PRACTICE GUIDE

MODERN PHYSICS

BACHELOR OF PHYSICS PROGRAM
DEPARTMENT OF PHYSICS
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LIST OF CONTENTS

MODULE I: GAMMA RAY ABSORPTION

Objective:

- To gain an understanding of how gamma radiation is detected using a scintillation detector
- To determine the absorption coefficients of different metals

Dasar Teori :

Gamma-ray spectrometry is an analytical technique used to identify and quantify isotopes that emit gamma radiation in different types of materials. The system typically consists of a gamma detector, preamplifier, amplifier, high-voltage and low-voltage power supplies, a multichannel analyzer (MCA), and a computer for data processing. Figure 1 shows the block diagram of the gamma-ray spectrometry system.

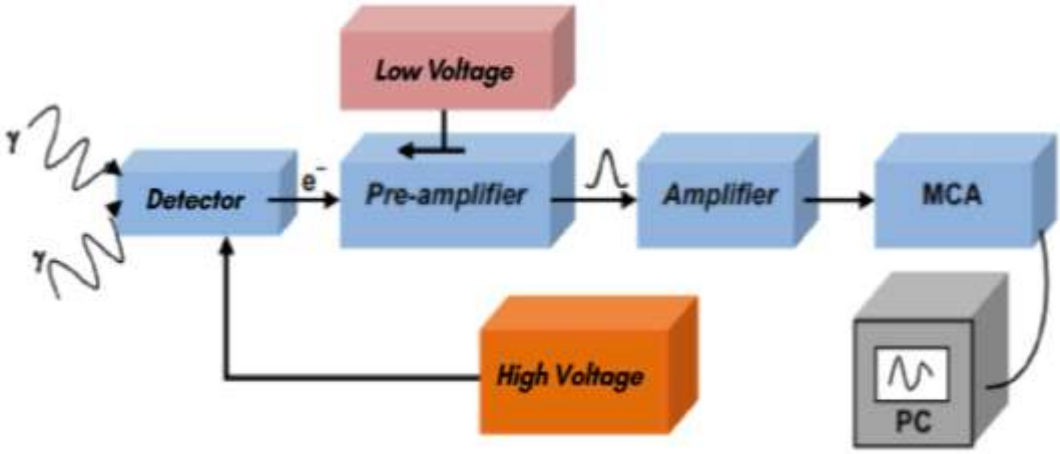

Figure 1. Block Diagram of the Gamma-Ray Spectrometry System

The NaI(Tl) detector is the most commonly used scintillator for gamma-ray detection. It consists of two main components. The first is the scintillation medium, namely the NaI(Tl) crystal, where incoming radiation interactions produce light pulses. The second component is the Photomultiplier Tube (PMT), which converts these light pulses into electrical signals through a multiplication process.

As gamma rays pass through a material, they experience attenuation (absorption), resulting in a decrease in radiation intensity compared to the initial value. The degree of attenuation depends on factors such as atomic number, density, thickness, and hardness of the material. The absorption coefficient (μ) can be determined using Equation (1).

$$I = I_0 \, e^{-\mu x} \quad \ldots\ldots(1)$$

Where:

I = intensity after passing through material

I_0 = initial intensity

μ = absorption coefficient

x = thickness of material.

Experimental Method

Equipment and Materials:

1. Cassy Sensor and MCA Box
2. Cs-137 Radioisotope and NaI(Tl) Scintillation Detector
3. High Voltage Power Supply (1.5 kV)
4. PC and Cassy Lab 2 software

Procedure:

1. Set up the apparatus as shown in Figure 2.
2. Launch the Cassy Lab 2 software and load the settings for the experiment "Detecting gamma radiation with a scintillation counter Cs-137."
3. Switch on the power supply and gradually adjust the knob until the voltage reaches 700–900 V.
4. Record the gamma radiation measurement for 100 seconds.
5. Convert the x-axis variable from channel to energy.
6. Repeat the measurement (step 4) for different metal thicknesses and types of metals.

Figure 2. Experimental Setup for Gamma Radiation Detection Using a Scintillation Detector

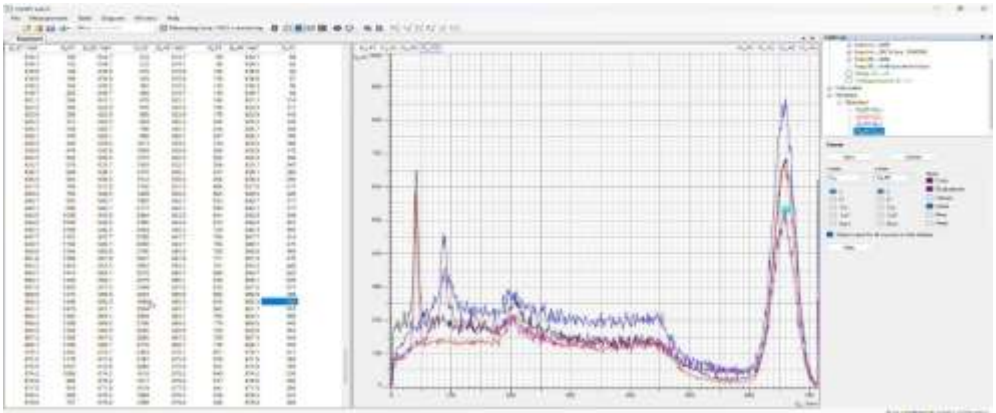

Figure 3. Example of Experimental Results

MODULE II: SINGLE SLIT LIGHT DIFFRACTION

Objective:

