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University of Michigan

Polarization

Fundamental Laboratory Experiments

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Education Systems from Thorlabs, Inc.

Providing knowledge for the trade

Fundamental Kit EDKPOL1

Manual EDKPOL1-M ver 0.9 (Draft)

Laser safety is the avoidance of laser accidents, especially those involving eye injuries. Since even relatively small amounts of laser light can lead to permanent eye injuries, the sale and usage of lasers is typically subject to government regulations.

Moderate and high-power lasers are potentially hazardous because they can burn the retina of the eye, or even the skin. To control the risk of injury, various specifications, for example ANSI Z136 in the US and IEC 60825 internationally, define "classes" of laser depending on their power and wavelength. These regulations also prescribe required safety measures, such as labeling lasers with specific warnings, and wearing laser safety goggles when operating lasers.

Table of Contents

Experiments Categories

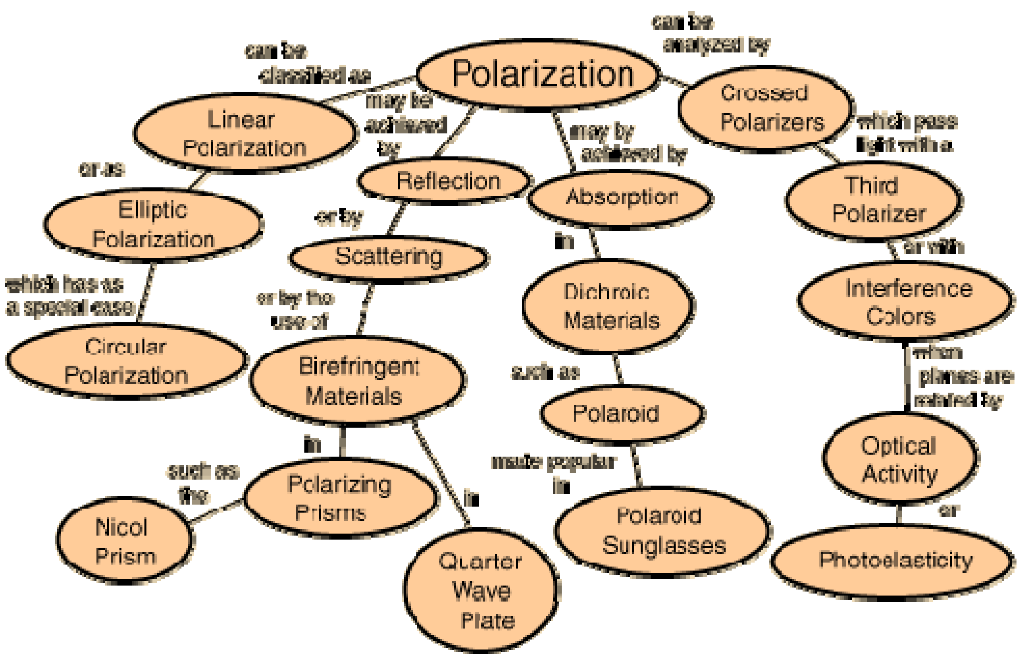
Fundamental experiment may be accomplished using the kit consisting selected Thorlabs product line. A combination of product will produce experimental hands on experiments in fundamental physics interrogating polarization. All Educational Series kits contains building blocks to build experiments in that category.

