**EXPERIMENT:** Determination of the refractive index \((n)\) of the material of a prism using spectrometer

1. **The Aim**
   
   We try to calculate the Refractive Index \((n)\) of the Prism for various wavelengths of the Mercury Spectrum and then plot the Dispersion and Calibration Curves using a Prism Spectrometer.

2. **Apparatus required**
   
   a) Mercury lamp (as source of **white light**)
   b) Spectrometer
   c) Prism

3. **Theory of experiment**
   
   The spectrometer is an instrument for analyzing the spectra of radiations. The glass-prism spectrometer is suitable for measuring ray deviations and refractive indices. Sometimes a diffraction grating is used in place of the prism for studying optical spectra. A prism refracts the light into a single spectrum, whereas the diffraction grating divides the available light into several spectra. Because of this, slit images formed using a prism are generally brighter than those formed using a grating. Spectral lines that are too dim to be seen with a grating can often be seen using a prism. Unfortunately, the increased brightness of the spectral lines is offset by a decreased resolution, since the prism doesn’t separate the different lines as effectively as the grating. However, the brighter lines allow a narrow slit width to be used, which partially compensates for the reduced resolution.

   With a prism, the angle of refraction is not directly proportional to the wavelength of the light. Therefore, to measure wavelengths using a prism, a calibration graph of the angle of deviation versus wavelength must be constructed using a light source with a known spectrum. The wavelength of unknown spectral lines can then be interpolated from the graph. Once a calibration graph is created for the prism, future wavelength determinations are valid only if they are made with the prism aligned precisely as it was when the graph was produced. To ensure that this alignment can be reproduced, all measurements are made with the prism aligned so that the light is refracted at the angle of minimum deviation.

   The light to be examined is rendered parallel by a collimator consisting of a tube with a slit of adjustable width at one end and a convex lens at the other. The collimator has to be focused by adjusting the position of the slit until it is at the focal point of the lens. The parallel beam of light from the collimator passes through a glass prism standing on a prism-table which can be rotated, raised or lowered, and levelled. The prism deviates the component
colors of the emitted light by different amounts and the spectrum so produced is examined by means of a telescope, which is mounted on a rotating arm and moves over a divided angular scale.

The theory of the prism spectrometer indicates that a spectrum of maximum definition is obtained when the angular deviation of a light ray passing through the prism is a minimum. Under such conditions it can be shown that the ray passes through the prism symmetrically. For a given wavelength of light traversing a given prism, there is a characteristic angle of incidence for which the angle of deviation is a minimum. This angle depends only on the index of refraction of the prism and the angle between the two sides of the prism traversed by the light. The relationship between these variables is given by the equation:

\[ n = \frac{\sin(A + \delta_m)}{2 \sin A} \]

(1)

Where (A) is the apex angle of the prism, (n) is the index of refraction of the prism and (\(\delta_m\)) is the angle between the sides of the prism traversed by the light and is the angle of minimum deviation. Since the refractive index (n) varies with wavelength (\(\lambda\)), the angle of minimum deviation (\(\theta_m\)) also varies, but it is constant for any particular wavelength.

The telescope can also be locked or moved very slowly by a fine adjustment screw and the instrument is provided with a heavy base for stability. To obtain sharp spectral lines the slit width should be quite small.

The amount by which the visible spectrum spreads out into its constituent colors depends on how rapidly the refractive index (n) of the prism material varies with the wavelength (\(\lambda\)) of the radiation, i.e. \(dn/d\lambda\). This quantity is called the dispersion and is of prime importance in spectroscopy, since if the dispersion is small, radiation of slightly differing wavelengths cannot be resolved into separate and distinct spectral lines.
4. Procedure

- First, the telescope has to be focused distant objects i.e. infinity and this has to be maintained until the experiment is over, so as not to refocus again. Then, the cross-wires should be focused by moving the eye-piece of the telescope.
- Adjust the Collimator such that the image seen in the telescope is sharp of the slit without the prism.

- **Measuring the Apex Angle of the Prism (A):**
  Place the prism on the Prism Table and lock the prism table in the position so the incident beam falls on one of the edges of the prism. Now, move the telescope and locate the images of the slit and note down the angles. The difference between both the angles is (2A). Hence, half of the difference will give us (A).

- **Measuring the Angle of Minimum Deviation (δ_m):**
  - Now, choose an angle of incidence other than the previous chosen one and with eye locate approximately the angle at which the spectrum starts to move in the opposite direction as the prism table is rotated, and lock the prism table. Now, using the telescope, fix the telescope on one of the spectrum lines, and then use the fine adjustment for the movement of prism table to move the table so that we get the precise location of the angle where the line starts to move in the opposite direction, and note the angle for this.
  - Without disturbing anything, remove the prism and get the measure of the angle of the direct image of the slit in the telescope. The difference between these two angles is the Angle of Minimum Deviation (δ_m) for this spectral line (λ).
  - Repeat the same for all the spectral lines that are given by the mercury lamp.

- **Measuring the Refractive index (n):**
  - From the above data (A, δ_m) we can calculate the Refractive index (n) of the prism for various wavelengths (λ).
  - For the Calibration Curve, plot a graph of (δ_m) versus (λ).
  - For the Dispersion Curve, plot a graph of (n) versus (λ).
5. Calculations

<table>
<thead>
<tr>
<th>Colour</th>
<th>(\lambda) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>623.437</td>
</tr>
<tr>
<td>Yellow</td>
<td>576.959</td>
</tr>
<tr>
<td>Green</td>
<td>546.074</td>
</tr>
<tr>
<td>Blue</td>
<td>497.325</td>
</tr>
<tr>
<td>Violet</td>
<td>404.656</td>
</tr>
</tbody>
</table>

6. Results

Thus, the mean Refractive index \((n)\) of the material \((n = 1.6)\)

**A) Minimum Deviation**

The experiment shows that as the angle of incidence \((\theta_i)\) is increased from (zero), the deviation \((\delta)\) begins to decrease continuously to some value \((\delta_m)\), and then increases to a maximum as \((\theta_i)\) is increased. A graph of \((\delta)\) plotted against \((\theta_i)\) has the appearance of the curve (X), which has the minimum value at (R), Fig. 4.3. Experiment and theory show that the minimum deviation \((\delta_m)\) of the light occurs. Then, we can write the following Eqs.:

\[
A = \frac{A_1 + A_2}{2}
\]

\[
n = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\frac{A}{2}}
\]
B) Determination of the angle of minimum deviation ($\delta_m$)

1. Place the glass prism on the table so that the angle (A) which was measured serves as the refracting angle.

2. Turn the telescope till you get spectral lines and measure the minimum deviation angle ($\delta_m$) for each spectral line, and record the results in Table 1.

   - The position of minimum deviation ($\delta_m$) can be detected by looking to the spectrum through the telescope and rotating it until the spectrum reverses its direction.

<table>
<thead>
<tr>
<th></th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
<th>Violet</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_m$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) In the second part, Calculate the refractive index ($n$) for each spectrum from the relation:

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$

Note: To read the angle, first find where the zero point of the vernier scale aligns with the degree plate and record the value. In Figure 7, the zero point on the vernier scale is between the 155° and 155°30’ marks on the degree plate, so the recorded value is 155°. Now find the line on the vernier scale that aligns most closely with any line on the degree scale. In the figure, this is the line corresponding to a measurement of 15 minutes of arc. Add this value to the reading recorded above to get the correct measurement, i.e., 155° + 15’ = 155°15’.
The Prism Spectrometer
Prism apex angle $\alpha = 60^\circ$

<table>
<thead>
<tr>
<th>color</th>
<th>wavelength $\lambda$ (nm)</th>
<th>angle of deviation</th>
<th>Index of refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>690.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yellow 1</td>
<td>579.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yellow 2</td>
<td>577.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>green</td>
<td>546.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue-green (dim)</td>
<td>491.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue</td>
<td>435.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>violet</td>
<td>404.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix: Index of refraction ($n$) of a prism

1. Introduction

When a beam is transmitted through a triangular prism, the beam will be refracted twice and will emerge along a path that deviates from its original direction of propagation. By rotating the prism the angle of deviation can be made larger or smaller. The smallest angle that is possible to obtain is called the minimum angle of deviation ($\delta$). The index of refraction ($n$) is given by the formula:

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}}$$  \hspace{1cm} (1)

Where ($A$) is the apex angle of the prism and ($\delta_m$) is the angle of minimum deviation.

Figure (1). Dispersion by a prism. Different angles of deviation are observed for different colors.

Different colors (i.e., different wavelengths) have different values ($\delta_m$) (Figure 1). This is a phenomenon of dispersion. This dependence can be approximated by the **Cauchy formula:**

$$n = A + \frac{B}{\lambda^2}$$  \hspace{1cm} (2)

Where ($A$) and ($B$) are constants for the particular material. These constants can be found by measuring the index of refraction for two different wavelengths and solving the two Cauchy equations.
2. Measurements
Start the experiment only if the spectrometer has been properly aligned and you can clearly see the slit image and the cross-hairs are in focus.

You can find the apex angle (A) of the prism using a bulb lamp or a discharge lamp. However, it is easier to work with a bulb lamp. Move the telescope until an image of the slit, reflected from one surface of the prism, can be seen. Read the Vernier at this position. Rotate the telescope so the image reflected off the other side of the prism will be seen through the telescope. Read the Vernier setting. The apex angle (A) is one half the differences between the two readings. Repeat these measurements for two different orientations of the prism table and find the mean value of the apex angle.

The measurements of the minimum angle of deviation (δ_m) are illustrated in (Figure 3). As a source of light you will use a discharge lamp provided by the lab instructor. Most likely it will be a mercury lamp. As seen from (Figure 3) you need to find two angles. One corresponding to the original direction of the beam should be found with the prism removed.
from the table. Then mount the prism again on the table and rotate the telescope until you find the image of the slit. It will appear as a series of lines of different colors.

The position of the telescope at which the line of a given color is seen on the cross-hairs determines the angle of deviation, but this is not necessarily the angle of minimum deviation ($\delta_m$). To find this angle, rotate the prism table until the image comes to a position where its motion is reversed as the rotation of the prism table is continued. Where the image comes to a standstill, the angle of deviation is at minimum ($\delta_m$) and the position of the telescope should be read from the Vernier settings. The difference between the original direction of the beam (the non-deviated light) and the deviated light will be the angle of minimum deviation ($\delta_m$).

Repeat these procedures for as many lines as possible. Table (1) assigns the wavelengths of different colors of mercury, helium and hydrogen lamps. From the data calculate the index of refraction ($n$) of glass for different wavelengths and obtain the coefficients (A) and (B) in Cauchy's formula.

Table (1): Wavelengths in nanometers of selected lines of mercury, helium and hydrogen lamps.
COMPANY PROFILE

Lambda Scientific Systems, Inc. specializes in developing and marketing scientific instruments and systems designed and manufactured specifically for experimental education in physics at colleges and universities. Our mission is to become a premier supplier of high-quality, robust, easy-to-use, and affordable scientific instruments and systems to college educators and students for their teaching and learning of both fundamental and modern experiments in physics. Our products focus on comprehensive physics education kits, as well as light sources and opto-mechanic components.

Our physics education kits cover a wide range of experiments in general physics, especially in geometrical optics, physical optics, and fiber optics. Experiments include lens imaging, interferometry, diffraction, holography, polarization, laser physics, quantum optics, and Fourier optics through a series of the most representative apparatus such as Newton’s ring apparatus, Young’s modulus apparatus, Michelson interferometer, Fabry-Perot interferometer, Twyman-Green interferometer, Fourier spectrometer, and laser.

Our fiber optics education kits keep a pace with the advent of fiber optical communication technology by designing experimental systems to teach fundamental optical fiber concepts such as fiber-to-fiber coupling, fiber-to-source coupling, fiber numerical aperture, fiber mode, fiber transmission loss, and fiber sensing. These kits also give students an opportunity to be familiar with modern fiber optic components or apparatus such as Mach-Zehnder interferometer, variable optical attenuator, fiber isolator, fiber splitter, fiber switch, wavelength-division multiplexer, fiber amplifier, and transmitter.

Our light sources include Xenon lamp, Mercury lamp, Sodium lamp, Bromine Tungsten lamp and various lasers.

We also provide a variety of opto-mechanical components such as optical mounts, optical breadboards and translation stages. Our products have been sold worldwide. Lambda Scientific Systems, Inc is committed to providing high quality, cost effective products and on-time delivery.
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1. Introduction

The phenomenon of Newton's rings, named after Isaac Newton, is an interference pattern caused by the reflection of light between two surfaces - a spherical surface and an adjacent flat surface. When viewed with monochromatic light, it appears as a series of concentric, alternating bright and dark rings centered at the point of contact between the two surfaces. Using this device, observation of equal thickness interference and determination of the radius of curvature of a lens surface can be performed.

