Partha Mitra

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Optics
(Arindam Kundagrami and Ayan Banerjee)

Modern Physics
(Bheemalingam Chittari and Partha Mitra)

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Experiments:

1. Electron Diffraction,

2. Photo Electric effect,

3. Frank Hertz,

4. Velocity of Light,

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

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

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

Davisson and Germer in 1927

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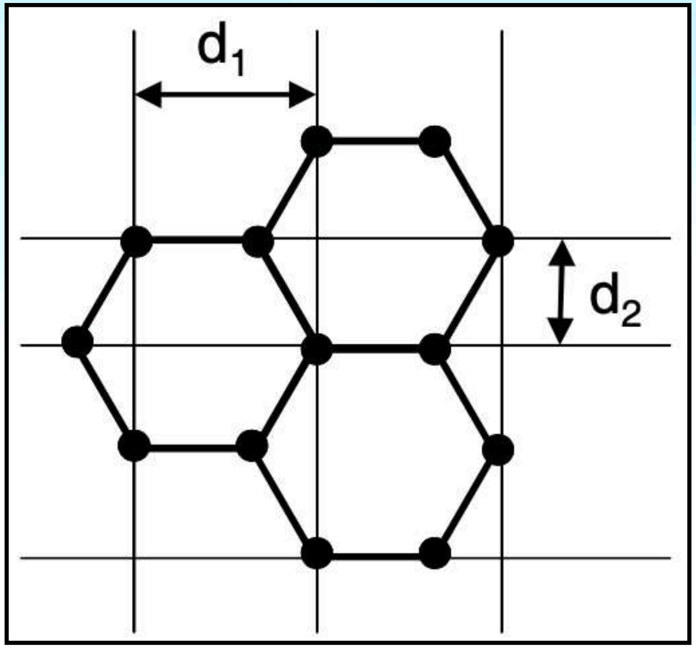
1. Electron Diffraction,

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

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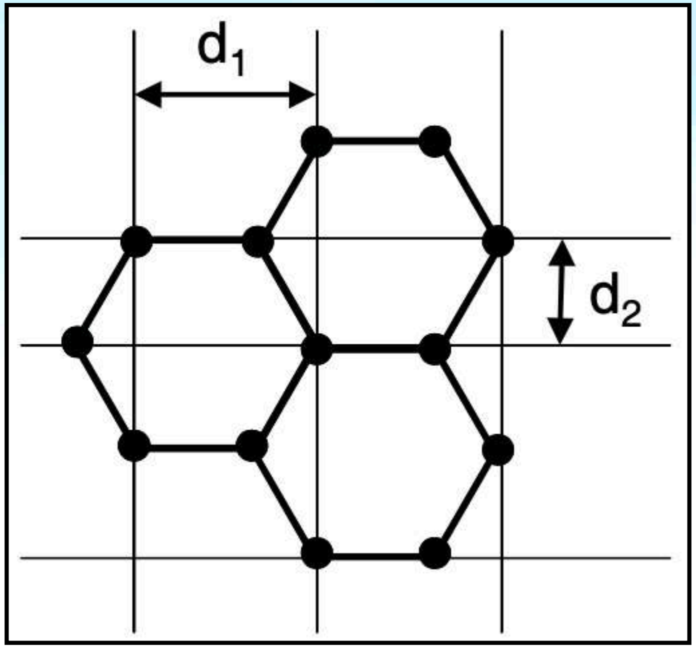

Lattice plane spacings in graphite

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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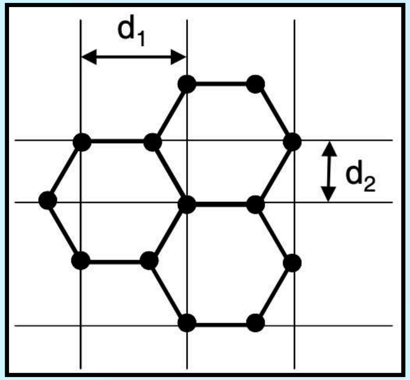

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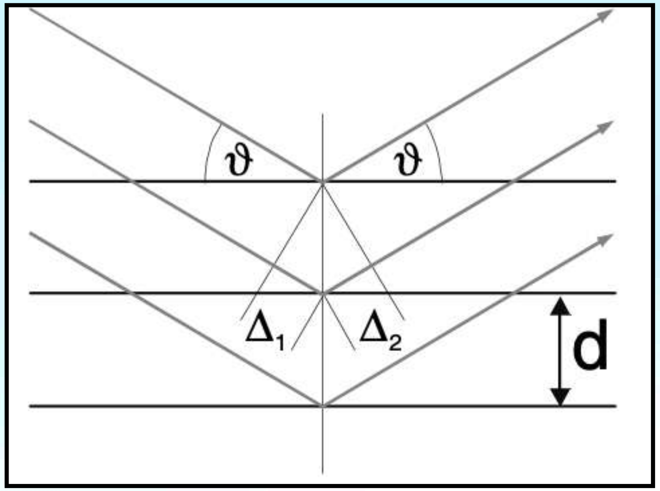

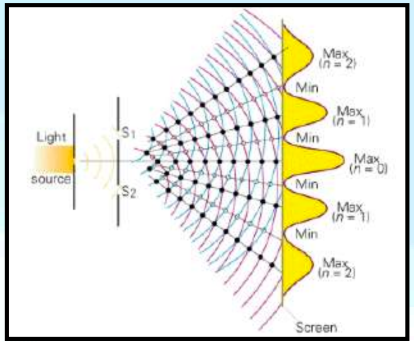

- These spherical wavelets create a "reflected" wave front. The wavelength λ remains unchanged with respect to the "incident" wave front, and the radiation directions which are perpendicular to the two wave fronts fulfil the condition "angle of incidence = angle of reflection"
- The constructive interference 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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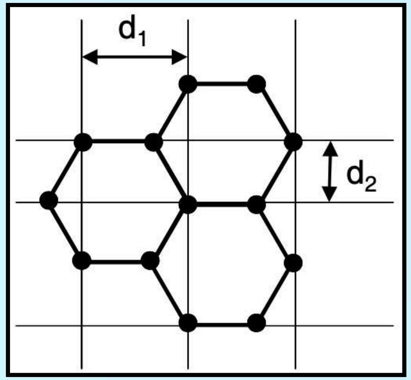
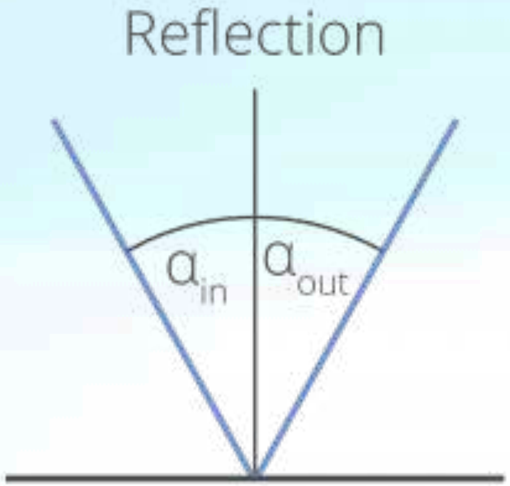


1. Electron Diffraction,

Diffraction is observed in two ways:



Davisson and Germer in 1927

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

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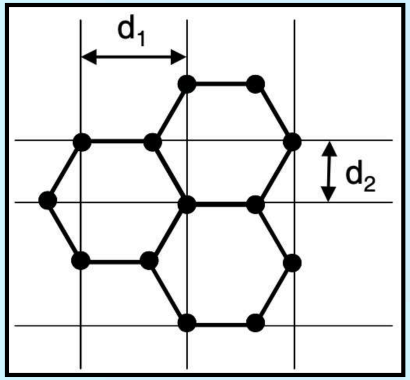

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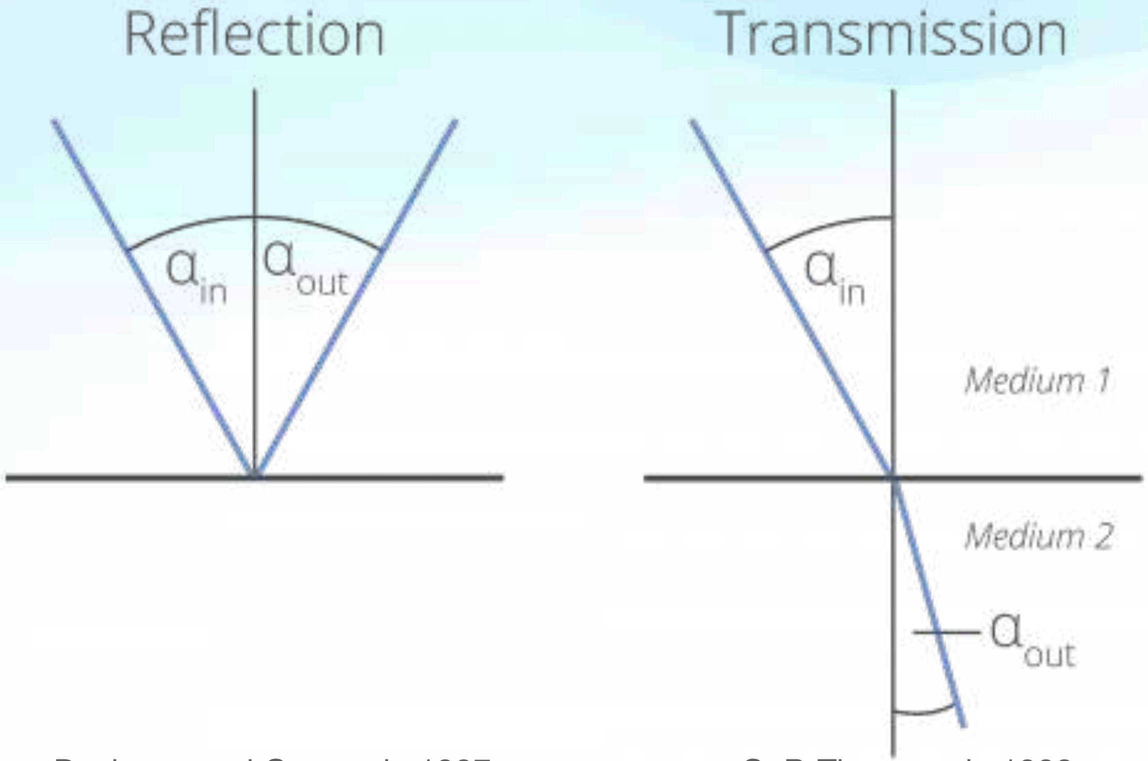

Davisson and Germer in 1927

G. P. Thomson in 1928

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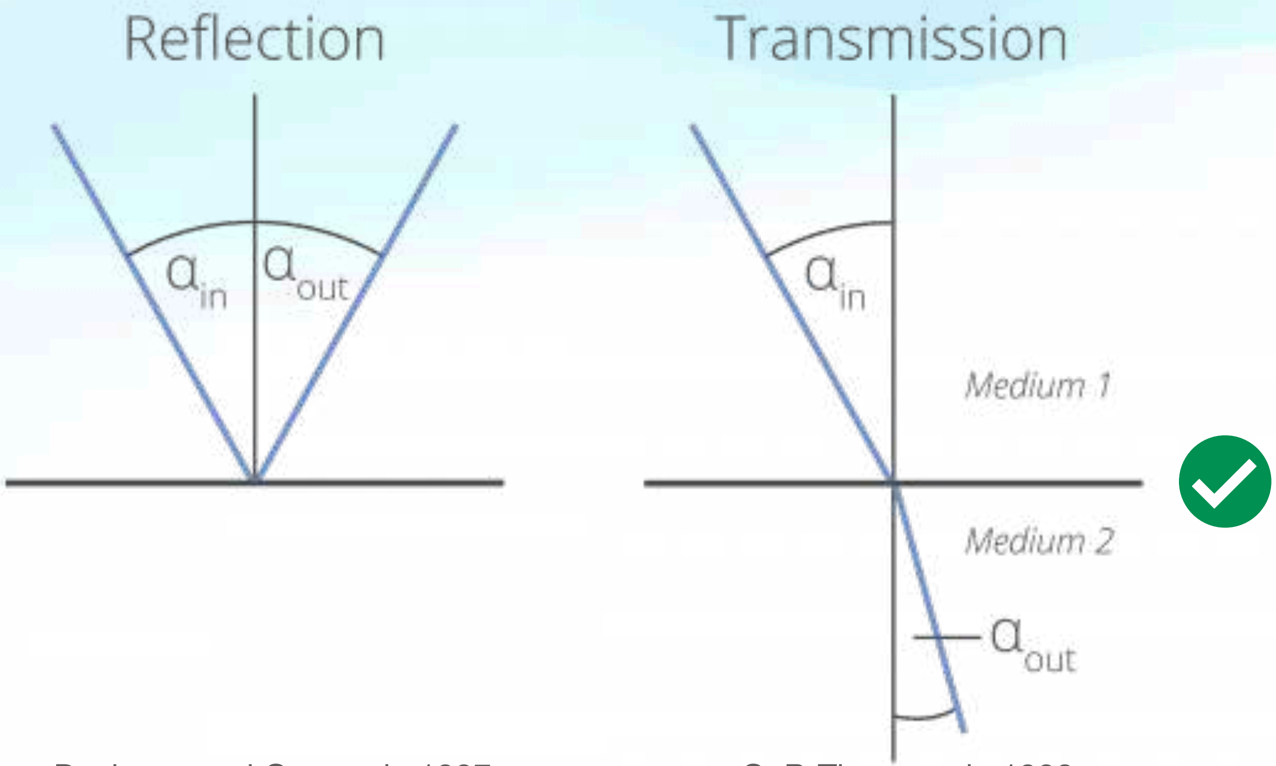

