

Instruction Manual

PH511: Physics Laboratory-III



DEPARTMENT OF PHYSICS
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
July- Nov 2014

LIST OF EXPERIMENTS

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i) Instructions to Students

The PH 511 course consists of nine general physics experiments. Two laboratory sessions of three hours each has been allotted for performing and submitting the reports of each of the nine experiments (No more than six laboratory hours would be permissible for each experiment). All experiments have to be performed independently by each student. This manual provides a brief theoretical background and complete procedure for performing the experiments. Refer to the weekly roster to find out the date-wise allotment of experiments. Study the theory behind the experiment and familiarize yourself with the experimental procedure before attempting to perform the experiment. **This calls for a thorough study of the instruction manual before coming to the lab.**

Devote a file folder for the lab report. Your preparation for the experiment (prior to entering the lab) includes a write-up containing the title, objective(s), diagram(s), formulae and tabular columns for entering data. The lab report of each experiment should be written on A4 size paper.

Assessment of PH 511 is based on **(i) your performance in the laboratory class, (ii) your laboratory report, and (iii) the end-semester practical examination.** You are expected to perform the experiment, complete the report in all respects and submit the hand written report within the six-hour experimental slot allotted for each experiment. The maximum possible error encountered in each experiment should be estimated and given along with the results. Attendance in all laboratory sessions is a must. A repeat / practice session would be given towards the end of the term (before the end-semester examination).

You are encouraged to freely use the instruments provided. However, handle instruments and optical / electronic components with care. **A set of questions is posed at the end of each experiment. Try to find answers to them and attempt to try out some of the extensions if you get some free time for the same during your six-hour slot.** Your feedback on the course is welcome at any stage of the course.

With best wishes,

Instructors, PH 511

ii) Introduction to error analysis

All physical measurements are subject to various types of error. In other words, every measurement has some associated errors. It is important to reduce the effect of errors to a minimum. In order to know the uncertainty in a measurement or to know the deviation from the true value of a measured quantity, it is important to have an idea of the sources of error as well as their estimates. Error involved in any measurement may be broadly classified as (a) systematic error and (b) random error.

(a) Systematic error

Errors that are not revealed through an entire set of measurements are termed systematic errors. Systematic errors may arise because of instrumental defect or experimenter's bias.

i. Instrumental errors

Zero off-set (ie., the instrument does not indicate zero when the input is zero) or incorrect calibration of the instrument or change in calibration (due to change in temperature, pressure or other environmental changes) are the example of instrumental errors. Zero error can be detected before hand and all the observations are to be corrected accordingly. *For the purpose of this course, it can be assumed that the given instrument has been calibrated correctly.*

ii. Experimenter's bias

This is a common source of error arising from some particular bias of the experimenter. Such errors are difficult to eradicate. For example, parallax error in reading an analog meter is often encountered if care is not taken to view the indicator needle perpendicular to the meter face.

Systematic errors are hard to handle. The only way to deal with them is to identify and eliminate them.

(b) Random error

Fluctuations in the instrumental measuring process result in random errors. The effect of random errors can be minimized by appropriate data processing techniques. Multiple measurements (repetition) followed by averaging minimize random errors in a measurement.

Probable error

It is known from experience that any long sequence of independent observations of a variable x shows up fluctuating deviation from the average. The probability of occurrence of these deviations is expressed by the normal distribution,

$$P(x)dx = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2\right]dx \quad (1)$$

where $P(x)dx$ is the probability that the observation lies in an interval dx around x , \bar{x} is the mean (average) given by

$$\bar{x} = \int_{-\infty}^{\infty} xP(x)dx \quad (2)$$

and σ is the standard deviation given by

$$\sigma = \left(\int_{-\infty}^{\infty} (x-\bar{x})^2 P(x)dx \right)^{\frac{1}{2}} \quad (3)$$

The quantity σ is a measure of the spread of the observations around \bar{x} . Specifically, 68% of all data is within the range $\bar{x} - \sigma$ to $\bar{x} + \sigma$. For a discrete set of data,

$$\bar{x} = \left(\frac{1}{N} \right) \sum_i x_i \quad (4)$$

$$\sigma = \left[\left(\frac{1}{N} \right) \sum_i (x_i - \bar{x})^2 \right]^{\frac{1}{2}} \quad (5)$$

For a small set of data, the best estimate of the standard deviation is given by

$$\sigma^2 = \left[\left(\frac{1}{N-1} \right) \sum_i (x_i - \bar{x})^2 \right] \quad (6)$$

where σ^2 is known as the variance.

Maximum possible error

In the above discussion, we have only considered the measurement of one quantity. Most of the experiments involve measurement of several different quantities. Measurement of each of these quantities is limited in accuracy by the least count of the instrument and error arising because of this is termed as maximum possible error. The maximum possible error can be estimated in the following manner.

Suppose a physical quantity y is a function of two independent (measurable) variables x_1 and x_2 given by

$$y = f(x_1, x_2)$$

Then maximum possible error in y is given by

$$\frac{\Delta y}{y} = \frac{1}{f} \left[\left(\frac{\partial f}{\partial x_1} \right) \Delta x_1 + \left(\frac{\partial f}{\partial x_2} \right) \Delta x_2 \right] \quad (7)$$

where Δx_1 and Δx_2 are the errors in quantities x_1 and x_2 respectively. If x_1 and x_2 are the measurable quantities, then Δx_1 and Δx_2 respectively are the least counts of the instrument used to measure them.

In all the experiments you are about to perform in this course, you are expected to estimate the maximum possible error from Eq. (7). Recall how the errors propagate in expressions containing powers!

