Instruction Manual

PH 310 Advanced Physics Laboratory

(Online mode)

B.Tech Engineering Physics 6th Semester

Physics

Department of Physics

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

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PH 310 Advanced Physics Laboratory

B.Tech Engg. Physics
Semester VI

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Instructions

This Laboratory manual contains six experiments picked up from different areas of contemporary physics. Being an advanced level lab, only a brief outline of each experiment is given. Guidelines for preparing tables, graphs to be plotted with the data collected, method of performing calculations using formulae given and estimation of errors in the measurements and their expression have not been given. You have to do this yourself with available material. You are also advised to refer other sources to learn more about each experiment.

However, this time the laboratory is going to be online. It will be held through MS Teams. A laboratory group will be subdivided into six small divisions excluding the introductory class. For example, PH310-Advance-Lab-Intro-Jan-2022, PH310-Division-1, PH310-Division-2, PH310-Division-3 ,……. PH310-Division-6 will be the names of the MS Team groups. The schedule and sub-group you belong will be informed. Students are supposed to join the corresponding MS team upon invitation. An Instructor/TA will present an online demonstration of an experiment (using Video and PPT). A pre-recorded data set will be provided to you on the first day of each lab experiment. For each experiment a specific assignment will be given by the instructor and you should submit the completed assignment on the next day by 9:20 AM (through MS Teams to the particular Division/Instructor). Do the calculations using the data, do error analysis, plot graphs (if required). Your calculation, graphs, error analysis, and final result with error bars will be verified by your instructor during the lab class. Then you submit a report. Viva-Voce will be taken by your instructor on the second day of each experiment.

10 Credits to each Experiment: Assignment weightage: 4 and weightage for Viva: 6

Total 6 experiments 6 × 10 = 60%, Weightage for Quiz: 40%

With Best Wishes
The Instructors,
January - April, 2022 session.

B. Errors in Measurements

When we measure a quantity with an instrument, it is prone to acquire three kinds of errors: (a) Systematic 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 calipers 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 probability 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, which is usually a small sample. 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 superposition 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 acquiring 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 instruments (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

Statistics of Radioactive Decay

Objectives

1. To determine the statistical distribution law of radioactive decay events
2. To determine the goodness of the fit by chi-square test.

Theory

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 of the decay events will be found out employing the Geiger-Müller Counter. This experiment may be divided into two parts as given below.

Counting Statistics: If N is the number of counts observed for a fixed duration of time, then the distribution $f(N)$ cannot be distinguished from a Gaussian distribution. $f(N)$ can be identified with the frequency of obtaining N counts for the same fixed duration of time.

Decay Statistics: This can be determined by observing the time sequence of the radioactive decays. It can be shown that the probability distribution is given by

$$f_n(\tau) = \rho\,(\rho\tau)^{n-1}\,e^{-\rho\tau} / (n-1)!$$

where n is the number of counts between which the time intervals τ are measured; for example, $n = 1$ if the time interval between every count is measured. Here ρ is the mean counts per unit time; the same time units are to be used for measuring τ.

In this experiment, you have to determine the Decay Statistics.

Procedure

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 given GM tube. The operating voltage may be around 550 V (verify!)
5. Set the Counting System in the “Acquisition Mode” and connect it to the DSO.
6. Observe the time sequence of events on the DSO.
7. Connect the DSO to the computer through the USB port.
8. Open the “NI Signal Express” program. Click “Next”, choose “TDS2000B”, and click “finish”.

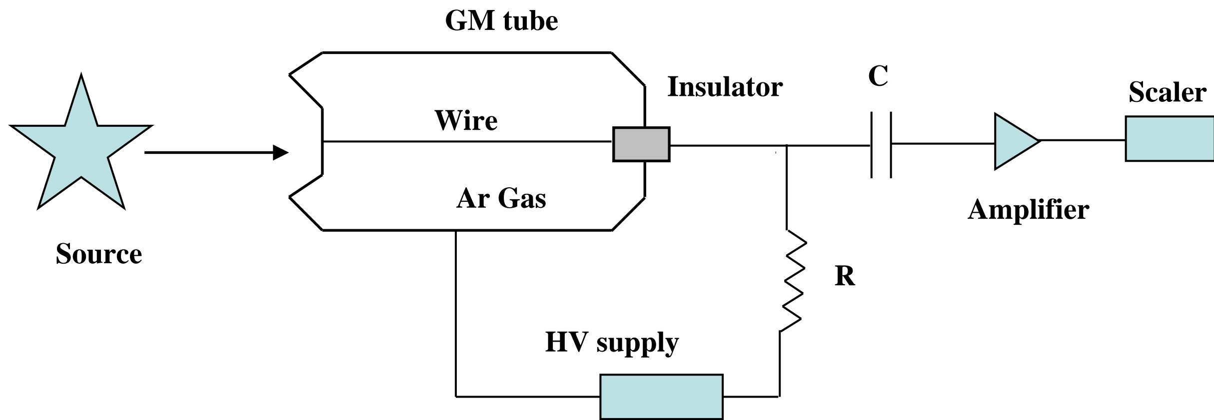

Fig. 1.1: Schematics of the GM tube and the associated electronics

9. Click “Sync to Scope” and click “Run”.
10. In “Step setup” click “vertical” and set “Channel No.”, “Scale” at 1 V/div. (or mV/div), “probe type” to voltage, “probe attenuation” at 1X, “position” at –3 or –3.5, “bandwidth” full. Then click “horizontal” and set “scale” around 10 ms and “acquisition mode” to sample.
11. Now click “data view”, drag the next icon (TDS2014B) to the window displaying a graph sheet.
12. Time sequence of peaks will be observed on the graph sheet.
13. Click “stop” and record the data.
14. Click “run”. Click “stop”. (Alternatively, click “Run Once”.) Record the data once again (in a separate table).
15. Repeat Step 11 many times until sufficient data is collected. From this data you should be able to find $f_n(\tau)$.
16. Plot histograms corresponding to $f_n(\tau)$ for $n = 1, 3$.
17. Find the parameter(s) of the distributions $f_n(\tau)$.
18. Superpose theoretical curves on the histograms.
19. Estimate the goodness of the fit for $n = 3$ by chi-square test.

Attention: Before leaving, decrease **slowly** the EHT voltage to zero; also set all other knobs to minimum.

References

1. G. Knoll, *Radiation Detection and Measurement*, John Wiley, 1999.
2. K. S. Krane, *Introductory Nuclear Physics,* John Wiley, 1988.
3. W. Feller, An Introduction to Probability Theory and its Applications, vols. 1 and 2, John Wiley.

Experiment No. 2A
Faraday Effect

Objective
To study the Faraday effect and to determine the Verdet constant of the material for a given wavelength of light

Principle: The Verdet constant is the proportionality constant between the angle of rotation θ of the plane polarized light and the product of the path length l through the sample and the applied magnetic field B, that is, $\theta = VlB$ or Verdet Constant, $V = \theta/lB$.