2. Specifications

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Division of drum</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>Magnification</td>
<td>20x, (1x, f=38 mm for Objectives; 20x, f=16.6 mm for Eyepiece)</td>
</tr>
<tr>
<td>Working distance</td>
<td>76 mm</td>
</tr>
<tr>
<td>Viewing field</td>
<td>10 mm</td>
</tr>
<tr>
<td>Measurement Accuracy</td>
<td>0.01</td>
</tr>
<tr>
<td>Sodium Lamp</td>
<td>15 ±5 V AC, 20W</td>
</tr>
<tr>
<td>Radius of curvature of Newton’s ring</td>
<td>868.5 mm</td>
</tr>
</tbody>
</table>

3. Description of Equipment
The LEOK-30 Newton’s Ring Apparatus includes the following equipment:

Reading microscope
Sodium lamp with power supply
Newton’s Ring
Beam splitter

4. Principle

The convex surface of a long focal length lens (large radius of curvature) is placed in contact with a plane glass and the two surfaces are clamped together with a thin film of air formed in between. If a ray of parallel light strikes them as shown in Figure 1, there will be a light path difference between the light beams reflected by the upper- and lower-surfaces of the air film. Thus, interference phenomenon occurs. The interference pattern is a series alternately dark and bright rings centered at the contact point of the lens and the plane glass. This is the phenomenon of Newton’s rings.

Figure 1 Schematic diagram showing a lens and flat plate used to form Newton’s Rings

where \( R \) is the radius of curvature of the convex lens, \( h \) is the thickness of the thin “air-film”, and \( r \) is the radius of an interference ring with respect to the point of contact \( C \). With these parameters, there exists an equation as:

\[
h = R - \sqrt{R^2 - r^2} \approx \frac{r^2}{2R}
\]  

There is no phase change at the glass-air surface of the convex lens (because the wave is going from a higher to a lower refractive index medium) whereas the reflection at the air-glass surface of the plane disk suffers a half-cycle phase shift. So the light path difference is:
\[ \delta = 2h + \lambda/2 \]  

The light path difference of the \( k^{\text{th}} \) order dark fringe is:

\[ \delta = (2k + 1) \frac{\lambda}{2}, \text{ where } k=0, 1, 2\ldots \]

So the radius of the \( k^{\text{th}} \) dark ring is given by

\[ r_k = \sqrt{kR\lambda} \quad k=0, 1, 2\ldots \]  

(3)

It provides a method to measure the radius of curvature of the convex surface. However, very small dust particles may lift the contact point slightly above the surface of the optical flat, so the center of the rings is irregular and \( r_k \) cannot be measured precisely. To address this uncertainty, the radii of two rings (the \( m^{\text{th}} \) and the \( n^{\text{th}} \), \( m > n \)) should be measured to calculate \( R \) as follows

\[ R = \frac{r_m^2 - r_n^2}{(m-n)\lambda} = \frac{d_m^2 - d_n^2}{4\lambda(m-n)} \]  

(4)

where \( d_m \) and \( d_n \) are the diameters of dark rings of the \( m^{\text{th}} \) and \( n^{\text{th}} \) orders, respectively.

5 Experimental Procedure

5.1 Observation of Newton’s Rings

Step 1: Open the metal cover and install the Sodium lamp bulb to the lamp housing.

Step 2: Turn on the Sodium lamp and warm up for about 5 minutes.

Step 3: Insert the Newton’s ring in the holder on the base with three screws up. Secure the Direct Measurement Microscope in focusing device.

Notice
Before inserting the Newton’s ring in the holder on the lamp base, carefully adjust the three screws on Newton’s ring until several small rings move to the center of the lens.

Do not over-tighten the screws on Newton’s ring assembly to avoid damage to the device.

Step 4: Rotate beam splitter to let Sodium light illuminate the Newton’s Ring. When the beam splitter is oriented 45° to the optical axis of the DMM, fine rings can be seen through the eyepiece. Lock the beam splitter. If the interference pattern is not clear, rotate the focusing knob to focus the microscope.

Step 5: Carefully turn eyepiece until cross hair is seen clearly.
Carefully adjust the focusing knob until a clear image of the equal- thickness rings is observed.

Step 6: Adjust the three screws on frame of Newton’s ring to let center ring move to the
center of the viewing field. Tighten any two of the three crews on Newton’s ring, distorted rings should be observed.

**Notice**
Do not over-tighten the screws on frame of Newton’s ring to avoid damage of the lens.

### 5.2 Determination of Radius of Curvature of Lens

**Step 1:** Turn on the sodium lamp and get Newton’s rings. For details, please refer to 5.1.

**Step 2:** Rotate the drum and set the cross hairs on the 5th ring on the left hand side of the interference pattern and record the reading of the drum. Similarly, go to the 14th ring on the same side of the pattern and record the drum reading. Repeat these steps for several rings and record the data in the following table. Repeat these steps on the right hand side of the interference pattern.

**Notice**
To minimize reading error due to backlash while turning the micrometer knob, first begin with a full counterclockwise turn, and then turn the knob only counterclockwise when counting fringes, this will eliminate reading errors caused by backlash.

<table>
<thead>
<tr>
<th>Ring #</th>
<th>L5</th>
<th>L6</th>
<th>L7</th>
<th>L8</th>
<th>L9</th>
<th>L10</th>
<th>L11</th>
<th>L12</th>
<th>L13</th>
<th>L14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ring #</td>
<td>R5</td>
<td>R6</td>
<td>R7</td>
<td>R8</td>
<td>R9</td>
<td>R10</td>
<td>R11</td>
<td>R12</td>
<td>R13</td>
<td>R14</td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Step 3:**
Determine $d_5$, $d_6$, ..., $d_{14}$ from measured data and calculate $(d_{14})^2-(d_9)^2$, $(d_{13})^2-(d_8)^2$, $(d_{12})^2-(d_7)^2$, $(d_{11})^2-(d_6)^2$, $(d_{10})^2-(d_5)^2$ and their average ($m-n=5$). Then calculate the radius of curvature of the lens by using the mean wavelength, 589.3 nm, of Sodium D-lines in equation (4).

### 6. Maintenance

#### 6.1 Optical Components
The mirror surfaces are precisely polished and coated. Dirt, scratches, finger print will distort the fringe pattern, so handle all optical surfaces with care. Clean the surfaces occasionally with a lens tissue when necessary.

#### 6.2 Direct Measurement Microscope
The reading microscope is calibrated before shipping. If recalibration becomes necessary, use
the following procedure:

When the drum reads zero, but the reticle does not read at zero

1. Loosen the three screws at the drum.
2. Adjust the drum till the long vertical line in viewing field coincides with the zero line of the reticle.
3. Adjust the drum till the zero line on the drum coincides with the zero line of the reticle.
4. Tighten the three screws on the drum.

When the microscope is not in focus

1. Place the microscope on a plane sample.
2. If the image of the sample on the reticule is not clear, loosen the screw on the tube base. Turn the tube base against the tube, until a clear image of the sample is observed.
3. Secure the screw.

Notice
Please do not disassemble the microscope as otherwise permanent damage to the microscope may occur.

7. Handling Precautions and Safety Warning of Low-Pressure Sodium Lamp

Operation and Handling Precautions:

- Do not touch the glass cover of the Sodium lamp with bare hands, wear plastic gloves when handling the lamp to avoid finger prints or oil grease on the glass cover.
- Make sure the electric power to the lamp is turned off when installing or removing the lamp to or from the housing.
- The lamp is designed to work with the housing provided. Using the lamp with other housings is prohibited.
- The Sodium lamp needs a warm-up time of approximately 20 minutes to reach steady output.
- Once the lamp is turned on, the housing can become very hot over time so avoid touching the hot housing or moving it around.
- After turning the lamp off, wait at least 30 minutes for the lamp to cool down before turning the lamp back on or moving the housing around.
- The lifetime of the lamp decreases with an increase in the number of turn-on/turn-off times of the lamp.
• The low-pressure Sodium light source is NOT designed for personal or consumer use at home.

Safety Warning:

• Sodium contained in the light bulb, constitutes an ignitable hazardous waste when reacted with water under the case of a broken lamp.
• In the case of glass cuts by a broken lamp, do not use water to clean cut. Use antiseptic cream instead and seek medical treatments immediately.
• Prior to lamp disposal, the lamp has to be broken into pieces in a dry container with strict safety and handling precautions. The operator must wear gloves and safety goggles to prevent the possibility of injury from broken glasses. The operation should be conducted in a well-ventilated area to avoid inhalation of the dust when breaking up the lamp. The broken lamp should be covered with water from a water hose, with the operator standing from a safe distance (5 meters away from the broken lamp). After a few minutes when the reaction between Sodium and water is complete, the broken lamp can be disposed as broken glasses.*

*Subject to applicable federal, state, and local regulations.

Lambda Scientific Systems, Inc will take no liability for any injury or damage that may be caused by improper handling and/or incorrect using of low-pressure Sodium lamps. Lambda Scientific Systems, Inc assumes no responsibility for the accuracy and/or the suitability of the information provided in this notice. Using low-pressure Sodium lamps for intended applications by user is user’s own judgment and responsibility.
Physics Lab

The Diffraction Grating: Measuring the Wavelengths of Light

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Click here to enter text.

Click here to enter text.
The Diffraction Grating Spectrometer: Measuring the Wavelengths of Light

1. INTRODUCTION

A prism will separate light into colors. It can be placed in a device known as a prism spectrometer, which has to be calibrated in terms of known wavelengths before we are able to experimentally determine unknown wavelengths of light. How, then, are the wavelengths of spectral lines or colors initially determined? This is most commonly done with a diffraction grating, which is a simple device that allows for the study of spectra and the measurement of wavelengths.

By replacing the prism with a diffraction grating, a prism spectrometer becomes a grating spectrometer. In the case of the diffraction grating, the angle(s) at which the incident beam is diffracted are directly related to the wavelength(s) of the light. In this experiment the properties of a transmission grating will be investigated and the wavelengths of several spectral lines will be determined.

2. EQUIPMENT NEEDED

- Spectrometer
- Diffraction grating and holder
- Mercury discharge tube
- Power supply for discharge tube

3. THEORY

A diffraction grating consists of a piece of metal or glass with a very large number of evenly spaced parallel lines, usually 10,000 to 20,000 lines/in.

Reflection gratings are ruled on polished metal surfaces and light is reflected from the ruled areas which act as a row of "slits." Transmission gratings are ruled on glass and the ruled slit areas transmit incident light. (The transmission type is used in this experiment.)

Diffraction refers to the "bending" or deviation of waves around sharp edges or corners. The slits of a grating give rise to diffraction and the diffracted light interferes so as to set up interference patterns (Fig.1). Complete constructive interference of the waves occurs when the phase or path difference is equal to one wavelength, and the first-order maximum occurs for \( n = 1 \):

\[
d \sin \theta_1 = \lambda
\]
where \( d \) is the grating constant or the distance between the grating lines, \( \theta \), the angle the rays are diffracted from the incident direction, and \( d \sin \theta \), the path difference between adjacent rays. The grating constant is given by:

\[
d = 1/N
\]

where \( N \) is the number of lines per length (usually per mm or per in.) of the grating.

A second-order maximum occurs for \( (d \sin \theta_2 = 2\lambda) \), and so on, such that in general we may write:

\[
d \sin \theta_n = n \lambda \quad n = 1, 2, 3, \ldots
\]

where \( n \) is the order of the image maximum. The interference is symmetric on either side of an un-deviated and un-diffracted central maximum of the slit image.

In practice, only the first few orders are easily observed, with the number of orders depending on the grating constant. If the incident light is other than monochromatic, each order corresponds to a spectrum. That is, the grating spreads the light out into a spectrum. As can be seen from (Eq.1), since \( d \) is constant, each wavelength (color) is deviated by a slightly different angle, so that the component wavelengths are separated into a spectrum. Each diffraction order in this case corresponds to a spectrum order.
4. EXPERIMENTAL PROCEDURE

1. Review the operation of a spectrometer if necessary. The diffraction grating used for this experiment has 6000 lines per cm. Record the number of lines per unit length of your diffraction grating in the Laboratory Report. Mount the grating on the spectrometer table with the grating ruling parallel to the collimator slit and the plane of the grating perpendicular to the collimator axis.
### Determination of the Wavelength Range of the Visible Spectrum

2. Mount the light source in front of the collimator slit. Move the spectrometer telescope into the line of the slit of the collimator and focus the cross-hairs on the central slit image. Make sure the angle (θ) scale is set to zero when the telescope crosshair is centered on the slit image. Notice that this central maximum or "zeroth"-order image does not depend on the wavelength of light, so that a white image is observed. Then move the telescope to the left side of the incident beam and observe the first- and second-order spectra.