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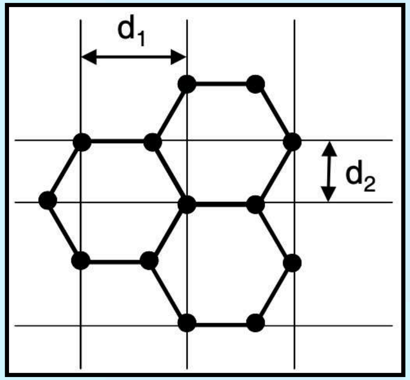

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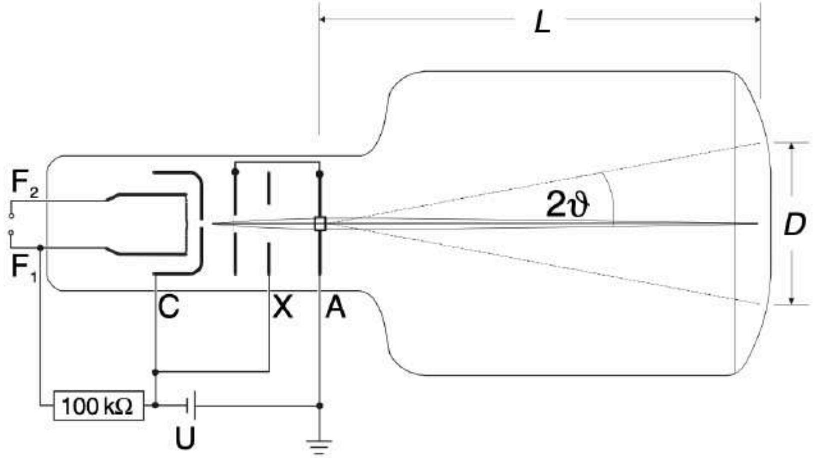

Fig. 4: Schematic sketch for determining the diffraction angle.
L = 13.5 cm (distance between graphite foil and screen),
D: diameter of a diffraction ring observed on the screen
ϑ: diffraction angle
For meaning of F_1, F_2, C, X and A see Fig. 5.

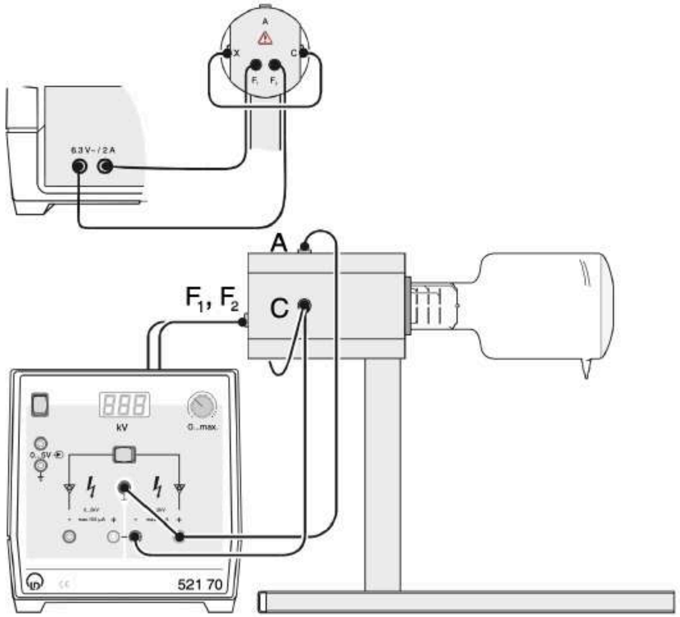

Fig. 5: Experimental setup (wiring diagram) for observing the electron diffraction on graphite. Pin connection:
F_1, F_2: sockets for cathode heating
C: cathode cap
X: focusing electrode
A: anode (with polycrystalline graphite foil see Fig. 4)

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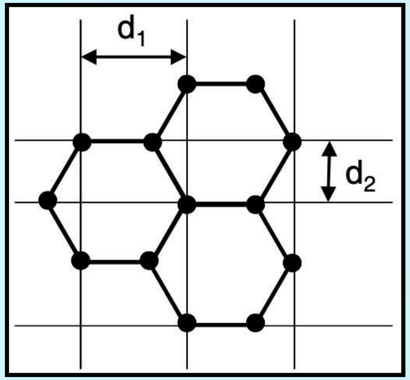
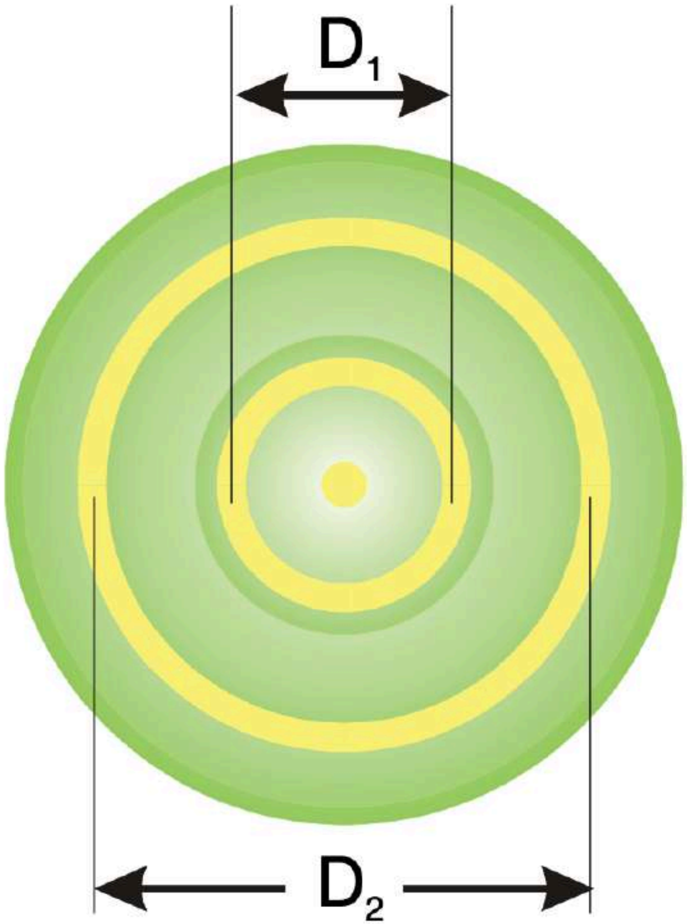


1. Electron Diffraction,

- 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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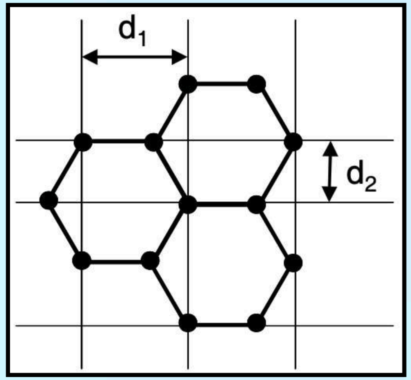
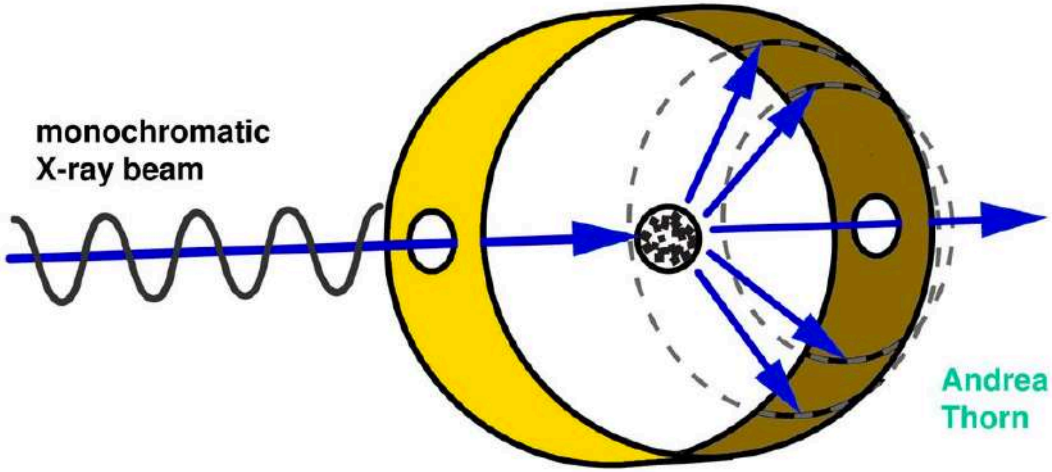
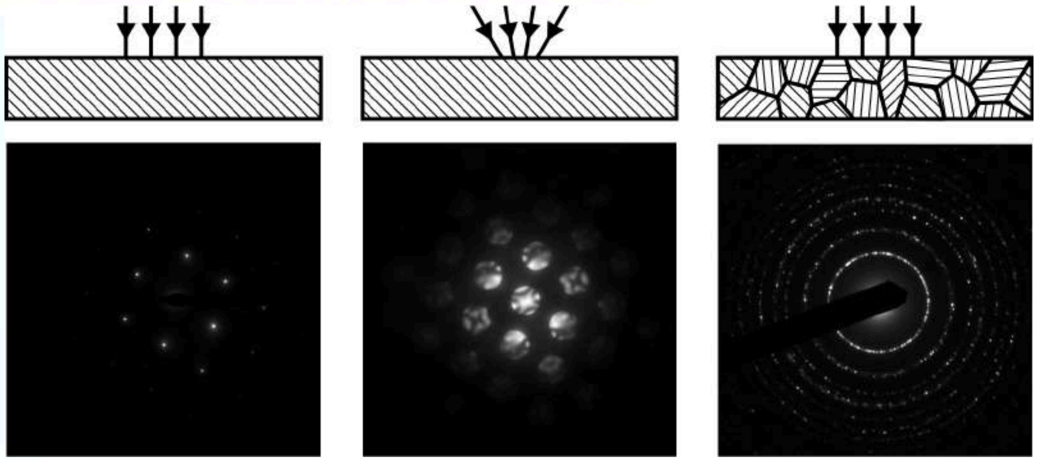