- To gain an understanding of diffraction phenomena
- To measure the wavelength of a light source

Teory :

Light diffraction refers to the deviation of light as it encounters an obstacle. This phenomenon can be observed when a beam of light passes through a single slit of width d, causing the light to spread out and interfere at a point P on a screen positioned at a distance L from the slit, as illustrated in Figure 1.

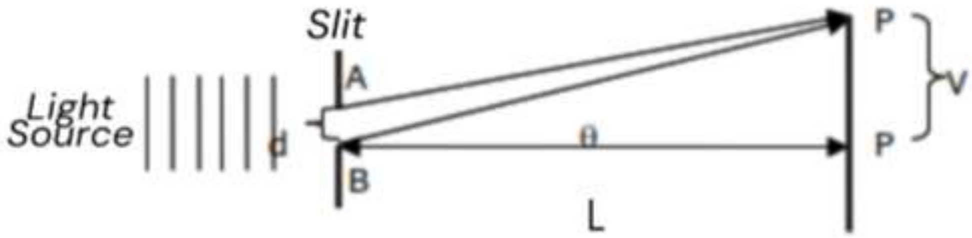

Figure 1. Analysis of diffraction patterns, P is the center of diffraction

Based on Huygens' principle, when the primary wavefront passes through a slit, it produces secondary wavelets. These wavelets interfere at point P on a screen positioned far from the slit, resulting in diffraction patterns whose intensity is described by the equation:

$$I = I_o \left(\frac{\sin\beta}{\beta}\right)^2 \quad \text{.........} (1)$$

Where I_o is the initial intensity of the light source and β is the phase difference, defined as:

$$\beta = (\pi d/\lambda) \sin\theta \quad \text{.........} (2)$$

On the screen, the intensity distribution can be seen in Figure 2.

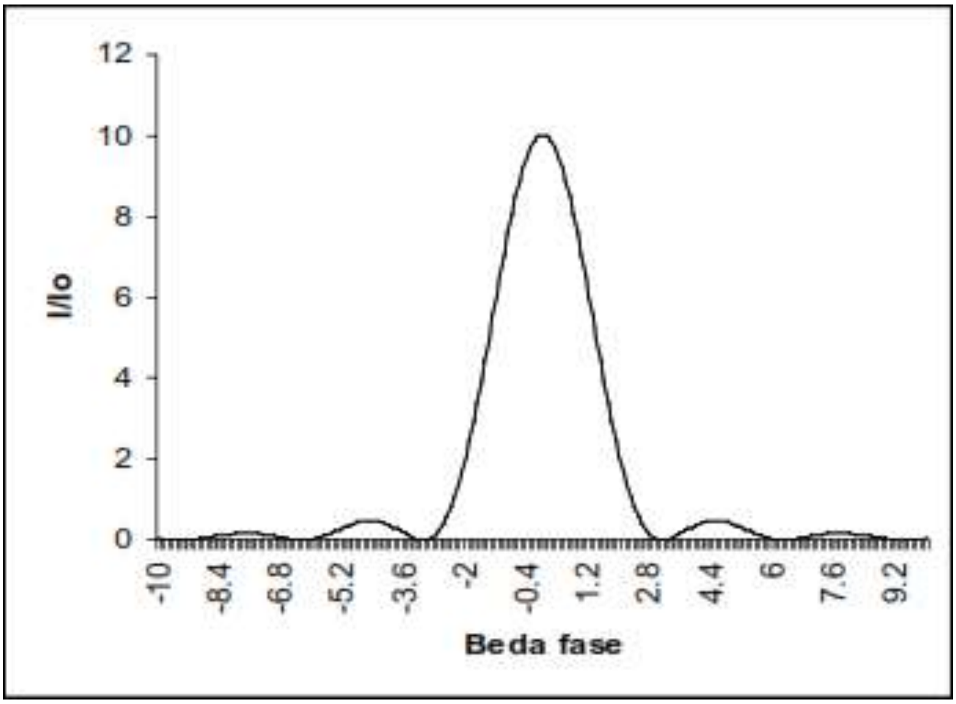

Figure 2. Diffraction Intensity Distribution

Minimum intensity occurs when sin β = 0, or β = nπ with n = 1, 2, 3, 4, … and so on. Thus, the diffraction equation for minimum intensity is obtained:

$$d \sin \theta = n \lambda \qquad (3)$$

Where

$$\sin \theta = \frac{y}{\sqrt{L^2 + y^2}} \qquad (4)$$

From Equations (3) and (4), by varying L, the value of y_n (the distance of the nth dark fringe from the center) can be measured for a given d, allowing the wavelength λ to be determined

Experimental Method

Equipment and Materials:

1. Light source (He–Ne Laser)
2. Single slit with micrometer scale
3. Measuring tape
4. Millimeter block paper

Procedure:

1. Pass the laser beam through the slit, with its width determined using the micrometer scale.
2. Adjust the slit width by rotating the micrometer and observe the resulting diffraction patterns. The patterns become clearly visible when the slit width is less than 1 mm; select a suitable width to facilitate observation.
3. Change the distance between the slit and the screen, then measure the shift in the position of the first (or second) dark fringe relative to the center. Plot y as a function of L.