Least squares fit:

Suppose you are measuring two quantities x and y linearly related by $y = ax + b$. (8)

The best estimates for the slope a and intercept b of the straight line are obtained as follows. Suppose that (y_i, x_i) be the measured value. If $y(x_i)$ is the value defined by Eq. (8), then one should minimize the quantity, $\sum_i (y(x_i) - y_i)^2 = \sum_i (y_i - ax_i - b)^2$ with respect to a and b .

Setting the differentials to zero and solving the two simultaneous equations, gives the best estimates of a and b as

$$a = \frac{N \sum_i x_i y_i - \sum_i x_i \sum_i y_i}{N \sum_i x_i^2 - \left(\sum_i x_i \right)^2} \quad (9)$$

$$b = \frac{\left(\sum_i x_i^2 \sum_i y_i - \sum_i x_i \sum_i x_i y_i \right)}{N \sum_i x_i^2 - \left(\sum_i x_i \right)^2} \quad (10)$$

After obtaining the values of a and b , plot the straight line $y = ax + b$ using values of a and b obtained by Eqs. (9) and (10). Plot the measured points (y_i, x_i) too on the same graph. **See how well the experimental data points are clustered around this straight line!**

Quite often you may be able to reduce the equation containing exponents to the linear form by suitable rearrangements. For example, $y = ce^x$ can be rewritten as $\ln y = \ln c + x$, so a plot of $\ln y$ versus x would be a straight line.

Experiment #1: Electron spin resonance

Objective:

To measure the Lande's g-factor in a free radical using an electron spin resonance spectrometer.

Theory:

When a particle with a magnetic moment μ is placed in a uniform magnetic field of intensity H_0 , (Fig 1.1a) then the moment will precess around H_0 with a Larmor frequency of

$$\omega_0 = g [e/(2mc)] H_0 \quad (1)$$

where g is the Lande's g-factor ($g = 1$ for pure orbital momentum and $g = 2$ for a free electron). In the case of an anion in a crystal, the Lande's g-factor deviates from the Lande's g-factor and is known as the spectroscopic splitting factor.

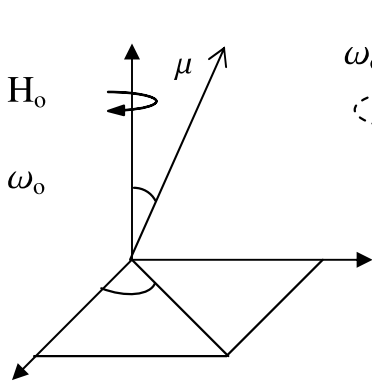


Fig. 1.1(a)

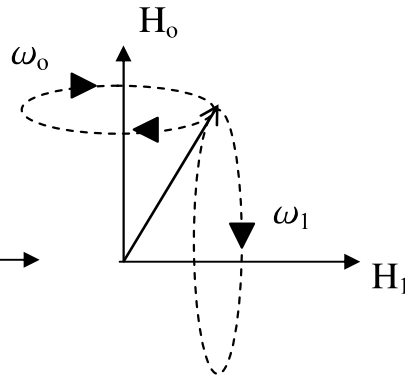


Fig. 1.1(b)

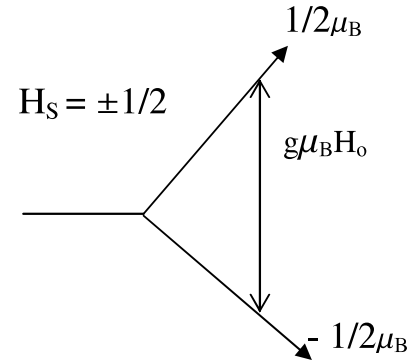


Fig. 1.1(c)

Now consider applying a weak magnetic field H_1 oriented in the XY plane and rotating about Z-axis (Fig. 1.1b) in the same direction as the Larmor precession. If the angular frequency ω_1 of the magnetic field is not equal to ω_0 , then the angle θ between μ and H_1 will continuously change and hence the net interaction would become zero. If on the other hand if $\omega_1 = \omega_0$, then the net interaction will not be zero. If one looks at this spin system from a reference frame rotating about the z-axis with angular velocity ω_0 , then it would appear that the spin is making an angle $\Psi = 90^\circ - \theta$ with H_1 (and would precess about H_1). The change in θ is the classical analogy to a transition between magnetic sublevels. Let us consider the quantum picture of magnetic resonance. Let the intrinsic angular momentum of the electron S couples with the orbital angular momentum of electron L to give the resultant J . The energy difference ΔE between adjacent magnetic sublevels is $\Delta E = g\mu_B H_0$, where μ_B is the Bohr magneton and the quantum mechanical value of g is

$$g = 1 + [J(J+1) + S(S+1) - L(L+1)] / 2J(J+1) \quad (2)$$

Now consider the particle perturbed by an alternating magnetic field with frequency ν_1 . If the energy difference between two magnetic sublevels is ΔE exactly equals $h\nu_1$ and if the direction

of the perturbing magnetic field is perpendicular to the direction of the static magnetic field, then there will be an induced transition between neighboring sublevels (as permitted by the selection rule $\Delta m = \pm 1$). Therefore the condition for resonance is

$$\Delta E = g\mu_B H_0 = h\nu_0 = h\nu_1 \quad (3)$$

where ν_1 is the resonance frequency. The above condition is identical to the classical case of $\omega_1 = \omega_0$. For a free electron $g = 2.00$, $\mu_B = 0.927 \times 10^{-20}$ erg/Gauss and $h = 6.625 \times 10^{-27}$ erg-sec. Substituting these values in Eq. (3) we get $\nu_0/H_0 = 2.8$ MHz/Gauss. This implies that electron spin resonance (ESR) can be observed in RF range with magnetic field of a few gauss or in a microwave region with a few kilogauss. The latter give a better results but the instrumentation becomes highly sophisticated and costly. Here ESR is observed in RF range, for this, the sample under study is placed between a pair of Helmholtz coils (which is the part of a tank circuit of an oscillator). Whenever the sample absorbs power (usually at resonance), the power load on the oscillator circuit decreases. The change in the power ΔW is measured by measuring the change in the current through the oscillator. The block diagram of the ESR spectrometer is shown below. Understand the function of each module.