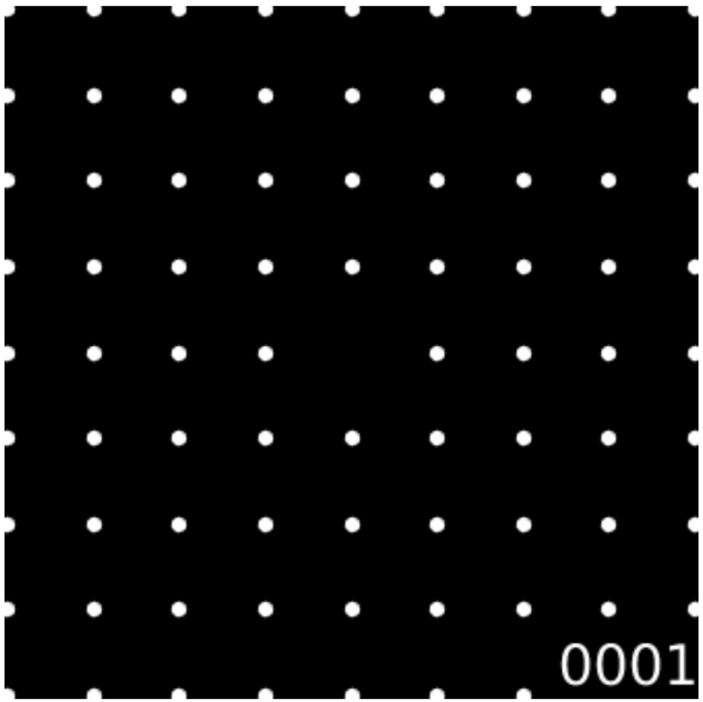
1. Electron Diffraction,

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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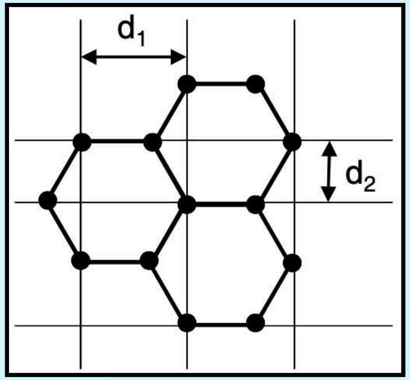

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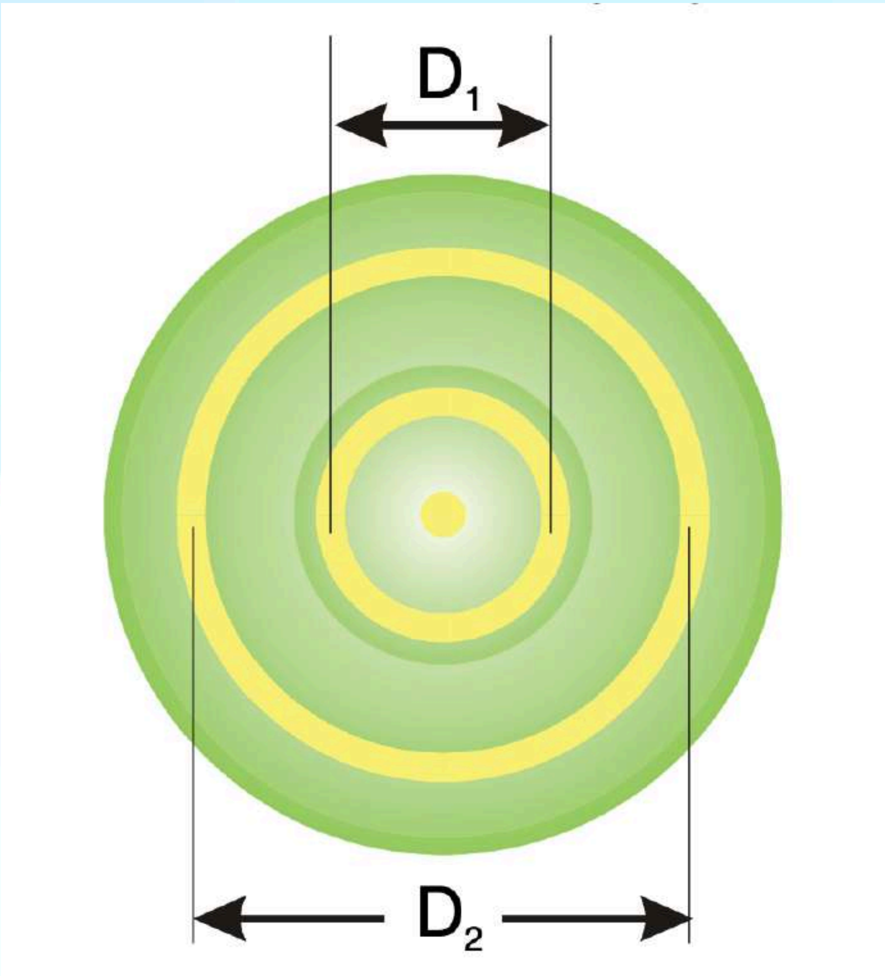

$$\lambda = \frac{h}{P}$$

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

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

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

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

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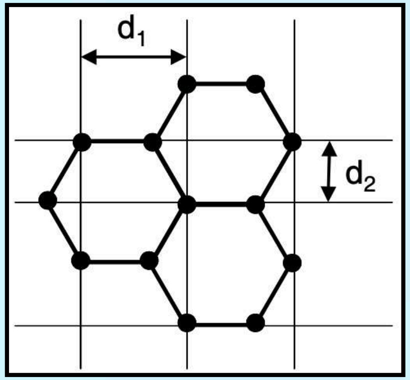

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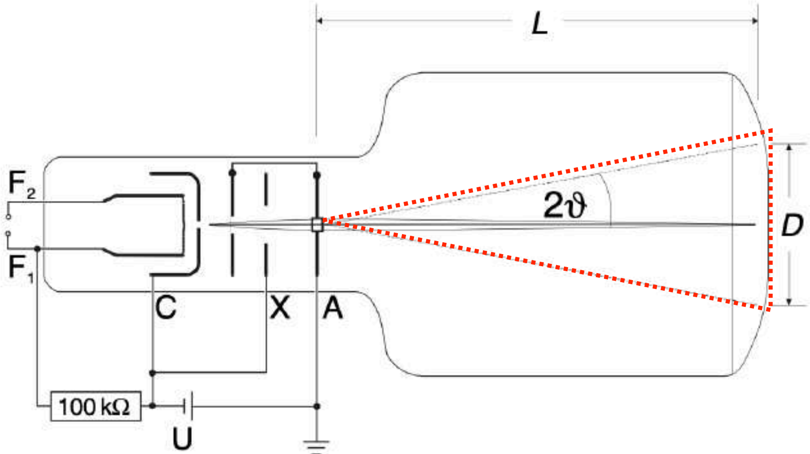

$$\tan\,(2\vartheta) = \frac{\mathrm{D}}{2\mathrm{L}}$$

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

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

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

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

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

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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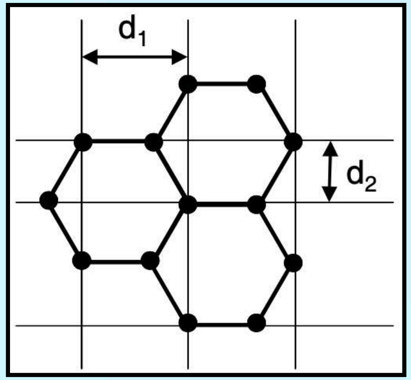
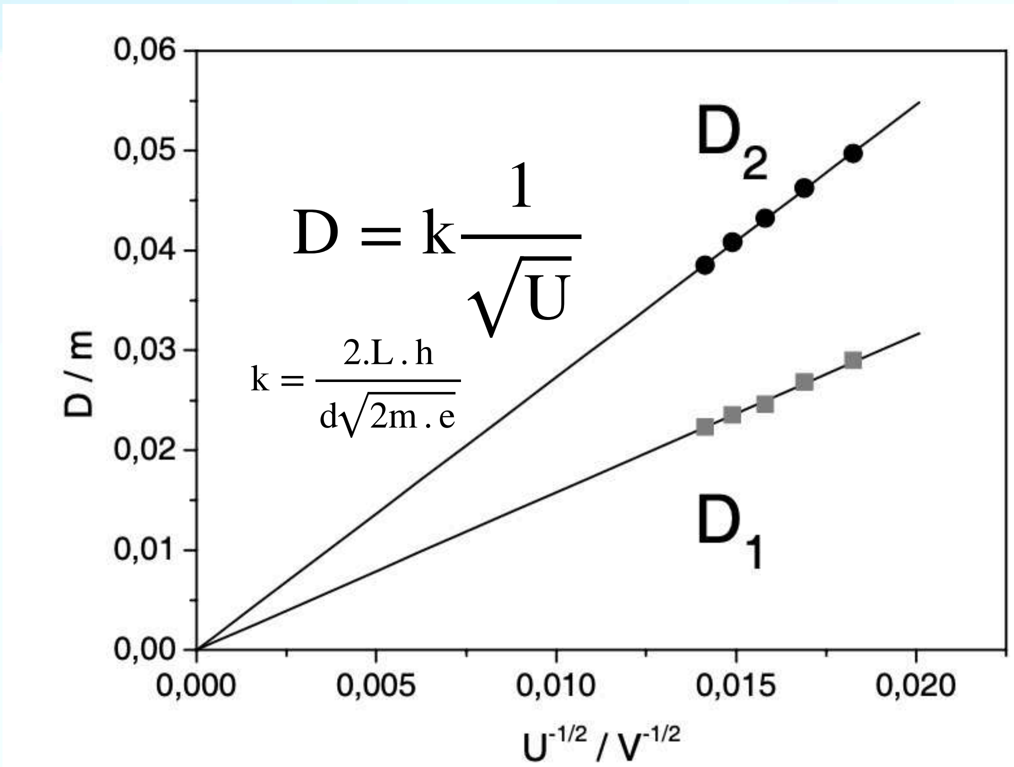


1. Electron Diffraction,

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,

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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 : Plank′s constant, ν : Frequency

2. Photo Electric effect,

- Energy of the bound electrons in metal is:

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

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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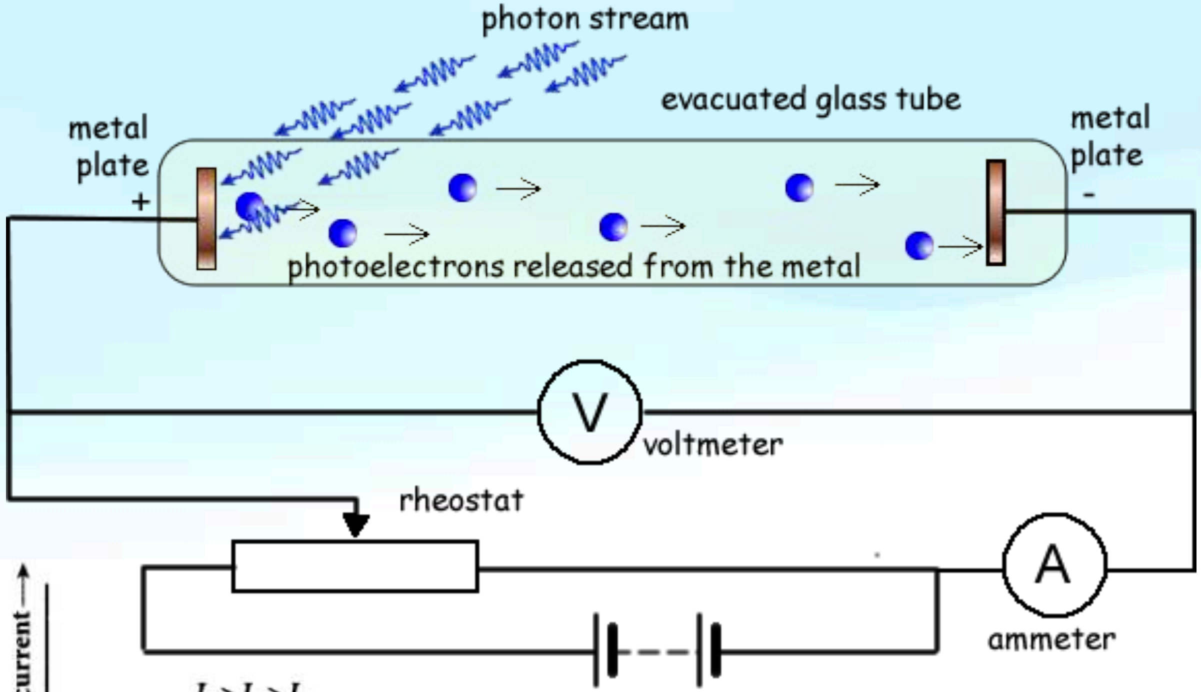
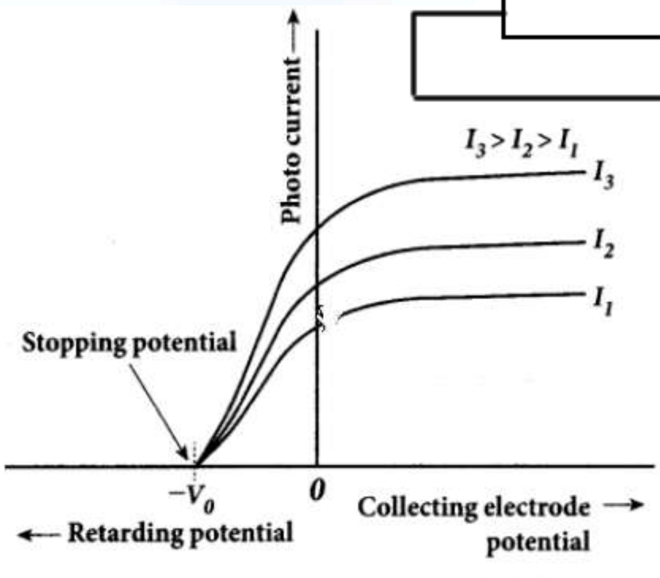
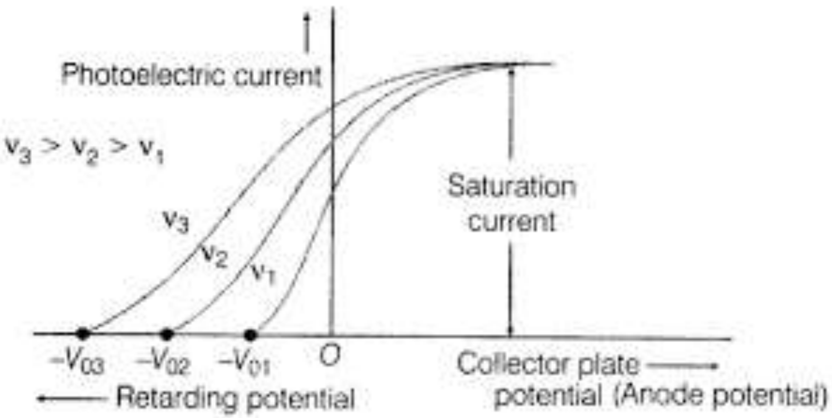
2. Photo Electric effect,