MODULE III: PHOTOELECTRIC EFFECT

Objective:

- To understand the dual nature of light
- To determine the value of Planck's constant

Teory:

The photoelectric effect is a phenomenon in which electrons are emitted from a metal surface when it is exposed to light. In this process, a vacuum tube contains two electrodes connected to an external circuit, with the irradiated metal plate functioning as the anode. Some of the emitted electrons possess enough energy to reach the cathode.

As the retarding potential V increases, fewer electrons are able to reach the cathode, causing the current to decrease. When V reaches or exceeds a certain threshold value V_0 (typically a few volts), no electrons reach the cathode and the current becomes zero. This phenomenon demonstrates that light carries energy, and part of the absorbed energy can be transferred to electrons as kinetic energy.

The number of electrons emitted from the metal surface strongly depends on the intensity of the incident light, while their energy depends on the frequency (ν). If Planck's constant is known, $h = 6.626 \times 10^{-34}$ J·s, then the energy of the photoelectric effect is given by:

$$E = h\nu \qquad (1)$$

If an electron is bound with energy W, known as the work function, then the photon energy becomes:

$$E = h\nu - W \qquad (2)$$

Since photon energy is a form of kinetic energy, Einstein's equation applies.

$$\tfrac{1}{2} mv^2 = h\nu - W \qquad (3)$$

Where:
m = mass of the electron
v = velocity of the electron
W = work function required to remove the electron from the cathode

With the applied retarding potential, known as the stopping potential, the following equation applies.

$$h\nu - W = e\,U_0 \qquad (4)$$

When the light frequency increases by $\Delta\nu$, the electron energy rises by $h\Delta\nu$. Consequently, the stopping potential must also be increased by ΔU_0 to bring the current back to zero. Therefore, the following relationship holds.

$$e\,\Delta U_0 = h\,\Delta\nu \qquad (5)$$

The increase in energy $h\Delta\nu$ is compensated by the loss of energy $e\Delta U_0$. If the stopping potential U_0 is plotted against ν, a straight line is obtained with a slope (α) given by:

$$\alpha = \frac{\Delta U0}{\Delta \nu} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

If e is the elementary charge (1.6×10^{-19} C), then:

$$h = e\,\alpha = e\,\frac{\Delta U0}{\Delta \nu} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (7)$$

Experimental Method

Procedure:

1. Set up the apparatus as shown in Figure 1.
2. Switch on the power supply and the halogen lamp.
3. Adjust the control knob until the voltage display reads 0 V, then record the current.
4. Repeat step 3 for each available filter by rotating the filter wheel; there are five filters, each corresponding to a different wavelength.