Procedure:

1. Connect the X and Y terminals to the corresponding terminals of the CRO by connecting leads, Helmholtz Coil leads to terminal marked "H-Coils".
2. Adjust the "current" knob fully anticlockwise (minimum).
3. Set FREQUENCY knob to "center", sensitivity to "maximum" and phase KNOB to "centre" Position.
4. Switch on "H-Coil" power and set the current to (say) 150mA.
5. Four peaks would be observed on the screen (Understand the origin of the four peaks). Adjust the PHASE knob to coincide two peaks over the other two.
6. Adjust FREQUENCY and SENSITIVITY knobs of the spectrometer and the SENSITIVITY knob of the CRO such that sharp peaks are obtained.
7. Adjust PHASE knob to merge the four into two (as far as possible).
8. Pick-up the RF signal with the help of copper strip wrapped around the RF coil and feed the signal on to digital storage Oscilloscope (DSO, 100 MHz) for the measurement of the resonance frequency.

Measurements:

Resonance Field:

Let the position between the peaks is $2Q$ division (mm) and the horizontal deflection is P division (mm) (Fig. 1.3a). Then the corresponding peak-to-peak magnetic field $H_{pp} = 165.25$ Gauss/amp (assuming radius of coil as 7.7 cm and number of turns in the coil as 500). The resonance field H_0 is given by

$$H_0 = 165.25 * I * Q / P \quad (4)$$

Calculate the g-factor using Eq.3. Repeat the measurement for several values of I and calculate the average value of g .

Plot $1/I$ vs Q and determine the slope. The slope will give $Q \cdot I$. Using this value of $Q \cdot I$, calculate the Lande's factor again.

If you are unable to merge the four peaks into two very precisely, make the peaks to cross near baseline as shown in Fig 1.2(b). Mark the points P_1 , P_2 , Q_1 and Q_2 on a tracing paper and measure $2Q$ with the help of graph paper. Change the frequency using the frequency knob and repeat the measurement for three different frequencies.

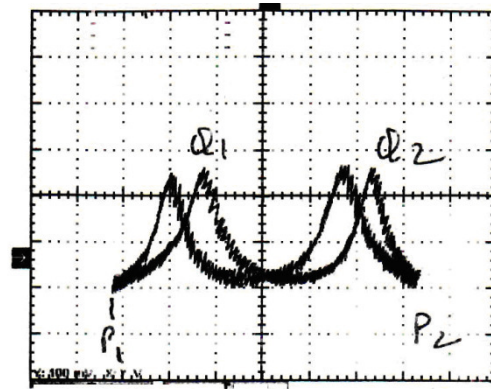
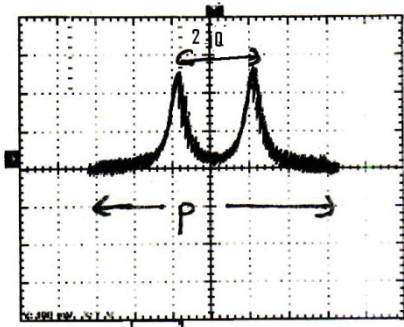


Fig. 1.2 (a) and (b)

Questions?

1. What is the sample used? Do your results agree with those expected for the given sample?
2. What are the major sources of error in this experiment?

Experiment # 2: Magnetoresistance of a semiconductor

Objective:

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

Theory:

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.

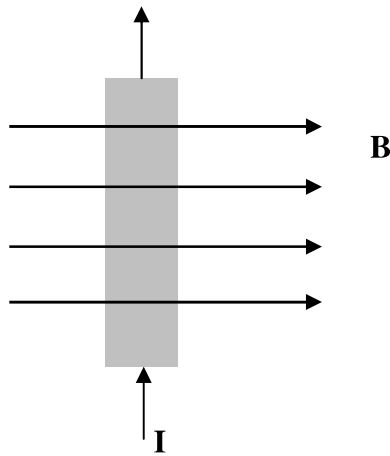


Fig. 2.1

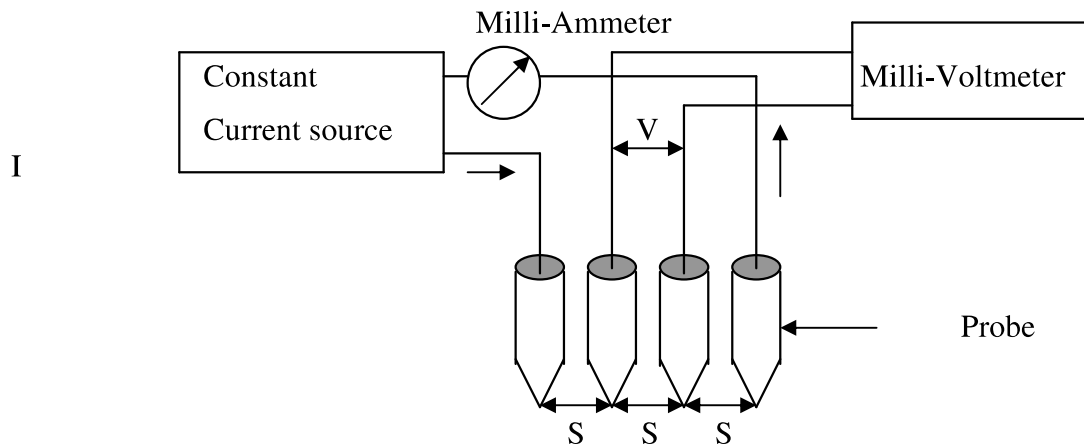


Fig. 2.2

For small field we can write transverse magnetoresistance as

$$\frac{\Delta\rho}{\rho_0} = \frac{\rho - \rho_0}{\rho_0} \propto H^2 \text{ or} \quad (1)$$