Variation of photocurrent with potential difference



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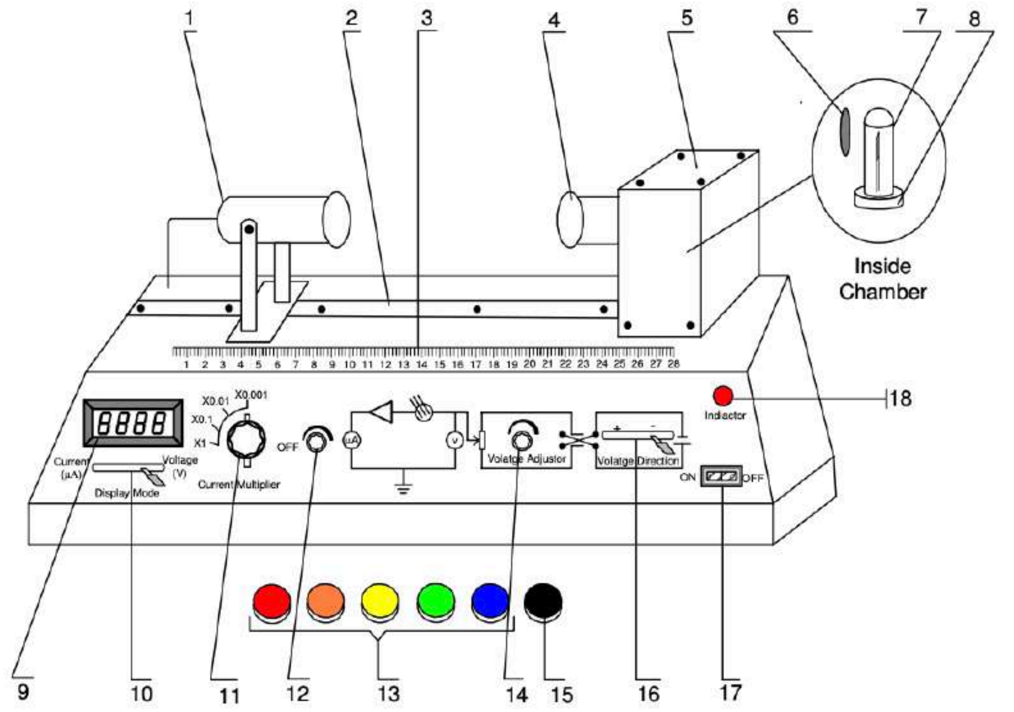
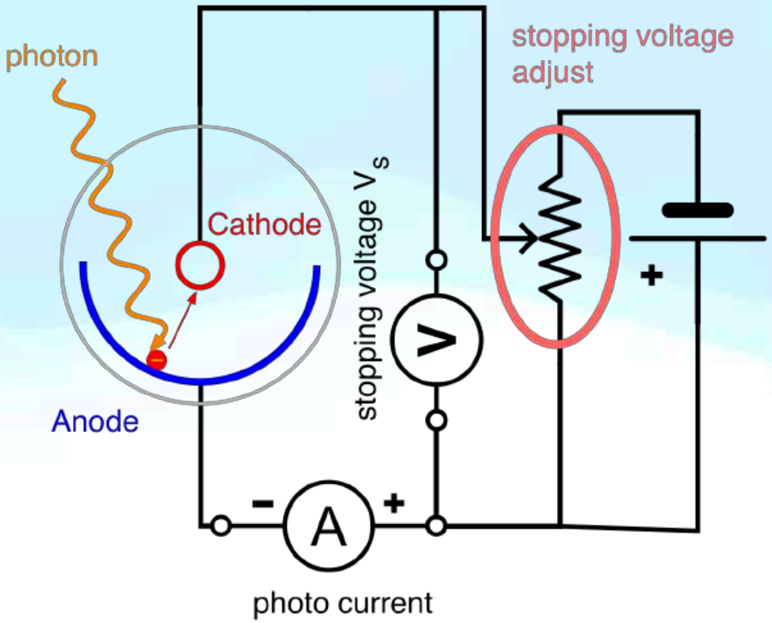
2. Photo Electric effect,



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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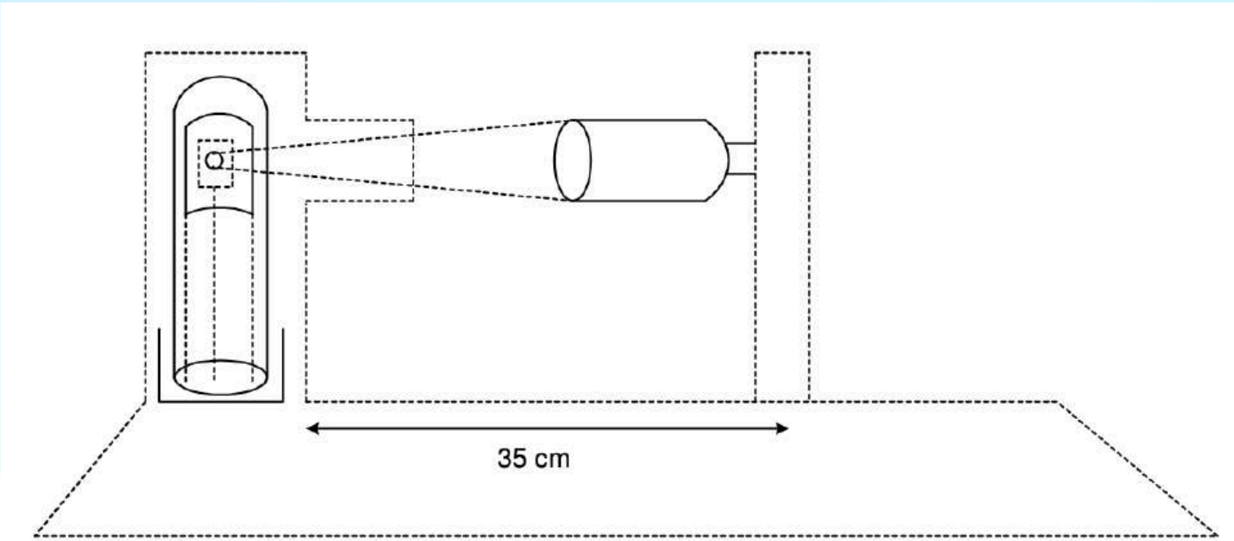
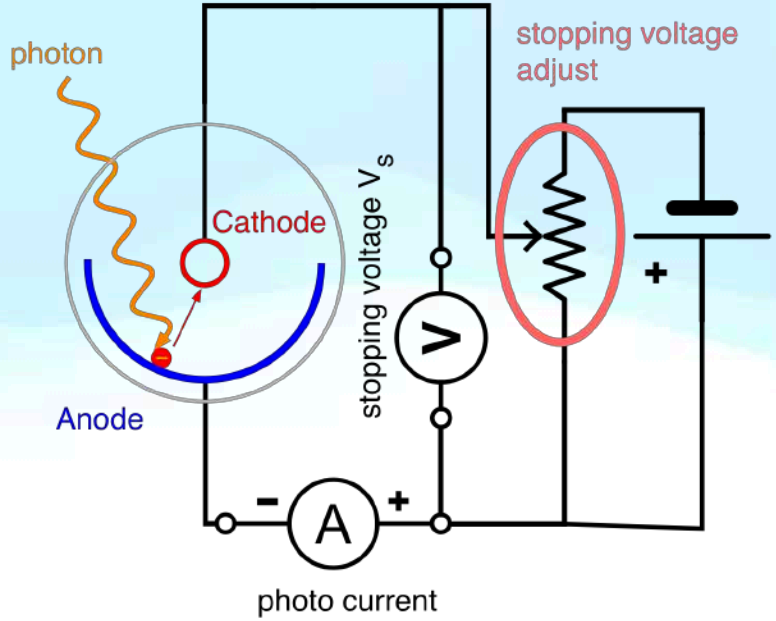
2. Photo Electric effect,





- 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,

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

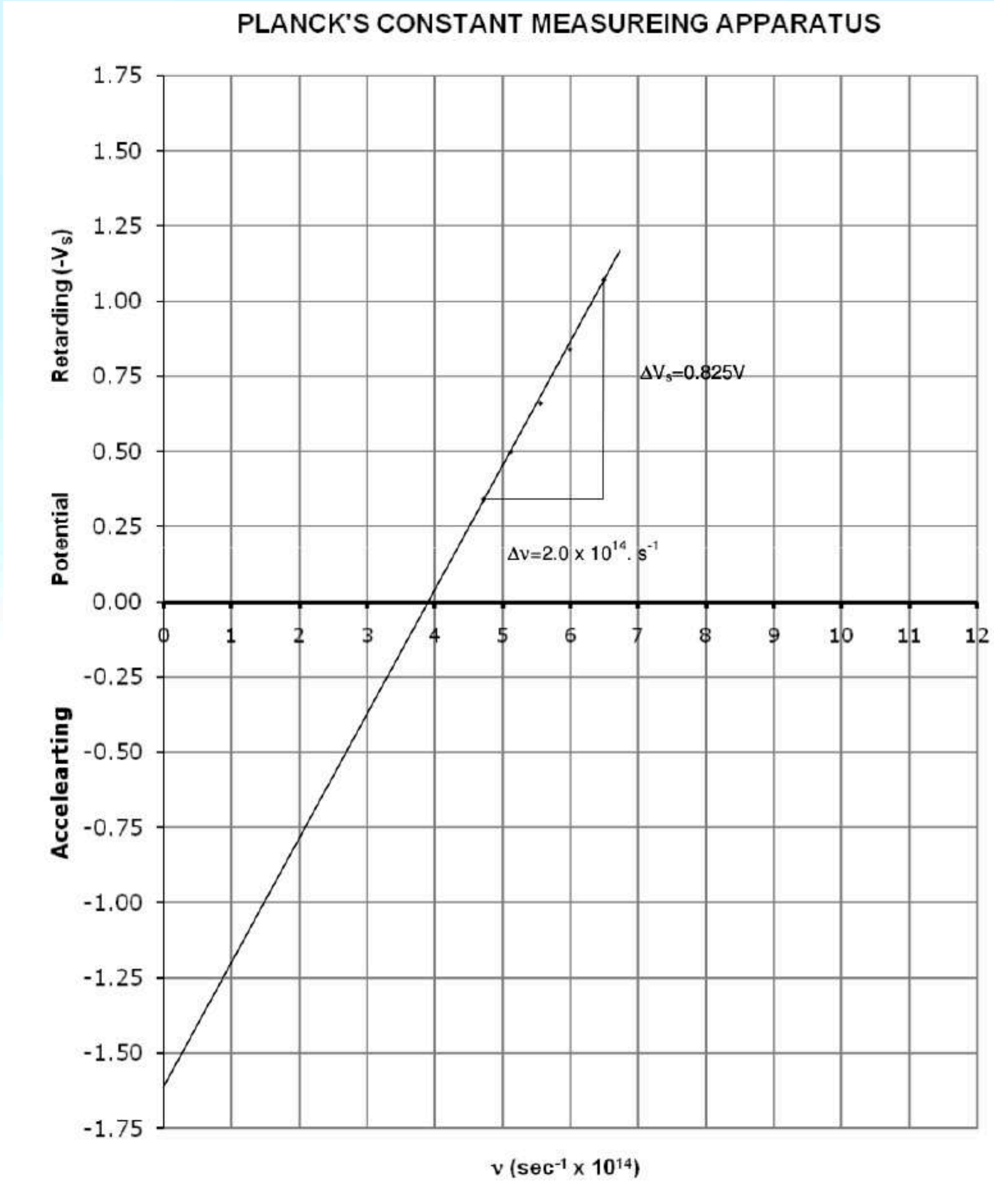
$$V_s = \frac{h}{e}\nu - \phi$$

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

- **Determination of Planck's Constant**

Form the slope of the equation:

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



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3. Frank Hertz,

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Atoms emit radiations at discrete frequencies

Frank and Hertz in 1914

- From Bohr’s model, the frequency of the radiation ν is related to the change of energy levels through $\Delta E = h\nu$.
- It is then expected to be that transfer of the energy to atomic electrons by any mechanism should always be in discrete amounts.
- One such mechanism of energy transfer is through the inelastic scattering of low-energy electrons.