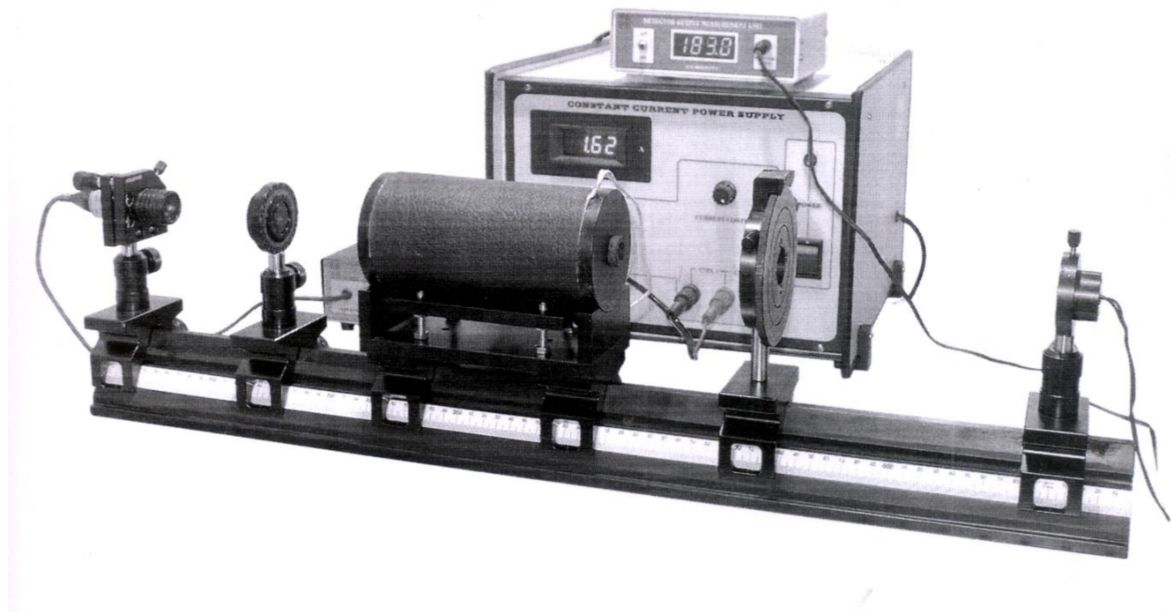

Fig. 2A.1 : Experimental setup

Theory: The Faraday Effect is a widely used magneto-optical effect in which the plane of polarization is rotated as it passes through a medium placed in a magnetic field. The magnetic moment associated with the electron spin in the medium experiences a force trying to align it along the DC magnetic field. This results in a precession of the spinning electrons about the direction of the magnetic field. A linearly polarized light beam passing through the medium parallel to the magnetic field can be considered to be comprising two opposite circular polarizations. Owing to the precession of the magnetic moments each circular polarization experiences a different magnetic permeability inside the medium. As a result the two circular polarizations travel with different speeds and come out from the other side of the medium with a phase difference. These two opposite circular polarizations when recombined gives rise to a linear polarization rotated by a certain angle with respect to the original polarization direction. The amount of rotation is proportional to the distance travelled by the light through the medium and the strength of the magnetic field. Thus $\theta = VlB$. The proportionality constant V is called the Verdet constant. The strength of the magnetic field is $B = \pi NI$, where N is the number of turns per unit length of the solenoid and I the current through the solenoid.

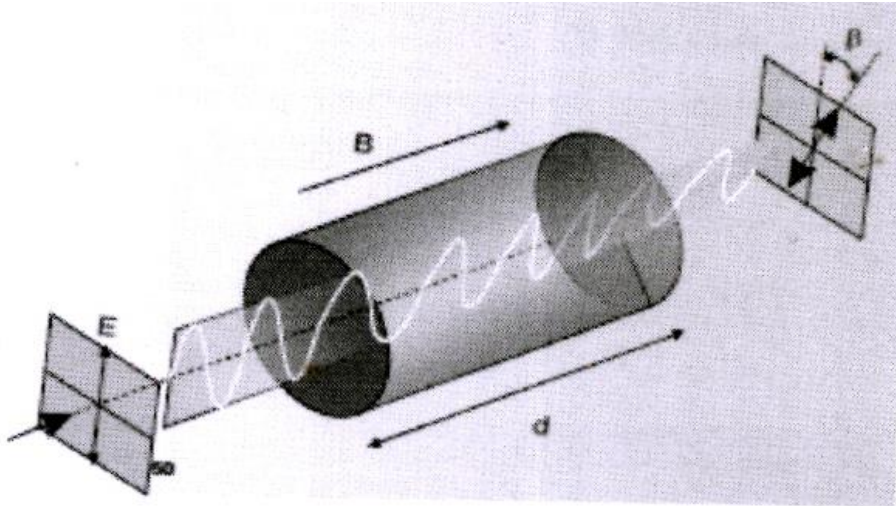

Fig. 2A.2 : Rotation of the polarization plane

Procedure:
Arrange the components as shown in figure 2A.1 above. Align the laser beam in order to pass it through the axis of the solenoid containing the glass rod and the centre of the pin hole detector. Rotate the polarizer and the analyzer to get the maximum transmitted light. Now rotate the analyzer to get the minimum intensity. Switch on the power supply of the electro magnet. Increase the current through the solenoid at suitable intervals (so that the change in polarization angle can be detected) starting with zero current. The intensity will increase slightly. Now rotate the lead screw of the analyzer in order to get a minimum intensity position and note the corresponding readings from the dial of the analyzer (relative to the zero current position). This is the angle of rotation θ. Perform the experiment for both the lasers (green and red) and comment on your observations.

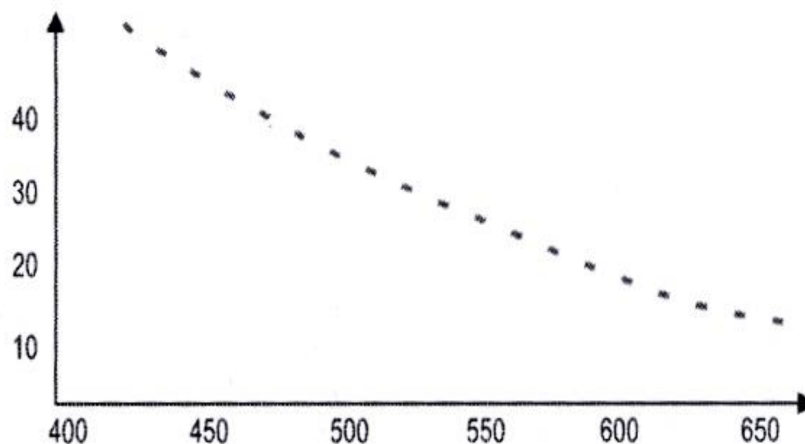

Fig. 2A.3 : Verdet constant as a function of wavelength

Observations:

Number of turns in the solenoid = 2508

Length of the solenoid = 15 cm

Number of turns per unit length *N* = $2508/15 = 167.2\ cm^{-1}$

Length of the glass rod l = 10 cm

Calculate the Least count (in minutes).

