Experimental Physics II
(Course PHY 221)

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General Information

This laboratory is focused on experiments in optics and heat. The descriptions of the procedures and the instruments appearing in this manual are only meant to give you an overview of the experiments to be done in this course. The manual provides neither a step-by-step description of the procedure, nor a full analysis of the experiment. You have to put in your effort to read up and understand the finer details.

Please make sure that this printed copy stays with the apparatus. Do not take this away. An electronic copy is available on the course web page.

The Experiments

Experiments to be done as part of this lab are grouped as follows

A. Heat

(a) Thermal conductivity by Lee's Method

(b) Specific heat of solids

(c) Stefan's law of radiation

(d) Thermal Expansion

(e) Thermistor Characteristics

B. Optics

(a) Newton's Rings

(b) Gratings and Prism Spectrometer

(c) Resolving Power of a Telescope

(d) Malus' Law

(e) Optical Rotation

References

A generally useful book for this course is *Art of Experimental Physics* (by Daryl Preston), of which the library has several copies. In addition to this manual, there are manuals pertaining to some experiments. Do refer to them for details of the instrument and the procedure for making measurements.

In addition to this manual, there are detailed write-ups related to some of the experiments.

You should also look up information related to errors in experiments, graphical representation of data and fitting data to a function (some information is posted on the course website).

Grading and Evaluation

- 50% towards continuous evaluation. Hands on-skills, data logging, neatness of work will be judged. Over the entire semester, you are expected to undergo a viva for all experiments. Additional work and novel initiatives will be rewarded.
- 25% for Lab notebook (write-up, graphs, analysis).
- 25% for final exam

You are expected to carry out at least 3 experiments in each group to be considered for a pass grade, and 4 in each group to be considered for a A grade.

Lab reports will have to be completed within a week of the experiment, and the report will be assessed at the time of the viva. You will be assigned experiments according to a fixed schedule. Accordingly, you should prepare for the experiment ahead of time. Apart from the lab manual provided by us you should refer to other material elsewhere (library, internet, etc.)

Thermal conductivity by Lee's Method

Motivation and Aim

In this experiment the thermal conductivity of a bad conductor is measured.

Apparatus

1. Lee's Apparatus
2. Bad conductor samples (glass and ebonite discs).
3. Two thermometers
4. Boiler and Heater
5. Stop watch
6. Weighing balance
7. Vernier Calliper

Procedure

Fill the boiler with water to nearly half and heat it to produce steam. In the mean time, weigh the disc D_1 on which the apparatus rests. Further, measure the diameter of specimen disc d with a vernier calliper and its thickness using a screw gauge at several spaces and determine the mean thickness.

Clamp the glass specimen between the base disk D_2 of the steam jacket and the auxiliary brass disc D_1. Insert the thermometers (either mercury thermometer or thermocouples) in the two brass disks D_1, D_2. Check if they show the same readings at room temperature. If not, note the difference T'.

Connect the boiler outlet with the inlet of the steam chamber by a rubber tube. Continue passing steam until the two brass disks reach a steady temperature. Note down the temperatures T_1 and T_2 of the two discs.

The second part of the experiment involves the determination of the cooling rate of disc D_1 alone. Remove the sample disc. Heat the disc D_1 directly by the steam chamber till its temperature is about $T_1 + 10^\circ$ C. Remove the steam chamber and place the insulating disk on it. Record the temperature of the brass disc at half minute intervals. Continue till the temperature falls to about $T_1 - 7^\circ$ C.

Theory

Fourier's Law of heat conductance gives the rate of transfer of heat between two objects at temperatures T_2 and T_1 connected by a conductor with conductivity k and cross-sectional areas A (assumed uniform) and length l as

$$\frac{\Delta Q}{\Delta t} = k\frac{A}{l}(T_2 - T_1)$$

This equation governs the rate of heat transfer from disc D_2 to D_1 in the first half of the experiment.