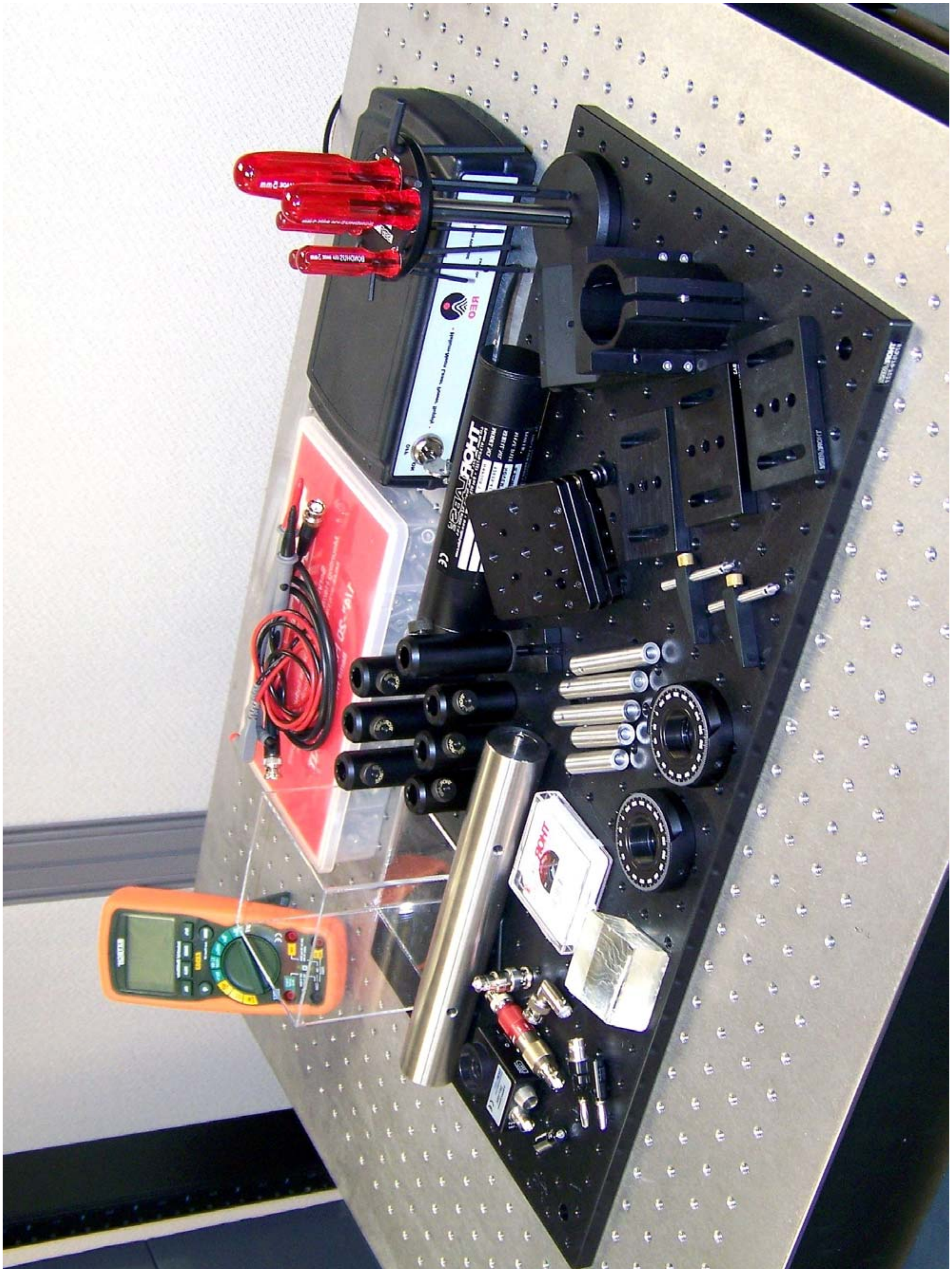
Extensive Experiments Categories

Extensive categories in Thorlabs product line. Each category is contains extensive building blocks to build experiments in that spans fundamental category. Experiment in this category will be much more detailed and complex. These experiments cannot be completed in a short interval. Such experiments may be chosen as a dedicated experiment for the semester typical interval, 1 to 2 experiments in 15 weeks. (Typical semester run time)

Objective

The following experiments are buildable from kits available from Thorlabs. Each experiment deals with a specific effect. A major kit would give you the resource to build all the experiments. Minor kits would give you the resource to build selected experiments. Lab manuals should be provided with each experiment including parts list. Parts list should reflect also on restocking individual components in the kits.





EDKPOL1 parts List

Polarization Experiments		
Part Number	qty	Description
HRR008	1	HeNe Laser (polarized)
PM2	2	Clamp
C1503	1	C1503 Kinematic V-clamp
P8	1	Mounting Post
MB1224	1	Optical Breadboard
LPVISE100-A1	2	1” dia sheet polarizers
WPQ05M-633	1	¼ Wave Plate for 632nm Wavelength
KM200B	1	3x3 inch Kinematic Platform
RSP1	2	Rotational Platform
TR3	3	3” TR posts
BH3	3	3” PH Post Holders
PH2-ST	3	2” PH Post Holders
UPH3	2	1 3" High Universal Post Holder
BA2	3	BA2 base plates
DVM1*	1	DVM digital voltmeter
DET36A	1	Photo Detector
VT1	1	Variable in-line terminator
2249-C-36	1	36” BNC Cable
T1269	1	BNC Female to Banana adapter
T3534	1	BNC Elbow M-F
TC2	1	Ball Driver Kit
HW-KIT2	1	¼”-20 Cap Screw and Hardware Kit
A23	1	Replacement 12 V Battery for DET Series
GC24	1	Acrylic Speciment Cell (Cuvette)
C1500	1	Compact P-Series Post Clamp
VC3	1	Large V-Clamp with PM2 Clamping Arm
KC1-T	1	SM1 Threaded Kinematic Mount for Ø1" Optics
EDKPOL1-M ver1.0		Fundamental Laboratory Experiments Manual

Theory

Birefringence, or double refraction, is the decomposition of a ray of light into two rays. The ordinary ray and the extraordinary ray as it passes through certain types of material depending on the polarization of the light. This effect can occur only if the structure of the material is directionally dependent or anisotropic. If the material has a single axis of anisotropy or optical axis, birefringence can be assigned with two different refractive indices to the material for different polarizations.