SI No.	Current I (ampere)	θ (minute)	Magnetic Field $B=\mu_0 NI$ (oersted)	Verdet Constant $V = \theta / lB$
				Find the Verdet constant by plotting I vs θ and making a least square fit.

Note that N is the number of turns per unit length

Result: Verdet constant of the substance = ... minute / oersted / cm

Reference

K. Iizuka, *Elements of Photonics*, Wiley-Interscience (2002)

Experiment No. 2B
Raman Effect

Objective

To record and study the Raman spectrum of the given liquid sample.

Background and Theory

This effect was discovered by the Indian Physicist C.V. Raman in 1928 that awarded him with the 1930 Nobel Prize for Physics. Raman spectroscopy is an extremely useful tool that has several applications such as in chemical analysis of materials, in the field of medicine such as to find the composition of pharmaceuticals, or to find composition of materials inside the body, in environmental science, to identify water pollutants, for art historians, to analyze the composition of a work of art, in electronics especially when studying semiconductors, to measure the stress in a material, etc.

When non resonant radiation interacts with a molecule, the scattered photon usually has the same energy as the incident photon (Rayleigh scattering). However the scattering event can be inelastic and the molecule can be left in a different vibrational or rotational state. This phenomenon is called the Raman Effect. Since the Raman Effect is very weak, lasers are commonly employed to observe this effect. A Raman spectrum is obtained by measuring the energy lost (or gain) by the scattered photon. Raman Effect is particularly useful for measuring the vibrational frequencies of large molecules.

Figure 2B.1 illustrates the three main types of scattering. In Rayleigh scattering, photons scatter off individual molecules; the energy of the photon remaining the same as that of the incident photon. In the Raman scattering corresponding to the Stokes lines, a photon scatters off with lower energy, whereas for anti-Stokes lines, a photon scatter off with higher energy. The change in energy ΔE between the incident photon and scattered photon is related to the difference $\left|\frac{1}{\lambda}-\frac{1}{\lambda'}\right|$ (find out the exact relationship for yourself).

The selection rules for the Raman Effect are different from the normal dipolar interaction as the transition operator involves matrix elements of the molecular polarizability tensor rather than the dipole moment operator. For example, the rotational selection rules for the vibration-rotation Raman spectrum of HCl are $\Delta J= 0, \pm 2$ rather than $\Delta J= \pm 1$ dipole selection rules. For molecules like CO_2 that have a center of inversion symmetry, the infrared active modes are Raman inactive and vice versa. Raman spectroscopy thus has complementary selection rules to ordinary infrared spectroscopy.

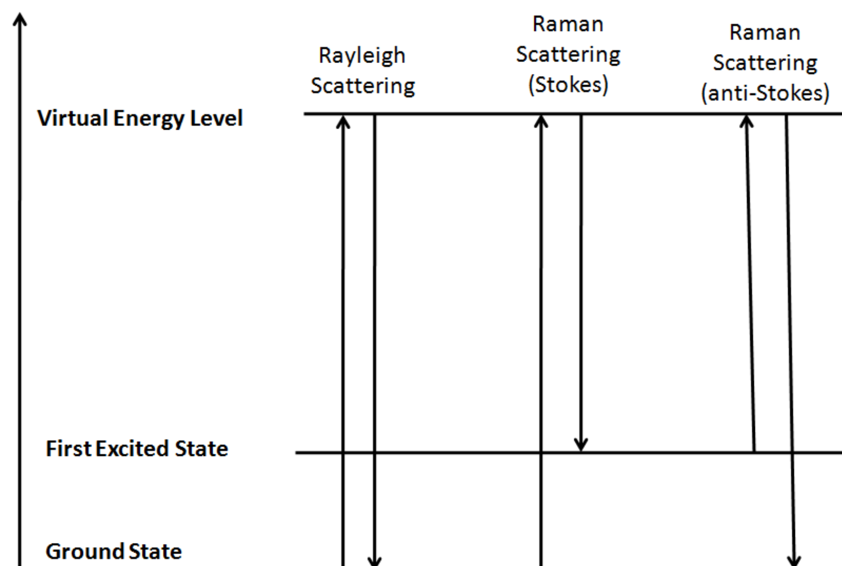

Fig. 2B.1

Procedure

1. Fix the sample in the holder fitted inside the irradiation. Switch on the laser. Adjust the laser beam and the sample cell so that the laser beam is aligned with the axis of the cylindrical sample cell.
2. Adjust the condenser lens and the concave mirror and close all covers.
3. Adjust gain, etc.
4. On the computer open application "Laser Raman Spectrometer"
5. Set the wavelength range and step size.
6. Click scan to obtain the spectrum.
7. Verify calibration from the Rayleigh line.
8. Note down the Stokes and anti-Stokes lines.
9. Trace the spectrum on a trace paper (along with coordinate axes)
10. Use the second sample and repeat the above steps.
11. Calculate frequency of the vibration modes corresponding to the Raman lines.

    (Given: Wavelength of the laser light=532nm)

Questions

1. In the Stokes process, what happens to the remaining energy of the photon?
2. In the anti-Stokes scattering, why does the photon get scattered with a higher energy?
3. Is there any effect of temperature on the Raman (Stokes and anti-Stokes) lines?
4. Is Raman Effect different from fluorescence?
5. Why are the intensities of the Stokes lines much higher than the anti Stokes lines?

Reference

B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules, Pearson.

Experiment No. 3
Microwave Antenna

Objective

(a) To study the polarization properties of microwave using horn antennas.
(b) To find the wavelength of microwave radiation using Lloyd's Mirror.
(c) To study diffraction of microwave using double slit.

Background

Horn antennas can produce a uniform wave front. Such antennas are not new; the Indian physicist, Jagadish Chandra Bose, constructed a pyramidal horn antenna in 1897. In this experiment, two pyramidal horns will be used — one functioning as the radiator (or transmitter) while the other as detector (or receiver). Both the horns are mounted on graduated rails (scales) and their position can be varied. The transmitter emits in the microwave region. In this experiment various properties of microwaves will be studied.