$$\frac{\Delta R}{R_0} \propto H^2$$

where ρ_0 is resistivity of the material in zero field, ρ is resistivity in a magnetic field H . Similarly R_0 and R represent corresponding resistances. However, in higher field the dependence is quite often linear. In case of longitudinal magnetoresistance, the Eq. (1) holds except that the constant of proportionality between $\Delta R/R_0$ and H^2 is much smaller than that of the transverse case. Fig.2.1 shows the schematic of the setup and Fig. 10.2 shows the four probe configuration similar to four probe measurement set up used by you in previous semester.

Procedure:

1. Adjust the air-gap (10 mm) between the pole pieces of the electromagnet (EMU-50)
2. Measure the magnetic field in 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. Place the sample in between the pole pieces of the magnet such that magnetic field is perpendicular to the direction of the current.
4. Outer two probes are to be used for passing current and inner two probes for the voltage measurement.
5. Measure the resistance R_0 without any magnetic field by recording the voltage drop as a function of current.
6. Measure the resistance R for different magnetic fields.
7. Repeat the above step by reversing the direction of current.
8. Verify Eq. (1) by suitable plots.

Questions?

1. Can all materials have magnetoresistance?
2. What is the application of this phenomenon?

Experiment # 3: Geiger-Muller counter: Beta decay

Objectives:

1. To record the intensity vs. V characteristics of a Geiger-Muller (GM) counter.
2. To verify the inverse square law.
3. To measure the (beta) absorption coefficient of Aluminum.

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-Muller counter commonly called as G-M 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. 3.1). 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 and positive ions towards the negatively charged cylinder. 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. If one of these photons interacts by photoelectric absorption in some other region of the tube a new electron is liberated creating an avalanche 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. The schematic diagram of the GM tube and the associated electronic components is given below:

Procedure:

1. Make sure to begin with all the knobs are at **minimum** position.
2. After familiarizing yourself with the counter and its operation, record the background count (~60 sec) as a function of applied voltage at which counting starts

3. Place the given β source in one of the slots provided in GM tube assembly and record the counts as a function of voltage.
4. From the plot find the operating point by marking the central voltage of the plateau.
5. Set the counter for above voltage and count time ~06 minutes. Record the counts by changing the distance between the source and the GM tube.
6. Keep the position of the source fixed and record the count as a function of thickness of the absorber (Al). Thickness of the absorber can be increased by increasing the number of aluminum sheets.
7. Find the absorption coefficient of Al for β rays from the above data.

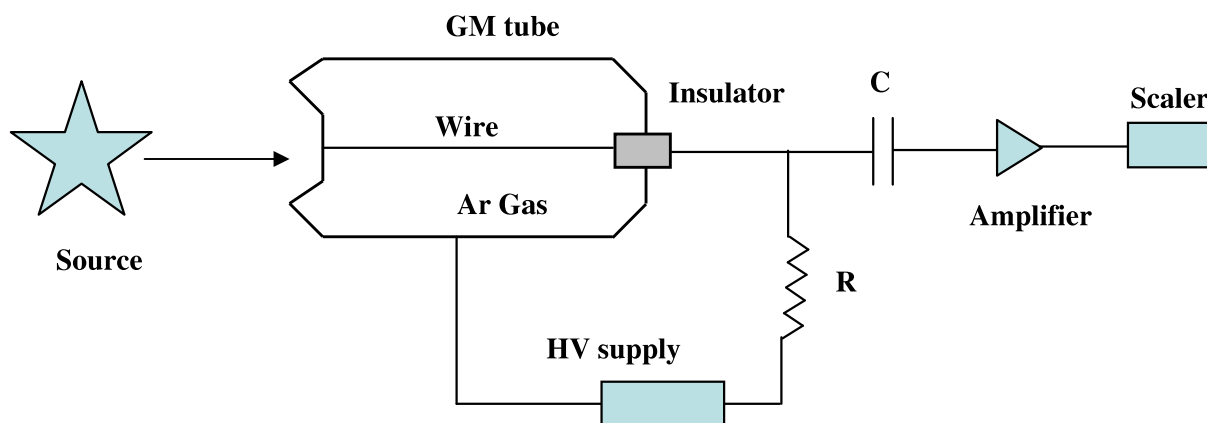


Fig. 3.1 Schematic of the GM tube and the associated electronics

Questions?

1. Can the GM tube be used in the “proportional” or “avalanche” region?
2. How do you know that the given source is a β source?

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, 1967.