Many plastics are birefringent, because their molecules are 'frozen' in a stretched conformation when the plastic is molded or extruded.. Cellophane is a cheap birefringent material, and Polaroid sheets (sheet polarizers) are commonly used to examine for orientation in birefringent plastics like polystyrene and polycarbonate. Birefringent materials are used in many devices which manipulate the polarization of light, such as wave plates and polarizing prisms.

Objectives

(write up)

Experimental Setup

(write up + image)

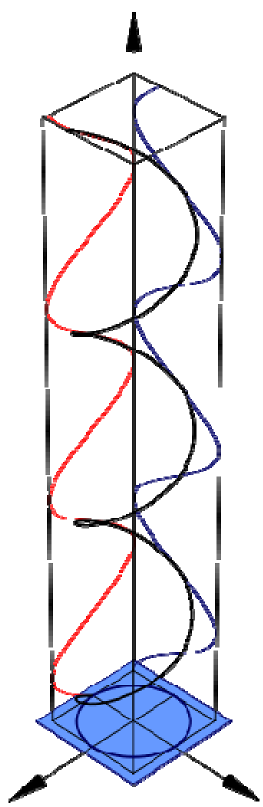
Parts List

1	HRR008 HeNe Laser (polarized)
2	PM2 Clamp
1	C1503 Kinematic V-clamp
1	P8 Mounting Post
1	MB1224 Optical Breadboard
1	1" dia sheet polarizers - 1**
1	WPQ05M-633 ¼ Wave Plate for 632nm Wavelength
2	RSP1 Rotational Platform
2	3" TR posts
2	2" PH Post Holders
2	BA2 base plates
1	DVM digital voltmeter*
1	DET36A Photo Detector
1	VT1 Variable in-line terminator
1	2249-C-36 36" BNC Cable
1	T1269 BNC Female to Banana adapter
2	T3534 BNC Elbow M-F
1	TC2 Ball Driver Kit
1	HW-KIT2 - ¼"-20 Cap Screw and Hardware Kit

1	A23 Replacement 12 V Battery for DET Series

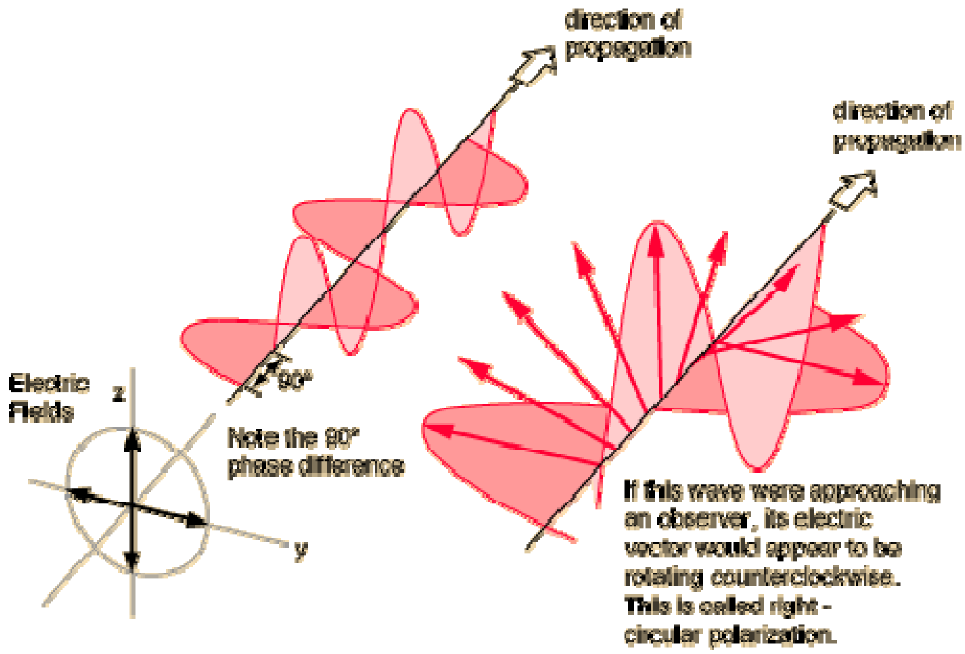
Theory
The quarter-wave retardation plate is a sheet of birefringent (double refracting) material such a s ¼ wave plate of thickness such that horizontally and vertically polarized light entering in phase will emerge from the retardation plate 1/4 of a wavelength out of phase. Unpolarized light is not affected by this retardation plate (or by any thickness of birefringent material) because the retardation plate only changes the phase of each component of polarization -- incident light polarized in all directions (which is unpolarized light) will emerge as light polarized in all directions. The situation dramatically changes when the incident light is polarized.

Objectives
A polarizing filter is placed in front of the quarter-wave plate at an angle of 45° w.r.t. it (so that the incident horizontal and vertical components are of equal intensity). Because of the phase shift between the two components as they pass through the retardation plate, the direction of polarization of the light that emerges from the wave plate will rotate in time. Thus incident unpolarized light emerges as circularly polarized light. More generally, if the angle between the wave plate and polarizing filter is not 45°, the two components will differ in intensity and the emerging light will be elliptically polarized.