Procedure for Polarization measurements

1. Set the rails holding the transmitter and receiver collinearly.
2. On the Gunn Power Supply Box, set the "Gunn Bias" high.
3. On the Microwave Receiver Box, set the "Gain" high.
4. Adjust the "Sensitivity" knobs so that a proper zero offset is made.
5. The settings at the transmitter and receiver knobs should be such that full scale (or large) deflection can be observed on the meter connected with the receiver. Care should be taken the zero offset is maintained. Check for zero offset after doing all adjustments.
6. Rotate the receiver about its "axis" in steps of 10° and note down the meter readings.
7. Plot a suitable graph with the above data.
8. Set the receiver so that it is in the same orientation as the transmitter (use above result).
9. Put the polarizer between the transmitter and receiver (so that the slits are inclined at 45°).
10. Repeat steps 6 and 7 above.

Procedure for Lloyd's Mirror experiment

1. Set the transmitter and receiver arms collinearly and at the same distance from the centre.
2. Use the previous results to set the receiver and transmitter in the same orientation.
3. Set the third arm perpendicular to the transmitter and put the reflector on it.
4. Slide the reflector backward from the centre.
5. Record deflections and the corresponding positions of the reflector as it is moved in steps of a few millimetres.
6. Draw suitable graph using the above data.
7. Find the wavelength of the microwave radiation from the above.

Procedure for Double slit diffraction measurements

1. Use the previous results to set the receiver and transmitter in the same orientation.
2. Put the double slit arrangement between the transmitter and receiver.
3. Measure the slit widths with a scale.
4. Note down the meter reading when the receiver arm is collinear with the transmitter arm.
5. Rotate the receiver arm in steps of 1° or 2° and note down the corresponding deflections.
6. Plot a suitable graph to see the diffraction pattern.
7. From the above, find the wavelength of the microwave radiation.

References

1. J. D. Kraus, *Antennas*, Tata McGraw-Hill, 2nd edition, New Delhi.
2. D. M. Pozar, *Microwave Engineering*, John Wiley, 3rd edition,

Experiment No. 4
Solar Cell

The experiment consists three parts

Objectives

(a) To demonstrate the I-V and P-V characteristics of PV module with varying radiation and temperature level.

(b) To demonstrate the I-V and P-V characteristics of series and parallel combination of PV modules.

Theory: Part (a)

PV module is characterized by its I-V and P-V characteristics. At a particular solar insolation and temperature, module characteristic curves are shown in Fig. 4.1 and 4.2 respectively.

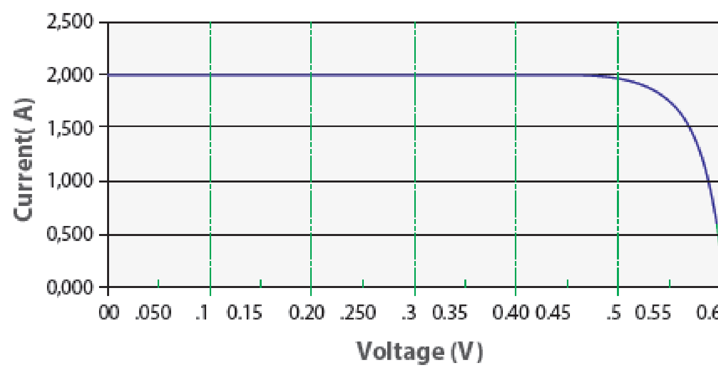

Fig. 4.1: I-V characteristic of PV module

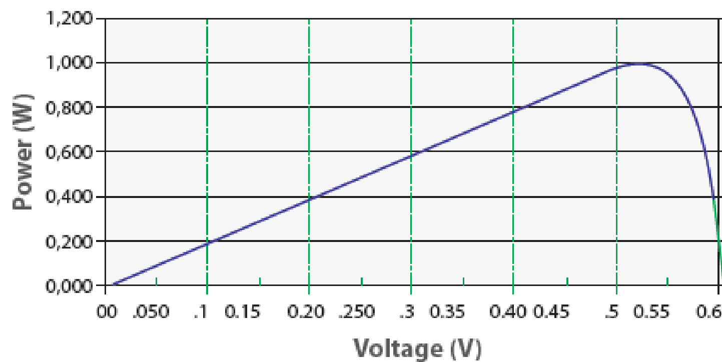

Fig. 4.2: P-V characteristic of PV module

Characteristic curves of solar cell

In I-V characteristic maximum current at zero voltage is the short circuit current (Isc) which can be measured by shorting the PV module and maximum voltage at zero current is the open circuit voltage (Voc). In P-V curve the maximum power is achieved only at a single point which is called MPP (maximum power point) and the voltage and current corresponding to this point are referred as Vmp and Imp. On increasing the temperature, Voc of module decreases as shown in Fig. 4.3, while Isc remains the same which in turn reduces the power. For most crystalline silicon solar cells modules the reduction is about 0.50%/°C.

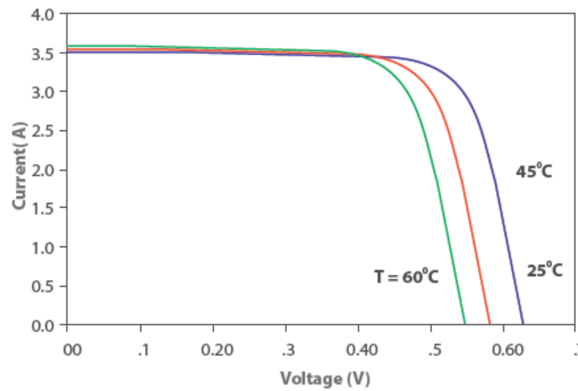

Fig. 4.3: Variation in V_{OC} with change in temperature

On changing the solar insolation Isc of the module increases while the Voc increases very slightly as shown in Fig. 4.4

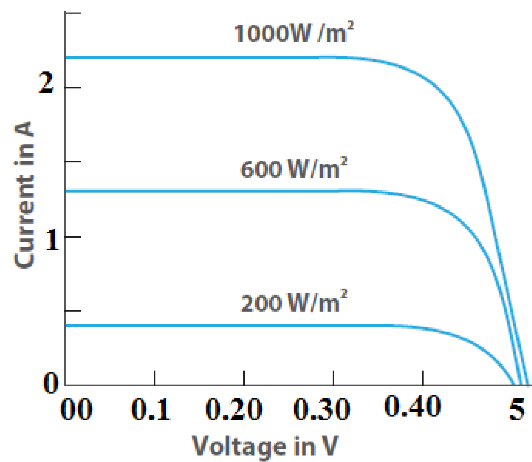

Fig. 4.4: Variation in I-V characteristic with insolation

Fill factor:

The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is the ratio of the actual achievable maximum power to the theoretical maximum power (PT) that would be achieved with open circuit voltage and short circuit current together. FF can also be interpreted graphically as the ratio of the rectangular areas depicted in Fig.4.5. A larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like. Typical fill factors range from 0.5 to 0.82. Fill factor is also often represented as a percentage.