1. It is possible to excite atoms by low energy electron bombardment.
2. The energy transferred from electrons to the atoms always had discrete values.
3. The values so obtained for the energy levels were in agreement with spectroscopic results.

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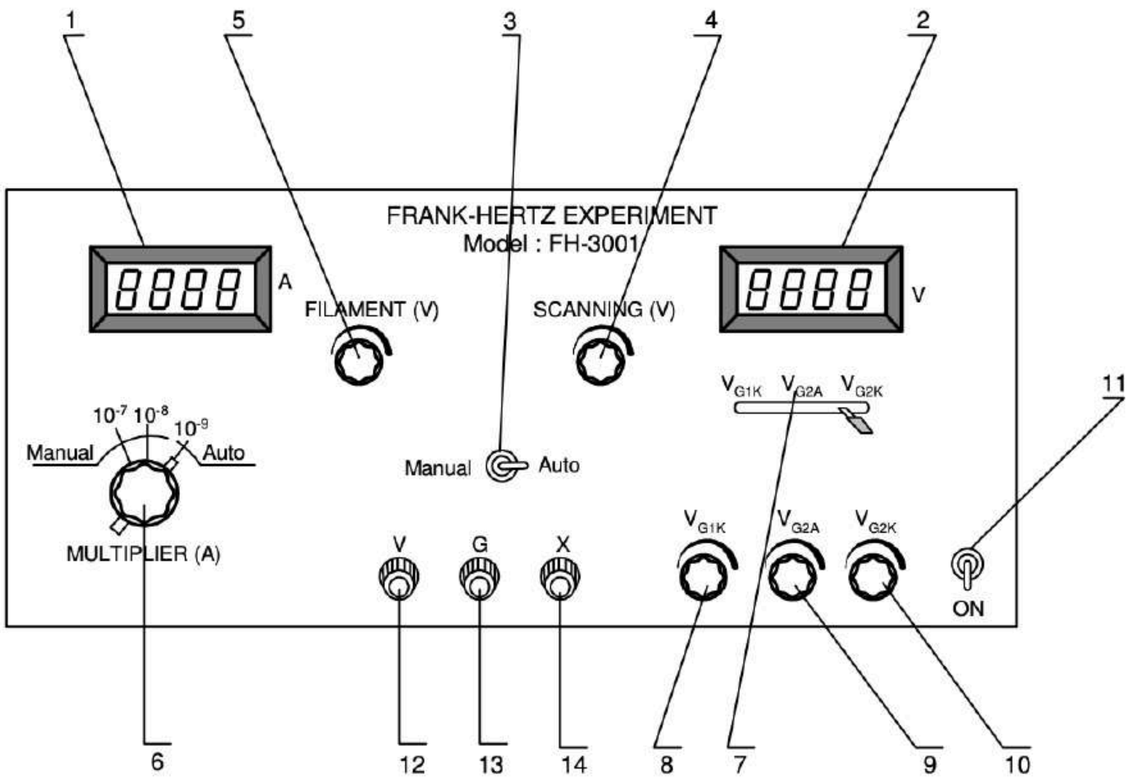
3. Frank Hertz,



1) Ammeter
2) Voltmeter
3) Manual - Auto Switch
4) Scanning Voltage Knob
5) Filament Voltage Knob
6) Current Multiplier Knob
7) Voltage Display Selector: V_{G_1K}, V_{G_2A} or V_{G_2K}
8) V_{G_1K} Adjust knob : 1.3 - 5V
9) V_{G_2A} Adjust Knob : 1.3 - 15 V
10) V_{G_2K} Adjust knob : 2.0 - 90V
11) Power Switch
12) Y-Output Terminal
13) Ground Terminal
14) X-output Terminal

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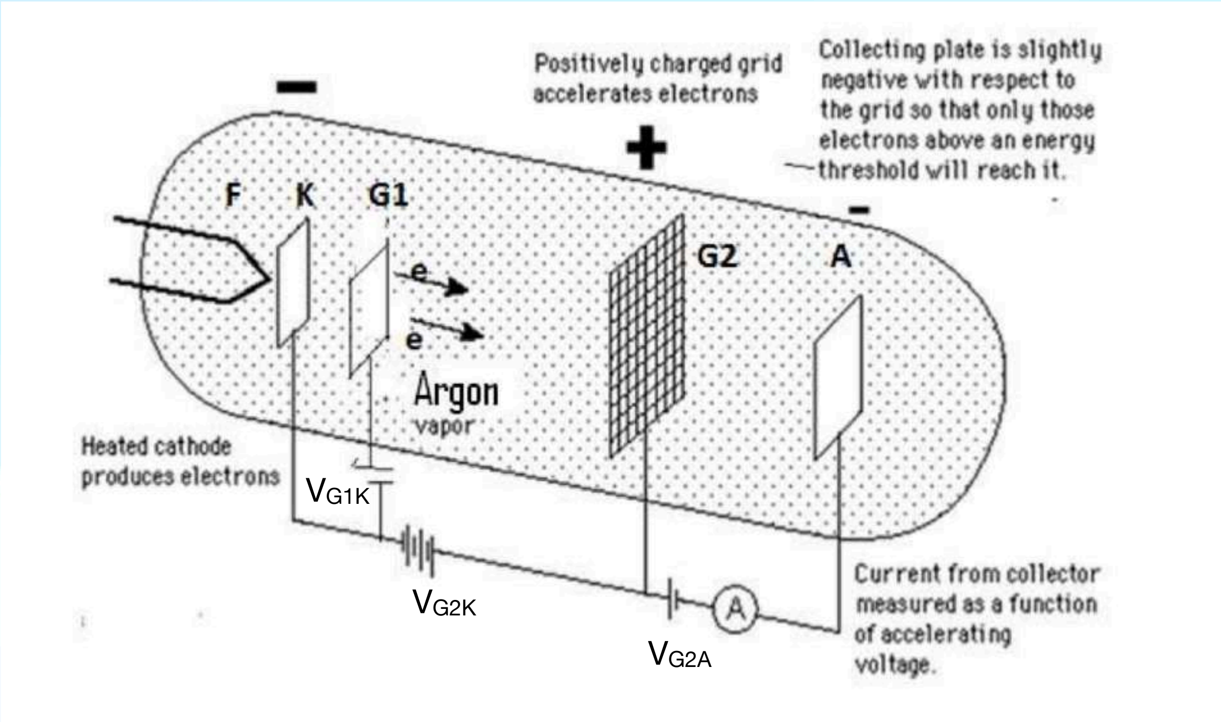
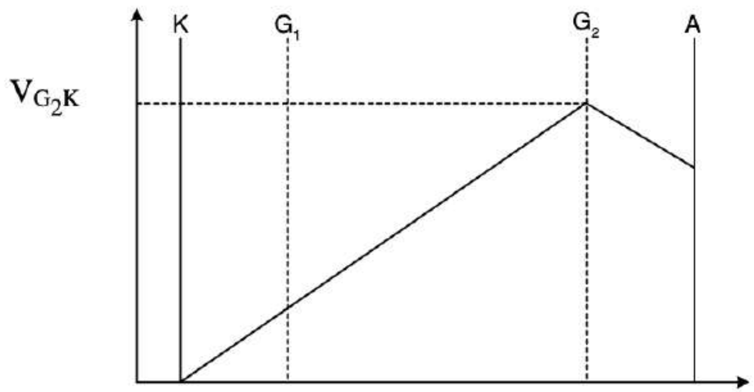
3. Frank Hertz,





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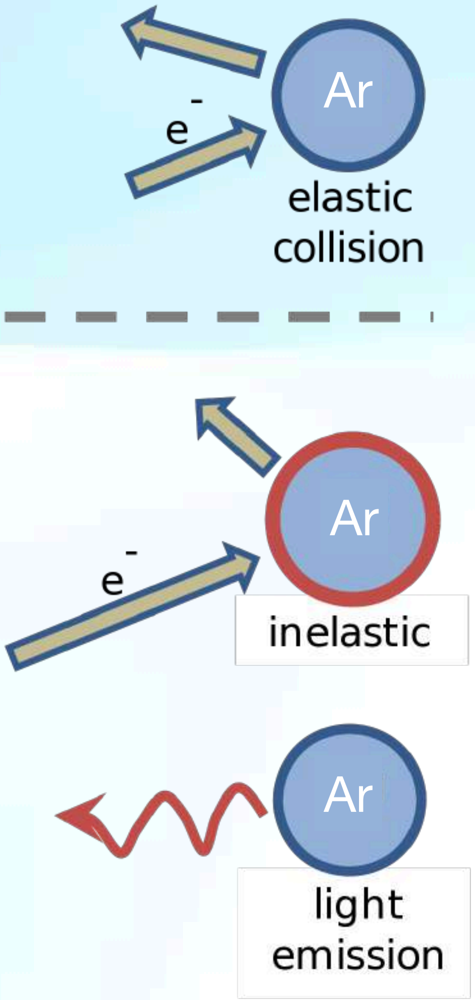
3. Frank Hertz,

An elastic collision conserve the kinetic energy, where as the inelastic collision is not



1. Low energy electrons undergo elastic collision with the Argon atoms and don’t change their energy but changes their direction.

3. During the elastic collision the current shows the linear behaviour.

5. The higher energy (increasing of V_{G2K}), electrons undergo inelastic collision and loose their energy. The energy is transferred to the Argon atoms, and they get excited.

