PH 511 General Physics Laboratory II

M.Sc.

III Semester

INSTRUCTION MANUAL

Department of Physics

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

July --- November 2015

PH 511 General Physics Laboratory II

Contents

A. Instructions

This Lab manual contains eight experiments from different areas of Physics. Only a brief outline of each experiment is given in this manual. Not given in the manual are: guidelines for preparing tables, or what graphs are to be plotted, or how the calculations are to be performed, or how the errors are to be estimated --- you yourself have to make correct decisions for them. Moreover, to know more about the experiments, you have to study of your own from other sources.

You must read and understand the theory of your experiment **before** you come to the lab. Submit a writeup containing the **tiltle-page, aim** and **theory** (including schematic **diagram**) of the experiment as soon as you enter the lab --- you will undergo penalty in terms of marks if you do not have such prior preparation.

You are required to carry out ALL the experiments without missing any of them. This can be achieved by only one way --- by being regular. The experiments are already allotted date-wise to each student and you must abide by it. For each experiment, two laboratory classes will be available to each student --- you must finish everything (setting up apparatus, data recording, calculations, graphs, report writing, error estimation, etc.) within the period of the allotted two classes. Submit the lab report on the second day of the experiment. No extra time will be permissible.

Set up your apparatus and finish recording all data on the first day. Show the instructor that you have set the apparatus properly and you are able to record data, get the data signed by him. While leaving the lab, you must leave behind all papers/records related to your experiment. Taking any data outside the lab, even if it is yours, is not permissible. On the second day of the lab, you must finish all calculations, graphs, error estimations, etc., so that you submit your complete report of your experiment within the lab hour. No extra time will be permissible.

The experiments must be performed **independently** all by yourself. The data you use must be the ones that you have recorded yourself. Insert the original sheets of recorded **raw** data that have been signed by the instructor at the time when you actually recorded them. **A fair copy of data is not acceptable.** Heavy penalty, in terms of deduction of marks, which may even be high negative marks, will be in your way if you are found to use data other than your own or if you manipulate your own data.

Assessment of your performance will be based on **(a)** your initial submission, that is, title-page, aim, theory and diagram **(b)** how well you carry out the experiment **(c)** whether you have taken sufficient amount of relevant data **(d)** proper graphs, calculations, error analysis and error estimates, final results. Note that your final writeup should include all: titlepage, aim, theory, least counts, observation tables, graph plottings, calculations, error analysis and error estimates, final result. All these should be written on one side of A4 size sheets and they should be enclosed in a file. The file should be submitted to the lab and it must not be taken out of the lab. Further assessment will be through an end-semester examination.

You should handle all instruments carefully. Please do not hesitate to give your feedback at any time.

With Best Wishes
The Instructors
July – Nov 2015 session

B. Errors in Measurements

When we measure a quantity with an instrument, it is prone to acquire three kinds of errors: (a) Sytematic Error, (b) Human Error, and (c) Random Error.

A **Systematic Error** is a constant error in the sense that it is due to some imperfection in the construction or adjustment of the instrument. Such an error affects all repeated measurements equally and it can in principle be eliminated by employing proper correction to the observed data. Recall that the faulty zero offset of a vernier callipers or screw gauge, which introduces a systematic error in the measurement, can be eliminated by employing proper corrections. However, it is impossible to find out the effect of other unknown forms of systematic errors if they are hidden in the measuring devices. For this course, it will be assumed that there are no undetectable systematic errors.

A **Human Error** is basically a mistake or blunder on the part of the experimenter. Such an error can occur due to carelessness such as incorrect recording of data, not caring for parallax, incorrect counting, etc. Such errors do not follow any law and they cannot be corrected by any means. The experimenter must be very careful in order to avoid making such errors.

Sometimes, the notions of above two kinds could be mixed. For example if an experimenter makes the blunder of measuring only the length of the string of a simple pendulum and forgets to measure the radius of the bob then this human error is systematic and it can be eliminated.

A **Random Error** (also called **Accidental Error**) occurs inevitably in a measurement and its causes are unknown and indeterminate. Such an error follows the laws of chance and a meaningful estimate about it can be obtained by employing the theory of statistics.

Suppose X is the true value of a quantity and its measurement yields a value x. The corresponding error in the measurement is the deviation $\xi = x - X$. The probalilty of occurance of this error is given by the Gaussian distribution

$$P(\xi)d\xi = \frac{1}{\sigma_x\sqrt{2\pi}}\, e^{-\xi^2/2\sigma_x^2}\, d\xi$$

Note that all values of error in the range $-\infty < \xi < +\infty$ are possible, but they are not equally probable. Higher errors are much less probable than the lower ones.

In an experiment, a repeated measurement of X is performed and a set of data $\{x_1, x_2, \ldots, x_N\}$ is obtained. From this data, it is impossible to obtain the true value X. However, it is possible to find the best possible value X_{best} by employing the law of least squares on $S = \sum_i \xi_i^2$, so that

$$X_{\text{best}} = \frac{1}{N}\sum_i x_i = \bar{x}$$

which explains why you calculate the average of a repeated measurement. However, the true value X is still unknown and we are unable to calculate the (square of) standard deviation

$$\sigma_x^2 = \frac{1}{N}\sum_i \xi_i^2$$

To get around this difficulty, we work with residuals defined by $r_i = x_i - \bar{x}$. It can be shown that

$$r_i = -\frac{\xi_1}{N} - \frac{\xi_2}{N} - \ldots + \left(1 - \frac{1}{N}\right)\xi_i - \ldots - \frac{\xi_N}{N}$$

so that a residual turns out to be a linear suprposition of the errors. Since the errors are normally distributed, such a combination yields a normal distribution for the residuals. The (square of) standard deviation of the residuals is defined by

$$s_x^2 = \frac{1}{N}\sum_i r_i^2$$

We can easily deduce the relation $(N-1)\sigma_x^2 = N s_x^2$, leading to

$$\sigma_x^2 = \frac{1}{N-1}\sum_i (x_i - \bar{x})^2$$

so that we can finally calculate the standard deviation σ_x even without the knowledge of the true value X. This explains why we use $(N-1)$ in the formula for σ_x^2.

This standard deviation is the uncertainty associated with each of the measurements. Since the mean $\bar{x}$ is obtained as a result of N individual measurements, it can easily be shown that the standard deviation of the mean is given by

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

This gives the uncertainty in the mean and we can have 68% confidence for it to lie within $\sigma_{\bar{x}}$ of the true value X. We can express this result as $\bar{x} \pm \sigma_{\bar{x}}$.

Propagation of Errors

Suppose we want to find the uncertainty in $F = F(X, Y)$ when the two mutually independent quantities X and Y are measured with errors ξ and η, respectively. You can easily show that the error ϕ in F would be the linear combination

$$\phi = \frac{\partial F}{\partial X}\xi + \frac{\partial F}{\partial Y}\eta$$

implying that the error ϕ is normally distributed. The corresponding standard deviations are therefore related by

$$\sigma_f^2 = \left(\frac{\partial F}{\partial X}\right)^2 \sigma_x^2 + \left(\frac{\partial F}{\partial Y}\right)^2 \sigma_y^2$$

This can be generalized to cases when F depends on more than two variables.