3. (a) Focus the cross-hairs on the blue (violet) end of the first-order spectrum at the position where you judge the spectrum just becomes visible. Record the divided circle reading (to the nearest tenth of a degree) in Data Table 1. (Note – example degree scale on the right shows 14.2°)
(b) Move the telescope to the other (red) end of the spectrum and record the divided circle reading of its visible limit.

4. Compute the grating constant (d), and with the experimentally measured (θ's), compute the range of the wavelengths of the visible spectrum in centimeters and angstrom units (1 Å = 10⁻⁸ cm).

Record the grating constant of your telescope:

\[ N = 6,000 \text{ cm}^{-1} \] (N is the number of grooves per centimeter)
\[ d = \frac{1}{N} = 1.67 \times 10^{-4} \text{ cm} = 1.67 \times 10^4 \text{ Angstroms} \]

**DETERMINATION OF THE WAVELENGTHS (λ) OF SPECTRAL LINES**

* The symbol for Angstroms is 10⁻⁸ cm
5. **Mount the mercury discharge tube** in its power supply holder and place in front of the collimator slit. *(Caution* should be observed, as the discharge tube operates at high voltage and you could receive an electrical shock. If a large mercury source is used, it should be properly shielded because of the ultraviolet radiation that may be emitted. Consult with your instructor.) Turn on the power supply and observe the first \((n = 1)\) - and second \((n = 2)\) - order mercury line spectra on the left of the central image.

6. Because some of the lines are brighter than others and the weaker lines are difficult to observe in the second-order spectra, the wavelengths of only the brightest lines will be determined. Find the listing of the mercury spectral lines in the Appendix Table, and record the color and wavelength (in Å) in Data Table 2. Then, beginning with either first-order spectra, set the telescope cross-hairs on each of the four brightest spectral lines and record the divided circle readings (read to the nearest minute of arc). Repeat the readings for the first-order spectrum on the opposite (right) side of the central image.

7. Repeat the measurement procedure for the four lines in the second-order spectra and, using Eq. 3, compute the wavelength of each of the lines for both order spectra. Compare with the accepted values by computing the percent error of your measurements in each case. *(Note: In the second-order spectra, two yellow lines—a doublet—may be observed. Make certain that you choose the appropriate line.)* *(Hint: See the wavelengths of the yellow lines in the Appendix Table at the end of the lab. Which is closer to the red end of the spectrum?)*

---

**Un-deviated Light (0°)**

**Mercury Lamp – Yellow Doublet**

**Mercury Lamp – Green Line**

**Mercury Lamp – Blue Line**
LABORATORY REPORT

Number of lines per unit length on grating (N): Click here to enter.

Grating constant, $d = 1/N$ = Click here to enter. (cm)

A. Spectrometer Method  
Determination of the Wavelength Range

of the Visible Spectrum DATA TABLE 1

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>$\theta$</th>
<th>$\sin \theta$</th>
<th>Computed Wavelength (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations (show work)

<table>
<thead>
<tr>
<th>Wavelengths of Spectral Lines</th>
<th>Mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda$(Å)</td>
<td>Color</td>
</tr>
<tr>
<td>4047</td>
<td>Violet</td>
</tr>
<tr>
<td>4078</td>
<td>Violet</td>
</tr>
<tr>
<td>4358</td>
<td>Blue-Violet</td>
</tr>
<tr>
<td>4916</td>
<td>Blue-Green</td>
</tr>
<tr>
<td>5461</td>
<td>Green</td>
</tr>
<tr>
<td>5770</td>
<td>Yellow</td>
</tr>
<tr>
<td>5791</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Click here to enter calculations.
Determination of the Wavelengths ($\lambda$) of Spectral Lines

DATA TABLE 2 (Mercury Spectrum)

N = (300) Lines/mm

d = (1/N) = 1/(300 lines/mm) = (1/300) (mm/line) = 0.00333 (mm/line)

= 3.33 x 10^{-3} \text{ mm} = 3.33 x 10^{-6} \text{ m} = 3.33 x 10^{-6} (100 \text{ cm})

= 3.33 x 10^{-6} (100 \times 10^8 \text{ Å}) = 3.33 x 10^{-6} (10^{10} \text{ Å})

= 3.3333 x 10^4 \text{ Å} = 33333 \text{ Å}

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength ($\lambda$)</th>
<th>$\sin \theta$</th>
<th>Computed $\lambda$ (Å)</th>
<th>Percent error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>4916</td>
<td>7</td>
<td>0.121869 (33333) (0.121869)</td>
<td>4062 Å = $\lambda$</td>
</tr>
<tr>
<td>Green</td>
<td>5461</td>
<td>9</td>
<td>0.156434</td>
<td>5214 Å</td>
</tr>
<tr>
<td>Orange</td>
<td>5900</td>
<td>10</td>
<td>0.173648</td>
<td>5788 Å</td>
</tr>
<tr>
<td>Violet</td>
<td>4078</td>
<td>15</td>
<td>0.258819</td>
<td>8627 Å</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength ($\lambda$)</th>
<th>$\sin \theta$</th>
<th>Computed $\lambda$ (Å)</th>
<th>Percent error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>4916</td>
<td>17</td>
<td>0.29237 (33333) (0.29237)</td>
<td>4872 Å = $\lambda$</td>
</tr>
<tr>
<td>Green</td>
<td>5461</td>
<td>19</td>
<td>0.32557</td>
<td>5426 Å</td>
</tr>
<tr>
<td>Orange</td>
<td>5900</td>
<td>20</td>
<td>0.34202</td>
<td>4700 Å</td>
</tr>
<tr>
<td>Violet</td>
<td>4078</td>
<td>21</td>
<td>0.35837</td>
<td>5972 Å</td>
</tr>
</tbody>
</table>

Calculations (show example work for a first order line and a second order line)

Click here to enter calculations.
Conclusion

After group discussion, write a conclusion which summarizes the results of this experiment.

Click here to enter calculations.
## APPENDIX

### TABLE: Major Visible Spectral Lines of Some Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Wavelength (Å)</th>
<th>Color</th>
<th>Relative intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helium</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3889</td>
<td>Violet</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>3965</td>
<td>Violet</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>4026</td>
<td>Violet</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>4388</td>
<td>Blue-violet</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4471</td>
<td>Dark blue</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>4713</td>
<td>Blue</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>4922</td>
<td>Blue-green</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5015</td>
<td>Green</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>5876</td>
<td>Yellow</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td><strong>Mercury</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6678</td>
<td>Red</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>7065</td>
<td>Red</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>4047</td>
<td>Violet</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>4078</td>
<td>Violet</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>4358</td>
<td>Blue</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>4916</td>
<td>Blue-green</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5015</td>
<td>Green</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td><strong>Sodium</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5770</td>
<td>Yellow</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>5790</td>
<td>Yellow</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>6907</td>
<td>Red</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>4494</td>
<td>Blue</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>4498</td>
<td>Blue</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>4665</td>
<td>Blue</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>4669</td>
<td>Blue</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>4983</td>
<td>Green</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>5149</td>
<td>Green</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>5153</td>
<td>Green</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>5670</td>
<td>Green</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>5675</td>
<td>Green</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>5876</td>
<td>Yellow</td>
<td>1000</td>
<td></td>
</tr>
</tbody>
</table>

### Wavelengths of various colors (A)

<table>
<thead>
<tr>
<th>Color</th>
<th>Representative</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>6500</td>
<td>6470 - 7000</td>
</tr>
<tr>
<td>Orange</td>
<td>6000</td>
<td>5840 - 6470</td>
</tr>
<tr>
<td>Yellow</td>
<td>5800</td>
<td>5750 - 5850</td>
</tr>
<tr>
<td>Green</td>
<td>5200</td>
<td>4912 - 5750</td>
</tr>
<tr>
<td>Blue</td>
<td>4700</td>
<td>4240 - 4912</td>
</tr>
<tr>
<td>Violet</td>
<td>4100</td>
<td>4000 - 4200</td>
</tr>
</tbody>
</table>

Visible spectrum = 4000 - 7000
Optics
Velocity of light
Measuring with short light pulses

Determining the velocity of light in the air from the path and transit time of a short light pulse

Objects of the experiment
- Relatively measuring the transit time \( t \) of a short light pulse with an oscilloscope as a function of the position \( s \) of the reflecting mirror.
- Determining the velocity of light in the air from the slope of the graph \( s = f(t) \).
- Absolutely measuring the transit time \( t \) of a short light pulse with an oscilloscope for a given path \( 2s \) by marking the zero point with a reference mirror.
- Determining the velocity of light in the air as the quotient of the path and the transit time.
- Calibrating the time measurement using a quartz-controlled oscillator signal.
- Absolutely measuring the transit time \( t \) of a short light pulse for a given path \( 2s \) by marking the zero point with a reference mirror.
- Determining the velocity of light in the air as the quotient of the path and the calibrated transit time.

Principles
The light velocity measuring instrument emits extremely short pulses of red light with a pulse width of about 20 ns via a high-performance LED. After traversing a known measuring distance in both directions, the light pulses are converted into voltage pulses for observation on the oscilloscope.

Path of the light:
The light source, a bright red (\( \lambda = 615 \text{ nm} \)) LED, is focused through the window \( F_1 \) of the light velocity measuring instrument on infinity by the lens \( L \). The large triple mirror \( T_1 \) reflects the beam path on itself, so that the LED is imaged on itself (see Fig. 1).

The beam divider \( S \) in the light velocity measuring instrument reflects the returning light downward onto the photodiode \( D \). At the same time, it reflects half of the light coming from the LED upward, where it emerges through window \( F_2 \). This upward beam path is equivalent to the horizontal path.

The small triple mirror \( T_2 \) directly above \( F_2 \) generates a reference pulse with negligible transit-time delay and has no effect on the measuring beam.

Measuring method:
A measuring distance of 10 m corresponds to a transit time of the light pulse of around 60 ns for the outgoing and return distances. The pulse width of approx. 20 ns is matched to this transit time. The special design of the light velocity measuring instrument permits the use of a relatively simple oscilloscope.
The light pulses are emitted with a high repetition frequency of 40 kHz. This ensures sufficient brightness of the signal on the oscilloscope screen, even when using the maximum deflection speed of the oscilloscope.

Just before the light pulse is emitted in the light velocity measuring instrument, a trigger signal is output for externally triggering the oscilloscope. Therefore, the complete voltage pulse appears on the oscilloscope screen even when the transit time of the light pulse is negligibly short, i.e. when the triple mirror is at a minimum distance in front of F1 or above F2. It is thus not necessary to use an oscilloscope with built-in delay line.

When we increase the distance between the large triple mirror and the outlet window, the pulse signal on the oscilloscope is shifted farther to the right in response to the longer transit time. We can calculate the velocity of light as the quotient of the change in the distance and the change in the transit time. When using the reference pulse via the small triple mirror, the total transit time can be determined on the oscilloscope in absolute terms. The light velocity is then calculated as the quotient of the distance and the transit time.

To calibrate the time measurement, a quartz-controlled oscillator signal can be displayed simultaneously on the oscilloscope. As the oscillator signal can by shifted by more than one period with respect to the measuring pulse, its edges are most suitable for use as a measuring benchmark. In this case, the time measurement is independent of the time base of the oscilloscope.

The light pulses are emitted with a high repetition frequency of 40 kHz. This ensures sufficient brightness of the signal on the oscilloscope screen, even when using the maximum deflection speed of the oscilloscope.

Just before the light pulse is emitted in the light velocity measuring instrument, a trigger signal is output for externally triggering the oscilloscope. Therefore, the complete voltage pulse appears on the oscilloscope screen even when the transit time of the light pulse is negligibly short, i.e. when the triple mirror is at a minimum distance in front of F1 or above F2. It is thus not necessary to use an oscilloscope with built-in delay line.

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The light pulses are emitted with a high repetition frequency of 40 kHz. This ensures sufficient brightness of the signal on the oscilloscope screen, even when using the maximum deflection speed of the oscilloscope.

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To calibrate the time measurement, a quartz-controlled oscillator signal can be displayed simultaneously on the oscilloscope. As the oscillator signal can by shifted by more than one period with respect to the measuring pulse, its edges are most suitable for use as a measuring benchmark. In this case, the time measurement is independent of the time base of the oscilloscope.