7. During the inelastic collision the current drops drastically

9. The excited Argon atoms subsequently emits light and returns to its original state.

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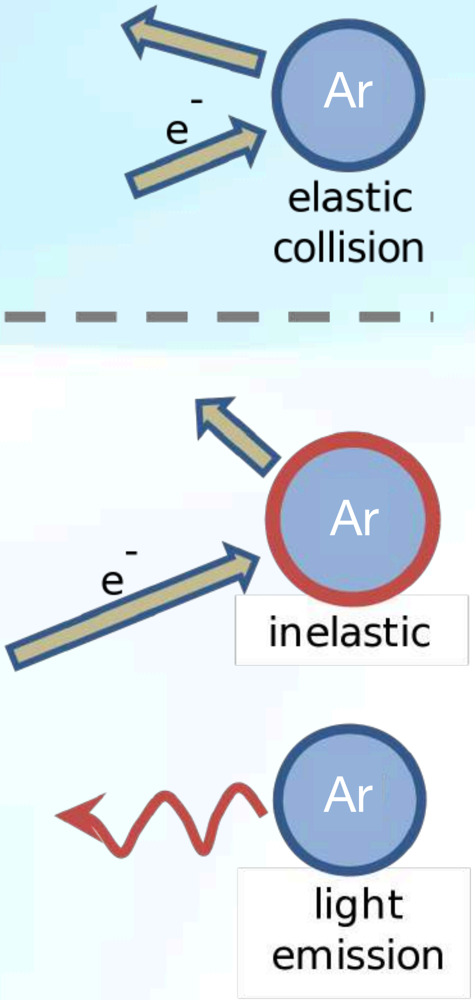
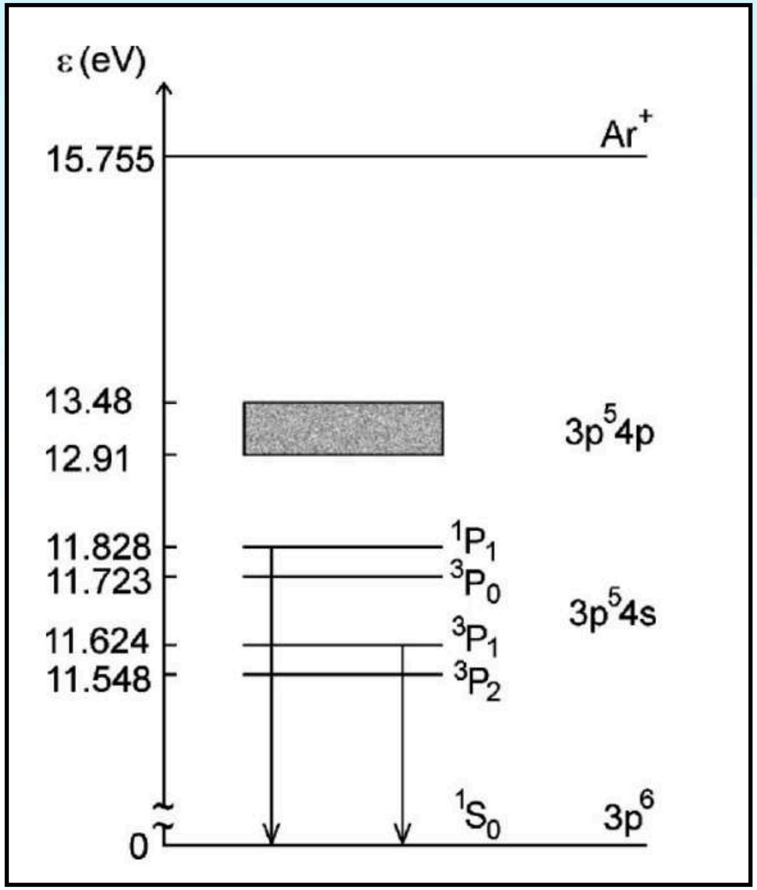
An elastic collision conserve the kinetic energy, where as the inelastic collision is not





Argon atomic first excited stable state is at 11.83 eV

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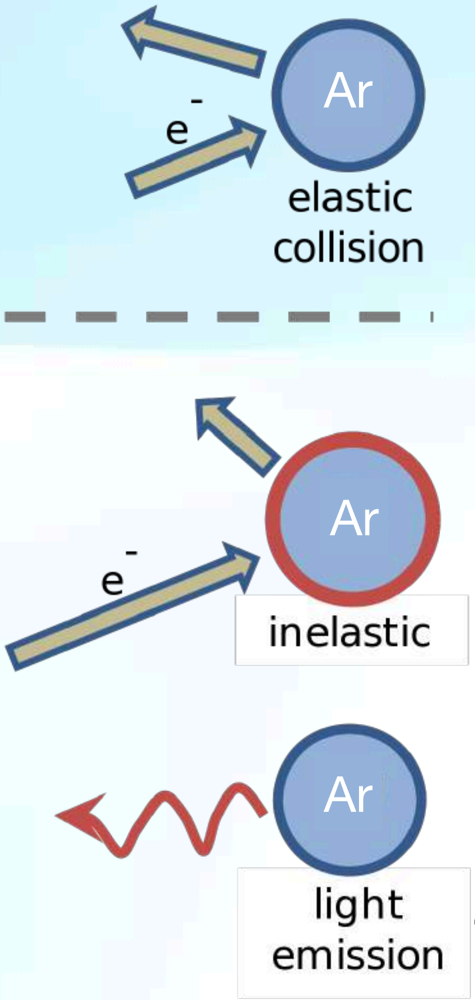

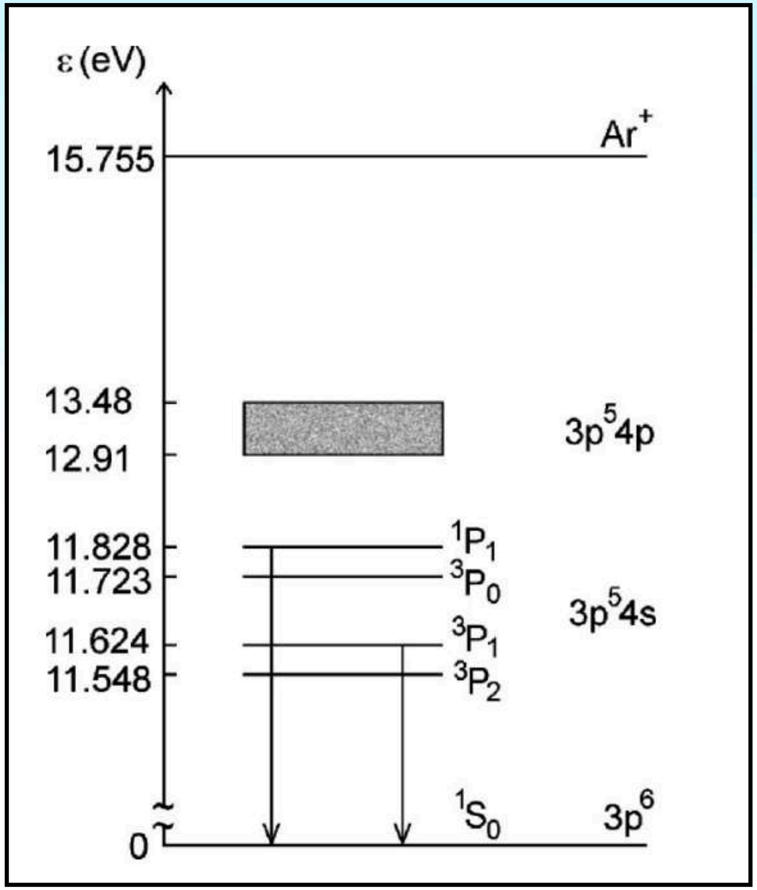

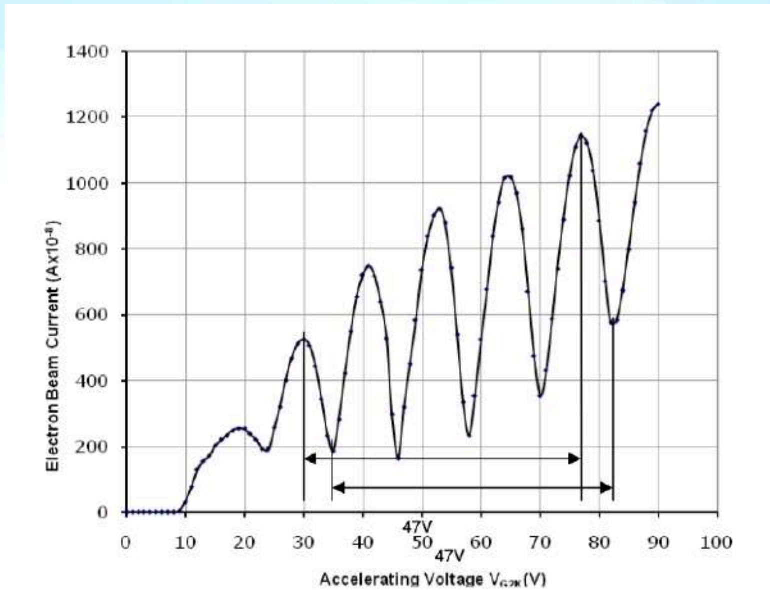

The existence of atomic energy levels put forward by Bohr is proved directly

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4. Velocity of Light,

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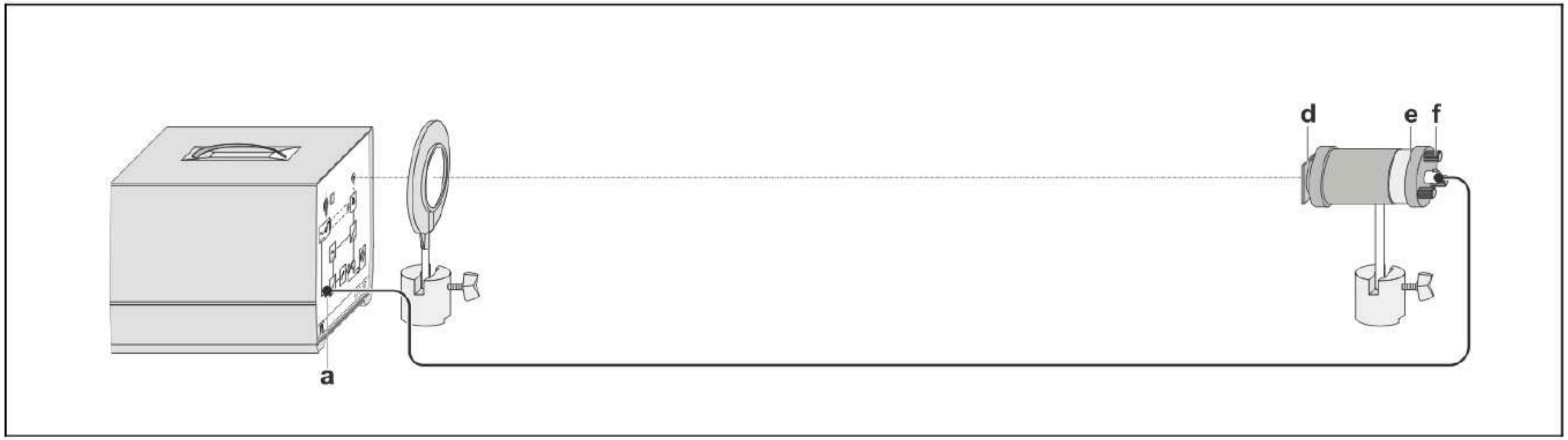
4. Velocity of Light,

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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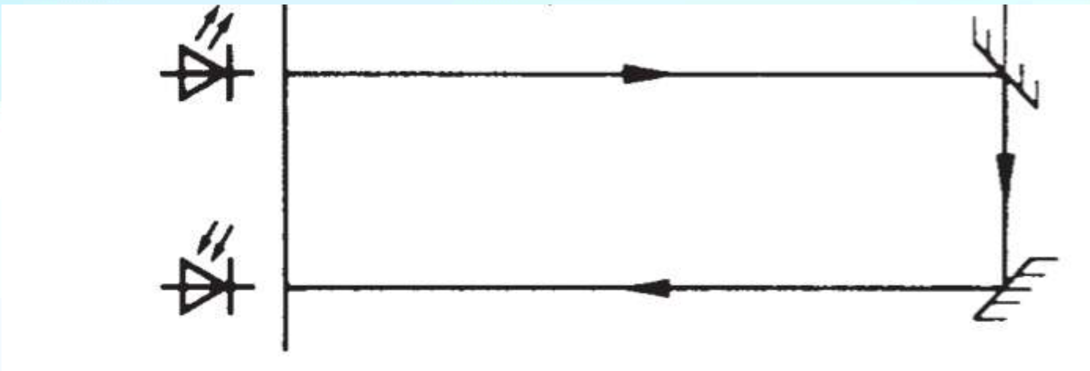
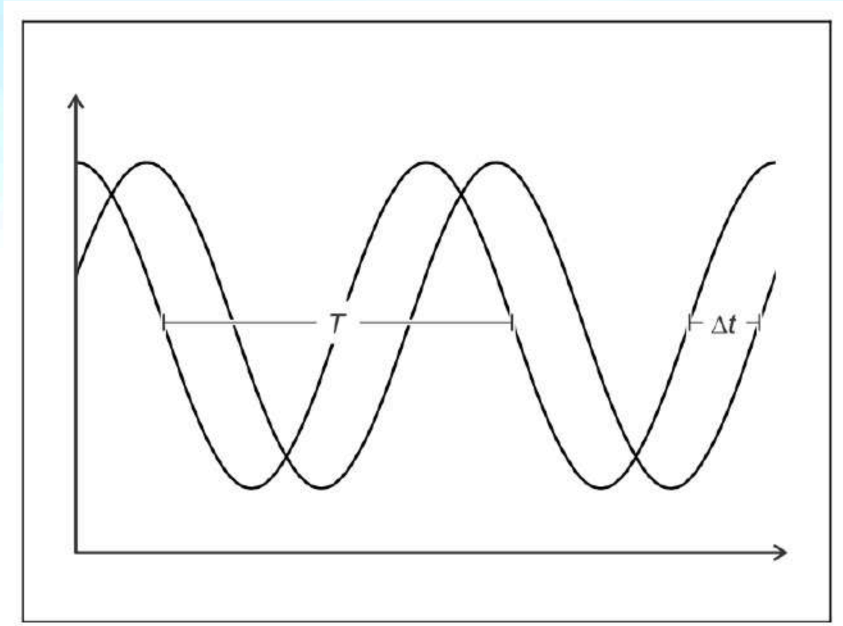
4. Velocity of Light,