The instantaneous rate at which a warm body loses heat to surroundings is given by Newton's law of cooling (which is a special case of Stefan's law, when the temperature differences are small, and there are losses other than radiative losses).

$$\frac{dT}{dt} = -b(T - T_a),$$

where T_a is the ambient temperature.

This law governs the rate at which the disc D_1 cools in the second half of the experiment. If m is the mass of the disk and s is the specific heat of the material of D_1 (brass in this case), then the rate at which heat is lost by the disc D_1

$$\frac{\Delta Q_1}{\Delta t} = ms(dT_1/dt)$$

Analysis

In the steady state achieved in the first half of the experiment, the heat supplied by the steam is lost by cooling of disc D_1. Hence the heat balance in the experiment is given by combining equations two heat transfer equations.

$$ms\frac{dT}{dt} = k\frac{A}{l}(T_2 - T_1)$$

dT/dt for D_1 can be determined from the cooling curve obtained in the second part of the experiment. As an approximation a single value of dT/dt can be used for this calculation. It is calculated at the value T_1 during the cooling of the disc D_1 from $T_1 + 10^\circ$ C to $T_1 - 10^\circ$ C. From the known value of $s = 0.380$ J/g/K for brass, k can be determined.

Note that if the two thermometers do not initially show the same reading, the difference $T_2 - T_1$ will have to be corrected by the quantity T' determined at the beginning of the experiment.

Points to Ponder

1. Why is it necessary to have a thin disk in the experiment?
2. Would this method work for measuring the conductivity of a good conductor?
3. In the cooling part of the experiment, why is the brass disc D_1 covered by the glass disc? Is it crucial to do so?
4. Why do we take the cooling data asymmetrically around T_1 in the second half of the experiment?

Specific heat of solids

Motivation and Aim

The change in temperature (ΔT) of a material when supplied with a certain (fixed) amount of heat (ΔQ) depends on the type of material and is inversely proportional to the the mass m of the material. The material dependence is given the quantity called the specific heat c of the substance. The interdependence of these quantities is summarised by the equation

$$\Delta Q = cm\Delta T$$

To measure the specific of a substance we supply a fixed amount of heat and measure the rise in its temperature.

Apparatus

1. Dewar
2. Thermometers
3. Weighing Balance
4. Shots of various materials
5. Steam Generator

Procedure

Measure the mass of the shots of each material. Place as many shots of a given material into the steam chamber and leave them there long enough for them to come to equilibrium with steam temperature (20 min). Then drop the shots (which are now at 100 °C) into the transfer mesh and insert them in the Dewar that has about 180 g water at room temperature. Keep the Dewar closed. Thoroughly mix the water and observe the maximum rise in temperature of the water. Repeat with shots of different materials and measure the temperature change in each case.

Theory

The amount of heat required to raise the temperature of a unit mass of a substance by 1 degree is called the specific heat of the substance. The SI unit of specific heat is [J/kg/K]. The specific heat of water is among the highest of all substances. Historically the specific heat of water is arbitrarily set as 1 cal/g/ °C. The equivalent SI value is 4184 J/kg/K. A related quantity is the molar specific heat, which is the specific heat for 1 mol of a substance. Metals have very low specific heats, in comparison. At room temperature the molar heat capacity of all crystalline solids is more or less the same. This is because the vibrational energy levels in a solid are more or less similar and the main contribution to the specific heats are from vibrations of the atoms in a solid. Exceptions to this are for instance diamond, which has extremely low specific heat.

Analysis

Heat lost by the shots is

$$\Delta Q_s = c_s m_s(\theta_s - \theta_m)$$

where θ_s is the initial temperature of the shots, θ_m is the final temperature of the mixture of water and shots.