$$FF = \frac{P_{MAX}}{P_T} = \frac{I_{MP} \bullet V_{MP}}{I_{SC} \bullet V_{OC}}$$

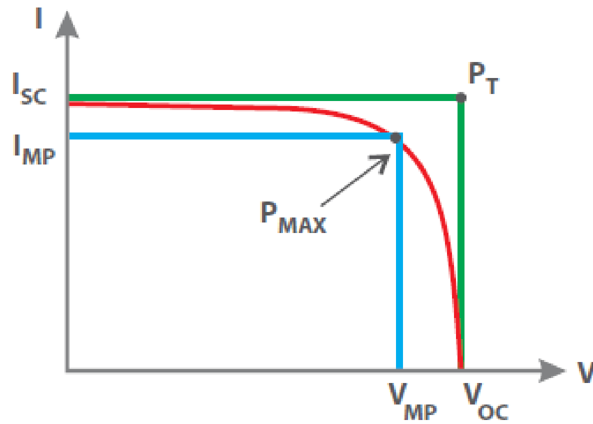

Fig. 4.5: Graphical interpretation of the Fill factor (FF)

Experimental set-up

The circuit diagram to evaluate I-V and P-V characteristics of a module is shown in Fig.4.6. Form a PV system which includes PV module and a variable resistor (pot meter) with ammeter and voltmeter for measurement. Pot meter in this circuit works as a variable load for the module. When load on the module is varied by pot meter the current and voltage of the module gets changed which shift the operating point on I-V and P-V characteristics.

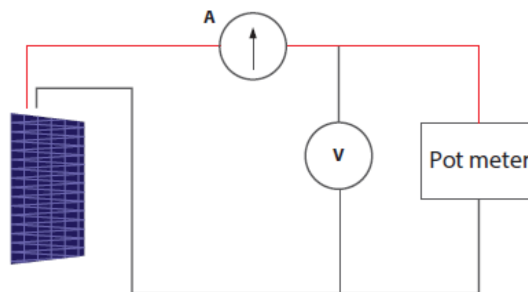

Fig. 4.6: Circuit diagram for evaluation of I-V and P-V characteristics

Observations:

Table for I-V and P-V characteristics of PV module :

Set-					
S.No.	Radiation	Temperature	V	I	P
1			Voc	0	
2					
3					
4					
5					
6			0	Isc	

Take 3 sets of data for different radiation and temperature levels but in one set the values of radiation and temperature will be constant.

Theory: Part (b)

PV module is characterized by its I-V and P-V characteristics. At a particular level of solar insolation and temperature it will show a unique I-V and P-V characteristics. These characteristics can be altered as per requirement by connecting both modules in series or parallel to get higher voltage or higher current as shown in Fig. 4.7 and 4.8 respectively. Therefore, if modules are connected in series then power reduction is twice when connected in parallel. On changing the solar insolation, Isc of the module increases while the Voc increases very slightly, therefore there is overall power increase. In parallel connection power increment is twice than when connected in series. On increasing the temperature, Voc of modules decrease while Isc remains same which in turn reduces the power.

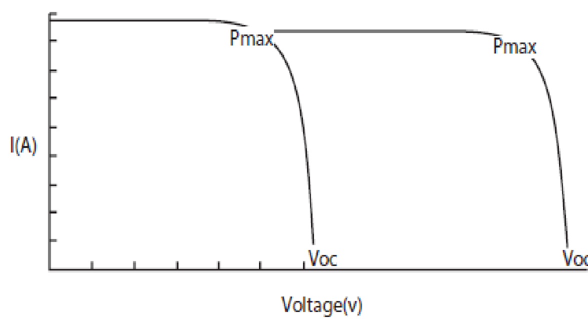

Fig. 4.7: I-V characteristic of series connected modules

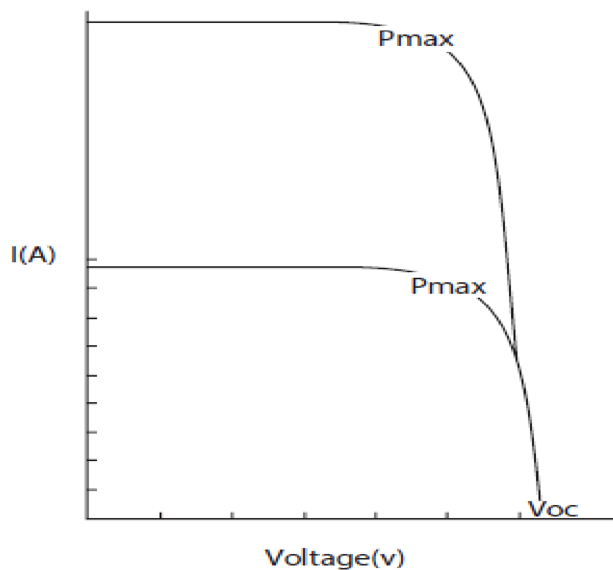

Fig. 4.8: I-V characteristic of parallel connected modules

Experimental set-up

Form a PV system with modules in either series or parallel and a variable resistor (Pot meter) with ammeter and voltmeter for measurement. Modules in series or parallel are connected to variable load (pot meter). The effect of load change on output voltage and current of the modules connected in series or parallel can be seen by varying load resistance (pot meter).

Observations:

Table for I-V and P-V characteristics of PV modules in series:

Set-					
S.No.	**Radiation**	**Temperature**	**V**	**I**	**P**
1			Voc	0	
2					
3					
4					
5					
6			0	Isc	

Table for I-V and P-V characteristics of PV modules in parallel:

Set-					
S.No.	**Radiation**	**Temperature**	**V**	**I**	**P**
1			Voc	0	
2					
3					
4					
5					
6			0	Isc	

Experiment No. 5
X-ray

(Do not operate the instrument without the presence of the lab demonstrator)

PART A: Moseley's law and the Rydberg constant

1. Analyse the copper X-radiation with the aid of a LiF monocrystal and as a function of the Bragg angle without and with several K edge absorption samples as absorbers. Determine the K absorption edges of different absorbers based on the spectra.
2. Calculate the Rydberg constant and the screening constant based on the energy values of the K absorption edges.

Principle
Samples of various thicknesses are irradiated with the polychromatic X-rays of a copper X-ray tube. The radiation that passes through the samples is analysed with the aid of a monocrystal. The Rydberg constant is calculated based on the glancing angles of the absorption edges.