All the above procedures should be employed to calculate the uncertainty in the measured data while or after acquring the real experimental data. For example, the uncertainty in the final result of F could be expressed as $\bar{f} \pm \sigma_{\bar{f}}$, with $\sigma_{\bar{f}}$ given by the propagation of errors.

Error Analysis

Such analysis is required before you start performing the experiment in order to justify (or make) the choice of instuments (where possible). For example, you do not need the accuracy of a screw gauge in measuring the length of a simple pendulum, the accuracy of a meter scale will be good enough. To do so, you need to calculate the maximum error

$$\Delta f = \left|\frac{\partial F}{\partial X}\right| \Delta x + \left|\frac{\partial F}{\partial Y}\right| \Delta y$$

with a desired value for Δf and see, by hit and trial, what values of Δx and Δy (given by the respective measuring apparatuses, multiple choices may be possible) give you the desired tolerance.

If the available instruments are limited, this method should be employed to find out the maximum expected uncertainty corresponding to the available instruments.

C. Least Square Fit

In an experiment we often require to plot a graph of y as a function of x. Many times it will be possible to transform the formulas connecting the measured variables into a linear relationship like $y = mx + c$. The data points will of course not fall strictly on a straight line. Then the question arises: what is the best fit? That is, what is the best straight line? In other words, what are the best values for m and c?

In the analysis it will be assumed that there are no errors in x and all errors occur in y. The errors in y could be written as $\eta_i = y_i - (mx_i + c)$. Employing the method of least squares to $S = \sum_i \eta_i^2$ we get the best values as

$$m_{\text{best}} = \frac{\langle xy\rangle - \langle x\rangle\langle y\rangle}{\langle x^2\rangle - \langle x\rangle^2} \qquad \text{and} \qquad c_{\text{best}} = \frac{\langle x^2\rangle\langle y\rangle - \langle x\rangle\langle xy\rangle}{\langle x^2\rangle - \langle x\rangle^2}$$

Further, it can be shown that these values are linear superpositions of the y_i values from which their standard deviations can obtained as

$$\sigma_m^2 = \frac{1}{\langle x^2\rangle - \langle x\rangle^2}\,\frac{\sigma_y^2}{N} \qquad \text{and} \qquad \sigma_c^2 = \frac{\langle x^2\rangle}{\langle x^2\rangle - \langle x\rangle^2}\,\frac{\sigma_y^2}{N}$$

The standard deviation σ_y can be calculated from the reduced set of degrees of freedom as $\sigma_y^2 = \frac{1}{N-2}\sum_i \eta_i^2$ leading to

$$\sigma_y^2 = \frac{N}{N-2}\left[\left(\langle y^2\rangle - \langle y\rangle^2\right) - \frac{\left(\langle xy\rangle - \langle x\rangle\langle y\rangle\right)^2}{\langle x^2\rangle - \langle x\rangle^2}\right]$$

Note that the angular brackets denote average over the data points:

$$\langle x\rangle = \frac{1}{N}\sum_i x_i \quad \text{and} \quad \langle x^2\rangle = \frac{1}{N}\sum_i x_i^2 \quad \text{and} \quad \langle xy\rangle = \frac{1}{N}\sum_i x_i y_i \quad \text{etc.}$$

Experiment No. 1

Geiger-Müller Counter

Objectives

1. To study the characteristics of a Geiger-Müller Tube
2. To determine the counting statistics of radioactive decay

Theory

All nuclear radiations, whether they are charged particles or gamma rays, ionize atoms/molecules while passing through a gaseous medium. This ionizing property of a nuclear radiation is utilized for its detection. The Geiger-Müller counter (commonly called a GM counter or simply a Geiger tube) is one of the oldest and widely used nuclear radiation detectors. It consists of a metallic tube with a thin wire mounted along its axis. The wire is insulated from the tube using a ceramic feed-through (Fig. 1.1). The central wire (anode) is kept at a positive potential of a few hundred volts or more with respect to the metallic tube, which is grounded. The tube is filled with argon gas mixed with 5-10% of ethyl alcohol or halogens (Chlorine or Bromine).

When an ionizing radiation enters the Geiger tube some of the energy of the radiation may get transferred to a gas molecule within the tube. This absorption of energy results in ionization, producing an electron-ion pair (primary ions). The liberated electrons move towards the central wire (anode) and positive ions towards the cylinder (cathode). The electrons now cause further ionization by virtue of the acceleration due to the intense electric field. These secondary ions may produce other ions and these in turn still other ions before reaching the electrodes. This cascading effect produces an avalanche of ions. In an avalanche created by a single original electron many excited gas molecules are formed by electron collisions in addition to secondary ions. In a very short time of few nanoseconds these excited molecules return to ground state through emission of photons in the visible or ultraviolet region. These photons are the key element in the propagation of the chain reaction that makes up the Geiger discharge. These photons interact by absorption in other regions of the tube and create further ionizing events resulting in secondary avalanches at a different location in the tube. The arrival of these avalanches at the anode causes a drop in the potential between the central wire and the cylinder. This process gives rise to a very large pulse with amplitude independent of the type and energy of the incident radiation. The pulse is communicated to the amplifier through an appropriate RC circuit, and then to a counter which is called as Scalar. Suitable arrangements are made to measure the counts for a preset time interval.

Radioactive decay of a nucleus is a random process governed by the laws of quantum mechanics. Thus we can talk about only the probability of a decay. Most radioactive samples that are handled in the laboratory classes have long half-lives indicating that the probability of decay is small. In this experiment the statistical distribution law for a large number of decay events will be found out employing the Geiger-Müller Counter.

Counting Statistics: Let N be the number of counts observed for a fixed duration of time, and $f(N)$ the frequency of obtaining N counts for the same fixed duration of time. Then the distribution $f(N)$ approaches a Gaussian distribution for large N.

Part 1: GM Characteristics

1. Before switching on, make sure that all the knobs are set at minimum.
2. Place the given β source at ~2 cm from the end window of the GM tube.
3. Increase the EHT voltage supply to the GM tube and stop exactly when the counter starts recording counting. Note down this voltage.
4. Increase the EHT in steps of 15 V and keep recording counts for 60 sec at each voltage.
5. Step 4 should be continued until after the count rate starts to increase quickly.
6. Plot a suitable graph and determine the starting voltage, plateau threshold, plateau length, operating voltage, and plateau slope.