Heat gained by the water is

$$\Delta Q_w = c_w m_w(\theta_w - \theta_m),$$

assuming that no heat is absorbed by the flask. However, this is not correct, and we make a correction by replacing m_w by $m_w + m_f$, where m_f is the equivalent mass of water that would have absorbed the same amount of heat as the flask. Since $Q_1 = Q_2$, and $c_w = 1$, we have

$$c_s = \frac{(m_w + m_f)(\theta_w - \theta_m)}{m_s(\theta_s - \theta_m)}$$

Points to Ponder

1. How would you determine the water equivalent of the Dewar, if it were not given to you?

Stefan's law of radiation

Motivation and Aim

A body at an absolute temperature T is found to radiate heat at a rate that is proportional to the fourth power of T. In this experiment a heated tungsten filament is taken to be a blackbody source of radiation. Since the filament is in vacuum, the only source of heat dissipation is by radiation. By measuring the electrical power consumed by the filament as a function of temperature, we determine whether the fourth power law holds.

Apparatus

1. A tungsten filament in an evacuated glass bulb
2. Millimameter
2. Constant voltage source
4. Voltmeter

Procedure

A tungsten filament is heated using a constant voltage source. Setting a voltage, the current in the filament is is allowed to stabilise and measured in a steady state. The voltage is increased in steps and from the measured steady current, the resistance of the filament is determined at each setting.

Finally, we carefully measure the current at which the filament just starts glowing, and determine R_G, the resistance at the temperature at which the filament just starts glowing.

Theory

Based on the equation for the spectral distribution of blackbody radiation, we can determine the total power radiated by the blackbody:

$$P_{\text{rad}} \propto T^4$$

This law is called Stefan's law. All bodies at finite temperature constantly radiate and simultaneously absorb heat from their surroundings. If the temperature of the body is T and the ambient temperature is T_a, the rate of heat exchange is given by the expression

$$\dot{Q} = \varepsilon\sigma(T^4 - T_a^4)$$

where σ is a universal constant called the Stefan's constant and ε is a factor less than 1, which accounts for non-ideal behaviour of the body. For a blackbody, $\varepsilon = 1$.

Analysis

The resistance R of heated tungsten filament changes as a function of temperature T, so the electrical power dissipated by the filament at a constant voltage also changes. The power dissipated is $P = VI$ where V and I are the voltage across and the current through the filament. The resistance of the filament is $R = V/I$. Since the resistance depends on the temperature of a substance, the temperature can be determined from the measured resistance at each stage.

The temperature dependence of resistance is given by the equation

$$R(T) = R_0(1 + \alpha T + \beta T^2)$$

For tungsten $\alpha = 5.21 \times 10^{-3}$ [K]$^{-1}$ and $\beta = 7.2 \times 10^{-7}$ [K]$^{-2}$.

1. Using the measured value of R_G and the known glowing temperature $T_G = 800$ K, we calculate R_0 using the above equation.

2. Plot the electrical power dissipated P $(= VI)$ at each setting vs. the temperature T calculated from the measured value of the resistance (V/I) at each setting.

3. Using the graph verify the fourth power law and determine the constant of proportionality in the equation for the radiated power for the tungsten filament.

Points to Ponder

1. How would you reduce the error in determining when the filament just starts glowing?
2. How much is the error in neglecting the T_a term in the heat exchange expression?

Thermal Expansion

Motivation and Aim

All materials expand when heated and contract when cooled. Heating changes the length, area, as well as the volume of the substance. The rate of change of length of a substance with temperature is called the coefficient of thermal expansion α of that material. In this experiment α is measured for three metals.

Apparatus

1. Pullinger's Apparatus
2. Thermometer
3. Brass, Aluminium and Copper rods
4. Steam bath

Procedure

Place the brass rod in the apparatus along with the thermometer. Ensure that the thermometer is in contact with the rod. Note the position of the top end of the rod by moving the spherometer and getting it to just touch the end face of the rod. Contact will be indicated by the buzzer or LED connected to the spherometer. After noting the spherometer reading move the spindle away from the rod face.

Heat the rod by passing steam through the jacket of the apparatus. Wait until the temperature of the rod becomes steady, and reaches close to the steam temperature.

Turn the spherometer spindle downwards until it just touches the rod and note the temperature of the rod. Repeat this as the rod cools down and note the spherometer reading each time, until the rod returns to room temperature.