Theory
When X-rays interacts with matter, they lose energy due to Compton scattering, pair production, and photoelectric effects. The respective strengths of these three effects depend on the energy of the radiation. In the range of energy in this experiment, the photoelectric effect plays the most important role. The cause of the irregularity that is known as "edge absorption" is the photoelectric effect. The binding energy E_n of an electron in the nth shell is approximately:

$$E_n = -\frac{m_e e^4}{8\varepsilon_0{}^2 h^2}(Z-\sigma)^2\frac{1}{n^2} \quad (1)$$

where σ = screening constant, n is the principal quantum number. Equation 1 can be written in terms of Rydberg constant R as

$$E_n = -R\,(Z-\sigma)^2 / n^2 \quad (2)$$

For electrons in the K shell (n=1), $\sigma \approx 1$. Using Bragg equation $2d\sin\theta = n\lambda$, with n=1 and $E = hc/\lambda$ gives the edge absorption $E = (hc)/(2d \sin\theta)$. Thus from equation (2), we have

$$Z = (E/R)^{1/2} + \sigma \quad (3)$$

Setup: Take help of your demonstrator to connect the goniometer if not connected already.
Preparation of samples: At least four samples are already prepared

Settings of the goniometer and X-ray unit:
- 2:1 coupling mode
- Scanning range: 4°-21°
- Angle step width 0.1°
- Anode voltage U_A = 35 kV; anode current I_A = 1 mA

Recording without an absorber: Gate time 2s
Recording with a K edge absorber: Gate time 4s

Procedure

1. Connect the X-ray unit via USB cable to the USB port of your computer
2. Start the “measure” program. A virtual X-ray unit will be displayed on the screen.
3. You can control the X-ray unit by clicking the various features on and under the virtual X-ray unit. Alternatively, you can also change the parameters at the real X-ray unit. The program will automatically adopt the settings.
4. Click the experiment chamber to change the parameters for the experiment. Select the settings as shown in the overview for the various experiments.
5. For the recording, use the diaphragm tube with a diameter of 2 mm.
6. If you click the X-ray tube you can change the voltage and current of the X-ray tube.
7. Start the measurement by clicking the red circle.

Observations

1. Record the characteristic spectrum of Cu using the LiF crystal *without* absorber
2. Record the characteristic spectrum of Cu using the LiF crystal *with* the given absorbers
3. Identify the K absorption edges
4. Determine the edge absorption energy E. For LiF, interplanar spacing d = 201.4 pm.
5. Present your result in the following tabular form

Element	Atomic number (Z)	θ_{exp} (in degrees)	K Edge energy E in keV

6. Make a plot of Z vs $\sqrt{E}$, which should follow a straight line.
7. Determine R (in eV) and σ from the plot (via least square fit).

Fig. 5.1: Diaphragm and the goniometer setup

PART B: Structural analysis using Laue method

Objectives

1. Take a photograph of the Laue pattern of a LiF monocrystal.
2. Assign the Laue reflections to the lattice planes of the crystal.

Principle

Laue diagrams are produced when mono-crystals are irradiated with polychromatic X-rays. This method is primarily used for the determination of crystal symmetries and the orientation of crystals. When a LiF mono-crystal is irradiated with polychromatic X-rays, a characteristic diffraction pattern results in. This pattern is photographed and then evaluated.

Theory

Laue diagrams are produced when mono-crystals are irradiated with polychromatic X-rays. This method is used mainly for the determination of crystal symmetries and the orientation of crystals. A complete analysis of the diagrams is only possible with simple crystal structures. A necessary, although insufficient, condition for the constructive reflection at the various lattice planes is the Bragg condition:

$$2d\sin\theta = n\lambda \tag{4}$$

(d = inter-planar spacing, θ = glancing angle, λ = wavelength, and n = 1, 2, 3, ...)

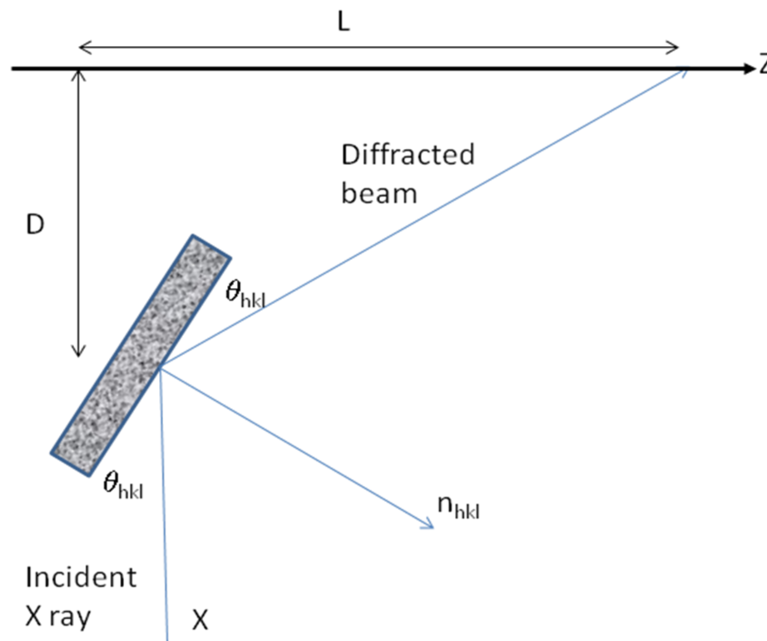

Fig. 5.2

With the lattice constant a of a cubic crystal, the following is valid for the spacing $d(hkl)$ between the individual lattice planes:

$$d(hkl) = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \tag{5}$$

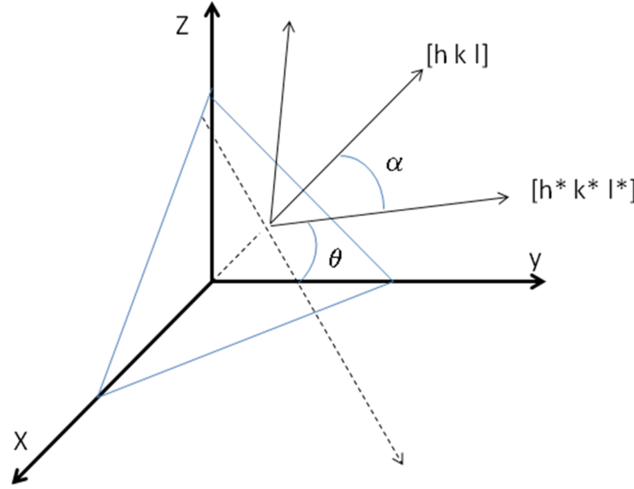

Fig. 5.3

If L is the distance between a reflection and the centre of the Laue pattern, and D the distance between the film and the sample (Fig. 5.2), then the glancing angle θ_{exp} that is determined in an experimental manner is:

$$\theta_{\exp} = \frac{1}{2}\arctan\frac{L}{D}; \quad L = \sqrt{x^2 + y^2} \tag{6}$$

y and z are the distances of the reflection in a system of rectangular coordinates with its origin in the centre of the pattern.