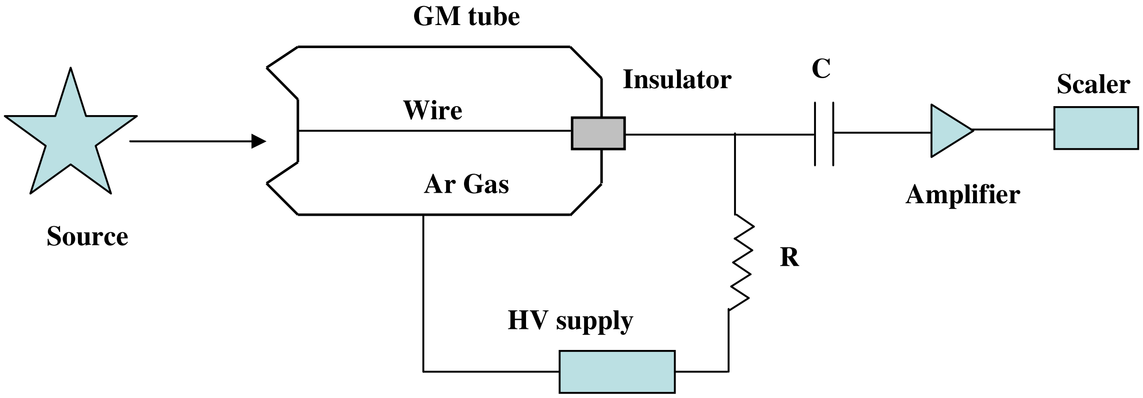

Fig. 1.1 Schematics of the GM tube and the associated electronics

Important

1. Finish Part 1 (including graph plotting) on the **first** day. Hence determine the operating voltage. (Use this operating voltage in Part 2).
2. Take all data for Part 2 on the **first** day.

Part 2: Counting Statistics

1. Before switching on, make sure that all the knobs are set at minimum.
2. Place the given source (say Cs^{137}) at 1 or 2 cm from the end window of the GM tube.
3. Increase slowly the EHT voltage supply to the GM tube and stop exactly when the counter starts recording counting. Verify whether this voltage is a reasonable value of *starting voltage*. If yes, proceed to the next step.
4. Continue to increase slowly the EHT voltage and set it to the *operating voltage* of the GM tube. (Use the operating voltage obtained in Part A).
5. Set the preset time (for registering counts) to 20 or 30 sec.
6. Find the number of counts.

7. Repeat step 6 many times (say, 100) and note down the readings.
8. Draw a histogram [which should be able to produce $f(N)$].
9. Calculate mean and standard deviation from raw data.
10. Plot the distribution function (superpose it on the histogram to see whether the distribution is Gaussian).
11. Estimate the goodness of the fit by χ^2 test (chi-square test).

Questions

1. Explain the differences between ionization chamber, proportional counter, and the Geiger-Müller counter in terms of construction, operation, and function.
2. Can the GM tube be used in the "proportional" region?
3. What particles are emitted by the source?
4. What is dead time? What measurements would you make to find it?
5. Do you think cosmic ray events would modify your results?
6. What is the functional form of $f(N)$?

References

1. G. Knoll, *Radiation Detection and Measurement*, John Wiley, 1999.
2. K. S. Krane, *Introductory Nuclear Physics,* John Wiley, 1988.
3. R. R. Roy and B. P. Nigam, *Nuclear Physics: Theory and Experiment*, New Age.
4. W. Feller, *An Introduction to Probability Theory and its Applications*, vols. 1 and 2, John Wiley.

Experiment No. 2
Electron Spin Resonance

Objective:

To determine the Landé g-factor in a free radical using an electron spin resonance spectrometer.

Theory:

The magnetic moment $\boldsymbol{\mu}$ due to an electron arises from its intrinsic spin angular momentum $\mathbf{S}$ and its orbital angular momentum $\mathbf{L}$ so that one may write $\boldsymbol{\mu} = -(e/2mc)(g_L\,\mathbf{L} + g_S\,\mathbf{S})$, where g_L (=1) and g_S (=2.00232) are the respective gyromagnetic factors for an electron. When the electron is subjected to a uniform magnetic field $\mathbf{B}$ (in the z-direction, say), its Hamiltonian can be written as $H = -\boldsymbol{\mu}\cdot\mathbf{B}$. Now we can approximately write $H = (e/2mc)(\mathbf{J} + \mathbf{S})\cdot\mathbf{B}$ where $\mathbf{J} = \mathbf{L} + \mathbf{S}$ is the total angular momentum. The expectation value of this Hamiltonian can be calculated in the coupled basis using the Wigner-Eckart theorem. The energy levels turn out to be

$$E(m_j) = g\,(eB/2mc)\,m_j\hbar = g\,\mu_B\,B\,m_j \qquad (1)$$

where $\mu_B = e\hbar/2mc$ is the Bohr magneton and g is the Landé g-factor given by

$$g = 1 + [j\,(j+1) + s(s+1) - l\,(l+1)]\,/\,2j\,(j+1). \qquad (2)$$

However, a good sample of electrons is difficult to find, and alternatively an organic free radical having an unpaired electron is employed in the laboratory. Such an electron behaves as though it is (nearly) free. A difference, although small, is expected to occur due to interaction with the rest of the radical. This electron, when subjected to an external magnetic field, can be assumed to form a two-state system with an energy gap $\Delta E = E(+\frac{1}{2}) - E(-\frac{1}{2})$. Now if the sample is exposed to an electromagnetic radiation of appropriate frequency ν given by $h\nu = \Delta E$, each electron in the ground state will absorb a photon and make a transition to the excited state. Experimentally, this will be observed as a resonance, in the classical sense of the term. (Find the working formula yourself).

In this experiment, the standard free radical 2,2'-**Dip**henyl-1-**p**icry**h**ydrazyl (commonly called DPPH) will be used as the sample (see Fig. 2.1). This sample is placed in a magnetic field produced by a pair of Helmholtz coils. Wound around the sample is a small induction-coil that supplies the necessary irradiating field (in the RF range). The induction-coil is basically a part of an LC circuit of the apparatus (see Fig. 2.2).

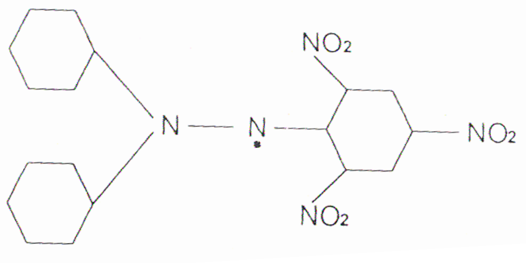

Fig. 2.1: Chemical Configuration of DPPH.

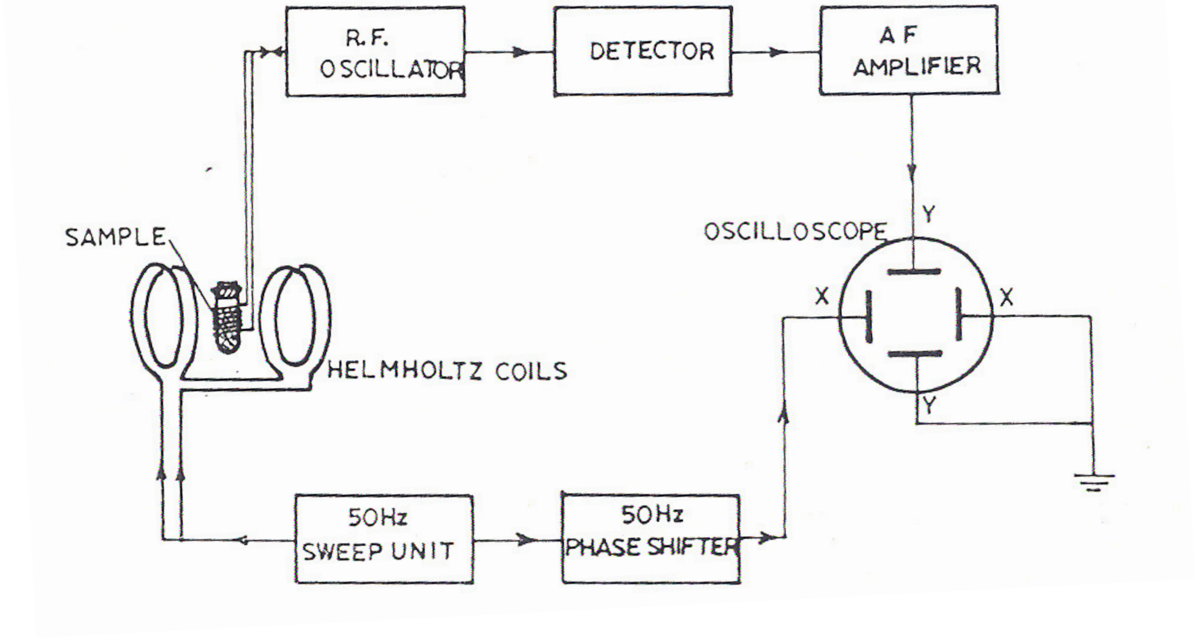

Fig. 2.2: Block diagram of the ESR setup.