Theory

It is empirically observed that the change in length due to temperature depends on both, the initial length and the change in temperature of a substance. For solids close to room temperature, the dependence can be taken to be linear, thereby obtaining the equation:

$$\Delta L = L_0 \alpha (T - T_0)$$

However this linear dependence is not universal. There are exceptions to this, a prime example being the behaviour of water near 4 °C.

Analysis

1. Plot a graph of spherometer reading vs. Temperature.
2. From the slope of this graph determine the coefficient of thermal expansion.

Points to Ponder

1. It is possible to note the rod length as the rod is heating up and while it is cooling down. Which readings will be more reliable? Why?
2. What are the major sources of systematic errors in this experiment?
3. To what extent does the error in initial length measurement affect the outcome of the experiment?

Thermistor Characteristics

Motivation and Aim

Resistivity of materials is a function of temperature. For certain semiconductors, the change in resistivity with temperature can be very rapid. Such materials can be used to make resistors with high temperature sensitivity, and are called thermistors. They can be used as temperature sensors.

Apparatus

1. A thermistor
2. A mercury thermometer
3. A water bath
4. Electric heater
5. Ice

Procedure

The thermistor is connected to a voltage source and placed in a water bath. The temperature of the water bath is changed and at each steady temperature its resistance is determined using a precision multimeter. Measurements are repeated for several temperatures, both as the water heats up and then again as it cools down. Further, the temperature is reduced by introducing ice to the bath and taking readings as the water cools and then as it return to room temperature.

Theory

The temperature dependence of the resistance of a semiconductor can be modelled as

$$\frac{1}{T} = A + B\ln(R) + C[\ln(R)]^3$$

Analysis

After plotting a graph of $1/T$ vs. $\ln(R(T))$ where R_T is the room temperature, the coefficients can be determined by a cubic fit to the data.

Points to Ponder

1. On the basis of observations can you find a range in which a thermistor is a linear device device?
2. Is a thermistor more useful for measuring accurately small changes, or large changes, in temperature?

Newton's Rings

Motivation and Aim

Newton's Rings is an experimental set up to observe the interference effect in light, which provides evidence for the wave nature of light. Newton's rings are an example of interference arising from a thin film of smoothly varying thickness. The varying thickness film is created by placing together a glass flat and a curved glass plate of a very small curvature (barely noticeable by eye!) and illuminating the gap by a normally incident monochromatic source. By examining the circular interference pattern the radius of curvature of the plate is to be determined.

Apparatus

1. A glass flat
2. Travelling Microscope
3. A plano convex lens
4. Monochromatic light source (e.g. Sodium lamp)
5. Partially silvered mirror

Procedure

Obtain a parallel beam of monochromatic light from the sodium lamp and make it incident on the partially reflecting mirror. Adjust the mirror so that the beam is reflected towards the lens and plate assembly. Ensure normal incidence on the face of the lens.

Observe the light reflected upwards from the lens and plate assembly through the microscope. By levelling the plate and focusing the microscope on the plate carefully a series of dark and bright rings are seen. The diameter of successive dark rings is measured for as many rings as possible by translating the microscope. Ensure that the microscope path does in fact traverse a diameter, not a chord of the ring.

Extra

Replace the sodium lamp by a LED or a He-Ne laser. Determine the fringe spacing for this source as was done using the sodium lamp. While using the laser, DO NOT point it directly at the 45° plate – let the laser beam pass through a diffuser e.g. a ground glass plate.

Theory

Rays of monochromatic light strike the upper surface of the air film nearly along normal. These rays are partly reflected and partly refracted and the ray refracted in the air film is also reflected partly at the lower surface of the film. The two reflected rays, i.e. produced at the upper and lower surface of the film, are coherent and interfere constructively or destructively, depending on the thickness of the air gap along the path of the ray.