Circular polarized light (maybe spiral)

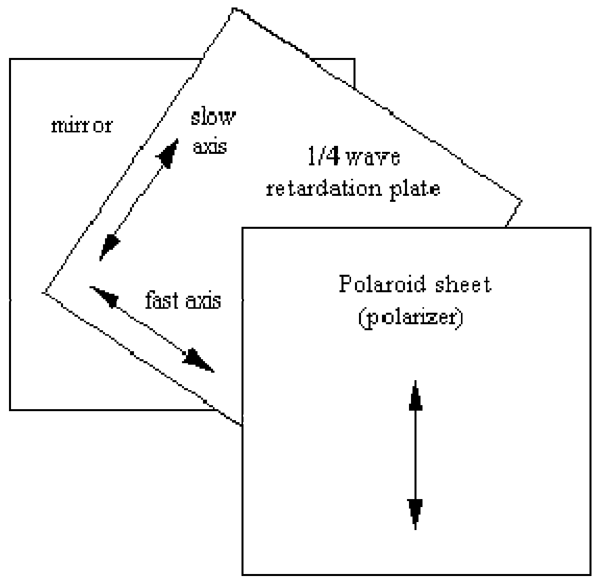
The circular polarization produced by the linear polarizer/quarter-wave plate sandwich is made evident by placing a mirror behind it and looking through the circular polarizer at the mirror reflection. The mirror reverses the direction of circular polarization, and the reflected reversed circularly polarized light is converted back into linearly polarized light by the wave plate.



However, it is now polarized perpendicular to the linear polarizing filter's orientation, so it is absorbed and the mirror appears dark [2] . The effect is undone by rotating the linear polarizer w.r.t. the wave plate. The effect is also undone by reversing the order of the polarizer and wave plate. Finally, one can substitute a non-reversing mirror (two mirrors mounted together at right angles) to see what happens!

Experimental Setup

The mirror should be propped up and clamped on the lecture bench while the linear polarizer and quarter-wave plate are hand-held in place. The simplest way to perform the experiment is to look through the circular polarizer and view your own reflection in the mirror as the angle between the polarizer and wave plate is changed. Unhappily, the audience cannot appreciate the effect you are seeing so we substitute a TV camera for you. On the TV monitor, the audience will see the reflection of the camera in the mirror fade in and out as you rotate the polarizer (or wave plate). If the class is small, you may wish to invite students to come up after the lecture and experience the anti-reflection effect first-hand.



The circular polarization produced by the linear polarizer/quarter-wave plate sandwich is made evident by placing a mirror behind it and looking through the circular polarizer at the mirror reflection. The mirror reverses the direction of circular polarization, and the reflected reversed circularly polarized light is converted back into linearly polarized light by the wave plate. However, it is now polarized perpendicular to the linear polarizing filter's orientation, so it is absorbed and the mirror appears dark [2]. The effect is undone by rotating the linear polarizer w.r.t. the wave plate. The effect is also undone by reversing the order of the polarizer and wave plate. Finally, one can substitute a non-reversing mirror (two mirrors mounted together at right angles) to see what happens!

Circular polarizers are used to reduce annoying reflections, eliminate glare, and enhance contrast for a variety of commercial applications.

Note that retardation plates do not influence the state of polarization of incident linearly polarized light, if the light's polarization direction lies along either the slow or the fast axis of the retardation plate. Also, a retardation plate can't convert unpolarized light into polarized light. We also have a half-wave and a full-wave plate available. A half-wave plate converts right-handed circularly polarized light into left-handed circularly polarized light and vice versa.

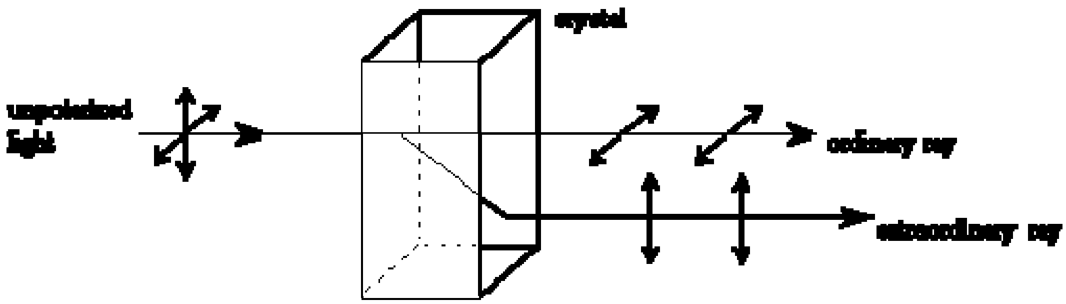
Parts List

Qty	Description
1	HRR008 HeNe Laser (polarized
2	PM2 Clamp
1	C1503 Kinematic V-clamp
1	P8 Mounting Post
1	MB1224 Optical Breadboard