Note that in the experiment the magnetic field is varied rather than the irradiating field to get resonance at the relevant value. At resonance the *LC* circuit undergoes maximum power loss which is detected by the internal circuitry and displayed on the CRO. The magnetic field at the "central region" of the Helmholtz coils is, to a very good approximation, given by

$$B = (8\mu_0 NI)/(a\sqrt{125}) \text{ in SI, and}$$
$$B = (32\pi NI)/(10a\sqrt{125}) \text{ in CGS Gaussian } (I \text{ in amp, } a \text{ in cm, and } B \text{ in Gauss}). \quad (3)$$

The parameters of the given Helmholtz coils are:

N = 500 in each coil
Diameter of the windings = 15.4 cm
Separation between the coils = 7.7 cm.

The radio-frequency (RF) oscillator operates in the range 9.5—18.0 MHz.

Procedure

1. Connect the **induction coil** to the **oscillator socket** of the **ESR Spectrometer**.
2. Connect the **Helmholtz coil** to the socket marked **H-coil**.
3. Connect the **X**, **Y,** and **E** sockets to the ***X-plate***, ***Y-plate***, and ***Earth*** of the ***CRO***.
4. Set the knobs on the panel of the **ESR Spectrometer** as follows:
    Current knob: Minimum (turn it fully anti-clockwise)
    Frequency knob: Centred
    Phase knob: Centred
    Sensitivity knob: Maximum (turn it fully clockwise)
5. Switch on the ***CRO***.
6. Switch on the **ESR Spectrometer.**
7. Switch on **H-Coil** power and set the **Current** at about 150 mA.

8. Four peaks will be seen to form on the CRO screen (see Fig. 2.4).
9. Adjust **Frequency** and **Sensitivity knobs** of the **ESR Spectrometer** and the ***Sensitivity*** of the ***CRO*** to get sharp peaks and good signal-to-noise ratio.
10. Adjust the **Phase knob** to coincide two peaks with the other two (see Fig. 2.3).
11. Measure the resonance frequency of the RF signal.

Determination of g-factor

The deflection due to X-plates of the CRO is caused by the same source that feeds current to the Helmholtz coils. Calibrating the X-deflection of the will thus give the amplitude of the applied magnetic field.

Adjust the X-amplifier on the CRO and maximize the X-deflection (span) to full X-range of the CRO screen. Note down the maximum span in terms of **number of small divisions**, call it P divisions (see Fig. 2.3). Verify this reading by turning off the Y-signal to the CRO (which is more reliable). The peak-to-peak magnetic field will be $B_{pp} = kP$ where k is the constant of proportionality. Note that $B_{pp} = 2\sqrt{2}\, B_{r.m.s.}$ so that $k = 2\sqrt{2}\, B_{r.m.s}/P$. Now let $2Q$ be the number of small divisions by which the two peaks are separated (see Fig. 2.3). The magnetic field B_R (at which resonance occurs) will be given by $B_R = kQ = 2\sqrt{2}\, QB_{r.m.s}/P$. Now read the **current** that is being supplied to the Helmholtz coils. This will give $I_{r.m.s.}$ which can be related $B_{r.m.s.}$ (see Eq. 3). Find a relation between B_R and $I_{r.m.s.}$ and Q and P.

Fix the radio frequency. Record data for several values of $I_{r.m.s.}$. **(Caution: Do not increase the current beyond 180 mA r.m.s.).** Plot a suitable graph from which you should be able to determine the value of B_R. Calculate the g-factor and its error estimates. Express your result to significant figures (can you get it up to four decimal places?) and the uncertainty in its value.

Repeat the above with a second value of radio frequency.

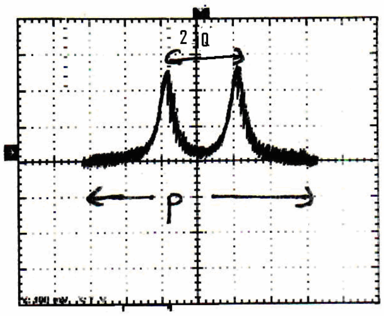

Fig. 2.3

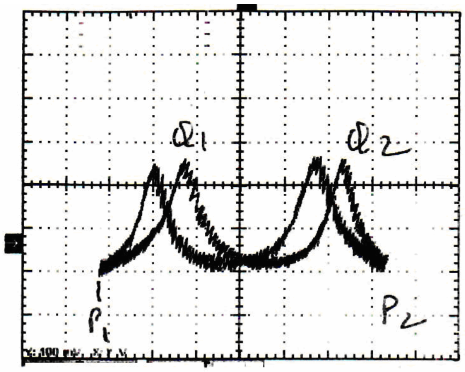

Fig. 2.4

Questions

1. Does earth's magnetic field (B_E) affect your result? If so, how can you find B_E?
2. Explain why there are four peaks. Can you make all of them coincide?
3. Can you perform ESR in the microwave range? If yes, at what magnetic field strength?
4. Expression (3) says that the magnetic field at the "central region" of the Helmholtz coils is constant to a very good approximation. How would you justify such claim?
5. Derive expression (3) from Biot-Savart law.
6. Can you find the line-width and relaxation time?

Experiment No. 3

Magnetic Susceptibility of a Paramagnetic Liquid

Objective

To determine the magnetic susceptibility of the given paramagnetic liquid using Quincke's method.

Theory

The bulk magnetic property of a magnetic substance can be measured by its magnetization **M**. For a paramagnetic substance, the magnetization is induced by the applied magnetic field **B** which is parallel to **M** for a linear medium.

The volume susceptibility is defined by the relations,

$$\mu_r = 1 + \chi , \qquad \chi = M / H \tag{1}$$

where the magnetic intensity $\boldsymbol{H}$ is related to $\boldsymbol{B}$ through $\boldsymbol{B} = \mu_0 \mu_r \boldsymbol{H}$.