The diameter D_n of the n^{th} dark ring and the wavelength λ of the light used and the radius of curvature R of the convex lens are related through

$$\frac{D_n^2}{4R} = n\lambda$$

Analysis

1. Plot a graph of D_n versus n or D_n^2 vs n.
2. Obtain a fit to the graph including the errors in your measurement and hence obtain the radius of curvature of the lens. (Use the known value of $\lambda = 589.2$ nm for sodium lamp.)
3. Using the value of the radius of curvature above, determine the wavelength of the second source of light.

Points to Ponder

1. How does the formula for the diameter of the dark ring come about? Are there any approximations involved? Are they satisfied in your experiments?

2. Why is it recommended to measure the diameter of the dark ring instead of the bright ring? What is the formula for the diameter of a bright ring?

3. The central spot is usually dark, but may occasionally be bright. How do these two situations arise? Which is the more advantageous setting for determining R?

4. What would happen to the rings if the air gap between the plate and the lens were filled with oil?

5. Can you think of an arrangement in which the fringes will be parallel lines with increasing spacings?

6. Could you have made a guesstimate (to an order of magnitude) for the radius of curvature? By what means?

Grating and Prism Spectrometer

Motivation and Aim

To separate light into its component wavelengths, that is, disperse it by the wavelength, we can exploit its wave nature or exploit the manner in which it interacts with a medium. A grating is a device that uses the interference phenomena in waves to achieve dispersion. A prism, on the other hand disperses light based on the dependence of the refractive of a medium on the wavelength of the light passing through it. In this experiment we study the dispersion of white light by both techniques and for the latter technique we obtain the refractive index as a a function of wavelength.

Apparatus

1. An optical spectrometer
2. A transmission grating
2. A prism
4. A sodium lamp
5. A mercury lamp

Procedure

Caution! *Do not touch the grating surface or the faces of the prism. Hold the former by its frame edge and the latter by gripping its bottom and top triangular faces.*

Adjust the spectroscope for parallel beam of light (Ref: Schuster's method). Locate the position of the direct beam and set this reading of the turret as the zero reference.

For the Grating

Place the grating normal to the incident beam and locate the central maximum of the light transmitted by the grating by observing through the telescope. Reduce the slit as much as possible. Then turn the telescope to locate the maxima at different wavelengths resulting from dispersion by the grating, on either side of the central maximum.

For the Prism

Determine the angle of the prism by placing the prism with its apex towards the source and locate the reflection of the source slits from the two faces. The angular separation between the reflected images is twice the angle of the prism. Place the prism in the minimum deviation position and determine the angular positions of the lines in the spectrum.

Theory

Grating

When a wave encounters an obstacle whose size is comparable to its wavelength, secondary waves are formed, with obstacle acting as a secondary source. This is the phenomenon of diffraction. Diffraction is observed for a beam of light, providing evidence for its wave nature. If there is a periodic set of such obstacles in the path of a parallel beam of light, scattered light from adjacent obstacles interferes, leading to the observation of minima and maxima in the intensity of light falling on a screen placed in front of the periodic obstacle. Such an obstacle is called a diffraction grating. Successive maxima in the intensity occur when the condition

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

is satisfied, m being an integer, d and λ being the grating period and λ the wavelength of incident light.

The intensity of light from a slit of width d falling on a screen is given by

$$I = I_0 \frac{\sin^2(\delta/2)}{(\delta/2)^2}$$

where $\delta = 2\pi d \sin\theta/\lambda$ and θ is the angle between the ray at the point of observation and the normal. If the slit is replaced by an array of slits with N rulings per unit length, then the formular for the intensity becomes

$$I = I_0 \frac{\sin^2(N\delta/2)}{(\delta/2)^2}$$

Prism

For a prism, the refractive index for a particular wavelength is given by

$$n_\lambda = \frac{\sin[(\delta_\lambda + A)/2]}{sin(A/2)}$$

where δ_λ is the angle of minimum deviation for that wavelength and A is the apex angle of the prism.