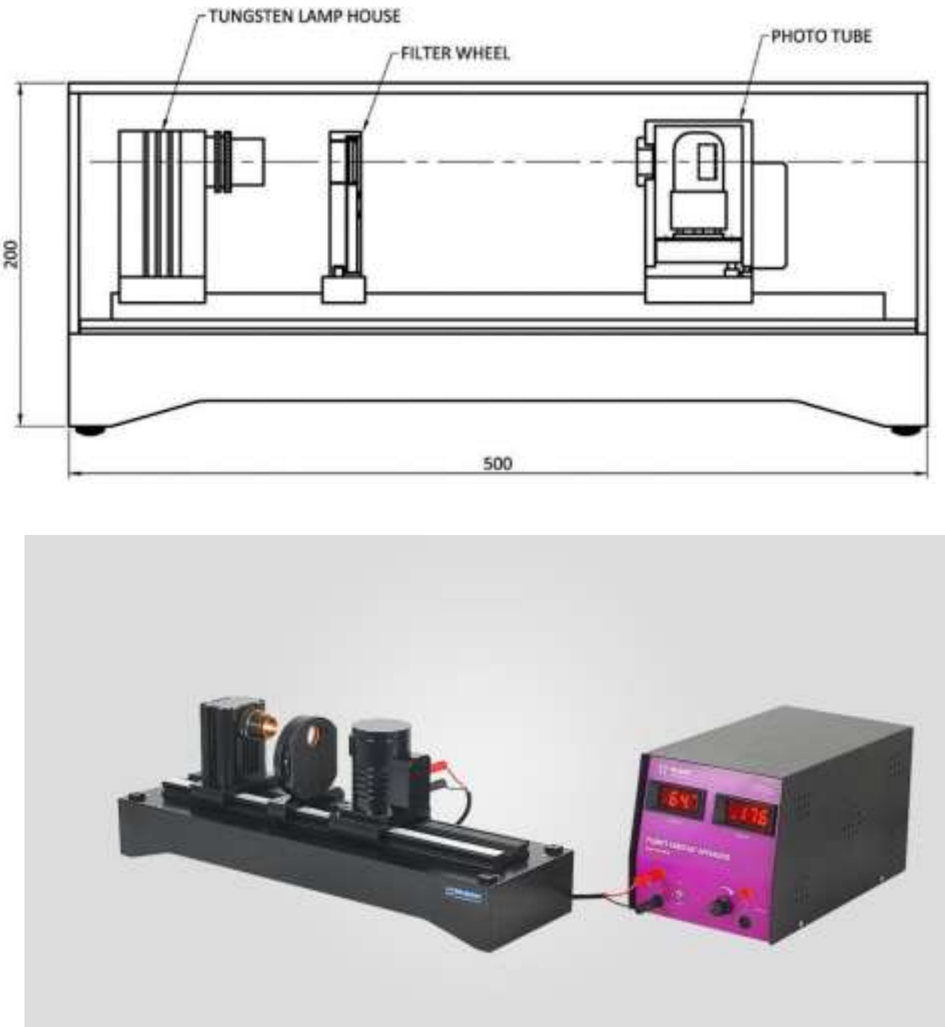

Figure 1. Photoelectric Effect Experimental Setup

MODULE IIV: MILLIKAN OIL DROP

Objective:

To determine the value of the elementary charge using the equilibrium (floating voltage) method along with the upward and downward motion methods

Teory:

Atomized oil droplets move into a uniform electric field between capacitor plates. In this process, each droplet gains a charge Q due to electrical interactions. A droplet with mass m_{oil} placed in an electric field of strength E experiences the following forces.
The forces acting on the droplet are:

- Electric force : $Q E$
- Gravitational force : $m_{oil}\ g$

Provided that the droplet is in air, there are also additional forces:

- Buoyant force $(m_l\ g)$
  where m_l is the mass of air displaced by the oil droplet
- Stokes' drag force $(6\pi\ r\ \eta\ v)$
  when the oil droplet moves relative to the surrounding air
  (r: radius of the droplet assumed spherical, η: viscosity of air, v: velocity)

The falling velocity in a region without an electric field (1) is used to determine the droplet radius (r). When an oil droplet falls freely at a constant velocity v_1, the effective gravitational force (after accounting for buoyancy) is balanced by the Stokes drag force opposing the droplet's motion.

$$m_{oil}\ g - m_1\ g - 6\ \pi\ r\ \eta\ v_1 = 0$$

With $m_{oil} - m_l = m$, it is obtained that:

$$m\ g - G\ \pi\ r\ \eta\ v_1 = 0$$

$m\ g$ is the effective gravitational force reduced by buoyancy, where $(P_{oil} - P_l) = P$
where:
P_{oil} = density of oil
P_l = density of air
Thus, it can be obtained:

$$VPg - G\ \pi\ r\ \eta\ v_1 = 0$$

The volume of the oil droplet is $V = {}^4/_3\ \pi\ r^3$

$$^4/_3\ \pi\ r^3 - G\ \pi\ r\ \eta\ v_1 = 0$$

From the above equation, the radius of the oil droplet can be calculated

$$r = \sqrt{\frac{g\ \pi v}{2pg}} \qquad (1)$$

If a voltage U is applied across the capacitor plates separated by a distance d, the droplet will rise with a constant velocity v_2. The effective gravitational force reduced by buoyancy, the Stokes drag force, and the electric force cause the droplet to move upward, described by the equation:

$$m g + G \pi r \eta v_2 - Q E = 0$$

With E = U/d and $mg = {}^4/_3 \pi^3 \rho g$

the equation becomes:

$$^4/_3 \pi r^3 \rho g - Q U/d + G \pi r \eta v_2 = 0 \quad (2)$$

If the electric field is adjusted such that the oil droplet is suspended (floating), then the Stokes drag force is zero, and the equation becomes:

$$^4/_3 \pi r^3 \rho g - Q U/d = 0 \quad (3)$$

The determination of the charge *Q* of an oil droplet is carried out using the Millikan apparatus through the following two methods:

1. Equilibrium Method

   The equilibrium method involves determining the voltage at which a charged oil droplet remains suspended in equilibrium. Millikan then measures the droplet's falling velocity under free-fall conditions after the voltage is switched off. In this approach, a voltage is applied to the capacitor to keep the droplet in a suspended state (3), and the velocity v_1 is measured. Once the voltage is removed, the droplet begins to fall (1). By substituting Equation (1) into Equation (3) and eliminating Q, the following equation is obtained.

   $$Q = \frac{G\pi\pi d n_1}{U}\sqrt{\frac{g n v_1}{2\rho\rho}}$$

2. Dynamic Method

   The dynamic method consists of measuring the droplet's falling velocity after the voltage is switched off and its rising velocity when a specific voltage is applied. In this approach, the downward velocity v_1 in a field-free region (1) and the upward velocity v_2 under an applied voltage U (2) are determined. By substituting Equation (1) into Equation (2) and eliminating Q, a formula is obtained to calculate the charge Q.