- Mount the lens on the optical bench about 20 cm from the light velocity measuring instrument, with its midpoint at the same height as window F1.
- Attach the large triple mirror to stand material (see Fig. 2) and set it up several meters from the light velocity measuring instrument. Align the midpoint in the same height as the optical axis and the mirror surface approximately perpendicular to this axis.
- Switch on the light velocity measuring instrument by plugging in the plug-in unit.

If, when looking past the lens from a vantage point just above the light velocity measuring instrument, the triple mirror does not appear red or is red only at the edges:
- Vary the beam direction by tilting and swiveling the optical bench, and change the height of the lens if necessary, so that the beam strikes the triple mirror in the center.

Connecting the oscilloscope:
- Connect the “pulse” output with oscilloscope channel I and the “trigger” output to the external triggering input using BNC cables.

Table 1: Oscilloscope settings, e.g. for the two-channel oscilloscope 303 (Cat. No. 575 211).

<table>
<thead>
<tr>
<th>Operating mode:</th>
<th>Channel I only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel I:</td>
<td>DC, 5–100 mV/cm</td>
</tr>
<tr>
<td>Zero line:</td>
<td>bottom edge of screen</td>
</tr>
<tr>
<td>Triggering:</td>
<td>external, AC, + (rising edge)</td>
</tr>
<tr>
<td>Triggerlevel:</td>
<td>automatic</td>
</tr>
<tr>
<td>Time-base sweep:</td>
<td>0,2 μs/cm, cal.</td>
</tr>
<tr>
<td>X-magnification:</td>
<td>1×</td>
</tr>
<tr>
<td>Intensity:</td>
<td>maximum</td>
</tr>
</tbody>
</table>

- Using the oscilloscope settings from table 1, find a voltage pulse.
- Set up the large triple mirror at the maximum distance anticipated for this experiment and optimize the pulse amplitude by slightly varying the optical adjustment, particularly by moving the lens on the optical bench.
- Switch the x-magnification of the oscilloscope to 10×.

Carrying out the experiment

a) Measuring the transit time as a function of the position of the triple mirror:
- Set up the large triple mirror close to the optical bench and mark its position.
- Shift the maximum of the voltage pulse to a vertical grid line on the left side of the oscilloscope screen by varying the x-position (see Fig. 3, top).
- Move the large triple mirror in the beam path, measure the change in distance s and write this value in your experiment log.
- Read the shift in the time t of the voltage pulse from the oscilloscope (see Fig. 3, top) and write this value in your experiment log.
- Repeat your measurements for further shifts in s (see  table 2).

Setup
Set up the experiment as shown in Fig. 2.

Mechanical and optical setup:
- Place the optical bench on a table of suitable height and mount the light velocity measuring instrument on the optical bench so that window F1 is facing the lens (see Fig. 2).
- Mount the lens on the optical bench about 20 cm from the light velocity measuring instrument, with its midpoint at the same height as window F1.
- Attach the large triple mirror to stand material (see Fig. 2) and set it up several meters from the light velocity measuring instrument. Align the midpoint in the same height as the optical axis and the mirror surface approximately perpendicular to this axis.
- Switch on the light velocity measuring instrument by plugging in the plug-in unit.

If, when looking past the lens from a vantage point just above the light velocity measuring instrument, the triple mirror does not appear red or is red only at the edges:
- Vary the beam direction by tilting and swiveling the optical bench, and change the height of the lens if necessary, so that the beam strikes the triple mirror in the center.

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<tr>
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</tr>
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<td>1×</td>
</tr>
<tr>
<td>Intensity:</td>
<td>maximum</td>
</tr>
</tbody>
</table>

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- Set up the large triple mirror at the maximum distance anticipated for this experiment and optimize the pulse amplitude by slightly varying the optical adjustment, particularly by moving the lens on the optical bench.
- Switch the x-magnification of the oscilloscope to 10×.

Carrying out the experiment

a) Measuring the transit time as a function of the position of the triple mirror:
- Set up the large triple mirror close to the optical bench and mark its position.
- Shift the maximum of the voltage pulse to a vertical grid line on the left side of the oscilloscope screen by varying the x-position (see Fig. 3, top).
- Move the large triple mirror in the beam path, measure the change in distance s and write this value in your experiment log.
- Read the shift in the time t of the voltage pulse from the oscilloscope (see Fig. 3, top) and write this value in your experiment log.
- Repeat your measurements for further shifts in s (see table 2).
b) Measuring the transit time with a reference mirror:

- Push the assembly to the left-hand edge of the table, sight downward along the vertical edge of the light velocity measuring instrument and mark the position on the floor (see Fig. 4).
- Hold the small triple mirror directly in front of F₁ and shift the maximum of the voltage pulse to a vertical grid line on the left side of the oscilloscope screen by varying the x-position.
- Then, lay the small triple mirror on F₂ and make sure that the position of the reference pulse on the oscilloscope has not changed (equal light paths).
- Place the large triple mirror in the beam path at a distance of at least 10 meters so that the measurement pulse appears on the oscilloscope screen as a second signal at a clear distance from the reference pulse.
- By carefully moving the small triple mirror on the window opening, adjust the two signals to exactly the same amplitude. Shift the rising edge of the reference pulse so that it crosses the center line where this intersects with a vertical grid line (see Fig. 5).
- Read off the transit time \( t \) at the intersection of the second pulse with the center line (see Fig. 5) and write this value in your experiment log.

Note: the time interval between the reference pulse and the measuring pulse can only agree with the spacing between the two rising edges on the oscilloscope when both pulses have the same amplitude and the distance is significantly greater than the pulse width.

- Mark the position of the large triple mirror on the floor, measure the distance \( s \) to window F₁ and write this value in your experiment log (see Fig. 4).

---

Fig. 2: Experiment setup for measuring the velocity of light

Fig. 3: Relative measurement of the transit time \( t \) of the light pulse
c) Measuring the transit time with an externally calibrated time base:

- Place the small triple mirror on F2 and the large triple mirror in the beam path about 15 m away so that you can see two pulses on the oscilloscope screen.
- If necessary, maximize the distance between the two pulse signals on the oscilloscope screen by varying the time-base sweep.
- By carefully moving the small triple mirror on window opening F2, adjust the two signals to exactly the same amplitude.
- Connect the 10-MHz output of the light velocity measuring instrument to oscilloscope channel II via a third BNC cable.
- Select dual-channel mode (“dual” button) and activate oscilloscope channel II (AC, 0.1 V/cm), so that the measuring pulses and the oscillator signal are visible simultaneously.
- Using the phase adjuster on the light velocity measuring instrument, shift the 10 MHz signal so that the rising edge of the first voltage pulse is exactly coincident with a rising edge of the 10 MHz signal (see Fig. 6).
- Adjust the distance of the large triple mirror so that the rising edge of the second voltage pulse is exactly coincident with the next rising edge of the 10 MHz signal (see Fig. 6).
- If necessary, adjust the optical assembly or vary the triple mirrors until the voltage pulses of both triple mirrors are the same amplitude, and then readjust the positions of the rising edges.
- Mark the position of the light velocity measuring instrument and the large triple mirror on the floor (sight downward with one eye along the vertical edge of the device), measure the distance $s$ to window F1 and write this value in your experiment log (see Fig. 4).
Measuring example

a) Measuring the transit time as a function of the position of the triple mirror:

Table 2: Change in distance $s$ of the large triple mirror and the transit time $t$ of the light pulse

<table>
<thead>
<tr>
<th>$s$ [m]</th>
<th>$t$ [ns]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>3.0</td>
<td>20</td>
</tr>
<tr>
<td>6.0</td>
<td>41</td>
</tr>
<tr>
<td>9.0</td>
<td>60</td>
</tr>
<tr>
<td>12.0</td>
<td>81</td>
</tr>
<tr>
<td>15.0</td>
<td>101</td>
</tr>
<tr>
<td>18.0</td>
<td>122</td>
</tr>
</tbody>
</table>

b) Measuring the transit time with a reference mirror:

$s = 15.00$ m, $t = 99$ s

c) Measuring the transit time with an externally calibrated time base:

$s = 15.05$ m

Evaluation

a) Measuring the transit time as a function of the position of the triple mirror:

Fig. 6 shows the graph of the measured values for $s$ as a function of $t$. From the slope $a$ of the straight line through the measuring points, we obtain the following value for the velocity of light through air:

$$c = 2 \cdot a = 2.98 \cdot 10^8 \frac{m}{s}$$

b) Measuring the transit time with a reference mirror:

From the quotient of the distance $s$ and the transit time $t$, we obtain the following value for the velocity of light through air:

$$c = 2 \cdot \frac{s}{t} = 3.03 \cdot 10^8 \frac{m}{s}$$

c) Measuring the transit time with an externally calibrated time base:

The distance $s$ was selected so that the total transit time $t$ of the light pulse is 100 ns.

$$c = 2 \cdot \frac{s}{100 \text{ ns}} = 3.01 \cdot 10^8 \frac{m}{s}$$

d) Comparing the measuring methods:

In addition to the reading errors occurring for the time value in all measurements, we need to take the accuracy of the calibrated positions for the time-base sweep of the oscilloscope into consideration for measurements a) and b). For the oscilloscope used here, this value is 3 %.

e) Literature values

Velocity of light in a vacuum:

$$c_0 = 2.998 \cdot 10^8 \frac{m}{s}$$

Velocity of light through the air (phase velocity):

$$c = \frac{c_0}{n} = 2.997 \cdot 10^8 \frac{m}{s}$$

(Refractive index $n = 1.003$ at standard temperature and pressure)

Strictly speaking, the propagation velocity of the short light pulses in air corresponds to the group velocity of a wave packet. However, given the measuring accuracy attained here, there is no need to go into the difference between phase velocity and group velocity.
Irradiance and the inverse square law

What is irradiance?
Irradiance of radiation is a measure of the radiation falling on a surface. It is defined as the energy falling on a surface per unit time (i.e. the power per unit area, $P/A$). This relationship can be summarised:

$$I = \frac{P}{A}$$

$I$ = irradiance in (W/m$^2$)
$P$ = power in watts
$A$ = area in m$^2$

Why does the object of the irradiance?
An understanding of irradiance is relevant to a range of applications. For example, NASA observes solar irradiance to understand the activity of the Sun and climate scientists study solar irradiance to research the impact of solar activity on the Earth’s climate. Interactions between solar radiation and the atmosphere of the Earth can impact on air quality, and understanding of irradiance can allow investigation of the composition of the Earth’s atmosphere. Excessive exposure to sunlight has been linked to the development of a range of skin cancers. The performance of solar cells, an increasingly common use of solar radiation as an energy resource, requires an understanding of irradiance.

Investigating irradiance
The relationship between irradiance of a point source and the distance from that source can be investigated using a simple experimental set up: a light source and a linear light meter.

The graph of a typical set of results from such an experiment is shown below:

It is clear from this graph that the relationship between irradiance and distance is not a linear one ($P \propto 1/d^2$).
Graphing average irradiance against \((1/d)\) (\(d = \text{distance}\)) demonstrates that average irradiance is not proportional to \((1/d)\).

The graph of average irradiance against \((1/d^2)\) demonstrates a linear relationship.

From the graph:

\[ I \propto \frac{1}{d^2} \]

\(I = \text{irradiance in (W/m}^2)\)

\(Id^2 = \text{constant}\)

\(d = \text{the distance from a point source in m}\)

\(I_1d_1^2 = I_2d_2^2\)

This is described as an inverse square law.

A point source is one which irradiates equally in all directions, i.e. the volume that will be irradiated will be a sphere. The surface area of a sphere can be calculated using \((A = 4\pi r^2)\), i.e. the area which will be irradiated is proportional to \(r^2\) (or \(d^2\)).
Calculating solar irradiance and the power of the Sun: measuring a sunbeam
Watch the clip from ‘Measuring a sunbeam’ (BBC Wonders of the Solar System episode ‘Empire of the Sun’ at http://www.bbc.co.uk/programmes/p006szxm.

Professor Brian Cox uses a simple technique to measure the solar energy falling on the Earth, recreating an experiment first carried out by Sir John Herschel in 1838. Pause the clip and use your understanding of irradiance to make the calculations on the Sun’s irradiance.

Irradiance and the distance to the moon
When Neil Armstrong and Buzz Aldrin walked on the surface of the moon on 21 July 1969 as part of the Apollo mission, they set up a lunar laser ranging reflector array, a 0.6 m panel with 100 mirrors. This is the only experiment from the successful Apollo 11 mission that is still running.

The Apollo 11 lunar laser-ranging retro reflector array © NASA.

A laser pulse is transmitted from a telescope on Earth. The reflectors in the array are designed to send the pulse back precisely to the location from which it was transmitted. Telescopes on Earth receive the returned pulse.