The exact dependence of the refractive index of a medium on the incident wavelength can be quite complicated. An approximate relationship between the refractive index and the wavelength was given by the Cauchy:

$$n(\lambda) = A + \frac{B}{\lambda^2}$$

Analysis

1. Verify that the maxima of different spectral lines for the grating fall at the predicted positions.
2. Verify the Cauchy formula for the lines observed in the spectrum based on the measured values of the angles of deviation for each wavelength in the spectrum.

Points to Ponder

1. If you increase the number of grooves per unit length in the grating, its resolving power increases. Is there any downside to this?
2. Why is it recommended that the prism be set at the angle of minimum deviation?
3. Is this angle the same for all wavelengths?

Resolving Power of a Telescope

Motivation and Aim

The wave nature of light limits the ability of an optical system to resolve (i.e. form separate images) of nearby objects. The aim of this experiment is to study this limitation and obtain the resolving power of a telescope by attempting to obtaining separate images of two closely spaced sources of light.

Apparatus

1. A telescope
2. A sodium vapour lamp
3. A variable rectangular slit
4. A mask with parallel slits of different separations and different widths

Procedure

Turn on the lamp. Set up the telescope horizontally and open completely the rectangular slit mounted on its objective. Learn to use the screw to open and close the rectangular slit and determine the least count of the scale and its zero error.

Place a mask in front of the lamp. Make a note of the different pairs of slits, each pair is of different separation g. Place the telescope at a distance D from the sources. (A suggested starting value is $D = 1.0$ m.) Focus the telescope and adjust the mask so that you see two sharp and separated images of the slits with the largest separation (largest g) while the objective slit is fully open. If needed, use black card paper strips to darken all pairs of slits except the one you are examining.

Reduce the width of the rectangular slit slowly while observing through the telescope. As the slit gets narrower, diffraction patterns from the two sources will appear and start to spread. As the slit gets narrower, the dark region between the two sources becomes blurred and tends to vanish. At this stage the two sources are just resolved and the angle subtended by the sources is the minimum angle of resolution. Note down the width of the objective slit a.

Now reduce the width of the rectangular slit till the two images are completely merged. Slowly increase the width until the slits will appear just resolved. Measure the width of the rectangular slit again. Note down the width of the objective slit a.

Repeat the above two steps a few times, noting the value of a while closing and opening. Obtain the mean value of the slit width, which we call A. Repeat the measurement of for at least three different values of D.

Theory

A narrow source of light when imaged through a convex lens creates an image on a screen which shows alternate minima and maxima. The amplitudes of the maxima fall off as we move away from the central (principal) maximum. If two such coherent sources are placed close together, the image is an overlap of the diffraction pattern of each source taken separately. The angular separation α between the sources is equal to the angular separation between the two principal maxima when the principal maxima are well separated. When the principal maximum of one source falls exactly on the second minimum of the adjacent pattern, the intensity at the midpoint of the two maxima is zero, and this is the smallest value of α which will give zero intensity between the two maxima. The path difference between the rays forming the maximum and the rays forming the minimum is λ. Hence the angular separation α when the principal maximum of one source overlaps with the second minimum of the other source, is given by

$$\sin\alpha \approx \alpha = \lambda/D$$

Analysis

For each value of A, D calculate λ/A and g/D and plot a graph of g/D vs. λ/A and determine its the slope. From this verify the Rayleigh criterion.

Points to Ponder

1. How do you ensure that the telescope axis is normal to the plane containing the sources?
2. Is this a necessary condition for determining the resolving power experimentally?
3. Would a telescope with a higher magnification have a better resolving power? Why is this factor not addressed in the experiment?

Malus' Law

Motivation and Aim

When light (or any other electromagnetic wave) passes through a medium, the polarisation of the beam may get affected. An arbitrary polarisation can be resolved into two polarisation directions (e.g. horizontal and vertical). In certain media or at boundaries of two media, one polarisation direction may be retained and the other direction suppressed. In particular, some media may transmit only one polarisation. In this experiment the effect of such a medium on the intensity of plane polarised light is studied.