If the X-ray beam coincides with a certain crystallographic direction [h^*,k^*,l^*] (here, the [100] direction) and if it impinges on a crystal plane (h,k,l), then the angle of incidence α is determined by the scalar product of the normal vector of the plane and the incident vector.

$$\cos\alpha = \frac{hh^* + kk^* + ll^*}{\sqrt{(h^2 + k^2 + l^2)\{(h^*)^2 + (k^*)^2 + (l^*)^2\}}} \tag{7}$$

Then, the following is valid for the glancing angle: $\theta_{\mathrm{cal}} = 90° - \alpha$.

According to the addition theorem and with (h^*,k^*,l^*) = (100), it follows from (7) that:

$$\sin\theta = \frac{h}{\sqrt{h^2 + k^2 + l^2}} \tag{8}$$

Task 1*: Take a photograph of the Laue pattern of a* LiF *monocrystal*

If the diffraction pattern is rotated by 90° around the direction of the primary beam, it is again brought to coincidence. Since the primary beam impinges perpendicularly on the (100)-plane of the LiF crystal, the crystal direction [100] is a four fold axis of symmetry. The intensity of the reflections depends on the reflecting crystal surface as well as on the spectral intensity distribution of the X-rays.

Task 2*: Assign the Laue reflections to the lattice planes of the crystal*

The glancing angle θ_{cal} is calculated from (8) for all of the planes with low (h,k,l) indices. The angle $\theta_{\exp}$ is determined using (6) based on the diagram. The assignment of the reflections to the lattice planes is found when the angles coincide ($\theta_{\mathrm{cal}} = \theta_{\exp}$) and when the condition $k/l = y/z$ is fulfilled, with z and y being the coordinates of the reflections.

Present your result in the following tabular form:

Spot No.	*y* (mm)	*z* (mm)	*L* (mm)	θ_{exp} (in deg)	(h k l)	θ_{cal} (in deg)	*k/l*	*y/z*

Taking a Laue photograph with the aid of self-developing X-ray film
A monocrystal X-ray structure analysis can be performed with the aid of self developing X-ray films in combination with the XR 4.0 expert unit. The Cu X-ray tube takes only about10-12 minutes.

X ray unit settings for the Cu X-ray plug-in unit
Tube voltage: 35 kV
Beam current: 1 mA
Diaphragm: 1 mm
Exposure time: 25 minutes
Position of the screen: To be determined with the aid of the mm scale on the optical bench.

The X-ray film is not positioned centrally in front of the crystal. Instead, it is offset, since only a quadrant of the diagram is sufficient for the evaluation. As far as the development of the film is concerned, please refer to the instructions for use that are enclosed with the films. We recommend developing the film for 2 minutes instead of only 50 seconds. It is very important to hold the developed film under flowing water once it has been taken out of the wrap. Do not wipe the film with towels. Only let it air-dry.

Procedure
Insert the diaphragm tube with a diameter of 1 mm into the beam outlet of the X-ray plug-in unit. Add the crystal holder for Laue patterns. Install the LiF crystal with its two pins in the holder so that the rounded sides of the crystal holder face the X-ray tube. Position the film and confirm that the holder is firmly closed. Fix the holder into the holder of the fluorescent screen and position it on the internal optical bench at a distance D = 1.5-2 cm from the crystal. The precise determination of this distance is very important for the subsequent evaluation. The film plane should be parallel to the crystal surface.

The X-ray tube is used at maximum power (anode voltage U_A = 35 kV, anode current I_A = 1 mA). In the case of a tungsten tube, the exposure time is 15-30 minutes. It can be set and activated as follows:

1. Select the tube operating parameters and confirm them with “Enter”.
2. Under “Menu”, select “Timer” → “Duration”. Set the desired time with the aid of the arrow buttons. Confirm with “Enter”.
3. The window “Mode” appears. Select “On” and confirm with “Enter”.
4. To start the experiment, close and lock the sliding door and press the button under “Start”.

The irradiation starts. It will stop automatically after the preset exposure time. On the display, the remaining time can be observed based on a backwards running clock and a display bar.

Experiment No. 6

UV-VIS Spectroscopy

Objective:

- **To analyze the transmittance spectrum and determination of optical constants of thin films**

Theory

UV-VIS spectroscopy is a useful analytical tool to characterize the optical properties (i.e. absorption, transmission, and reflectivity) of a variety of technologically important materials, coatings, thin films and solutions. When the electromagnetic waves interact with a colored substance, a characteristic portion of the mixed wavelengths is absorbed while the complementary color appears in the transmission mode. The UV-VIS spectral range is approximately 190 to 750 nm, as defined by the working range of typical commercial UV-VIS spectrophotometers. In general, specific regions of the electromagnetic spectrum are absorbed by the sample depending on the band structure and the thickness of the sample.

The optical properties of the thin films were calculated using envelope technique. The fundamental optical constants such as linear refractive index (n), absorption coefficient (α), and optical bandgap (Eg) of the thin films were determined from transmission spectra. The spectral transmission characteristics of the films deposited onto transparent substrates measured in the wavelength range of 300 -900 nm using a UV-VIS-NIR spectrophotometer.

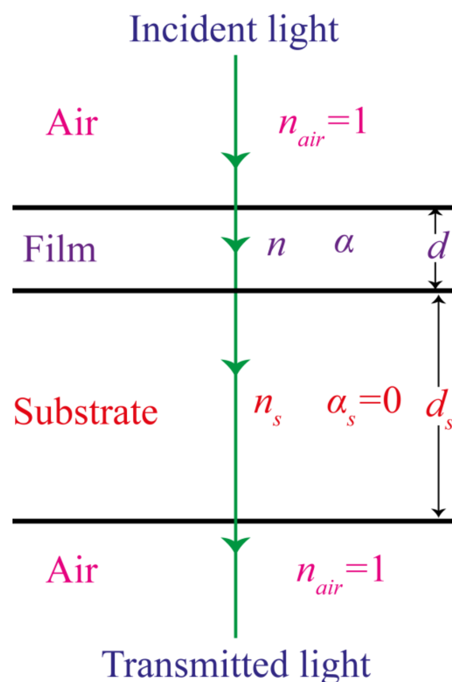

Figure 1: *Thin film on a transparent substrate.*

As shown in the figure 1, a film of refractive index n with the thickness d, deposited onto a transparent substrate having the refractive index n_s and thickness d_s. When the light is incident on the film, then some fraction of an incident is reflected and some fraction is transmitted at the interfaces of air-film, film-substrate, and substrate-air. The reflected and transmitted light may

exhibit the interference pattern because the beams originated from a single coherent source. The condition for the constructive interference is,

$$2nd = m\lambda \tag{1}$$

where, *m* is the order of interference, it is an integer for maxima and half integer for minima.