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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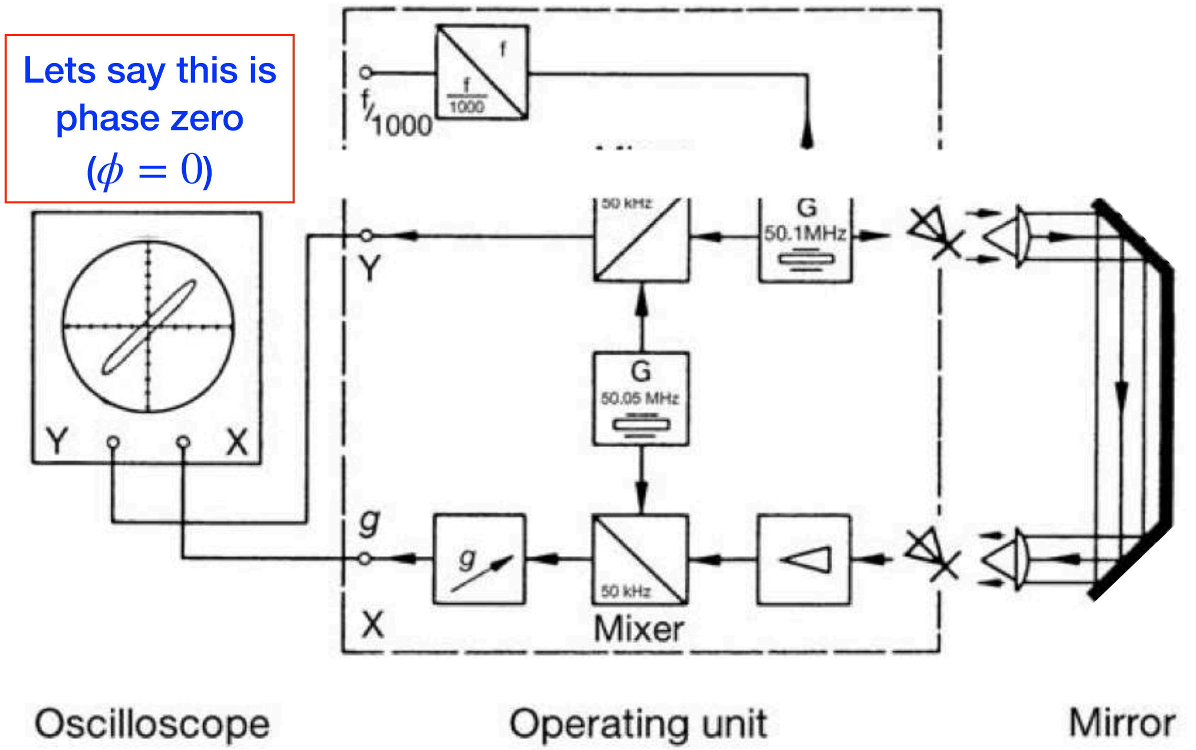
4. Velocity of Light,

Lets say this is phase zero ($\phi = 0$)



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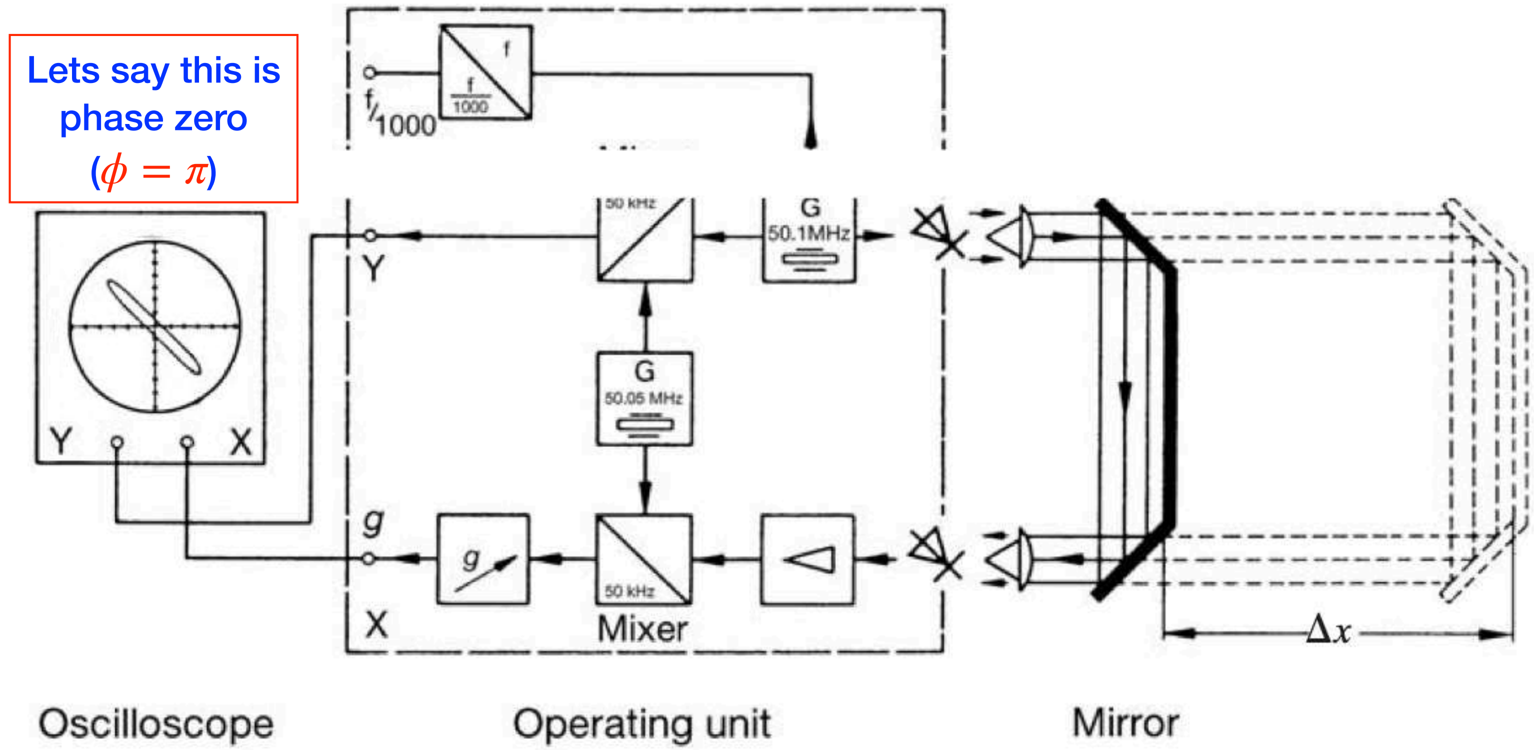
4. Velocity of Light,



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

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

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4. Velocity of Light, Determination of Refractive index:

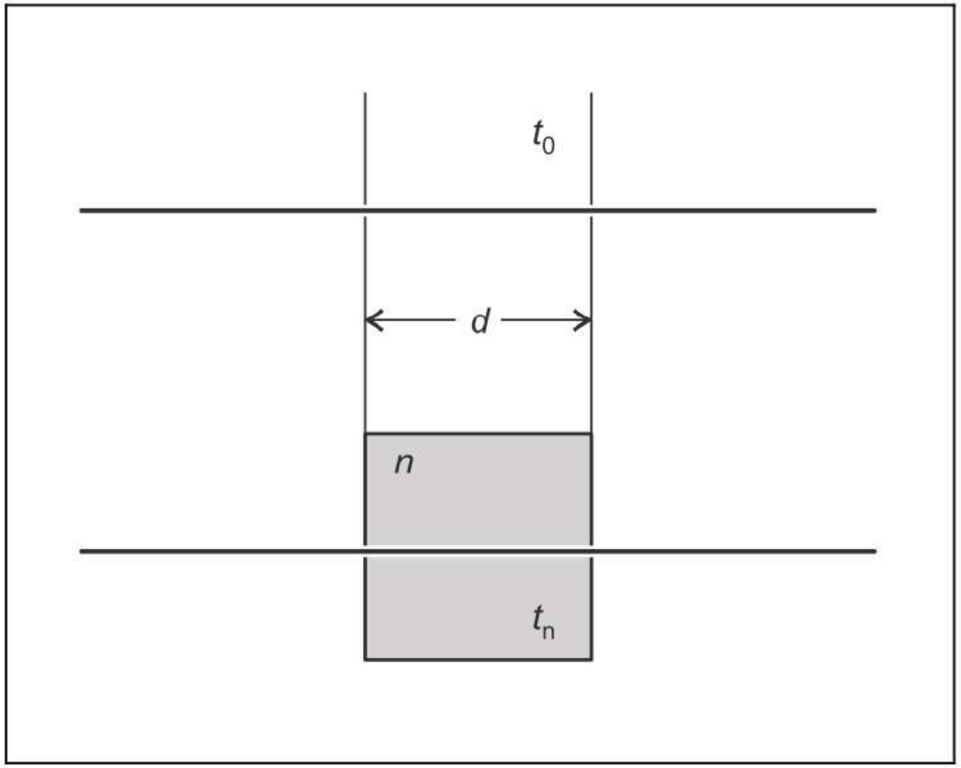

Fig. 1 In a medium with the refractive index *n* light propagates at a lower velocity than in vacuum. This leads to a change in the propagation time *t* of light along a path of length *d*.

Velocity of light in medium is:

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

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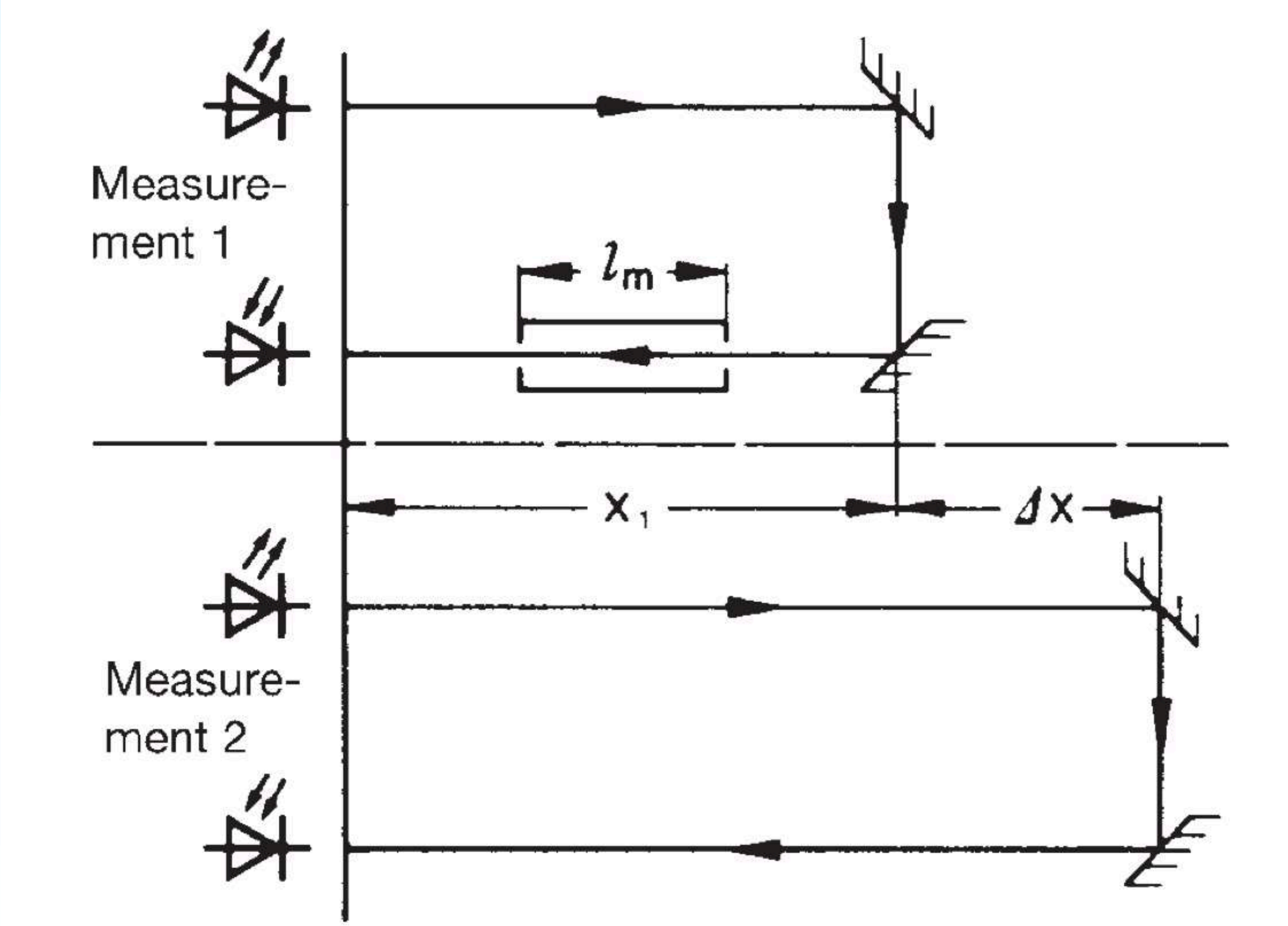
4. Velocity of Light, Determination of Refractive index:



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4. 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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5. Stefan Boltzmann,

5. Stefan Boltzmann,

The energy emitted by a black body per unit area and unit time is proportional to the fourth power of the body's absolute temperature (Stefan-Boltzmann law).