Among its aims, the APOLLO project will measure the \((1/r^2)\) law (i.e. the inverse square law) at the lunar (Moon) distance scale, i.e. approximately \(10^{12}\) m.

Irradiance and the electromagnetic spectrum
The inverse square law applies to all electromagnetic radiation, i.e. to visible light and all wavelengths on the electromagnetic spectrum, from radio waves to gamma rays.
Inverse-square Law for Light

**Objective:**
To observe the inverse-square law relationship between the intensity of a light bulb and the distance away from the light bulb

**Equipment:**
1) Optical bench
2) Light Bulb with its Source
3) Light sensor with meter
4) Banana leads

**Procedure**
1. Fixed the light source at the end of the bench
2. Switch on the light bulb (The power source not exceeds 5 Volt)
3. Place the sensor towards the light bulb at a certain distance for example (20 cm).
4. Record the readings of both distance \(d, 20\ cm\) and the sensor \(I, mA\) on a Table.
5. Repeat the steps (3) and (4) for different values of distance, 30, 40, 50, 60, 70 cm and measure the readings of the sensor for each distance.
6. Record all results on the Table.
7. Draw the relation between the Intensity (sensor reading, Y-axis) and the distance \(d, cm\) on (X-axis)
8. The relation will investigate the Inverse square law (the slope will be 2).

<table>
<thead>
<tr>
<th>Distance ((d, cm))</th>
<th>Intensity ((mA))</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

**Table: The Inverse Square law Experimental Results**
Malus's Law

According to Malus, when completely plane polarized light is incident on the analyzer, the intensity \( I \) of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer.

\[
i.e \quad I \propto \cos^2 \theta
\]

Suppose the angle between the transmission axes of the analyzer and the polarizer is \( \theta \). The completely plane polarized light form the polarizer is incident on the analyzer. If \( E_0 \) is the amplitude of the electric vector transmitted by the polarizer, then intensity \( I_0 \) of the light incident on the analyzer is

\[
I \propto E_0^2
\]

The electric field vector \( E_0 \) can be resolved into two rectangular components i.e \( E_0 \cos \theta \) and \( E_0 \sin \theta \). The analyzer will transmit only the component (i.e \( E_0 \cos \theta \)) which is parallel to its transmission axis. However, the component \( E_0 \sin \theta \) will be absorbed by the analyser. Therefore, the intensity \( I \) of light transmitted by the analyzer is,

\[
I \propto (E_0 \cos \theta)^2
\]

\[
(I / I_0) = (E_0 \cos \theta)^2 / E_0^2 = \cos^2 \theta
\]

\[
I = I_0 \times \cos^2 \theta
\]

Therefore, \( I \propto \cos^2 \theta \). This proves law of Malus.

When \( \theta = 0^\circ \) or \( 180^\circ \), \( I = I_0 \cos^2 0^\circ = I_0 \) That is the intensity of light transmitted by the analyzer is maximum when the transmission axes of the analyzer and the polarizer are parallel.

When \( \theta = 90^\circ \), \( I = I_0 \cos^2 90^\circ = 0 \) That is the intensity of light transmitted by the analyzer is minimum when the transmission axes of the analyzer and polarizer are perpendicular to each other.
Malus' law - 2.5.04-00

What you can learn about ...
- Electric theory of light
- Polarization
- Polarizer
- Analyzer
- Brewster's law
- Malus' law

Principle:
Linear polarized light passes through a polarization filter. Transmitted light intensity is determined as a function of the angular position of the polarization filter.

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser, He-Ne 1.0 mW, 230 VAC</td>
<td>08181.93</td>
<td>1</td>
</tr>
<tr>
<td>Optical profile bench, f = 600 mm</td>
<td>08283.00</td>
<td>1</td>
</tr>
<tr>
<td>Base for optical profile bench, adjustable</td>
<td>08284.00</td>
<td>2</td>
</tr>
<tr>
<td>Slide mount for optical profile bench, h = 30 mm</td>
<td>08286.01</td>
<td>3</td>
</tr>
<tr>
<td>Polarization filter on stem</td>
<td>08630.00</td>
<td>1</td>
</tr>
<tr>
<td>Photoelement for optical base plate</td>
<td>07174.00</td>
<td>1</td>
</tr>
<tr>
<td>Digital multimeter 2030</td>
<td>07128.00</td>
<td>1</td>
</tr>
</tbody>
</table>

Complete Equipment Set, Manual on CD-ROM included
Malus' law
P2250400

Corrected photo-cell current as a function of the angular position $\varphi$ of the polarization plane of the analyzer.

Tasks:

1. The plane of polarization of a linear polarized laser beam is to be determined.

2. The intensity of the light transmitted by the polarization filter is to be determined as a function of the angular position of the filter.

3. Malus' law must be verified.
Study of Polarization by verification of Malu’s law

Introduction

Linear polarized light passes through a polarization filter. Transmitted light intensity is determined as a function of the angular position of the polarization filter. From this experiment one you can learn about…Electric theory of light, polarization, polarizer, analyzer, Brewster's law, Malus' law.

Objectives:

1. To determine the plane of polarization of a linear polarized laser beam.
2. To determine the intensity of the light transmitted by the polarization filter as a function of the angular position of the filter.
3. Malus’ law must be verified.

Equipments Needed:

1. Laser, He-Ne 1.0 mW, 220 V AC
2. Optical profile bench, l = 60 cm
3. Polarising filter on stem
4. Photodetector
5. Digital multimeter

Set-up and procedure:

1. The experiment is set up according to Fig. 1. It must be made sure that the photocell is totally illuminated when the polarization filter is set up.
2. If the experiment is carried out in a non darkened room, the disturbing background current i0 must be determined with the laser switched off and this must be taken into account during evaluation.
3. The laser should be allowed to warm up for about 30 minutes to prevent disturbing intensity fluctuations.
4. The polarization filter is then rotated in steps of 5° between the filter positions +/- 90° and the corresponding photo cell current (most sensitive direct current range of the digital multimeter) is determined.

Fig. 1: Experimental set-up: Malus’ law.
Theory and evaluation:

Let AA’ be the Polarization planes of the analyzer in Fig. 2. If linearly polarized light, the vibrating plane of which forms an angle X with the polarization plane of the filter, impinges on the analyzer, only the part

\[ E_A = E_0 \cdot \cos \varphi \]  \hspace{1cm} (1)

will be transmitted.

As the intensity I of the light wave is proportional to the square of electric field intensity vector E, the following relation (Malus’ law) is obtained

\[ I_A = I_0 \cdot \cos^2 \varphi \]  \hspace{1cm} (2)

![Figure 2: Geometry for the determination of transmitted light intensity.](image)

1. The experiment is set up according to Fig. 1. It must be made sure that the photocell is totally illuminated.

2. Using a digital multimeter the disturbing background current \( i_0 \) must be determined with the laser switched off. This must be taken into account during evaluation.

3. Switch ON the laser. It should be allowed to warm up for about 30 minutes to prevent disturbing intensity fluctuations.

4. The polarization filter is then rotated in steps of 5° between the filter positions +/- 90° and the corresponding photo cell current (most sensitive direct current range of the digital multimeter) is determined.

5. Make the table required for angle and the corrected photo current. Identify the intensity peak and show that the polarization plane of the emitted laser beam has already been rotated by this angle against the vertical. It may look like Fig. 3 below.

6. Show that the corrected and normalized photo cell current as a function of the angular position of the analyzer. It may look like Fig. 4 below. Malus's law is verified from the slope of the line.
Fig 3: Corrected photo cell current as a function of the angular position $\phi$ of the polarization plane of the analyzer.

Fig 4: Normalized photo cell current as a function of $\cos 2 \phi$.

Results and Discussion:

1. Estimate the experimental errors.
2. Explain different light phenomenon happening during this experiment.
What is diffraction?
When parallel waves of light are obstructed by a very small object (i.e. sharp edge, slit, wire, etc.),
the waves spread around the edges of the obstruction and interfere, resulting in a pattern of dark and
light fringes.

What does diffraction look like?
When light diffracts off of the edge of an object, it creates a pattern of light referred to as a
diffraction pattern.

If a monochromatic light source, such as a laser, is used to observe diffraction, below are some
examples of diffraction patterns that are created by certain objects:

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>DIFFRACTION PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sharp edge (i.e. razor blade)</td>
<td><img src="image" alt="Sharp edge" /></td>
</tr>
<tr>
<td>• Slit</td>
<td><img src="image" alt="Slit" /></td>
</tr>
<tr>
<td>• Wire</td>
<td><img src="image" alt="Wire" /></td>
</tr>
<tr>
<td>• Circular hole</td>
<td><img src="image" alt="Circular hole" /></td>
</tr>
</tbody>
</table>
How can I determine the thickness of an object if I know certain dimensions of my diffraction pattern?

The intensity distribution for a diffraction pattern from a single slit is described mathematically as a $sinc$ function where:

$$ Intensity = \left( \frac{\sin(y)}{y} \right)^2 $$

The intensity looks like the plot below versus position $y$, where $y_z$ are the minimums (or zeros):

![Intensity plot](image)

Minimums are caused by the destructive interference of plane waves diffracting off the edges of the slit. Destructive interference happens when two plane waves are out of phase to one another. When the phase difference, $\beta$, of two plane waves are equal to multiples of $\pi$, then a minimum occurs. We have the following:

$$ \beta = \frac{\pi d}{\lambda} \sin \theta', \quad \text{and zeros occur when} \quad \beta = z\pi \quad \text{when} \quad z = \pm 1, \pm 2, \pm 3, \ldots $$

thus, zeros will occur when,

$$ z\lambda = dsin\theta' $$
Geometrically, we can derive the relationship between the diameter of the slit, \( d \), and the distance to a minimum or zero in the sinc function, \( y_z \). Here is how we set up the problem, we have:

- \( d \) = slit diameter
- \( z \) = a minimum or zero (\( \pm 1, \pm 2, \pm 3, \ldots \))
- \( \theta' \) = diffracted wave angle
- \( \lambda \) = laser wavelength
- \( \theta_z \) = sinc(y) function angle for zero
- \( D \) = distance from slit to screen
- \( y_z \) = distance from center of diffraction pattern to a minimum or zero.

**Assumptions:**

- \( D \gg d \), therefore \( \theta' \approx \theta_z \)

\[
\tan \theta_z = \frac{y_z}{D} \quad \text{and} \quad \tan \theta_z \approx \sin \theta_z \approx \theta \approx \frac{y_z}{D}
\]

**Condition for a zero:** \( D \sin \theta_z = z\lambda \)

Thus, \( d = \frac{z\lambda D}{y_z} \)

**Can one use the same formula for measuring the thickness of a wire or human hair?**

Yes. The distance from the minimums to the center of the diffraction pattern is still the same for the diffraction pattern caused by a wire of the same thickness as a slit. The only difference is that the center of the diffraction pattern looks brighter because the percentage of the laser beam that is not diffracted by the wire add to the intensity of the center of the pattern.

**One can also calculate the wavelength, \( \lambda \), of their laser if they measure \( y_z \) from a diffraction pattern of a slit or wire of known \( d \).**
How can you demonstrate the relationship between the diffraction pattern from a slit or a wire and the thickness of the slit or wire?

If we solved the previous equation for \( y_z \), (assuming that we will look at the first minimum in the pattern, \( z=1 \)) we get:

\[
y = \frac{\lambda D}{d}
\]

You can make a variable slit by using the following:

- (2) 1” square pieces of aluminum foil
- scotch tape
- 1 empty CD jewel case.

1. Fold each piece of aluminum foil in half and flatten the fold with something non-metallic (such as plastic scissor handles). Flattening the fold should create a sharper edge.

2. Tape one of the folded and flattened pieces of aluminum foil to the inside of the CD case. (see below left)

3. Overlap the other piece of folded aluminum foil (such that the folds are facing one another), and tilt it slightly until a variable thickness slit is formed. The slit should be very thin at the top and wider at the bottom. (see above right)

4. Stand the CD case upright, and using a laser, shine it through the slit so that the diffracted pattern can be seen on a wall, black board or screen behind the CD Case. Watch how the pattern changes in width as you move the laser up and down along the axis of the slit.

As the slit gets bigger, what happens to the width of the diffraction pattern? (Remember from the equation at the top of the page, that the thickness of the slit, \( d \), is in the denominator!)

Next ask, what would happen to the width of the pattern if the thickness of the slit stayed the same, but the wavelength of the laser, \( \lambda \), would change?
What would be a common object to compare the thicknesses using diffraction?

A human hair is ideal to compare in a classroom!