Experiment # 4: Absorption spectrum

Objectives:

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

Theory:

When light is incident on an absorbing medium as shown in figure 1, the output intensity I is governed by the Beer-Lambert's law which is

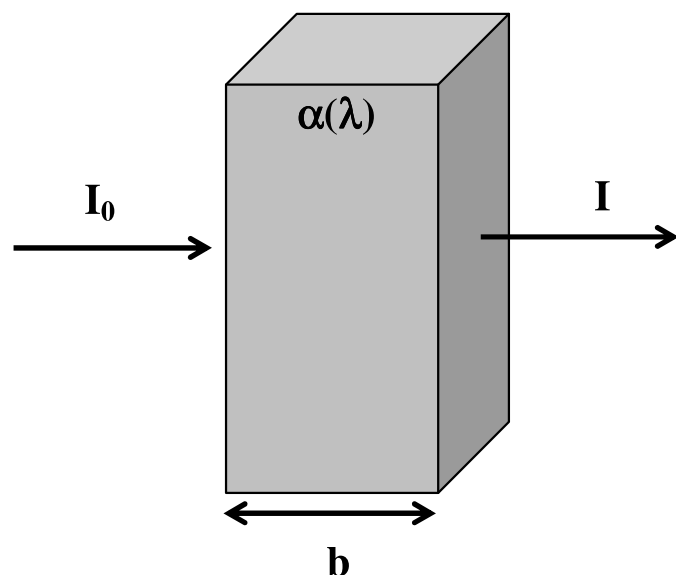


Fig. 4.1

$$I = I_0 \exp(-\alpha b) \quad (1)$$

Where I is the transmitted intensity, I_0 is the intensity incident on the medium, α is the absorption coefficient and b is the length of the medium through which light is traversed. Eq. (1) can also be expressed in terms of transmittance $T = I/I_0$, of the medium as

$$\alpha b = \ln(1/T) \quad (2)$$

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

$$I = I_0 \exp(-abC) \quad (3)$$

where a is the wavelength dependent absorptivity coefficient (in $M^{-1}cm^{-1}$) b is the path length (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 length the absorptivity coefficient can be measured at that wavelength.

The linearity of Beer-Lambert law is limited by chemical and instrumental factors. You will be using the absorption spectrophotometer for both the parts of the experiment

Procedure:

Familiarise yourself with all the controls provided on to the front panel of the absorption spectrophotometer before starting the experiment.

Recording of the transmitted spectra of potassium permanganate:

You will be provided with a master solution of potassium permanganate dissolved in distilled water.

1. Determine the density and hence the molarity of the master solution.
2. Record the transmitted spectrum of this master solution (in the spectral range of 400-960 nm in suitable regular interval). Use distilled water as reference and follow the **proper procedure of normalization of the data**.
3. Plot the transmitted spectrum
4. Note down the wavelengths corresponding to the minimum transmission as well as 2-3 wavelengths in addition near to the minimum transmission,
5. From the master solution make 8-10 dilute solutions by adding distilled water in **systematic and calculated** way so that the molarity of each solution is known to you.
6. Now note down the transmittance T of each solution corresponding to the wavelengths selected in the point no. 4 above.
7. Plot suitable curves and analyze the data with the appropriate equations given above to calculate the absorptivity at various wavelengths.

Questions?

1. What you record is the absorbance (A) as function of λ . Where does it figure in Eq. (1)?

Experiment # 5: Magnetic susceptibility of a paramagnetic liquid

Objective:

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

Theory:

Diamagnetic or paramagnetic substance when placed in a magnetic field, experience a repulsive or attractive force respectively. The force depends upon the susceptibility, χ , of the material which is the ratio of intensity of magnetization, M , to magnetic field, H . The measurement of the force permits us to calculate the susceptibility. The repulsive or attractive force acting on a substance in presence of a magnetic field can be measured with the help of an accurate balance in case of a solid (Guoy's balance method) or with the measurement of change in liquid level in a narrow capillary tube (Quinck's tube method). The value of susceptibility (χ) of a liquid, aqueous solution of a paramagnetic substance, in air is given by:

$$\chi = \frac{2(\rho - \sigma)gh}{\mu_o H^2} \quad (1)$$

Where ρ is the density of the liquid, σ is the density of air, g is the acceleration due to gravity, h is the height through which the liquid column changes in presence of a magnetic field H .

Procedure:

1. Adjust the air-gap (10mm) between the pole pieces of the electromagnet (EMU-50).
2. Measure the magnetic field in 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. Prepare a solution (molarity ~2.0 for FeCl_3) from the given sample.
4. Measure the density of the solution.
5. Fill the Quinck'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).
6. Note the position of lower meniscus of the solution with a traveling microscope.
7. 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.
8. Repeat above step for various concentrations of solution. (You may perform the experiment at molarities in the range of 0.5 to 2.0 M).
9. Plot suitable graph and analyze the data to obtain the susceptibility of the liquid for various concentrations.

Find the effect of the concentration of the paramagnetic ion on the susceptibility of the liquid.

Questions?

1. Can you derive Eq. 1?
2. Can you use the set-up for a diamagnetic liquid?

Experiment # 6: Excitation energy of argon

Objective:

To determine the first excitation energy of argon.