For the energy flux density L of a black body:

The energy emitted per unit area and unit time, $E = \dfrac{dL(\mathrm{T}, \lambda)}{d\lambda}$

T is temperature,

λ is wavelength and within the interval $d\lambda$,

Modern Physics Lab

5. Stefan Boltzmann,

The energy emitted by a black body per unit area and unit time is proportional to the fourth power of the body's absolute temperature (Stefan-Boltzmann law).

Planck's formula states :

$$\frac{dL(\mathrm{T},\lambda)}{d\lambda} = \frac{2C^2 h \lambda^{-5}}{e^{\frac{hC}{\lambda K t}} - 1}$$

Integrating over full wave length range :

$$\int_{\lambda=0}^{\lambda=\infty} dL(\mathrm{T},\lambda) = \int_{\lambda=0}^{\lambda=\infty} \frac{2C^2 h \lambda^{-5}}{e^{\frac{hC}{\lambda K t}} - 1} d\lambda$$

with: c = velocity of light (3.00 · 10^{8} [m/s])

h = Planck's constant (6.62 · 10^{-34} [J · s])

k = Boltzmann's constant (1.381 · 10^{-23} [J · K^{-1}])

Flux density is

$$L(\mathrm{T},\lambda) = \frac{2\pi^5}{15} . \frac{K^4}{C^2 h^3} . \mathrm{T}^4$$

$$L(\mathrm{T},\lambda) = \sigma . \mathrm{T}^4$$

with σ = 5.67 · 10^{-8} [W · m^{-2} · K^{-4}]

Stefan-Boltzmann law

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5. Stefan Boltzmann,

Stefan-Boltzmann law $L \sim \mathrm{T}^4$ is also valid for 'grey body'

- A grey body has a surface with a wavelength independent absorption coefficient of less than one.
- In this experiment the filament of an incandescent lamp is taken as a model for a grey body and its emission is investigated as a function of its temperature

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5. Stefan Boltzmann,

For a fixed distance between filament and thermopile, the energy flux ϕ which hits the thermopile is proportional to $L(\mathrm{T})$:

Then we can write,

$$\phi \sim L \sim \mathrm{T}^4$$

We know that the flux (ϕ) is proportional to the thermo-electric e.m.f (U_{therm}) of the thermopile

$$\phi \sim U_{\mathrm{therm}}$$

So,

$$U_{\mathrm{therm}} \sim \mathrm{T}^4$$

Assuming the thermopile is at zero temperature. We should remember that thermopile can radiate at room temperature ($\mathrm{T_R}$) due to T^4 law, so we have $U_{\mathrm{therm}} = f(\mathrm{T})$. We neglect $\mathrm{T_R}$ in our experiment

Finally we have,

$$\log U_{\mathrm{therm}} = 4 \log \mathrm{T} + const$$

Slope of the above straight line equation should be equal to 4

5. Stefan Boltzmann,

The absolute temperature $T = t + 273$ of the filament is calculated from the measured resistances $R(t)$, (t = temperature in centigrade)

$$R(t) = R_o(1 + \alpha t^2 + \beta t^3)$$

with R_0	= resistance at 0 °C	
α	$= 4.82 \cdot 10^{-3}\ K^{-1}$	
β	$= 6.76 \cdot 10^{-7}\ K^{-2}$	

Zero temperature resistance can be estimated

$$R_o = \frac{R(t_R)}{(1 + \alpha t^2 + \beta t^3)}$$

Then it is easy to estimate the temperature from the resistance measured at temperature

$$T = 273 + \frac{1}{2\beta}\left[\sqrt{\alpha^2 + 4\beta\left(\frac{R(t)}{R_o} - 1\right)} - \alpha\right]$$

5. Stefan Boltzmann,

$R(t_R)$ and $R(t)$ are found by applying Ohm's law, e.g. by voltage and current measurements across the filament.

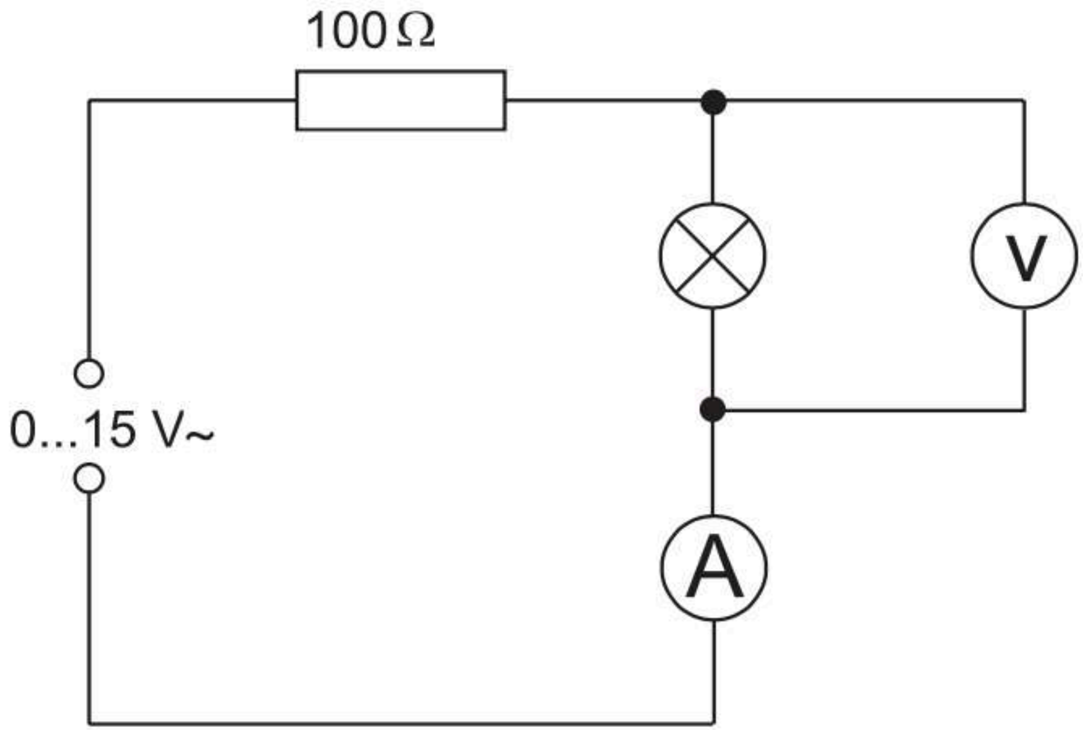

Fig. 3: Circuit for measuring the resistance of the lamp at room temperature.

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5. Stefan Boltzmann,

We can find the slope from data ($\log U_{\text{therm}}$ vs T) fitted to a straight line

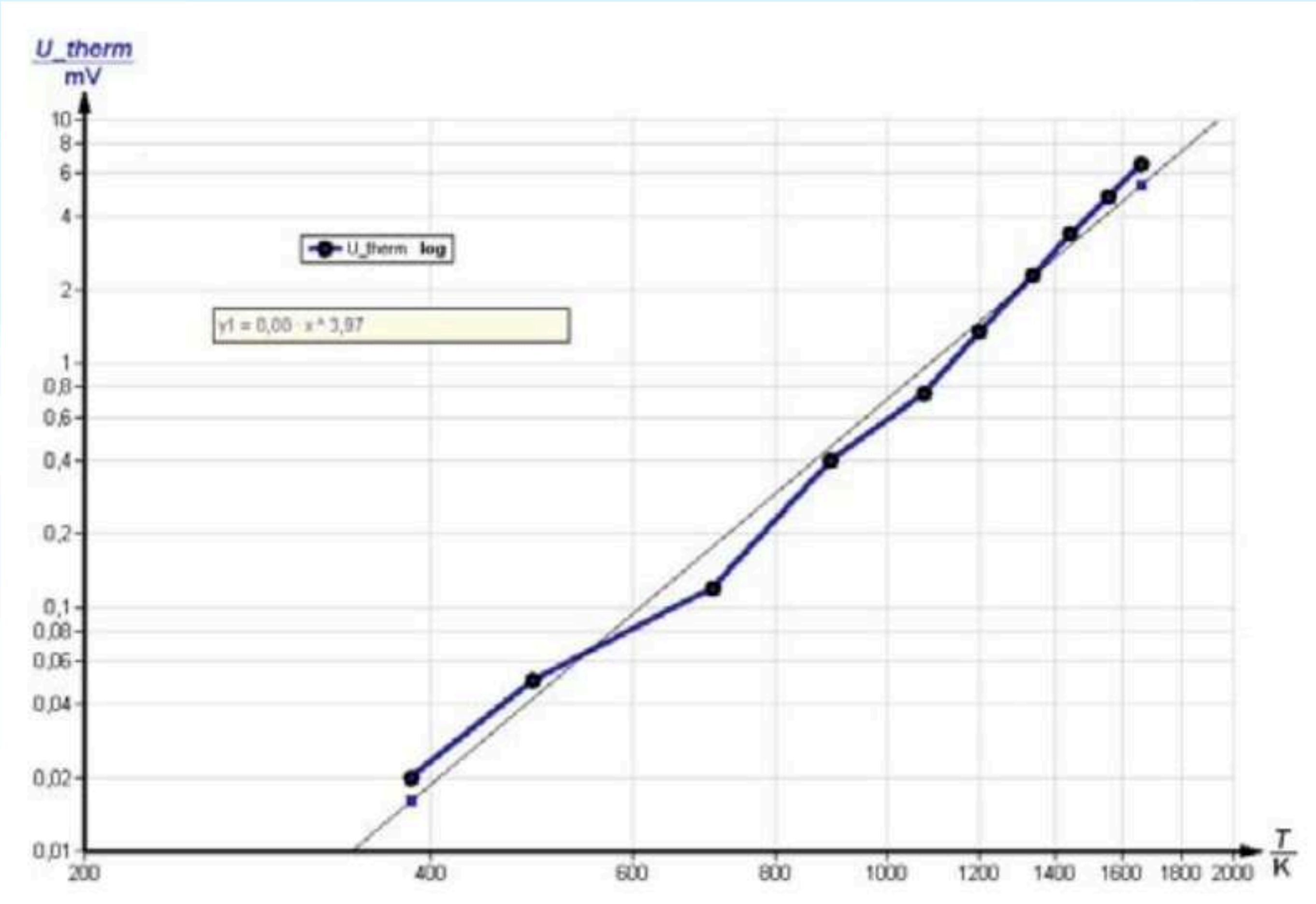

Fig. 7: Example of measurement results

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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 5 readings of diameter of each ring

2. Velocity of Light (Find the speed of light and refractive index of medium)
   - At least 10 Readings of c in air
   - 5 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 5 different current
   - V vs I
   - At least 5 reading in bulb glowing condition.

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Marks divison (Total 100 Marks)

1. Lab notes (30 Marks),
   - Each experiment carried 6M
2. Midsem VIVA (25 Marks)
   - After minimum three experiments done by all sub-groups
3. Endsem Practical (35 Marks),
4. Endsem VIVA (10 Marks)

All the best