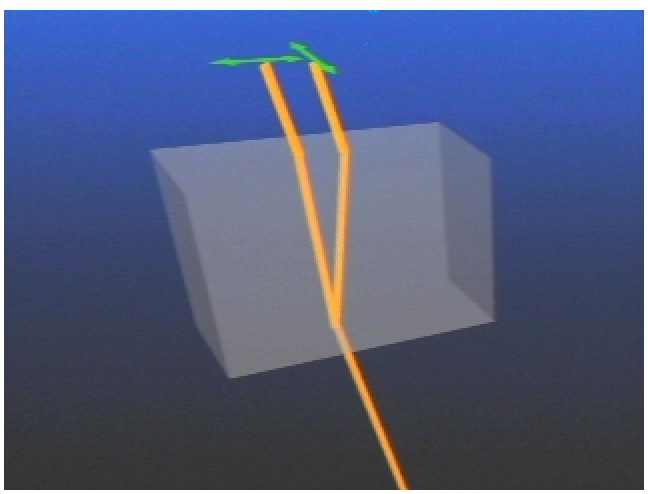
1	1" dia sheet polarizers - LPVISE100-A1**
1	WPQ05M-633 ¼ Wave Plate for 632nm Wavelength
2	RSP1 Rotational Mount
3	3" TR posts
2	2" PH Post Holders
2	BA2 base plates
1	UPH3 Utility Post Holder
1	DVM Digital Voltmeter*
1	DET36A Photo Detector
1	VT1 Variable in-line terminator
1	2249-C-36 36" BNC Cable
1	T1269 BNC Female to Banana adapter
2	T3534 BNC Elbow M-F
1	TC2 Ball Driver Kit
1	HW-KIT2 - 1/4"-20 Cap Screw and Hardware Kit
1	A23 Replacement 12 V Battery for DET Series

Theory

Double refraction or birefringence, is the decomposition of a ray of light into two rays. Called the ordinary ray and the extraordinary ray when it passes through certain types of material. A typical material is a calcite crystals. This effect can occur only if the structure of the material that is anisotropic meaning directionally dependent.



Birefringence in a calcite crystal



Objective

We will study the phenomena of double refraction using a calcite crystal. By placing the calcite on an object we can clearly see the double refractive effect. We can observe a double image. By placing the crystal on our platform mount we can send the HeNe beam through the crystal. We observe two beam emerging from the crystal. The ordinary ray and the offset extraordinary ray. By placing our sheet polarizer at the exit of the crystal we can rotate the polarizer and extinguish each ray as we begin to cross polarize each output.

Experimental Setup.

(write up + image)

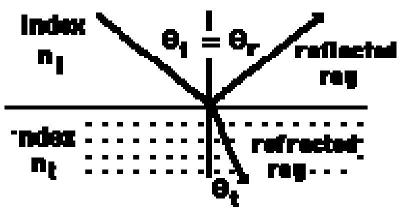
Parts List

Qty	Description
1	HRR008 HeNe Laser (polarized
2	PM2 Clamp
1	1503 Kinematic V-clamp
1	CXTAL Calcite Crystal
1	P8 Mounting Post
2	BA2 base plates
3	3” TR posts
2	2” PH Post Holders
1	KC1-T Kinematic Mount
1	MB1224 Optical Breadboard
1	KM200B 3x3 inch Kinematic Platform
1	Acrylic Specimen Cell (Cuvette)
1	TC2 Ball Driver Kit
1	HW-KIT2 - 1/4"-20 Cap Screw and Hardware Kit
1	A23 Replacement 12 V Battery for DET Series
1	Reflective Card (White Business Card)

Theory: Polarization by Reflection

Since the reflection coefficient for light which has electric field parallel to the plane of incidence goes to zero at some angle between 0° and 90°, the reflected light at that angle is linearly polarized with its electric field vectors perpendicular to the plane of incidence and parallel to the plane of the surface from which it is reflecting. The angle at which this occurs is called the polarizing angle or the Brewster angle. At other angles the reflected light is partially polarized.