For middle schoolers: students can compare the width of the diffraction pattern for different hairs measured. Keep the laser and the distance, D, to the wall or screen the same. Tape various students hairs vertically to the inside of a CD case (make sure you remember which hair is which!) Move the CD case so that each hair is illuminated in turn and have the students measure the width of the diffraction pattern from the center to the first minimum. Who has the thickest hair in the class based on the measurements? Who has the thinnest?

For high schoolers: students can measure the diffraction pattern with hairs set up the same as the in middle schoolers experiment, but, they can enter the measured data to actually calculate the thickness of each hair measured. Students can then determine the average hair thickness in their classroom and the standard deviation. Does curly hair tend to be thicker than straight hair? What about blonde hair and brown hair – any difference?

** for actual hair thickness measurements, the students will need to determine the wavelength of their laser. This can be accomplished by measuring the width of the diffraction pattern by using a wire of known thickness OR using a Compact Disc in the final experiment listed in this lesson plan.
What does diffraction look like for an object with a periodic structure?
If a laser is used to observe diffraction, below are some examples of diffraction patterns that are created by certain objects with repeating patterns:

<table>
<thead>
<tr>
<th>OBJECT (looking end-on)</th>
<th>DIFFRACTION PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grating</td>
<td>![Image of a grating diffraction pattern]</td>
</tr>
<tr>
<td>Mesh</td>
<td>![Image of a mesh diffraction pattern]</td>
</tr>
</tbody>
</table>
What is the relationship between the diffraction pattern and something with a periodic or repetitive structure like a grating?

The diffraction pattern from a grating differs from the pattern from and individual object. Let’s get a sense of the wave behavior from a number of slits combined. If we look at the combined wavelets shown by the figure below, one can see different orders, m, of wavelets moving away from the slits.

![Diffraction Patterns](image1.png)

It has been shown previously that the shape of a diffraction pattern intensity from a single slit. When plane waves diffracted from multiple slits (# = N), of equal distance apart, are combined, the diffraction pattern get more complicated mathematically. The equation for the diffraction pattern intensity becomes:

\[
\text{Intensity} \rightarrow \left(\frac{\sin \beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin \alpha}\right)^2
\]

where \( \beta = \) phase difference between diffracted waves from individual slit, and \( \alpha = \) phase difference between waves diffracted off of N slits

A generalized plot of the intensity is shown below.

![Generalized Plot](image2.png)
Let’s look at the geometry of two types of gratings, one that transmits and one that reflects.

The Grating Equation

Transmission Grating

\[ AB - CD = a \sin \theta_m - \sin \theta_i \]

Reflection Grating

\[ AB - CD = a \sin \theta_m - \sin \theta_i \]

When taking measurements on the diffraction pattern from a grating, one would measure the distances between the central order (or 0th order) and higher order maxima. Therefore, the measured areas of the pattern are where there is constructive interference. Maxima created by constructive interference occur when the difference in phase, \( \alpha \), is a multiple of \( \pi \). At normal incidence, when \( \theta_i = 0 \), we have the following:

\[ \alpha = \frac{\pi a}{\lambda} \sin \theta_m, \text{ and maxima occur when } \alpha = m\pi \text{ when } m = 0, \pm 1, \pm 2, \ldots \]

thus, maxima will occur when, \[ m\lambda = a \sin \theta_m \] The Grating Equation
Can one use a Compact Disc like a reflection grating?

Absolutely!! One can use a compact disc to determine the wavelength of your laser pointer. First, set your laser pointer up behind a cardboard screen with a hole in it for the laser to pass through. Then place the CD in the path of the laser (in the location indicated) so that the 0th order of the diffracted laser beam reflects back through the hole in the screen. (note: you can use the CD case to hold the CD upright. Notice the area of the CD that should be illuminated by the laser.)

We have,

\[ D = \text{distance from CD to screen.} \]
\[ y_1 = \text{distance from central beam to 1st diffracted order.} \]
\[ \theta_1 = \text{angle of 1st diffracted order.} \]
\[ \lambda = \text{laser wavelength} \]
\[ a = \text{CD pit spacing} = 1.6 \times 10^{-6} \text{ meters (shown below)} \]
Now, if we look at the geometry of our set-up, we have:

\[ \theta_1 - D \]

\[ \sin \theta_1 = \sin \left( \tan^{-1} \frac{y_1}{D} \right) \]

If your students are not familiar with trigonometry, then:

\[ \sin \theta_1 = \frac{y_1}{\sqrt{D^2 + y_1^2}} \]

and, \( \lambda = a \sin \theta_1 \)

Reference
Related topics
Interference, wavelength, refractive index, velocity of light, phase, virtual light source.

Principle and task
In the Michelson arrangement interference will occur by the use of 2 mirrors. The wavelength is determined by displacing one mirror using the micrometer screw.

Equipment
Michelson interferometer 08557.00 1
Laser, He-Ne 1.0 mW, 220 V AC 08181.93 1
Swinging arm 08256.00 1
Lens, mounted, f +20 mm 08018.01 1
Lens holder 08012.00 1
Slide mount f. opt. pr.-bench, h 30 mm 08286.01 3
Optical profile bench l = 60 cm 08283.00 1
Base f. opt. profile-bench, adjust. 08284.00 2
Screen, metal, 300×300 mm 08062.00 1
Barrel base -PASS- 02006.55 1

Problems
Determination of the wavelength of the light of the used laser.

Set-up and procedure
The experimental set up is as shown in Fig. 1. In order to obtain the largest possible number of interference fringes, the two mirrors of the interferometer are first of all adjusted; to do this, the lens is first of all removed. The laser beam strikes the half-silvered mirror at an angle of 45° splitting the beam. The resulting two beams are reflected by the mirror and impinge on the screen. By means of the two adjusting screws fitted to one of the mirrors, both points of light are made to coincide. If the lens is placed in the light beam, the points of light are enlarged and the interference patterns are observed on the screen (bands, circles). By careful readjustment, an interference image of concentric circles will be obtained.

To measure the wavelength, the micrometer screw is turned to any initial position at which the centre of the circles is dark. The micrometer screws is now further turned in the same direction and the light-dark periods thus produced are counted. The distance travelled by the mirror must be read off on the micrometer screw and divided by ten (lever reduction 1:10). Should the central point of the circles move outside the light spot area a readjustment has to be performed.

Caution: Never look directly into a non attenuated laser beam

Fig. 1: Experimental set-up for measuring wavelengths with the Michelson interferometer.
Theory and evaluation

If 2 waves of the same frequency $\omega$ but of different amplitude and different phase impinge on one point they are superimposed, or interfere, so that:

$$y = a_1 \sin (\omega t - \alpha_1) + a_2 \sin (\omega t - \alpha_2).$$

The resulting wave can be described as

$$y = A \sin (\omega t - \alpha)$$

with the amplitude

$$A_2 = a_1^2 + a_2^2 + 2a_1a_2 \cos \delta$$

and

$$\delta = \alpha_1 - \alpha_2.$$  \hspace{1cm} (1)

In a Michelson interferometer, light is split up into two beams by a half-silvered glass plate (amplitude splitting), reflected by two mirrors, and passed again through the glass plate to produce interference phenomena behind it.

A lens is inserted between the light beam and the glass plate so that the light source lies at the focal point, since only enlarged light spots can exhibit interference phenomena behind it.

If the actual mirror $M_2$ is replaced by its virtual image $M_2'$ which is formed by reflection at the glass plate, a point $P$ of the real light source is formed as the points $P'$ and $P''$ of the virtual light sources $L_1$ and $L_2$.

Based on the different light paths, the phase difference, using the symbols of Fig. 3, is:

$$\delta = \frac{2\pi}{\lambda} 2d \cos \theta$$

\hspace{1cm} (2)

where $\lambda$ is the wavelength of the light used in the experiment.

The intensity distribution for $a_1 = a_2 = a$ according to (1) is:

$$I = A^2 = 4a^2 \cos^2 \frac{\delta}{2}$$

\hspace{1cm} (3)

Maxima thus occur if $\delta$ is a multiple of $2\pi$, i.e. from equation (2), if

$$2d \cos \theta = m\lambda; m = 1, 2, \ldots$$

\hspace{1cm} (4)

i.e. circles are produced for a fixed value of $m$ and $d$ since $\theta$ remains constant (see Fig. 3).

If the position of the movable mirror $M_1$ is changed so that $d$ for example decreases then, according to equation (4), the diameter of the ring will also decrease since $m$ is fixed for this ring. A ring thus disappears each time $d$ is reduced by $\lambda/2$. The ring pattern disappears if $d = 0$.

If $M_1$ and $M_2$ are not parallel, curved bands are obtained which are converted to straight bands when $d = 0$.

To measure the wavelength of the light, 500 ring changes were counted. A 158 $\mu$m displacement of the mirror was measured. From this, the wavelength was obtained as:

$$\lambda = 632 \text{ nm}.$$
Physics 445LW
Modern Physics Laboratory
Stefan-Boltzmann

Introduction

The problem of blackbody radiation was one of the central sticking points of classical physics. Each time an explanation of the phenomena was proposed experimental results showed it to be inadequate. The problem was especially difficult when considering the thermal radiation analyzed over all wavelengths of light. In this experiment we will only consider the aggregate case.

Theory

Thermal radiation was defined by Maxwell as when "the hot body loses energy and the cold body gains energy by some process occurring in the intervening medium, which does not itself thereby absorb energy." If the intervening medium is vacuum or a gas consisting of symmetric molecules, then it can be considered to be "thermally transparent”. However, if the medium consists of non-symmetric molecules such as H₂O or CO₂ energy may be strongly absorbed at some wavelengths. [1]

The rate at which an object radiates energy is proportional to the fourth power of its absolute temperature. This is known as Stefan's law and is expressed as

\[ P = \alpha A e T^4 \]

where \( P \) is power in watts, \( A \) is the area of the object in square meters, \( e \) is the emissivity of the object which depends on the character of the object, \( T \) is the temperature in kelvins, and \( \alpha \) is a constant known as the Stefan-Boltzmann constant.

As an object radiates energy it also absorbs energy from its surroundings otherwise it would eventually radiate all its energy and reach absolute zero. So, if an object is at temperature \( T \) and its surroundings are at an average temperature \( T_0 \), then its net rate of energy change is given by

\[ P_{\text{net}} = \alpha A e (T^4 - T_0^4) \]

An object which absorbs all of the energy which falls on it is called an ideal absorber or blackbody. For such a body \( e = 1 \). In this experiment we will determine the constant \( \alpha \) which is referred to as the Stefan-Boltzmann constant. For more information see [6] or [7].
**Experimental Apparatus and Procedures**

**Apparatus**

The apparatus is the Laws of Radiation apparatus supplied by Klinger Educational Products with local modifications. The system consists of an electric oven that heats a burnished brass cylinder 3.5 cm in diameter by 10 cm long. The oven has a 2.9 cm hole in one end for emission of radiation and a 1.2 cm hole in the other end for the temperature probe. The temperature probe is a NiCr-Ni sensor with a digital thermometer. The oven is powered by a Powerstat variable autotransformer that is connected through a safety box. The oven is shielded by a water cooled blackbody accessory with a 1.7cm opening. The power is measured by a Scientech 361 power meter and sensor. The oven, temperature probe, blackbody accessory, and power meter sensor are all mounted on a graduated rail.

**Procedure**

First, check to see that all the electrical components are plugged in. Set the digital thermometer selector switch to ":<200°C". Turn on the cooling water. Set the power meter selector dial to .03 and zero the meter for ambient conditions. Record the ambient temperature. Switch on the transformer and the safety box. Set the transformer to 120 V. As the temperature increases we record the temperature and power meter readings at 25°C intervals when the temperature exceeds 200°C you will need to change the thermometer selector switch to ">200°C". When the temperature reaches a value between 350°C and 400°C rotate the transformer dial to zero and switch it off. Then record temperatures and power meter readings at 25 degree intervals as the temperature falls back to room temperature. Since we must account for both the energy emitted by the blackbody and the energy absorbed by the body we use the value $T^d - T_0^d$ to calculate the Stefan-Boltzmann constant. Also, we must calculate power per unit area and account for the emissivity of the burnished brass. For this experiment $e = 0.61$. [5].

**Conclusions**

Make plots of your data and compute the Stefan-Boltzmann constant. Discuss sources of error and do an error analysis.

Scientech 361 power meter

Digital thermometer sensor

Oven and accessory shield

Safety box

All components assembled
Stefan-Boltzmann law: measuring the radiant intensity of a “black body” as a function of temperature

Principles

All bodies radiate heat. The intensity of this thermally excited electromagnetic radiation increases with the temperature of the body, and is also dependent on the surface of this body. At a given wavelength, the more heat a body radiates, the better it can absorb this radiation.