Theory:

We know that the energy of an atom takes only discrete values. At the room temperature, most atoms are in 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. 6.1. The tube is filled with a gas of atoms under consideration. 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. 6.1

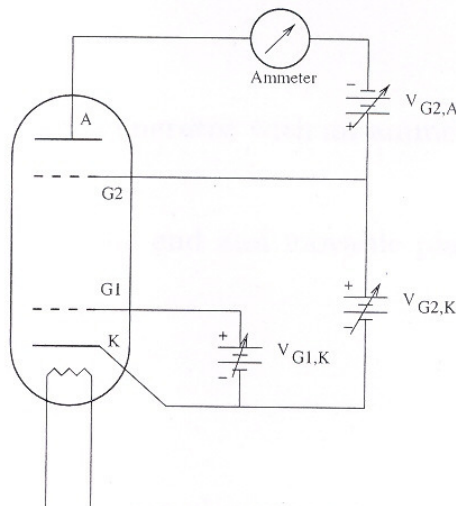


Figure 1: Schematic Diagram of Frank-Hertz Experiment

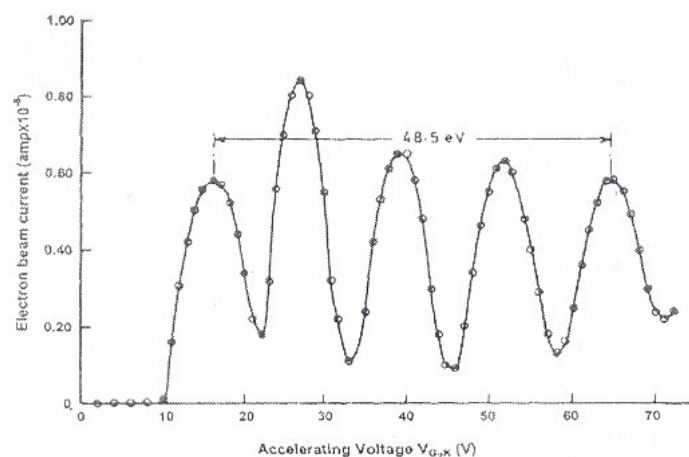


Fig. 3 Plot of beam current vs. accelerating voltage in Franck-Hertz. Experiment

Fig. 6.2: Plot of anode current vs $V_{G2,K}$

As we increase $V_{G2,K}$, the current through A increases. When the electron energies are just sufficient to excite atoms, they lose kinetic energy and cannot reach anode, resulting in the dip in the anode current. The elastic collisions occur near G2. If we increase $V_{G2,K}$ 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 $V_{G2,K}$ graph is shown in the Fig. 6.2. 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 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: 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 $V_{G2,K}$ 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 $V_{G2,K}$ is over 60V, pay attention to the ammeter. If the current rises suddenly, decrease voltage at once.

Procedure:

1. Vary the accelerating potential ($V_{G2,K}$) and record the anode current.
2. Plot I vs. $V_{G2,K}$ and determine the energies of the excited states.
3. Change values of $V_{G1,K}$ and $V_{G2,A}$ and repeat steps 1-2 for another two sets.

Questions?

1. Will the pressure inside the F-H tube matter?
2. Why are the second and third points in the precaution important?

Experiment # 7: Michelson interferometer

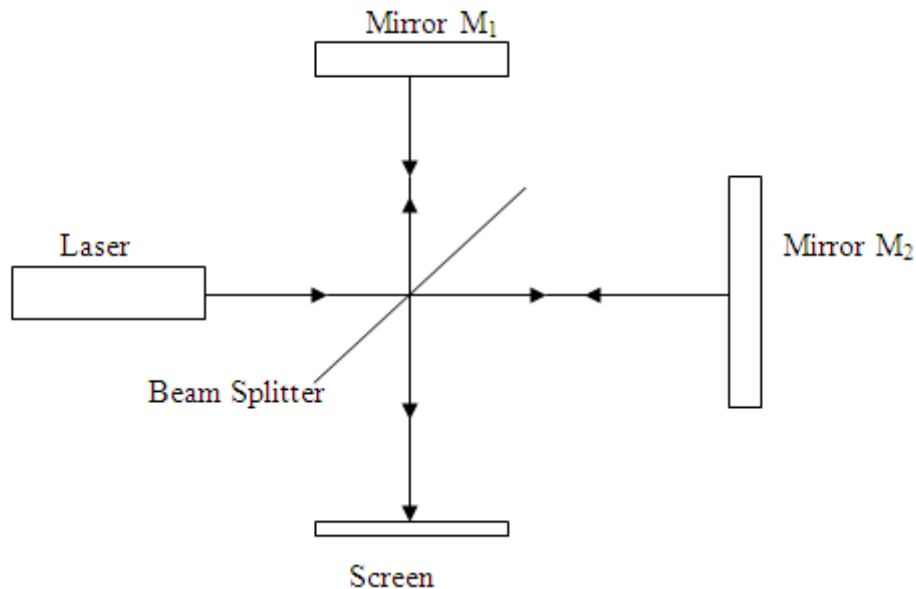
Objectives:

- (a) Refractive Index of Glass Slide
- (b) Refractive index of Air

Theory:

M_1 and M_2 are two plane mirrors silvered on the front surfaces. They are mounted vertically on two translation stages placed at the sides of an optical platform. Screws are provided at the back of the holders, adjusting of which allows M_1 and M_2 are to be tilted. M_1 can also be moved horizontally by a leadscrew attached to the M_1 holder.

The beam splitter, a planar glass plate partially silvered (50% - 50%) on one side. It is mounted vertically at an angle 45° to the incident light. When light from the laser ($\lambda=650$ nm) is allowed to fall on the beam splitter, one portion is transmitted through the beam splitter to M_1 and the other is reflected by beam splitter to M_2 . The reflected beam from M_1 and M_2 superimpose at the beam splitter and interference pattern can be observed on the screen.



(A) To measure the refractive Index of glass slide

We consider a glass slide introduced in the path of one of the beams. The light travels a greater length of glass as the plate is rotated. The change in the path length of the light beam as the glass plate is rotated and relates the change in path length with the laser beam through air.

The refractive index of glass slide,

$$n = \frac{(2t - N\lambda)(1 - \cos \theta)}{2t(1 - \cos \theta) - N\lambda}$$

Where **t** is the thickness of the glass slide, **N** is the number of fringes counted, λ is the wave length of light used and θ is the turned for **N** fringes.