From Fresnel's equations it can be determined that the parallel reflection coefficient is zero when the incident and transmitted angles sum to 90°. The use of Snell's law gives an expression for the Brewster angle.



$$r_\parallel = \frac{\tan(\theta_1 - \theta_t)}{\tan(\theta_1 + \theta_t)} = 0$$

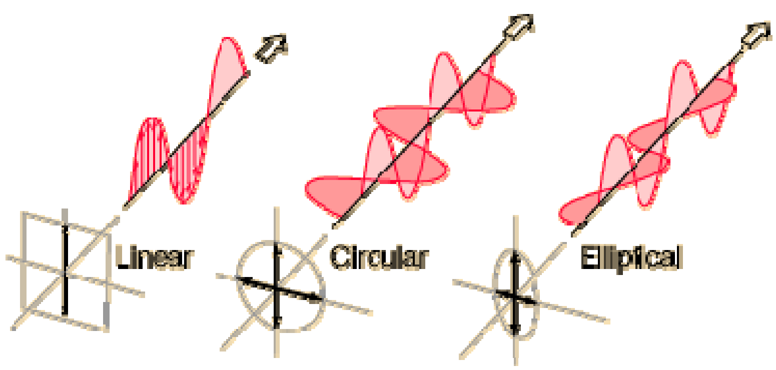
when $\theta_1 + \theta_t = 90°$.

$$n_1 \sin\theta_1 = n_t \sin(90° - \theta_1) \quad \text{by Snell's law}$$

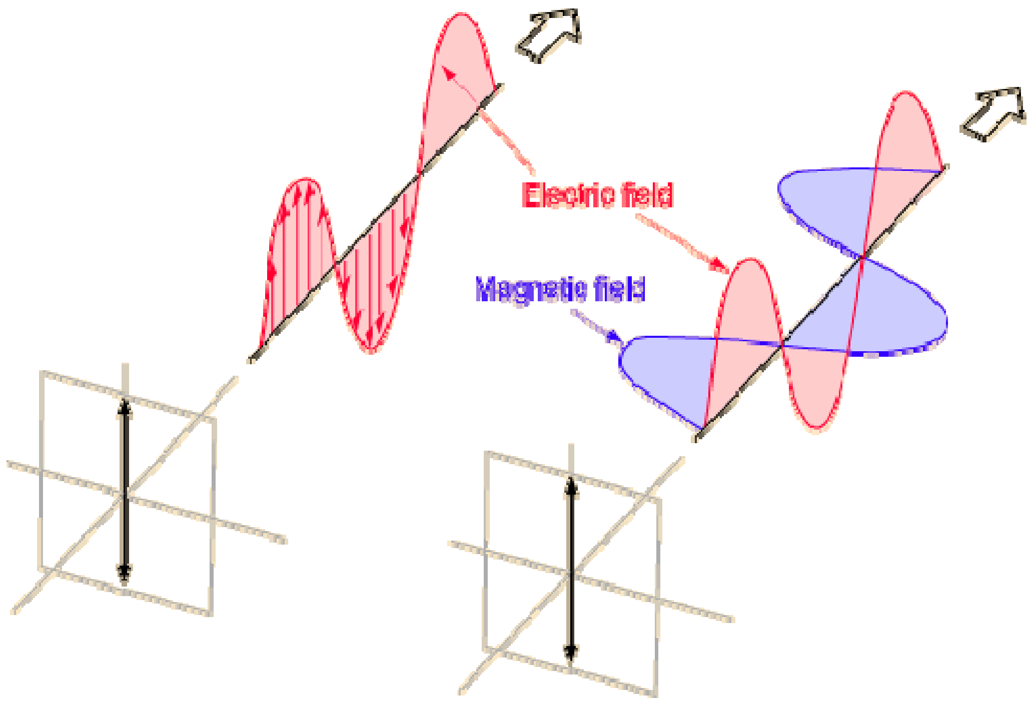
$$\tan\theta_1 = \frac{n_t}{n_1}$$

Classification of Polarization

Light in the form of a plane wave in space is said to be linearly polarized. Light is a transverse electromagnetic wave, but natural light is generally unpolarized, all planes of propagation being equally probable. If light is composed of two plane waves of equal amplitude by differing in phase by 90°, then the light is said to be circularly polarized. If two plane waves of differing amplitude are related in phase by 90°, or if the relative phase is other than 90° then the light is said to be elliptically polarized.



Linear Polarization
A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave is accompanied by a magnetic field wave as illustrated.



Objectives
In this experiment we will be looking a t the polarization properties of reflected light. Using this property we will calibrate the polarization orientation of our sheet polarizers. Our experimentn requires us to fill our cuvette with water and look at reflection of the top water surface at an angle. By rotating the sheet polarizer we can determine the state of polarization by the transmission of the reflection of the object.

(More write up)

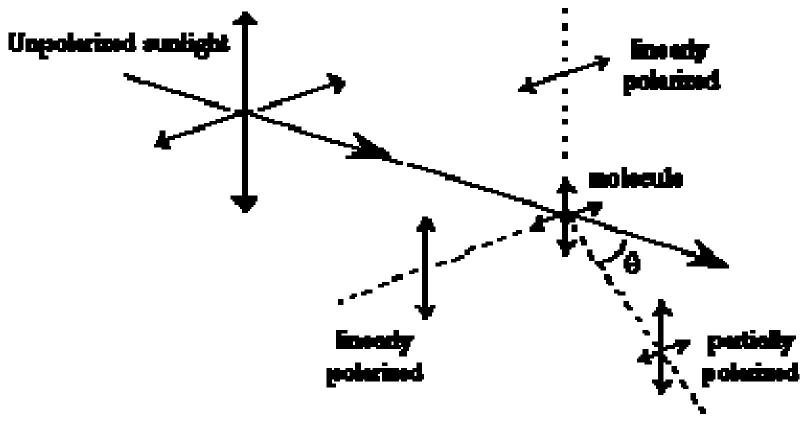
Experimental Setup
(write up + image)