Apparatus

1. A source of light
2. Two plane polarisers
3. A light detector
4. An optical rail.

Procedure

Place a source of light and a detector some distance apart on an optical rail. Fix one polariser close to the source and rotate the polariser to obtain the highest signal on the detector. Then place another polariser (called the analyser) closer to the detector and rotate it until the transmitted intensity is maximum. Take this as the reference angle. Then turn the polariser in steps (e.g. 15°) and note down the detector signal for each step over a complete rotation of the second polariser.

Theory

The transmitted intensity of plane polarised light varies as $\cos^2\theta$ where θ is the angle between the plane of polarisation of the incident beam and the orientation of the polariser.

Analysis

Plot a graph of signal voltage vs. $\cos^2\theta$ and fit a straight line to it.

Points to Ponder

1. Do you expect the fitted line in your graph to pass through the origin? Why? How do you ensure this?
2. If you plotted, instead of a graph of signal voltage vs. $\cos^2\theta$, a graph of signal vs. angle, what would you have obtained? How would you compare the two graphs?

Optical Rotation

Motivation and Aim

When molecules scatter light, the intensity of the scattered light at a particular angle depends on the polarisation of the incident light and the nature of the molecule.

Molecules that lack mirror symmetry occur in two chemically identical, but geometrically different (mirror image) conformations. These pairs of molecules are called enantiomers, and they scatter plane polarised light in different ways. For one kind of enantiomers (the so-called levo-rotatory or *l* molecules) scattering is such that the plane of polarisation is rotated in an anticlockwise direction as the beam propagates through the medium (the medium may be a solution of the compound, or a crystal of that compound). For the other type of molecule, the polarisation plane rotates in the clockwise sense. The two molecules are chemically equivalent, but optically they are different.

The amount of rotation depends on the concentration of the solution and the length of the path in the medium. In this experiment the specific optical rotation of sugar solution and tartaric acid solution is determined.

Apparatus

1. A source of white light
2. A plano convex lens
3. A pair of polarisers
4. A cuvette
5. Optical rail
6. Aqueous solutions of sugar and tartaric acid of different concentrations
5. Optical detector

Procedure

Caution! Do not interchange cuvettes of different compounds. Return the solutions to the respective beakers (of the correct compound, of the correct concentration) without fail and without mix-up.

Place the light source at one end of the optical rail and the detector at some distance. The distance should be adequate to accommodate two polarisers, a cuvette, and a lens. Adjust the lens position and the source mounting so as to get the highest possible intensity on the detector.

Place a cuvette and a polariser each on either side of the (empty) cuvette. Keep one polariser fixed and rotate the other (the *analyser*) until the transmitted intensity is zero (detector reads null on the most sensitive scale) and note this as the reference angle of the analyser. Pour the solution into the cuvette and note the detector reading. Null the reading by rotating the analyser. If the cuvette is rectangular, you can get two readings (for two different lengths) for the same sample.

Obtain the angle of rotation for each concentration and each path length for the sugar solution as well as the tartaric acid solution.

Theory

The optical activity of a molecule is defined as the amount of rotation of the plane of polarisation per unit concentration per unit path length at a given temperature. It is also a function of wavelength of light employed. The specific rotation $[\alpha]$ is given by

$$[\alpha] = \frac{\Delta\phi}{L \cdot \rho}$$

where the convention is to measure ρ in g/mL and L in decimeters.

Analysis

1. Using rotation data plot a graph of rotation angle vs. the product $L \cdot \rho$
2. From the graph determine α for both compounds.

Points to Ponder

1. A solution contains both *l* and *d* types of compounds in unequal proportions. How will you be able to determine whether this is indeed the case, and it is not merely a solution containing a small amount of the *l* or *d* compounds?

2. Can this experiment not be done by rotating the analyser to maximise the output intensity rather than seeking a null?

3. Did the least transmitted intensity correspond a zero reading of the detector? If it does not, how is your experiment affected?