A body which completely absorbs heat radiation of all wavelengths is called a black body. It was Kirchhoff who first proposed using a cavity as a virtually ideal black body. The black body has the greatest absorption factor, and thus, at a given temperature and wavelength, the highest possible emissivity as well.

The Stefan-Boltzmann law states that the total emitted radiation of a black body increases proportionally to the absolute temperature $T$ raised to the fourth power. More precisely, the radiant exitance $M$, i.e. the total power radiated on one side of the surface with reference to the area of the radiating surface, is defined as

$$M = \sigma T^4$$  \hspace{1cm} (I)

($\sigma = 5.67 \cdot 10^{-8} \text{ W/m}^2\text{K}^4$ Stefan-Boltzmann constant)

At the same time, the black body absorbs radiation from its environment. Thus, we do not measure the total radiated radiant exitance $M$, but rather the radiant exitance $M'$ withdrawn from the black body by radiation. The radiant exitance absorbed from the environment is

$$M_0 = \sigma T_0^4$$  \hspace{1cm} (II)

Therefore, it follows that

$$M' = \sigma (T^4 - T_0^4)$$  \hspace{1cm} (III).

In this experiment, an electric oven with a black body accessory is used as the “black body”. The black body accessory consists of a burnished brass cylinder and a screen. The brass cylinder, which is sealed at one end, is slid into the electric oven and heated to the desired temperature. The screen, which can be water-cooled if necessary, is arranged in front of the electric oven, so that essentially only the thermal radiation of the burnished cylinder is measured, and not the outer wall of the hot oven. An NiCr-Ni temperature sensor is used to measure the temperature at the brass cylinder.

The thermal radiation is measured using a Moll’s thermopile to which a microvoltmeter is connected. The thermopile contains a number of thermocouples connected in series. The measuring points absorb the incident radiation almost completely, while the comparison points are at the ambient temperature. We can thus take the output voltage of the thermopile as a relative measure of the radiant exitance $M'$. 
Avoid drafts and variations in room temperature during the experiment.

The intensity to be measured is very low; as a result, the measurement is extremely susceptible to interference from environmental influences:

- Never touch the thermopile with your hand during the measurement.
- Do not work close to the thermopile, and particularly not in front of it.
- Avoid drafts and variations in room temperature during the experiment.
- Avoid interfering radiation; if necessary, screen the assembly with cardboard.
- Darken the room if necessary.

### Interference radiation can be caused by:
- Direct radiation of body heat on the thermopile.
- Reflection of radiation at reflecting surfaces (e.g., light-colored clothing), radiators, sunlight and other light sources.

Allow the microvoltmeter to warm up for at least 10 minutes before starting the experiment.

Switch on the microvoltmeter via the mains switch on the rear of the device.

Fig. 1 shows the experiment setup.

### When using water cooling:
- Attach the silicone tubing to the immersion pump and the screen so that the inflow is at the bottom hose nipple and the outflow is at the top hose nipple of the screen.
- Fill the water vessel with water and attach the immersion pump to the rim of the water vessel e.g., using the mounting clamp so that the inlet opening is completely submerged and the maximum immersion depth of 17 cm is not exceeded (see Fig. 2; refer to the Instruction Sheet for a description of another mounting possibility).

### Then:
- Set up the electric oven, the screen of the black body accessory and the thermopile as shown in Fig. 1 so that the rod of the thermopile is about 15 cm in front of the opening of the electric oven. The screen of the black body accessory should be positioned about 5 – 10 mm in front of the electric oven, with the metal side facing the thermopile.

Note: the glass window absorbs long-wave radiation more than short-wave radiation, and thus systematically falsifies the temperature-dependent measurement of radiant intensity.

- Remove the glass window of the thermopile.
- Connect the NiCr-Ni temperature sensor to the digital thermometer and insert it in the small central hole in the burnished brass cylinder as far as it will go.
- Mount the temperature sensor in place with the universal clamp S and switch on the digital thermometer (measuring range > 200 °C).
- Align the openings of the electric oven, the screen of the black body accessory and the thermopile so that the radiant heat is directly incident on the opening of the thermopile.
- If you are using water cooling, switch on the immersion pump now.
- Connect the thermopile to the microvoltmeter as shown in Fig. 1 (measuring range $10^{-4}$ V); make sure the red socket on the thermopile is connected to the red socket on the microvoltmeter.
- Compensate the offset by pressing the key "auto comp"; if necessary, carry out the fine adjustment using the potentiometer to set the digital display to zero (see Instruction Sheet for the microvoltmeter).
Carrying out the experiment

First:

- Measure the temperature $\theta$ of the brass cylinder and the initial output voltage $U$ of the thermopile and write these values in your experiment log.

Then:

- Switch on the electric oven; for each temperature increase of 25 °C, write the measured values $\theta$ and $U$ in your experiment log.

When the temperature reaches a level between 400 °C and 500 °C:

- Switch off the electric oven; for each temperature decrease of 25 °C, write the measured values $\theta$ and $U$ in your experiment log.

- When the temperature reaches a level between 100 °C and room temperature, remove the temperature sensor from the electric oven, measure the room temperature and write this value in your experiment log.

- Screen the thermopile with dark cardboard, check the zero point of the voltmeter and write this value in your experiment log.
Measuring example and evaluation

Table 1: Measured values for heating and cooling

<table>
<thead>
<tr>
<th>C</th>
<th>K</th>
<th>T² - T₀² K²</th>
<th>U₀ mV</th>
<th>U₁ mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>297</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>323</td>
<td>0.31</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>75</td>
<td>348</td>
<td>0.69</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>100</td>
<td>373</td>
<td>1.16</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>125</td>
<td>398</td>
<td>1.73</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>150</td>
<td>423</td>
<td>2.42</td>
<td>0.52</td>
<td>0.51</td>
</tr>
<tr>
<td>175</td>
<td>448</td>
<td>3.25</td>
<td>0.70</td>
<td>0.68</td>
</tr>
<tr>
<td>200</td>
<td>473</td>
<td>4.23</td>
<td>0.91</td>
<td>0.89</td>
</tr>
<tr>
<td>225</td>
<td>498</td>
<td>5.37</td>
<td>1.16</td>
<td>1.13</td>
</tr>
<tr>
<td>250</td>
<td>523</td>
<td>6.70</td>
<td>1.43</td>
<td>1.41</td>
</tr>
<tr>
<td>275</td>
<td>548</td>
<td>8.24</td>
<td>1.75</td>
<td>1.72</td>
</tr>
<tr>
<td>300</td>
<td>573</td>
<td>10.00</td>
<td>2.11</td>
<td>2.07</td>
</tr>
<tr>
<td>325</td>
<td>598</td>
<td>12.01</td>
<td>2.50</td>
<td>2.46</td>
</tr>
<tr>
<td>350</td>
<td>623</td>
<td>14.29</td>
<td>2.93</td>
<td>2.90</td>
</tr>
<tr>
<td>375</td>
<td>648</td>
<td>16.85</td>
<td>3.42</td>
<td>3.38</td>
</tr>
<tr>
<td>400</td>
<td>673</td>
<td>19.74</td>
<td>3.95</td>
<td>3.92</td>
</tr>
<tr>
<td>425</td>
<td>698</td>
<td>22.96</td>
<td>4.53</td>
<td>4.50</td>
</tr>
<tr>
<td>450</td>
<td>723</td>
<td>26.55</td>
<td>5.17</td>
<td>5.17</td>
</tr>
</tbody>
</table>

Fig. 3: Graph of the output voltage $U$ as a function of $T^4 - T_0^4$.
The circles correspond to the measured values for heating, and the triangles represent the values for cooling.

Fig. 3 shows the output voltage $U$ of the thermopile as a function of the difference between the absolute oven temperature $T$ and the absolute room temperature $T_0$, each raised to the fourth power. This relationship is a close approximation of a straight line, as predicted by the Stefan-Boltzmann law. When we examine this curve closely, we can recognize a slight deviation from our best-fit straight line, which is the result of the following effects: the measurement with the thermopile is affected by convection and radiant losses to the environment, especially when the glass window is removed. Also, we cannot completely rule out increasing heat build-up in the comparison points of the thermopile as the oven temperature increases.
ABBE REFRACTOMETER

**Abbe Refractometer** is widely used for measuring refractive index \( n_D \) of transparent, translucent liquid or solid substance. This instrument also measures percentage of solids in sugar solution (brix value) along with temperature corrected brix value. **Abbe Refractometer** finds application in chemical, pharmaceutical, petroleum, sugar refining & food industries and also in research institutions.

**Features**
- Measurement of refractive index of transparent, translucent liquids and solid substances.
- Measurement of percentage of solids in sugar solution (brix).
- Automatic temperature correction of brix.
- RS-232 Interface.
- Backlite LCD.
- Prism made of hard glass.

**Specifications**
- Measuring Range: Refractive Index \( n_D \): 1.3000 to 1.7000
  - Brix: 0 to 95%
  - Brix-Tc: 0 to 95%
- Accuracy: Refractive Index \( n_D \): +/-0.0002
  - Brix: +/-0.1%
- Range of temperature display: 0 to 50°C
- Range of temperature for correction of Brix value: 15 to 45°C
- Power Supply: 220 V +/-10%, 50Hz
- Dimension: 330x180x380mm
- Weight: 10 kg

**The following schematic diagram shows the construction of the instruments**

Specifications and Designs are subject to changes for improvement

Refractive index \( (n) \) for some selected substances.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Refractive index ( (n) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isopropanol</td>
<td>1.3749 - 1.3802</td>
</tr>
<tr>
<td>Acetone</td>
<td>1.3560 - 1.3616</td>
</tr>
<tr>
<td>Ethyl Acetate</td>
<td>1.3700 - 1.3747</td>
</tr>
<tr>
<td>Water</td>
<td>1.3325 - 1.3334</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between sucrose percentage and refractive index](image)
Abbe's Refractometer

Aim:

1. To find refractive index of the given liquid samples.
2. To study the variation of refractive index with (a) temperature of the liquid sample.
   (b) wavelength of the light source
3. To determine the polarisability of the given liquid samples at a given temperature.

Apparatus

Abbe's refractometer, temperature controller, light source (Sodium Na lamp \( \lambda = 589.3 \text{ nm} \)), and samples.

Theory

The Refractometer is a device that is used to measure refractive index. Ernst Abbe of Germany was the first scientist to develop one called Abbe's refractometer. The working principle of most accurate refractometers is based on the measurement of the critical angle \( \phi_c \). In both the Pulfrich and Abbe types a convergent beam strikes the surface between the unknown sample, of index \( n \), and a prism of known index \( n' \) (Figure 1). Now \( n' \) is greater than \( n \), so the two must be interchanged in the equation:

![Figure 1: Refraction in the prism of Abbe refractometer.](image-url)
\[ n \sin 90 = n' \sin \varphi_c \leftrightarrow \sin \varphi_c = \frac{n}{n'} \]

The beam is so oriented that some of its rays just graze the surface, so that one observes in the transmitted light a sharp boundary between light and dark. Measurement of the angle at which this boundary occurs allows one to compute the value of \( \varphi_c \) and hence of \( n \).

The main part of Abbe's refractometer (Figure 2) is prism lens. It consists of two Abbe's prism of flint glasses of high refractive index, 1.75 cemented into mounting hollow cases. The cases act as jackets and water from the thermostat can be circulated around the prism for controlling temperature. The upper face of the lower prism is mounted so that it will act as a diffusion screen, giving rays in all directions and confines a thin sample of the liquid. The lower face of the upper prism, known as the refractive prism is highly polished. The two prism cases are lingered together, when the prisms are closed and touched by a locknut with a space of 0.1 to 0.14 mm between the faces of the prism. A small quantity of the sample under experiment is introduced in this narrow space.

The case of upper prism is rigidly attached to the index arm, which carries a scale at its upper end. The scale is graduated in terms of refractive index from 1.3 to 1.7 up to 3rd decimal.
Refractive index of a substance is a function of a wavelength. If the light source is not monochromatic (and in simple devices it rarely is) light gets dispersed and shadow boundary is not well defined, instead of seeing sharp edge between white and black, you will see a blurred blue or red border. In most cases that means measurements are either very inaccurate or even impossible. Therefore, to prevent dispersion Abbé added two compensating Amici prisms into his design.

A telescope is rigidly fixed into the sector which is attached to upright of base in such a way that the axis or the sector coincides with the rotation of the prism lens. The prism lens can be rotated by means of the arm which can be moved by a knob. The line of demonstration corresponds to the critical angle is seen through the telescope and the index arm is rotated so that the border line passes exactly through the refractive index, thereby intersecting the cross wires. The refractive index is read through the eyepiece at the upper end.