Parts List

Qty	Description
1	Acrylic or glass cell * + (Water and Scatter medium – milk)
1	P8 Mounting Post
1	MB1224 Optical Breadboard
2	1” dia sheet polarizers - LPVISE100-A1**
2	RSP1 Rotational Mount
2	3” TR posts
1	2” PH Post Holders
2	BA2 base plates
1	KM200B 3x3 inch Kinematic Platform

Theory

Un-polarized light passing through a fluid is scattered; the scattered light being partially or completely plane polarized. For scattering by particles of comparable size to the wavelength of the light, this process is called Rayleigh scattering. The wavelength dependence of this type of scattering is responsible for blue skies and red sunsets.



To show this, the student observes the cuvette at right angles to the initial direction of propagation of the light. A mirror angled over the tank allows them to see scattered light emerging from two surfaces perpendicular to each other. By placing a Polaroid sheet between the projector and the tank with its polarizing axis horizontally, the scattered light from the side of the fish tank is blocked, whereas that from the top of the tank remains unaffected. Rotating the Polaroid 90° blocks the light from the top of the tank, but now the scattered light from the side of the tank reappears. Alternatively, let the scattering process polarize an un-polarized beam from a source projector and let the Polaroid sheet be the analyzer.

Objectives

Light enters a acrylic cuvette of very slightly milky water. Some of the electromagnetic waves impinge on the colloidal particles and molecules in the water, are absorbed and re-radiated. The horizontal component (say) of the polarization decreases as $\cos^2\theta$, where θ is the scattering angle. The maximum scattered intensity is perpendicular to the plane of oscillation of the molecule, where it is also totally plane polarized, θ=90°. At other angles the light is partially plane polarized.

(write up)

Experimental Setup

(write up + image)

Parts List

1	Acrylic or glass cell * + (Water and Scatter medium – milk)
1	HRR008 HeNe Laser (polarized)
2	PM2 Clamp,
1	1503 Kinematic V-clamp
1	P8 Mounting Post
1	MB1224 Optical Breadboard
1	KM200B 3x3 inch Kinematic Platform
1	Acrylic Specimen Cell (Cuvette)
2	2” TR posts
2	BH3 Utility Post Holder
1	DVM digital voltmeter*
1	DET36A Photo Detector
1	VT1 Variable in-line terminator
1	2249-C-36 36” BNC Cable
1	T1269 BNC Female to Banana adapter
2	T3534 BNC Elbow M-F
1	TC2 Ball Driver Kit
1	HW-KIT2 - 1/4"-20 Cap Screw and Hardware Kit
1	A23 Replacement 12 V Battery for DET Series

Theory

A sheet polarizer, also known as Polaroid Sheet material is a polarizer which consists of many microscopic crystals of iodoquinine sulfate embedded in a transparent nitrocellulose polymer film. The needle-like crystals are aligned during manufacture of the film by stretching or by applying electric or magnetic fields. With the crystals aligned, the sheet becomes dichroic. It tends to absorb light which is polarised parallel to the direction of the crystal alignment, but transmits light which is polarised perpendicular to it.

The resultant electric field of an electromagnetic wave such as light determines its polarisation. If the wave interacts with a line of crystals as in a sheet of polaroid, any varying electric field in the direction parallel to the line of the crystals will cause a current to flow along this line. The electrons moving in this current will collide with other particles and re-emit the light backwards and forwards. This will cancel the incident wave causing little or no transmission through the sheet. The component of the electric field perpendicular to the line of crystals however can cause only small movements in the electrons as they can't move very much from side to side. This means there will be little change in the perpendicular component of the field leading to transmission of the part of the light wave polarized perpendicular to the crystals only, hence allowing the material to be used as a light polarizer.