Since the relative permeability, $\mu_r \approx 1$, the magnetisation is given by,

$$M = (\mu_r - 1)\frac{B}{\mu_0} = \frac{\chi B}{\mu_0} \tag{2}$$

On atomic level, the force **F**, on a magnetic dipole of moment **m** due to an applied magnetic field **B** is

$$\mathbf{F} = \nabla(\mathbf{m} \cdot \mathbf{B}) \tag{3}$$

Thus using equations (2) and (3), the force per unit volume experienced at a point in the liquid in the U-tube illustrated in the figure is given by

$$F_x = \chi \frac{B_z}{\mu_0} \cdot \frac{\mathrm{d}B_z}{\mathrm{d}x} \tag{4}$$

The force on the liquid due to the magnetic field can be calculated by integrating Eq. (4) with appropriate limits. This force is balanced by the weight of the column of liquid that rose in one arm against the other (assuming uniform cross section throughout). If the difference in column height is h, then the susceptibility is given by

$$\chi = 2\mu_0(\rho - \rho_0)gh / B^2 \tag{5}$$

where ρ and ρ_0 are the densities of the liquid and air and g is the acceleration due to gravity. Note that this relation is in the SI system of units.

The susceptibility can be obtained by plotting a graph between h and B^2.

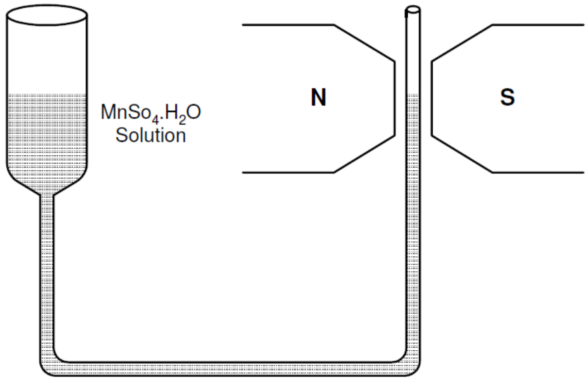

Fig. 3.1 The Quincke's Tube setup.

Note: A master solution of $FeCl_3$ *(instead of* $MnSO_4$*) will be supplied.*

Procedure

1. Adjust the air-gap between the pole pieces of the electromagnet so that the thin arm of the Quincke's tube can be inserted in the gap easily.
2. Measure the magnetic field between the pole pieces of the electromagnet as a function of current through it with the help of the hall probe and gauss meter. Plot the calibration curve.
3. You will be given a master solution of $FeCl_3$.
4. Take ~ 10 ml of the given solution. Measure the density of the solution using specific gravity bottle. Fill the Quincke's tube with the solution and place the narrow limb of the tube between the pole pieces such that the solution level is at the center of pole pieces (or slightly lower).
5. Note the position of lower meniscus of the solution with a traveling microscope. Record the change in height of the liquid column as a function of magnetic field applied. Whenever the magnetic field is changed wait for few minutes before taking the observation.
6. Repeat steps 4 and 5 for 2 – 3 different known concentrations of lower molarities by calculated diluting the master solution with distilled water.
7. Plot suitable graph and analyze the data to obtain the susceptibility of the liquid for various concentrations.

Questions

1. What is the direction of force in Eq. (4)? Justify the direction.
2. Can you derive Eq. (5)?
3. If the meniscus rises above the region of maximum magnetic field, do you think you will still get correct result if you use Eq. (5)?
4. If you repeat the experiment with the solution at a different temperature, would you expect a different answer for the susceptibility?
5. How has the diamagnetic contribution (coming from the same solution that you used) affected your result?
6. Can you use the set-up for a diamagnetic liquid?

Experiment No. 4

Magnetoresistance of a Semiconductor

Objective

To study the magnetic field dependence of the transverse magnetoresistance of a given semiconductor sample.

Theory

It was Lord Kelvin who first discovered this phenomenon. The magnetoresistance is defined as the ratio of change in resistance of a substance due to application of magnetic field to its resistance in zero field. Under the influence of a magnetic field, the electrons in a solid material do not follow the exact direction of superimposed electric field, instead take a curved path. This results, in effective decrease of the mean free path and hence an increase in the resistivity of the sample. When magnetic field is applied normal to the current flow, the effect is termed as transverse magnetoresistance and when field is applied parallel to the current flow, it is termed as longitudinal magnetoresistance.

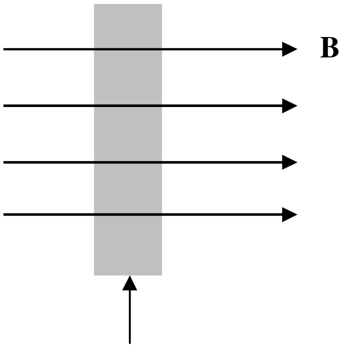

Fig. 4.1 Configuration of the experiment

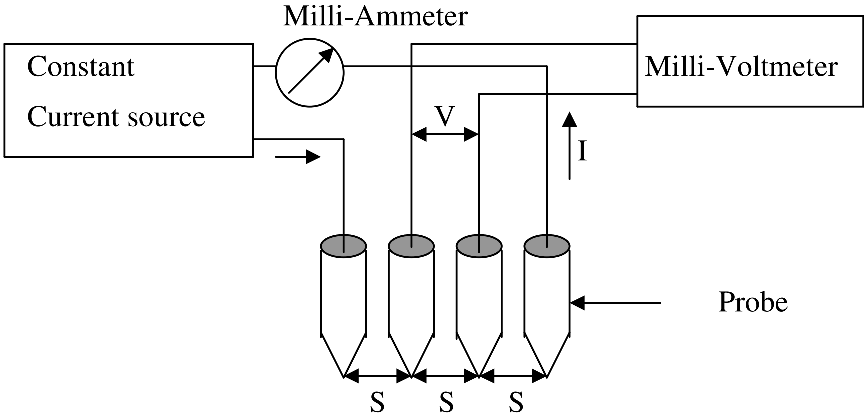

Fig. 4.2 The four-probe layout

For small field we can write transverse magnetoresistance as

$$\frac{\Delta\rho}{\rho_0} = \frac{\rho - \rho_0}{\rho_0} \propto \mathrm{H}^2 \text{ or} \tag{1}$$

$$\frac{\Delta\rho}{\rho_0} = \mathrm{C\,H}^2 \tag{2}$$

where ρ_0 is resistivity of the material in zero field, ρ is resistivity in a magnetic field *H*. However, in higher fields, the dependence is quite often linear. In case of longitudinal magnetoresistance, equation (2) holds except that the constant of proportionality C is much smaller than that in the transverse case. Recall that the potential difference between inner two probes can be written as

$$V = \frac{I\rho}{2\pi d}\int_s^{2s}\left(\frac{1}{r} + \frac{1}{3s - r}\right)dr = \frac{I}{\pi d}\rho \ln 2$$

$$\therefore \quad \rho = \frac{V\pi d}{I \ln 2}$$

Procedure

1. Make the connections as shown in Fig. 4.2.
2. First put the sample in air (away from the electromagnet). Caution: The electromagnet has a remnant magnetization.
3. Record the voltage as you vary the current through the sample. **Caution: Do not increase the current beyond 8 mA.**
4. Plot a graph between voltage and current. Obtain the slope by least square fit. Hence obtain the resistivity employing Eq. (4).
5. Adjust the air-gap between the pole pieces of the electromagnet so that the sample can be inserted in the air gap.
6. Measure the magnetic field between the pole pieces with the help of a Hall probe and Gauss meter. (Caution: Before doing so, ensure the zero setting of the Gauss meter.)
7. Place the sample between the pole pieces so that the magnetic field is perpendicular to the plane of the sample.
8. Repeat 3 and 4.
9. Repeat 6, 7, 3, and 4 for at least three different values of magnetic fields.
10. Verify equation (2) by a suitable plot.