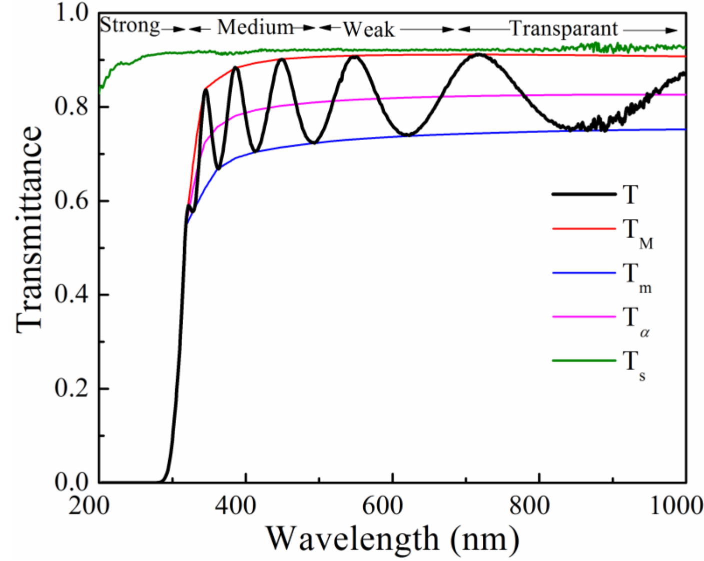

Figure 2: *Typical transmittance spectrum of a thin film.*

The typical transmittance spectrum of the film deposited onto a transparent substrate is shown in Figure 2. It is assumed that the transmission is a continuously varying function of wavelength; therefore, an envelope can be drawn across the spectrum by connecting the all maxima and all minima.

The expression for the transmittance (T) for normal incidence is given as,

$$T(\lambda, n_s, n, d, \alpha) = \frac{Ax}{B - Cx\cos\phi + Dx^2} \tag{2}$$

where, $A = 16n^2n_s$, $B = (n + 1)^3 (n + n_s)^2$, $C = 2(n^2-1)(n^2-n_s^2)$, $D = (n - 1)^3 (n - n_s^2)$,

$\varphi = 4\pi nd/\lambda$, $x = \exp(-\alpha d)$.

The extreme values of transmission at the constructive and destructive interference fringes are obtained by using the interference condition $\cos\phi = +1$ for maxima (T_M) and $\cos\phi = -1$ for minima (T_m) in equation 2.

The refractive index of the films calculated using the following expression,

$$n = \sqrt{N + \sqrt{N^2 - n_s^2}} \tag{3}$$

where,

$$N = 2n_s \frac{T_M - T_m}{T_M T_m} + \frac{n_s^2 + 1}{2} \tag{4}$$

$$n_s = \frac{1}{T_s} + \sqrt{\frac{1}{T_s^2} - 1} \quad (5)$$

If n_1 and n_2 are the refractive indices at two successive maxima (or minima) at wavelengths λ_1 and λ_2, then according to the constructive interference equation,

$$2n_1 d = m_1 \lambda_1 \quad (6)$$

and

$$2n_2 d = m_2 \lambda_2 \quad (7)$$

by solving the both equations using the rule $|m_1 - m_2| = 1$, then we get thickness of the film using the following expression.

$$d = \frac{\lambda_1 \lambda_2}{2(n_1 \lambda_2 - n_2 \lambda_1)} \quad (8)$$

From the Beer-Lambert's law,

$$I = I_0 \exp(-\alpha d) \quad (9)$$

where, I_0 is the incident light intensity, I is the intensity of the light at wavelength λ, d is the thickness of the film, and α is the absorption coefficient, which can be related to the transmittance as,

$$\alpha = \frac{-\ln T}{d} \quad (10)$$

where, $T = (T\%/100)$.

Further, knowing the values of α, the optical bandgap (E_g) of the films can be calculated using the Tauc relation,

$$(\alpha h v)^m = B(hv - E_g) \quad (11)$$

The E_g of the films would be obtained from the extrapolated linear portion of $(\alpha h\upsilon)^m$ versus $(h\upsilon)$ curve, where $h\upsilon$ is the incident photon energy, B is a measure of crystalline order, and m determines the type of electronic transition between the valence band and conduction band. The E_g can be calculated by assuming an allowed direct and indirect electronic transitions with m=2 and 0.5, respectively. The absorption coefficient (α) is related to the extinction coefficient (k) by the following equation
Also, hv=1236/λ

$$\alpha = \frac{4\pi k}{\lambda}$$

Instrumentation

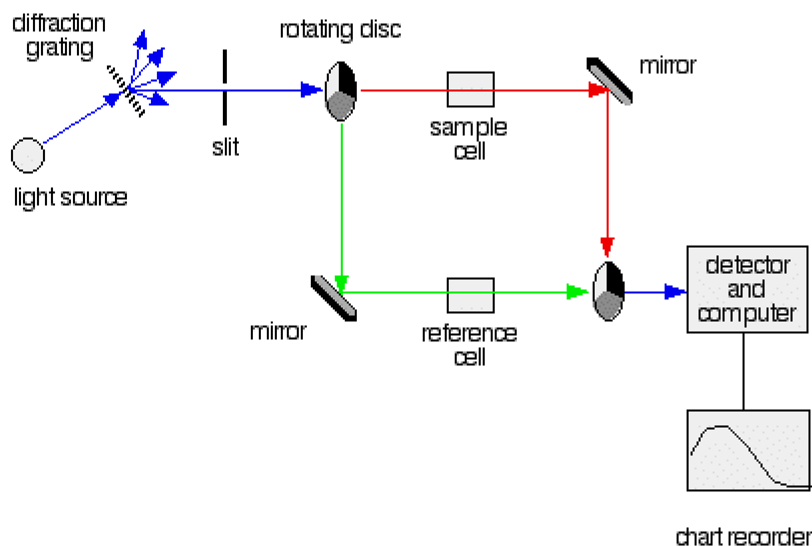

Fig. a double beam UV-VIS spectrophotometer. The incident light is split into two beams before it reaches the sample. One beam is used as the reference, the other beam passes through the sample. The detector alternates between measuring the sample beam and the reference beam. The instrument measures the intensity of incident light (I_0). The ratio I/I_0 is called the transmittance.

Procedure

1. Take the UV-vis transmittance spectrum of the filmss in the range 200-900 nm.
2. Calculate refractive index, extinction coefficient and thickness of the films.
3. Plot refractive index and extinction coeffieicnt as a function of wavelength.
4. Determine the direct and indirect band gap of the films using Tauc plot.

Reference:

1. UV Spectroscopy: Techniques, instrumentation and data handling B.J. Clark, T. Frost, M.A. Russell
2. J. C. Tauc, Optical Properties of Solids, F. Abeles ed. *North-Holland Publishing*, Amsterdam, (1972).
3. R. Swanepoel, *J. Phys. E: Sci. Instrum.* **16** [12] (1983) 1214.

………………..………………………Best Wishes……………………………………………