Experimental Method

Equipment and Materials:

1. Millikan apparatus
2. Netz Millikan apparatus
3. Stopwatch P
4. Counter device
5. Experimental cables (5 pieces)

Procedure

a. **Equilibrium Method**

1. Ensure switches (1) and (2) are turned on, the capacitor voltage supply is connected, and the stopwatch is prepared.

2. Adjusted the voltage *U* is with the control knob until a certain value of *U* is obtained.
3. Switch (2) is set so that the voltage *U* becomes zero (voltage is turned off), and simultaneously the stopwatch is started.
4. The rising/moving oil droplet is observed and the stopwatch is stopped.
5. Record the voltage *U*, the time taken (*t*), and the scale *x*.

b. **Dynamic Method**

1. Set switches (1) and (2), and ensure the stopwatch is ready for use.
2. Adjust the control knob to achieve the desired voltage *U*
3. Turn off switch (2) and start stopwatch 1 simultaneously.
4. Observe the motion of the oil droplet as it passes the measurement marks.
5. Turn on switch (2) and start stopwatch 2 at the same time.
6. Continue observing the oil droplet and stop stopwatch 2 when the measurement is complete.
7. Record the values of *U*, *x*, t_1, and t_2.

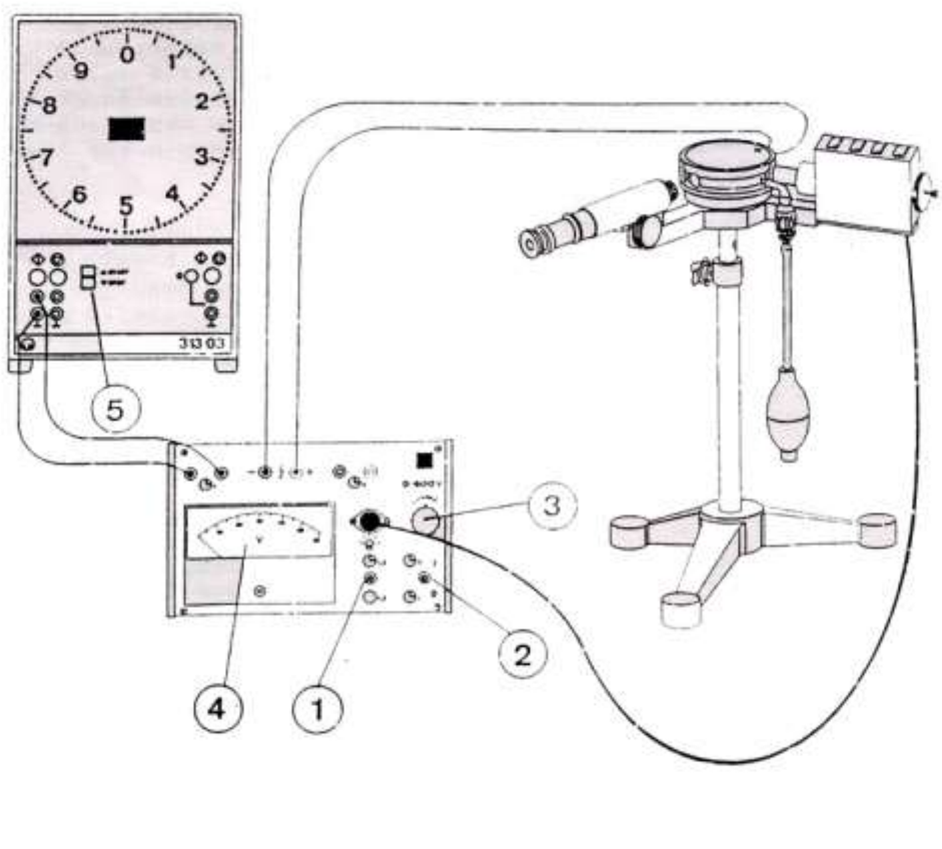

Figure 1. Set up

1. Switch for opening and closing the electric current to the stopwatch
2. Switch for turning the voltage on and off

3. DC voltage potentiometer
4. Voltmeter
5. Start/stop

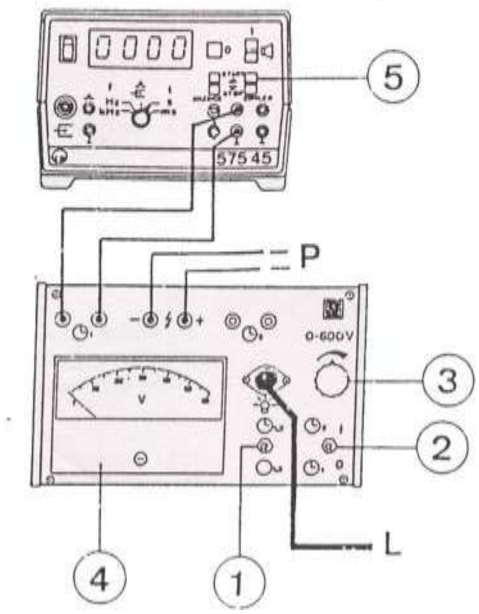

Figure 2. Installation of the Counter Device P in the Equilibrium Method

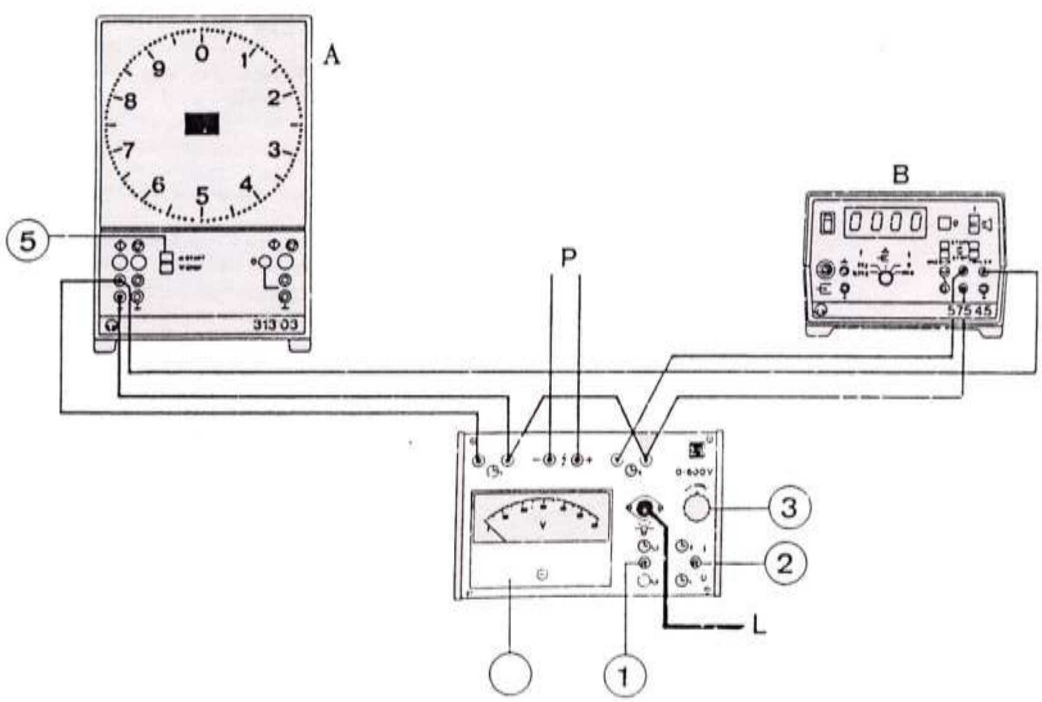

Figure 3. Connection of the Stopwatch for the Dynamic Method

P : Connected to the capacitor plates

L : Connected to the illumination lamp

MODULE V: e/m

Objective:

- To study the properties of the magnetic field of a Helmholtz coil
- To determine the value of *e/m*

Teory:

Electrons released from the filament, which serves as the cathode, through thermionic emission (heating of electrons), are accelerated toward a region with a potential difference V relative to the cathode. According to the conservation of energy, if no external forces act on the electrons, their kinetic energy is determined by the applied voltage V, expressed as:

$$E_k = \tfrac{1}{2} m v^2 = eV \qquad (1)$$

Where:

m : mass of the electron
e : charge of the electron
v : velocity of the electron
V : potential difference (voltage)

Thus, the velocity of the electron can be written as:

$$V = \sqrt{\frac{2eV}{m}} \qquad (2)$$

If a particle with charge *e* and velocity *v* moves through a magnetic field, its direction will change without a change in speed. Using the general expression, when a current flows through an element of length *dl* in a magnetic field, the force experienced is:

$$df = \mathbf{i}\, dl \times \mathbf{B} \qquad (3)$$

Where:

i : electric current (A)
B : magnetic field strength (T)
dl : length element

The above equation is the fundamental equation for electric motors, but it can also be applied to moving charged particles. Electric current in a conductor is usually expressed as charge per unit time:

$$I = \frac{q}{t} \qquad (4)$$

The current flowing in the element *dl* is equal to the charge moving with velocity

$$dl = \frac{qL}{t} = q\frac{L}{t} = qv \quad (5)$$

With v=L/t which represents the velocity or the time taken by charge *q* to travel a distance *L* (m s^{-1}).

In vector form, it is expressed as:

$$L\ dl = q\ \mathbf{v}\ dq \quad (6)$$

where *dq* is the charge within the conductor segment *dL*.