Hence obtain the value of *C* by least square fit. Estimate the error

Questions

1. Will Iron exhibit the phenomenon of magnetoresistance when subjected to a magnetic field?
2. Can you analyse this phenomenon in terms of the Lorentz force?
3. Do you think Copper will exhibit this phenomenon?

Experiment No. 5

Absorption Spectrum

Objectives

1. To record the transmitted (absorption) spectrum of potassium permanganate solution
2. To measure the absorptive coefficient of potassium permanganate

Theory

When light is incident on an absorbing medium as shown in Fig. 5.1, the output intensity I is governed by the Beer-Lambert's law, given by

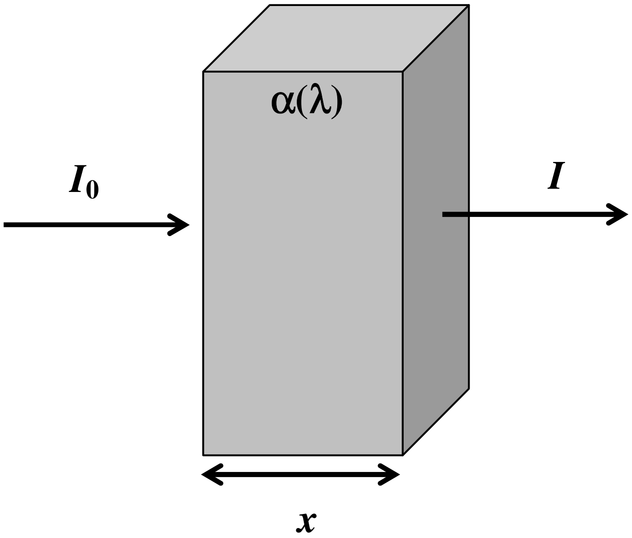

Fig. 5.1 Configuration of the experiment

$$I = I_0 \exp(-\alpha x) \tag{1}$$

where I is the transmitted intensity, I_0 is the intensity incident on the medium, α is the absorption coefficient and x is the path length traveled by light in the medium. Equation (1) can also be expressed in terms of transmittance $T = I / I_0$, of the medium as

$$\alpha x = \ln(1/T) \tag{2}$$

If the medium happens to be a solution then the equation (1) is modified into

$$I = I_0 \exp(-aCx) \tag{3}$$

where a is the wavelength dependent absorptivity coefficient (in $M^{-1}cm^{-1}$), x is the path length (in cm), and C is the concentration of the solute in the solution in terms of M (Molarity). Thus by recording the transmitted light at a particular wavelength as a function of concentration for a given wavelength, the corresponding absorptivity coefficient a can be measured. The Beer-Lambert law is limited by chemical and instrumental factors. You will be using an Absorption Spectrophotometer for the experiment

Procedure

Before starting the experiment, familiarize yourself with all the controls provided on the front panel of the Absorption Spectrophotometer. You may also go through the instrument manual available in the laboratory.

You are provided with a master solution of potassium permanganate in distilled water.

1. From the master solution make 4-5 dilute solutions by adding **calculated** amount of distilled water so that the molarity of each solution (including the master solution) is known to you. Note down your calculations corresponding to each molarity you have prepared.
2. Record the transmitted spectrum of each solution in the spectral range of 400-960 nm at suitable regular intervals (say, ~10 nm). Use distilled water as reference and follow the proper procedure for normalization of the data.
3. Plot the transmitted spectrum of each solution. Note down the wavelengths corresponding to the maximum absorption (as well as 2-3 additional wavelengths near to the maximum absorption).
4. Find the transmittance T of each solution corresponding to the wavelengths selected above.
5. Plot suitable curves and analyze the data with the appropriate equations given above to calculate the absorptivity at various wavelengths.

Questions

1. In the experiment, you study the absorbance as function of λ. Where does the wavelength dependence occur in Equation (1)?
2. What physical processes are responsible for the absorption (or attenuation) of light?
3. Why is the absorption spectrum continuous (not discrete)?

Experiment No. 6

Dielectric Constants of Liquids

Objective

To construct a Colpitt oscillator and use it to measure the dielectric constants of liquids

Theory

Dielectric constant K of a material is the ratio of the electrical permittivity ε of the material to that of free space ε_o, i.e. $K = \frac{\varepsilon}{\varepsilon_o}$. If the space between a parallel plate capacitor of cross sectional area A and separation d is filled with a dielectric medium of dielectric constant K then the capacity of the capacitor C is given by $C = \frac{K\varepsilon_o A}{d}$. Thus the dielectric constant of a medium can be measured by measuring the capacitance C, d and A. Capacitance of such a capacitor can be measured by measuring the frequency of oscillations of the Colpitt oscillator circuit shown in Fig. 6.1. Frequency of oscillation is given by $f = \frac{1}{2\pi\sqrt{LC_T}}$, where L is the inductance and the C_T is the effective capacitance of the tank circuit.

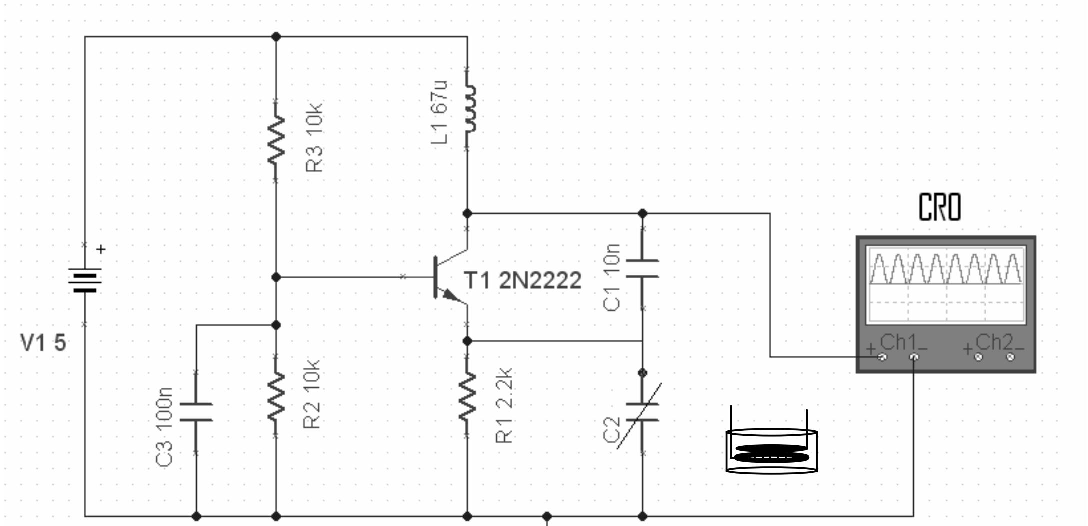

Fig. 6.1

Procedure

1. Assemble the Colpitt oscillator circuit on a bread board (see Fig. 6.1). C2 is the given parallel plate capacitor(s).
2. Switch on the power supply.
3. Adjust the voltage to the circuit so as to get a sinusoidal oscillation. (You might have to adjust the gain and bias voltage to get the sinusoidal waveform.)
4. Record the frequency of oscillations from the CRO. (Note that in the first observation, C2 should have air as the medium between its plates.)
5. Repeat the above for different values of C1.
6. Replace C2 with a parallel plate capacitor of different plate spacing.
7. Repeat 3, 4, and 5.
8. Immerse the parallel plate capacitor C2 in the given liquid.
9. Repeat 3—7.
10. Record the data (8 and 9) by changing the liquid.
11. Obtain the dielectric constant of the liquids used above.
12. Estimate the maximum possible error.