Procedure:

1. Switch ON the monochromatic Na light lamp and wait for about 5 minutes to allow lamp warm up.
2. Using a clean dropper, put 1 or 2 drops of the liquid whose refractive index is to be checked between illuminating and measuring prisms. Close the lower prism case.
3. Use rotating knob to align the X mark in the eyepiece with the shadow boundary separating the dark and bright areas seen in the field of view. The sharpness of the depth of field can be adjusted by moving the lens back and forth.
4. Read the refractive index from the scale. Liquid samples must be non-corrosive, to not damage surface of the prisms.
5. Clean the prisms with filter paper or a napkin and repeat steps 1-4 for solutions of various concentrations and for an unknown solution $n_x$.

Discussion:

1. What does refractive index mean?
2. Why should the sample refractive index be higher than that of the measuring prism?
WYA-2S DIGITAL ABBE REFRACTOMETER
OPERATING INSTRUCTION

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I. Applications of the instrument

This instrument can widely be used in petroleum, chemical, pharmaceutical, sugar refining and food industries, as well as in related colleges, universities and scientific research institutions for measuring the refractive index $n_0$ of transparent, subtransparent liquid or solid substance. This instrument can also be used to measure the Brix (BX) of the sugar solution, and correct the affect of temperature on the Brix automatically. In addition, this instrument can display the temperature of the sample.

II. Main specifications

I. Measuring range
- Refractive index $n_0$: 1.3000 – 1.7000
- Brix (BX-TC): 0 – 95%
- Brix (BX): 0 – 95%

II. Measuring accuracy (average)
- Refractive index $n_0$: ± 0.0002

III. Temperature
- Temperature display range: 0 – 50°C
- Correcting range of BX versus temperature: 15 – 45°C

IV. Overall dimensions of the instrument: 330mm $\times$ 180mm $\times$ 380mm

V. Weight of the instrument: 10kg

VI. Power supply: AC 220V – 240V frequency 50Hz

VII. Input power: 30W

VIII. Usage temperature range: room temperature – 35°C

IX. Lamp: (FANELL328 – 340) 6.5V, 0.3A

X. Fuse: F/A250V 1A

XI. Protection grade: IP20

III. Principle of operation

I. Principle block diagram

![Block diagram image]

Figure 1
II. Principle

The operational principle of the ABBE refractometer for measuring the refractive index of the transparent or subtransparent substance is based on the measurement of the critical angle. The observation system composed of the visual telescope unit and dispersion correction unit can be used to aim at the dividing line between the bright area and the dark area, that is, to aim at the critical angle. The angle–digit conversion unit can be used to convert the angular magnitude into digital magnitude, which will be sent into the microprocessor system for being data–processed. Then, the refractive index of Brix of the sample being measured will be displayed digitally.

IV. Construction of the instrument

![Figure 2]

1. Eyepiece  2. Dispersion correction hand–wheel
3. Display window  4. Power switch (POWER)
5. Reading display button (READ)  6. Brix (through temperature correction) display button (BX–TC)
7. Refractive index display button (n_d)  8. Brix (not through temperature correction)
11. Refracting prisms unit  12. Temperature display button (TEMP)
V. Operating procedure

I. When the power switch “POWER” (4, see fig. 2) is pressed, the illuminating lamp in the light-gathering illuminating unit (10) lights up; and at the same time, the display window (3) displays “0000” a few seconds later.

II. Open the refracting prisms unit (11), and remove the mirror-cleaning paper. Which is put in between the two prisms when the instrument is idle to prevent the hard particles possibly remaining on the prisms from damaging the working surfaces of the prisms. Only single-layer mirror-cleaning paper is needed.

III. Check the surfaces of the upper and lower prisms, and carefully clean their surfaces with water or alcohol. After a sample is measured. The surfaces of the two prisms should also be cleaned carefully, because a little of the original sample remaining on the prisms will affect the measuring accuracy of the next sample.

IV. Put the sample to be measured on the working surface of the lower refracting prism. If the sample to be measured is a kind of liquid, a clean dropper may be used to suck in one or two drops liquid sample and then put drops onto the working surface of the refracting prism. After that, the cup of the upper light-intake prism should be put on. If the sample to be measured is a kind of solid substance, the solid sample must have a smooth polished surface that should be wiped clean before performing the measurement. Put one or two drops of a transparent liquid (such as naphthalene bromide), the refractive index of which is higher than of the solid sample, onto the working surface of the refracting prism, then put polished surface on the working surface of the refracting prism and let them have a good contact (see fig. 3). When measuring the solid sample, there is no need to put on the cup of the light-intake prism.

![Figure 3](image)

1. Light-intake prism
2. Refracting prism
3. Thermostat (a mechanism used for flow of the constant temperature water)

V. Rotate the rotating arm and collecting lens cone of the light-gathering illuminating unit so as to make the light-intake surface of the upper light-intake prism (when measuring the liquid sample) or the light-intake surface in front of the solid sample (when measuring the solid sample) be illuminated evenly.

VI. Observe the field of view by means of the eyepiece (1), and at the same time, rotate the adjustable hand-wheel (9), so as to make the bright area dark area dividing line
fall in the cross-line view field. If you see the field of view is dark through the eyepiece. You may rotate the adjustable hand-wheel counter clockwise. If you see the field of view is bright, you may rotate the adjustable hand-wheel clockwise. The bright area is at the top of the view field. Under the condition of the bright view field. You may rotate the eyepiece to adjust the visibility for seeing the cross-line clearly.

VII. Rotate the dispersion correction hand-wheel (2) in the notch under the eyepiece sleeve. And at the same time, regulate the position of the light-gathering lens, so as to get a good contrast between the bright area and dark area in the view field, and to make the bright area-dark area dividing line have the minimum dispersion.

VIII. Rotate the adjustable hand-wheel so as to make the bright area-dark area dividing line be correctly aligned with the cross-point of the cross-line (see fig. 4).

IX. When the reading display button "READ" (5) is pressed, "00000" in the display window disappears, and "- - " is displayed: and a few seconds later, "- - " disappears, and the refractive index of the sample being measured will be displayed in the display window. If you want to know the Brix value of the sample being measured, you may press the Brix (not through temperature correction) display button 'BX' (8) or press the Brix (through temperature correction, ICUMSA) display button "BX-TC" (6). The three buttons "inc" (7), "BX-TC", and "BX" are used to select the measuring modes. After a measuring mode is selected, when the button "READ" is pressed, the display window will display the data in accordance with the pre-selected measuring mode. Sometimes, when the button "READ" is pressed, "- - " is displayed. And a few seconds later, "- - " disappears, and the display window becomes completely dark without any other displayed contents. It means that there is something wrong with the instrument, the instrument cannot operate normally now. And it needs to be inspected or repaired. When the selected measuring mode is "BX-TC" or "BX", if the rotation of the adjustable hand-wheel is out of the Brix measuring range (0–95%), when the button "READ" is pressed, "- - " will be displayed in the display windows.

X. If you want to measure the temperature of the sample, you may press the temperature display button "TEMP" (12), and the display window will display the temperature value of the sample being measured. The measurement of the sample temperature can always be performed except when the display window displays "- - " after the button "READ" is pressed. The pressing of the button "TEMP" is ineffective. When the temperature is displayed, if you press the button "inc", or button "BX-TC", or button "BX", the original refractive index or Brix will be displayed in the display window. In order to distinguish the displayed values between temperature and Brix.
there will be a sign of "^" added before the temperature value, a sign of "^" added before the value of BX–TC, and a sign of "^" added before the value of EX.

XI. After the measurement of the sample is completed, the refracting prisms unit must be carefully cleaned with alcohol or water (when the sample is sugar solution).

XII. There is a mechanism used for flow of the constant temperature water in the refracting prisms unit of the instrument. If you want to measure the refractive index of the sample at a specified temperature, an external thermostat can be connected to this instrument. Thus, you can perform the measurement of the sample after the temperature is regulated to the value you required.

XIII. First, send out a random character, then wait to receive (Parameter: baud-rate 2400, date-bits 8, stop-bit 1, byte length 18)

Remark:

♦ it is possible to appear the phenomena that the instrument reset automatically or stop working (seldom seen). It results from external strong static or electric network fluctuation. You could cut off power supply and turn on the instrument again.

♦ You should connect the water temperature correctly if measuring the refractive index of the sample at a specified temperature. The water temperature could bear definite pressure (nomore than 0.5MP). Incorrect connection or not clamping could result in the danger of electricity.

VI. Calibration of the instrument
The instrument should be calibrated periodically, or when the measuring data is under suspicion, the instrument may also be calibrated. When making the calibration, distilled water or glass standard block should be used. If there is an error between the measuring data and the standard one, you may use an inner-hexagon spanner, let it go into the small hole of the dispersion correction hand-wheel (2), and rotate the inside screw carefully, so as to make the cross line on the division plate move up and down (see fig.5). Then perform the measurement again until the measuring data meets the requirement.

![Figure 5](image.png)

*Screw Hole
When the sample is the standard block, the measuring data should conform to the specified data on the standard block. If the sample is distilled water, the measuring data should coincide with the data listed in the following table.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Refractive index ( n_\Delta )</th>
<th>Temperature (°C)</th>
<th>Refractive index ( n_\Delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1.33316</td>
<td>25</td>
<td>1.33250</td>
</tr>
<tr>
<td>19</td>
<td>1.33308</td>
<td>26</td>
<td>1.33239</td>
</tr>
<tr>
<td>20</td>
<td>1.33299</td>
<td>27</td>
<td>1.33228</td>
</tr>
<tr>
<td>21</td>
<td>1.33289</td>
<td>28</td>
<td>1.33217</td>
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<td>1.33260</td>
<td>29</td>
<td>1.33205</td>
</tr>
<tr>
<td>23</td>
<td>1.33270</td>
<td>30</td>
<td>1.33193</td>
</tr>
<tr>
<td>24</td>
<td>1.33260</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**VII. Maintenance**

I. The instrument should be positioned in a dry and well-ventilated place where the temperature is rather suitable, so as to prevent the optical components of the instrument from becoming damp and going moldy.

II. When moving the instrument, you should hold its bottom in the palm, not use rocker arm of the light-gathering illuminating unit (10) in order to avoid breaking the instrument.

III. Before and after using the instrument, or when changing the sample, the working surface of the refracting prisms system must be cleaned and wiped.

IV. No solid impurity is permitted to exist in the sample to be measured. When measuring the solid sample, the working surface of the refracting prisms should be prevented from being roughed and scratched. This instrument is strictly forbidden to measure relatively strong corrosive samples.

V. The instrument should avoid violent vibration and shock so as to prevent the optical components from being broken or loosened, for keeping the accuracy of the instrument.

VI. If the lamp bulb in the light-gathering illuminating system is out of order, first you should cut off power supply, remove the collecting lens cone axially, screw the faulty bulb off anti-clockwise, change the new one and screw down clockwise. After loading the collecting lens cone, turn on the instrument. Observing the facula projected on surface of refracting prisms, if it located in center, it is ok. If it deviates, regulate the position of the lamp bulb (join socket) right and left (by loosening the side fixed screw), so that the light can be gathered on the light-intake surface of the refracting prisms and no obvious inclination will occur.

VII. Since the collecting lens of the instrument is made of plastics, in order to prevent its surface from being damaged by the corrosive sample, when you use the instrument, you should cover the collecting lens with a transparent plastic hood.

VIII. When the instrument is not used, it should be covered with a plastic cover hood or put into a box.
IX X. The user is not allowed to disassemble and assemble the instrument arbitrarily, if the instrument is out of order, or the accuracy requirement can not be reached, it should be repaired without delay.

VIII. Complete set of the instrument (refer to packing list)

IX. Appendix one: how to protect and use naphthalene bromide correctly

- Naphthalene bromide is the strongly corrosion liquid. When using the instrument every time, you should carefully clean the surfaces that are put some drops of Naphthalene bromide with alcohol.
- The skin touched the naphthalene bromide will not result in adverse reaction. But you should wash your hands after using.
- Eating forbidden. In case of splashing in eyes or mouth, please clean with water immediately.

X. Appendix two

In case of an interruption in the mains longer than the specified (10ms) time, the power supply unit of the equipment is switched off. The switch-on may be carried out by the operator. In case of a disturbance like EFT (Electrical Fast Transients) occurring on AC power lines, the indication of the data will be incorrect or reset. The operator should push the "Ready" button to recover the normal operation.

In case of a ESD (Electromagnetic Discharge) occurring on the equipment, especially on the front panel. The equipment will be reset. The operator should push the "Ready" button to recover the normal operation.

Lambda Scientific Systems, Inc
14055 SW 142nd Ave, Suite 22
Miami, FL 33186, USA
Phone: 305-252-3838
Web: www.lambdasys.com

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