By substituting Equation (6) into Equation (3), we obtain:

$$dF = dq\ (\mathbf{v} \times \mathbf{B}) \quad (7)$$

For a charge equal to *e*, we get:

$$F = e\ (\mathbf{v} \times \mathbf{B}) \quad (8)$$

The above equation represents the Lorentz force. If $\mathbf{v} \perp \mathbf{B}$ maka $\mathbf{v} \times \mathbf{B} = vB$ thus

$$F = evB \quad (9)$$

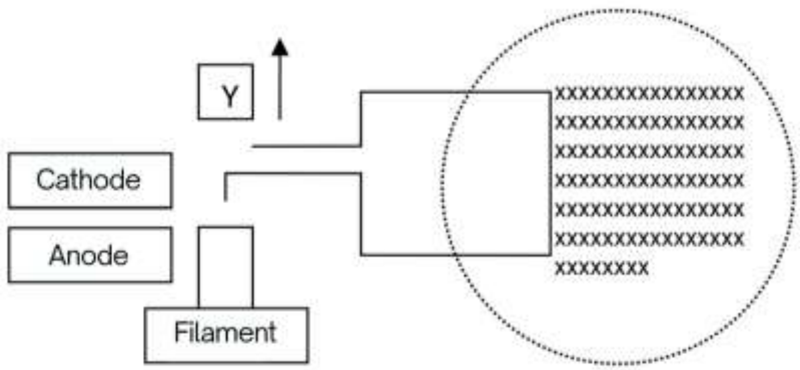

Figure 1. Apparatus for Determining e/m

Since the particle moves in a circular path, it experiences a centripetal force given by:

$$F = \frac{mV^2}{R} \quad (10)$$

By substituting Equations (10) and (9), we obtain:

$$evB = \frac{mV^2}{R}$$

$$\frac{e}{m} = \frac{V^2}{RvB}$$

$$\frac{e}{m} = \frac{v}{RB} \quad (11)$$

By substituting Equations (2) and (11), we obtain:

$$\frac{e}{m} = \frac{\sqrt{2e\frac{V}{m}}}{RB} \quad (12)$$

Squaring Equation (12), we obtain:

$$\left(\frac{e}{m}\right)^2 = \frac{2ev}{mR^2B^2}$$

$$\left(\frac{e}{m}\right)^2 \frac{m}{e} = \frac{2v}{(RB)^2}$$

$$\frac{e}{m} = \frac{2v}{(RB)^2} \qquad (13)$$

Where:
e : charge of the particle
m : mass of the particle (kg)
V : potential difference (V)
R : radius of the particle's circular path (m)
B : magnetic field strength (T)

The magnetic field used in this experiment is produced by a Helmholtz coil. For a coil with radius *R*, the magnetic field at the point x= 0, y= ½R and z= 0 is given by :

$$B = \frac{4{,}5.10^{-7} ni}{R} \qquad (14)$$

Where:
n : number of turns (260 turns)
R : 0,15 m
B : $7{,}8.10^{-4}$ i where *i* is the coil current

EXPERIMENTAL METHOD
Equipment and Materials:

1. Teslameter
2. Voltmeter
3. e/m apparatus system
4. Voltage and current power supply

Procedure:

1. Assemble the apparatus as illustrated in Figure 2.
2. Switch on the equipment and adjust the current to produce a stable magnetic field.
3. For each applied voltage from the power supply, measure the diameter of the electron beam circle.
4. Observe the experiment and record all results.

5. Before turning off the equipment, use a probe to measure the magnetic field at different distances.

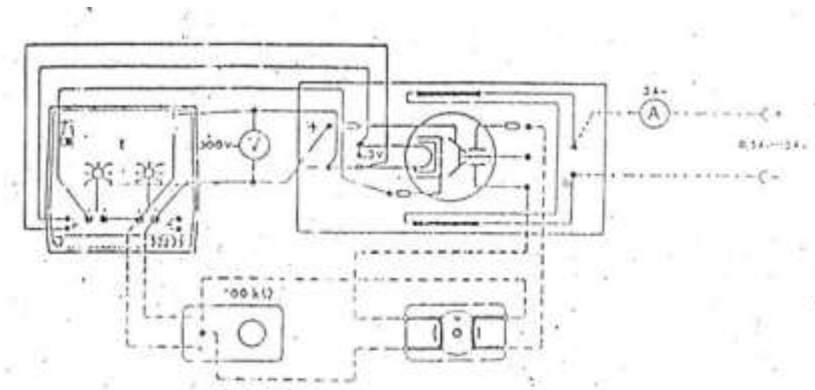

Figure 2. Equipment Setup

MODULE VI: MICHELSON INTERFEROMETER

Objective:

To determine the wavelength of Helium-Neon laser light

Theory:

Interference occurs when two or more wavefronts meet at a single point, resulting in a combined effect of the interacting waves. When the waves are in phase, they produce constructive interference, whereas waves that are out of phase create destructive interference.

To study interference, it is necessary to generate two light waves that start with the same phase, which cannot be achieved with separate sources. This is done by splitting a single light wave into two beams that travel along different paths and then recombining them at the same point on a screen. These two beams, having identical phase and frequency, are referred to as coherent light.