Questions

1. Can you find any property of the liquid used as dielectric medium?
2. Can you use a cylindrical (coaxial) capacitor and perform the same experiment?

Experiment No. 7

Franck-Hertz Experiment

Objective

To determine the first excitation energy of Argon.

Theory

We know that the energy of an atom takes only discrete values. At room temperature, most atoms are in the ground state. An atom jumps to higher level by absorbing energy in many different ways, for example, interaction with electromagnetic radiation or collisions with other particles like electrons. In 1914, Frank and Hertz verified that the atoms absorb energy only in discrete values by bombarding atoms with low energy electrons. In this experiment, applying electric field accelerates electrons. If electrons have sufficient kinetic energy to excite atoms to the first excited state, then the collisions are inelastic. Otherwise, the collisions are elastic and the electrons do not lose kinetic energy (atoms are heavy).

The schematic diagram of Frank-Hertz tube is shown in Fig. 7.2. The tube is filled with a gas of atoms under consideration (Argon). The electrons emitted by the cathode K are accelerated through potential $V_{G2K.}$ The grid G1 helps in minimizing the space charge effects. The plate A is at a potential slightly negative with respect to G2. This helps in making the dips in the plate current more prominent.

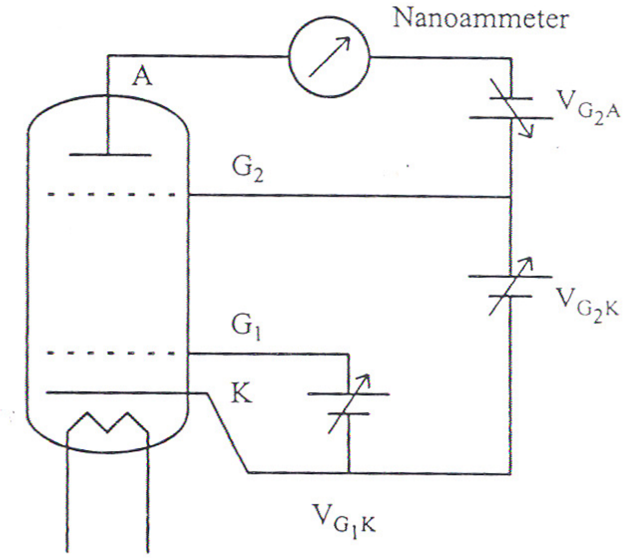

Fig. 7.1 Schematic diagram of Franck-Hertz experiment.

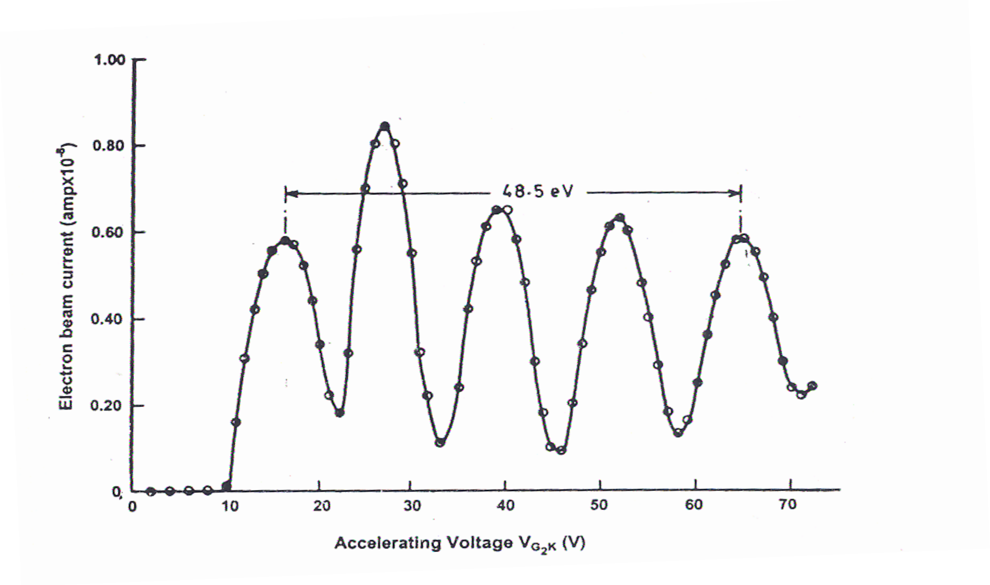

Fig. 7.2 Plot of anode current (ordinate) vs V_{G2K} (abcissa)

As we increase V_{G2K}, the current through A increases. When the electron energies are just sufficient to excite atoms, they lose kinetic energy and cannot reach the anode, resulting in a dip in the anode current. The elastic collisions occur near G2. If we increase V_{G2K} further the current increases until the potential is such that an electron undergoes two collisions inelastic with the atoms. This results in the second dip in the anode current. The anode current vs V_{G2K} graph is shown in the Fig. 7.3. The voltage difference between two successive peaks of anode current gives the excitation energy of the atom.

You have been provided with a Frank-Hertz tube filled with (neutral) Argon. You have to find the energy of an excited state. Table of first few levels is given below. Try to determine transitions that are possible in electron-Argon collision process.

Configuration	Term	J	Energy (eV)
$3p^6$	^1S	0	00.00
$3p^5(^2P_{3/2})4s$	$^2(3/2)$	2	11.54
		1	11.62
$3p^5(^2P_{1/2})4s$	$^2(1/2)$	0	11.72
		1	11.82
$3p^5(^2P_{3/2})4p$	$^2(1/2)$	1	12.90
		0	13.26

Table 7.1 Energy levels of neutral Argon

Typical operating parameters are given here.

Filament voltage : 2.6V (minimum position)
$V_{G1,K}$: 1.5 V
$V_{G2,A}$: 7.5 V
$V_{G2,K}$: 0-80 V
Current Multiplier : 10^{-7}

Precautions

1. Whenever you want to change any setting (including turning power ON/OFF switch), make sure V_{G2K} is set to zero (minimum position).
2. If heating filament voltage is changed, allow 2-3 minutes before making any observation.
3. During the experiment, if voltage V_{G2K} is over 60V, pay attention to the ammeter. If the current rises suddenly, decrease voltage at once.

Procedure

1. Vary the accelerating potential (V_{G2K}) and record the anode current I.
2. Plot I vs V_{G2K} and determine the first excitation energy.

Questions

1. Will the pressure inside the FH tube affect your results? Will the graph in Fig. 7.3 get modified if the pressure is different?
2. Why are the second and third points in the precaution important?
3. Why do you get a smooth curve like in Fig. 7.3? Instead, you should expect very sharp peaks due to the discreteness of the energy levels. How do you explain this?
4. Can you find higher excitation energies from the same graph?