(B) To measure the refractive index of air

When a piece of material of thickness **d** is placed in one arm of the Michelson Interferometer, the change in optical path length is given by $2dn$ where **n** is the difference in refractive index between the sample and the material it replaced (usually air). In other words, $2d(n_m - n_{air})/\lambda$ extra wavelength are introduced if air is replaced by a sample of refractive index **n_m**.

Let λ be the wavelength of light, **n** the refractive index of air at atmospheric pressure, **d** the length of the air cell, **P_{atm}** the current atmospheric pressure, and ΔP the pressure change. The relationship between the pressure change ΔP and the number of fringe shift **m_{ΔP}** is given by,

$$m_{\Delta P} = (2d(n - 1) / \lambda(\Delta P / P_{atm}))$$

(A) Procedure:

1. Align the laser and interferometer in the Michelson mode. Place the rotation stage between the beam splitter and one of the mirrors, perpendicular to the optical path. Mount the glass slide on the rotation stage.
2. Slowly rotate the rotation stage. Note down the angle turned for **N** fringes (say 20 fringes).

Measurements:

Trial No	Fringes Moved(N)	Angle rotated		Mean θ	Refractive index n
		Left	Right		
1					
2					
3					

Result:-

Refractive index of Glass Slide **n** =

(B) Procedure:-

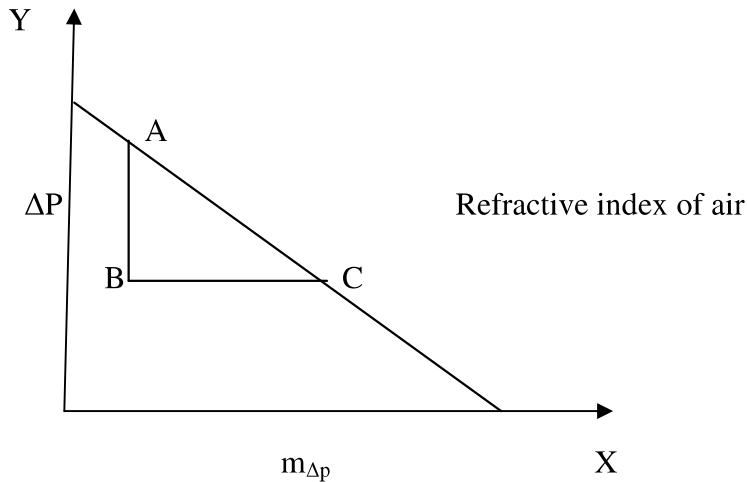
1. Arrange the Michelson Interferometer experimental set up. Introduce the pressure cell in any one of the arm of the interferometer.
2. Tune the micrometer in order to get the interference pattern in a good manner. Now pressurize the cell up to 300mm Hg. (Caution: Do not increase the pressure beyond 300 mm Hg since this may damage the manometer.)
3. Slowly release the air and count the number of fringes. Reading of pressure gauge may be tabulated up to the total release of air from the cell.
4. Plot a graph between number of fringes and the corresponding pressure. The slope of the graph will give the value $m_{\Delta P}/\Delta P$. Put this value in the equation given below.

$$m_{\Delta P} = (2d(n - 1) / \lambda(\Delta P / P_{atm}))$$

From the above equation, we can calculate the value of refractive index of air '**n**'.

Measurements:

Number of fringes Counted $m_{\Delta P}$	Pressure in the cell ΔP (mmHg)



We have,

$$m_{\Delta P}/\Delta P = (2d(n-1)/\lambda)(1/P_{\text{atm}})$$

Length of the pressure cell d =

Wavelength of the light used =

$m_{\Delta P}/\Delta P$ from graph =

$$(n-1) = (m_{\Delta P}/\Delta P)(\lambda/2d)P_{\text{atm}}$$

Substituting the values we can calculate refractive index of air.

Result:

Refractive index of air n =

Questions?

1. Can you estimate the coherence length of the monochromatic beam of light using the set-up?
If so, how?
2. What are the different types of fringe patterns one can obtain using the interferometer?

Experiment # 8: Fraunhofer diffraction

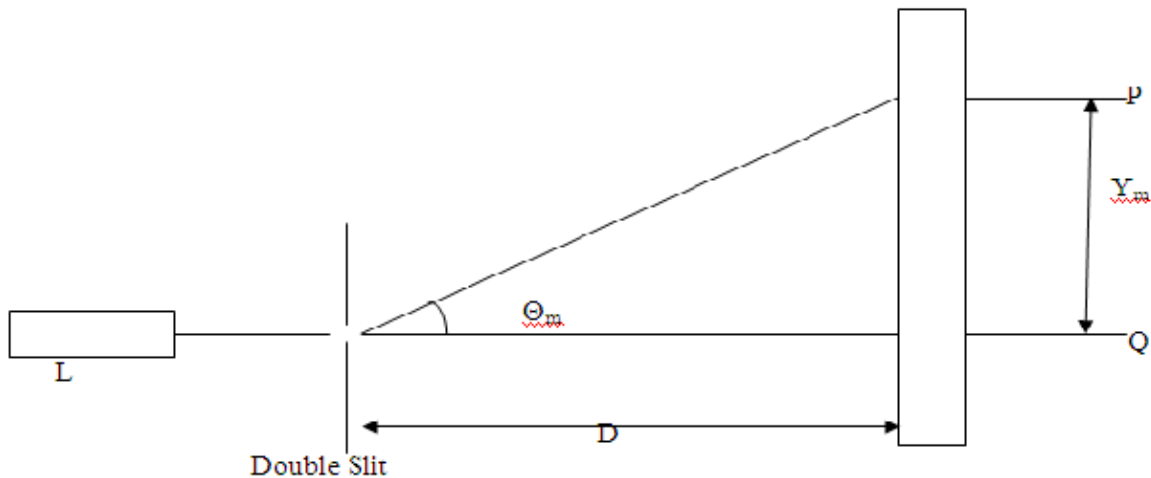
Objective

- (a) Diffraction of light by Double slit
- (b) Diffraction of light by Circular Aperture