Observations of interference are typically performed using a Michelson interferometer. In this setup, a monochromatic light beam is divided into two paths and later recombined. The difference in path lengths between the two beams produces an interference pattern.

Laser light (Light Amplification by Stimulated Emission of Radiation), first developed in 1960 by T.H. Maiman using a ruby crystal, emits a monochromatic and coherent beam of light in which all waves are in phase and travel parallel to each other. The beam can be focused to a very small spot, just a few micrometers in diameter. The Michelson interferometer is ideal for measuring minute changes in solid lengths and for determining laser wavelengths. In this experiment, a He–Ne laser is used, which emits red light at 632.8 nm with a power of 100 mW.

According to the Michelson interferometer setup shown in Figure 1, the system resembles a parallel air plate, producing concentric interference rings. These rings appear only when mirrors S1 and S2 are perpendicular. If the observed pattern appears fragmented or nearly straight, S1 must be adjusted.

Rotating the adjustment knob by one full turn of the micrometer screw shifts mirror S1 by 5×10^{-3} mm, causing the interference rings to expand or contract. To evaluate the pattern, the number of brightness changes at the center is counted, which corresponds to the displacement ΔL of mirror S1.

The relationship between the mirror displacement ΔL, the laser wavelength λ, and the number of observed maxima and minima is expressed as:

$$Z\lambda = 2\,\Delta L\,n$$

Where:

Z = number of micrometer screw rotations

λ = wavelength of the laser light

ΔL = number of fringes moving toward the center n = refractive index

By counting the number of fringes, the displacement corresponding to half the wavelength of the light used can be determined. This experiment is widely used in optical engineering for measuring the wavelength of light.

EXPERIMENTAL METHOD

Equipment and Materials:

1. He–Ne Laser
2. Interferometer base platform
3. Beam splitter (used to divide the laser beam)
4. Plane mirror
5. Lens (f = 50 mm)
6. Adjustment knob
7. Magnetic base stand

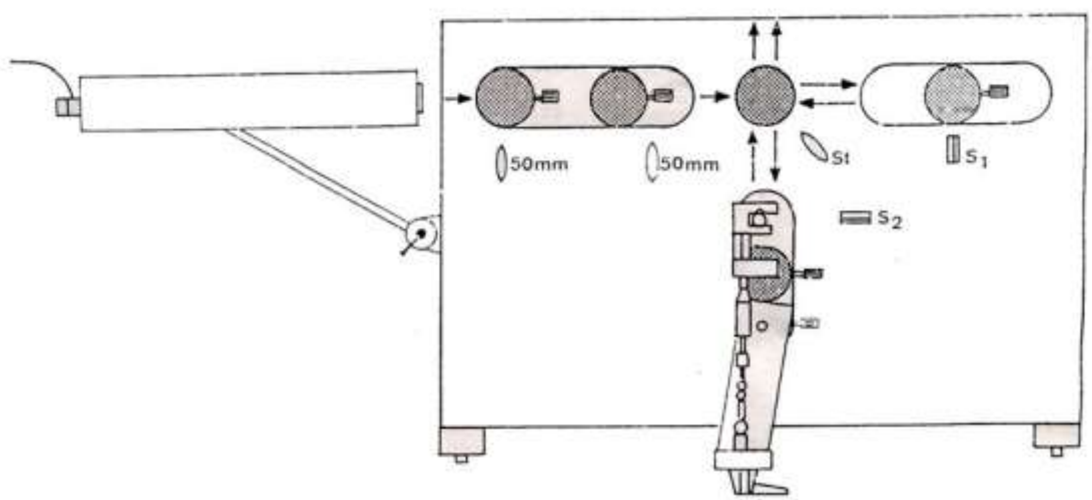

Figure 1. Michelson Interferometer with Base Platform

A : Laser
B : Lens (f = 50 mm)
C : Lens (f = 50 mm)
D : Beam splitter
E : Plane mirror (S1)
F : Plane mirror (S2)
G : Mirror adjuster
H : Interferometer base platform

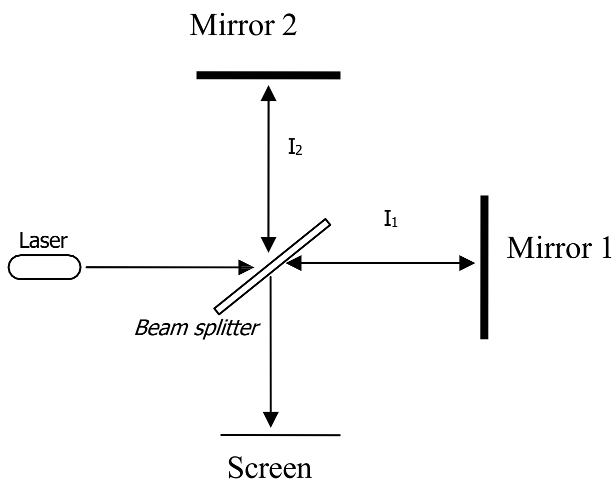

Figure 2. Michelson Interferometer