Experiment No. 8

Diffraction of Light

Objectives

To study the diffraction of laser light due to a double slit, grating, and circular aperture. Hence determine (a) the wavelength of the laser light, (b) the ruling density of the grating, and (c) the diameter of the circular aperture.

Double Slit

The corresponding conditions are (identify whether Maxima or minima)

$$a \sin\theta = \pm m\lambda$$
$$(a + b)\sin\theta = \pm n\lambda$$

where m and n are integers, a is the slit width, b is the size of the opaque region between the slits, λ is the wavelength of light undergoing diffraction, and θ is the angle of diffraction.

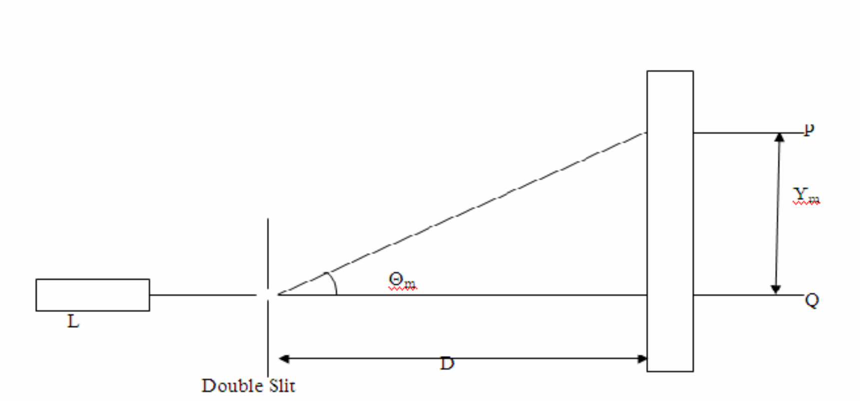

Fig 8.1 Parameters for the Double Slit experiment

Procedure

1. Switch on the laser and align the laser beam in such a way that the beam falls on the double slit and through it onto the detector.
2. Observe the diffraction pattern and scan it from left to right. Note down the distance moved by the micrometer and the corresponding output of the detector.
3. Measure the distance between the slit and the detector.
4. Measure the slit width.
5. Plot a graph between the micrometer reading and the output current.
6. Find the distance between the central maxima and the m^{th} order fringe from the graph.
7. Plot a suitable graph to obtain the wavelength of the laser light.

Grating

The conditions for primary maxima/minma (identify yourself) are

$$(a+b)\sin\theta = \pm n\lambda$$
$$(a+b)\sin\theta = \pm m\lambda/N$$

The procedure is similar. Use the wavelength obtained in the first part.

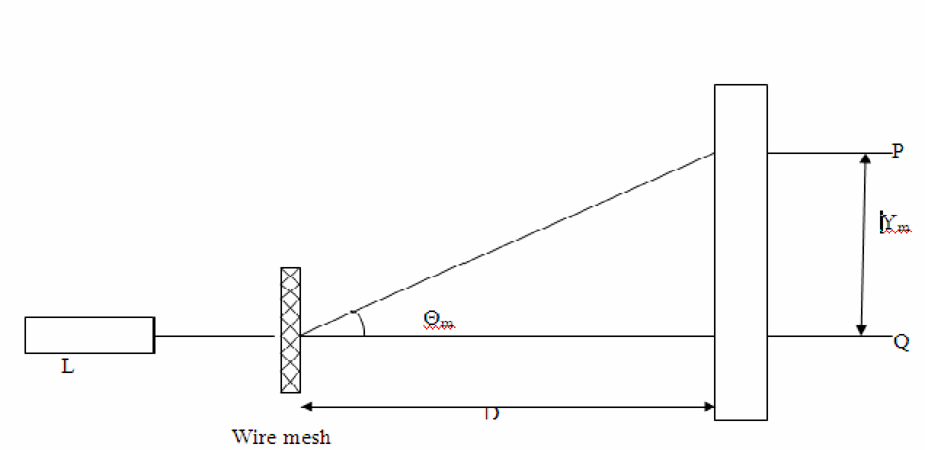

Fig 8.2 Parameters for the Wire mesh experiment

Circular Aperture (Pinhole)

The diffraction pattern resulting from a uniformly illuminated circular aperture has a bright region at the centre, known as the Airy's disc which, together with a series of concentric alternate dark and bright rings around, is called the Airy pattern. The diameter of this pattern is related to the wave length of the illuminating light and the diameter of the aperture. Now the condition for the first dark ring is

$$d\sin\theta = 1.22\,\lambda$$

where *d* is the diameter of the circular aperture.

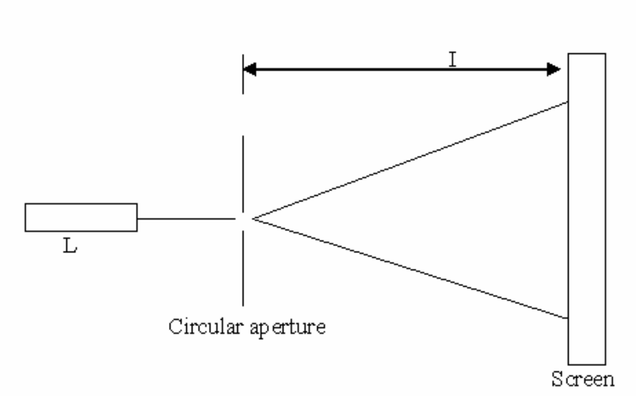

Fig 8.3 The Circular Aperture experiment

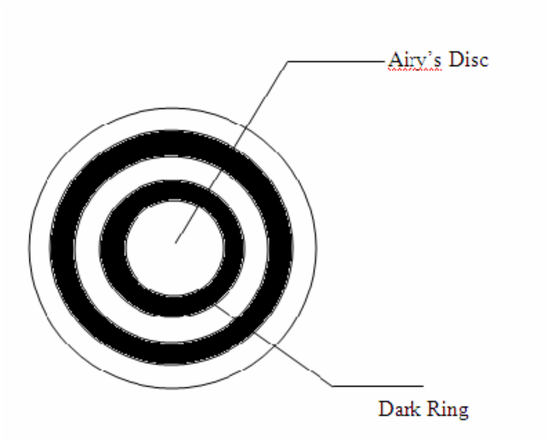

Fig 8.4 Airy's Disc

The procedure is essentially the same as before. Use the wavelength obtained in the first part for calculation. From the data, find the diameter of the Airy's disc. Hence obtain the diameter of the circular aperture.

Questions

1. What is the difference between Fraunhofer and Fresnle type of diffractions?
2. Which type of diffraction is occurring in this experiment?
3. 3. What are the expressions for intensity in the cases (a) single slit (b) double slit (c) grating (for Fraunhofer diffraction)?
4. How do you obtain the conditions of diffraction (the equuations given here)?

Hints on Observation Tables

Sl. No.	Micrometer Reading (mm)	Detector o/p Current (μA)

Order m	Distance between central maxima and m^{th} order maximum (Y_m)	$\theta_m = \tan^{-1}(Ym/D$	Sinθ_m	Plot a graph to find λ