Theory:

(A) To observe the diffraction pattern and calculate the slit width

Diffraction is the bending of waves around obstacles or the spreading of waves by passing them through an aperture / opening or change in the directions and intensities of a group of waves after passing by an obstacle or through an aperture whose size is comparable with the wavelength of the waves. Due to diffraction through double slit dark & bright spots can be seen on the screen.



The diffraction equation is,

$$\sin \theta_m = m\lambda / d$$

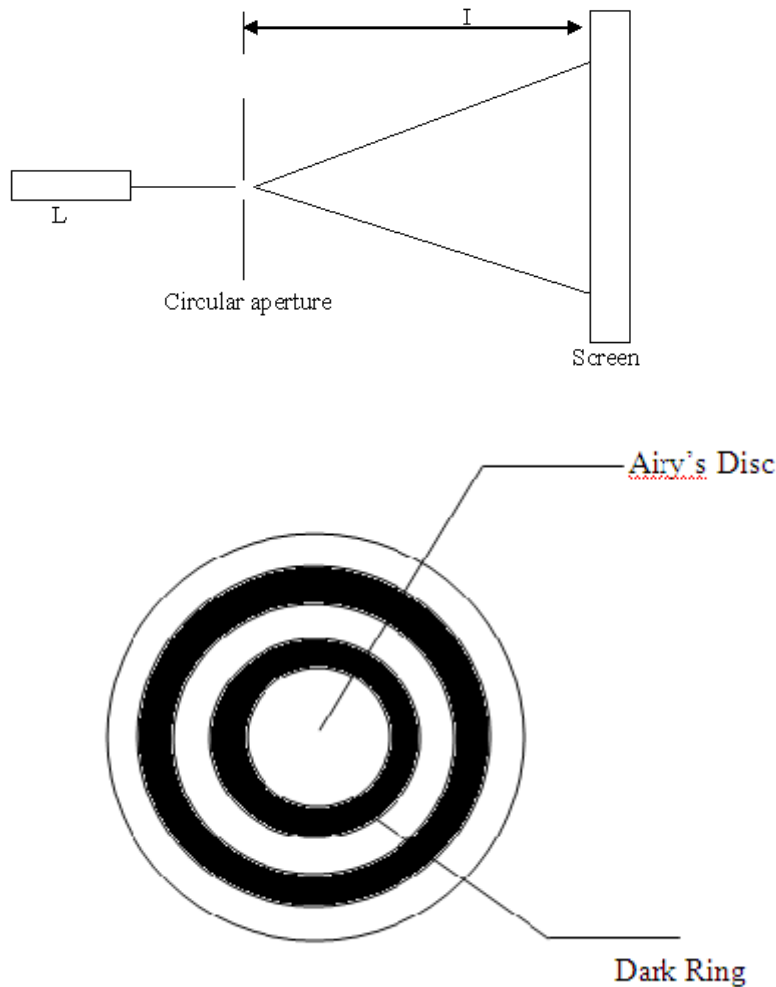
Where d =Slit width, m is the order, λ is the wavelength of laser used and θ_m is the angle subtended within the 'central maximum and m^{th} order maximum.

From this we can find out the slit width 'd' as,

$$d = m\lambda / \sin\theta_m$$

(B) To calculate the diameter of a 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 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 size of the central aperture. In the diffraction pattern, Airy's disc surrounded by alternate dark bright rings of decreasing intensity can be seen



Radius of the Airy's disc,
 $X = (1.22I\lambda)/a$

Where

a = Diameter of the aperture (pinhole),
 I = Distance between the pinhole and screen,
 λ = Wavelength of light,
 X = Radius of the Airy's disc

Thus we can find the diameter of the aperture (pinhole) a using equation

$$a = (1.22I\lambda)/X$$

(A) Procedure:

1. Switch 'ON' the laser and align the laser beam in such a way that the beam falls exactly on the double slit and through it onto the detector.
2. Observe the diffraction pattern and scan it from one end to the other. Note the output of the detector and corresponding distance from the micrometer each time, when the readings are taken.
3. Plot a graph with Micrometer reading on X-axis and output current on the Y-axis. From the graph we can find the distance between the central maximum and ' m^{th} order minimum'.

Measurements:

Wave length of the laser $\lambda=650$ nm

Observations:-

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

Distance between the screen and double slit =m

Order m	Distance between the screen and double slit	Distance between central maximum and m^{th} order maximum(Y_m)	$\theta_m = \tan^{-1}(Y_m/D)$	$\sin\theta_m$	$d = m\lambda / \sin\theta_m$

Slit width , d =.....

(B) Procedure:

Procedure is same as that of a double slit.

Measurements:

Wave length of the laser $\lambda=650$ nm

Observations:-

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

Sl.No.	Distance between the screen and Pinhole aperture(I)	Radius of the airy's disc (X)	Diameter of the Pinhole aperture $a = (1.22I\lambda)/X$

Result:

The intensity distribution in the diffraction pattern due to the circular aperture was studied.
Diameter of the circular aperture is.....Microns