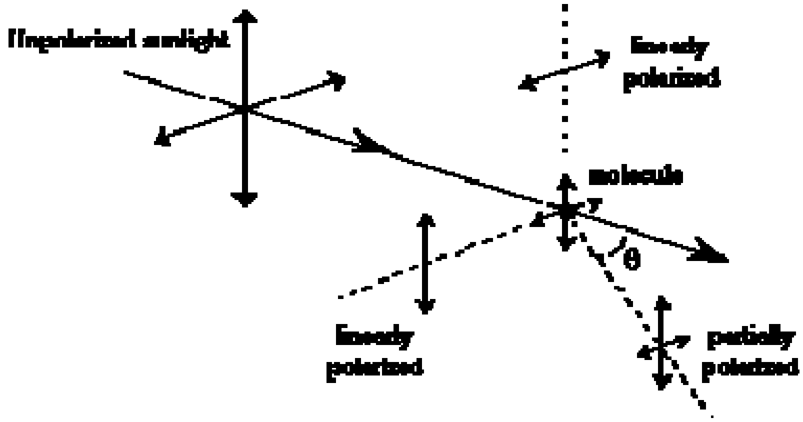
Polaroid sheets are used in liquid crystal displays, optical microscopes and sunglasses. Since Polaroid sheet is dichroic, it will absorb impinging light of one plane of polarisation, so sunglasses will reduce the partially-polarised light reflected from level surfaces such as windows and sheets of water.. They are also used to examine for chain orientation in transparent plastic products made from polystyrene or polycarbonate.

Objectives

In this experiment we will be looking a t the polarization properties of the output of the HeNe laser provided for the experiment. In order to measure the polarization properties we need some kind of polarizer. For our experiment we will use a sheet polarizer. Our sheet polarizer will be mounted in 1” rotating mount. We will need to find the orientation of the polarization. The direction in which needle-like crystals are aligned during manufacture of the film by stretching or by applying electric or magnetic fields.

(More write up)

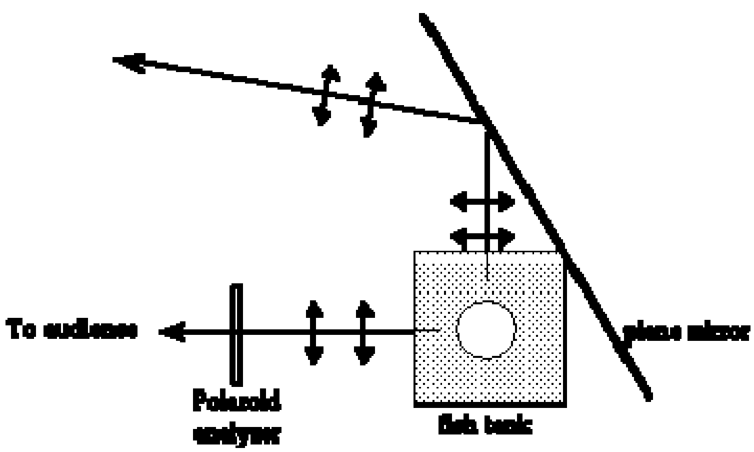
Experimental Setup



Polarization by scattering, Fig 1

Unpolarized light that passes through a colloidal fluid (milk + water) is scattered. The scattered light is now being partially or completely plane polarized. For scattering by particles of comparable size to the wavelength of the light, this process is called Rayleigh scattering. The wavelength dependence of this type of scattering is responsible for blue skies and red sunsets.

Unpolarized radiation (light) from the source enters the cuvette of the suspended milky water. (one or two drops of milk) Some of the electromagnetic waves impinge on the colloidal particles and molecules in the water, are absorbed and re-radiated. The horizontal component (say) of the polarization decreases as $\cos^2\theta$, where θ is the scattering angle (Fig 1) The maximum scattered intensity is perpendicular to the plane of oscillation of the molecule, where it is also totally plane polarized, θ=90°. At other angles the light is partially plane polarized.



Cuvette and mirror, looking into the beam. (Fig 2)

One can demonstrate this. Observes the cuvette at right angles to the initial direction of propagation of the light. A mirror angled over the cuvette allows one to observe the scattered light emerging from two surfaces perpendicular to each other (Fig 2). By placing a linear sheet polarizer between the source and the cuvette with its polarizing axis horizontally, the scattered light from the side of the cuvette is blocked, whereas that from the top of the tank remains unaffected. Rotating the Polaroid 90° blocks the light from the top of the tank, but now the scattered light from the side of the tank reappears.

Rayleigh scattering has a wavelength dependence of $1/(\lambda^4)$, so it affects blue light much more strongly than red. By adding milk to the tank, you increase the scattering; the milky water begins to develop a bluish tint and the unscattered beam reddish.

Parts List

Qty	Description
1	HRR008 HeNe Laser (polarized
2	PM2 Clamp
1	C1503 Kinematic V-clamp
1	P8 Mounting Post
1	MB1224 Optical Breadboard
2	1" dia sheet polarizers - LPVISE100-A1**
2	RSP1 Rotational Mount
3	3" TR posts
2	2" PH Post Holders
2	BA2 base plates
1	UPH3 Utility Post Holder
1	DVM Digital Voltmeter*
1	DET36A Photo Detector
1	VT1 Variable in-line terminator
1	2249-C-36 36" BNC Cable
1	T1269 BNC Female to Banana adapter
2	T3534 BNC Elbow M-F
1	TC2 Ball Driver Kit
1	HW-KIT2 - 1/4"-20 Cap Screw and Hardware Kit
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Theory

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The resultant electric field of an electromagnetic wave such as light determines its polarisation. If the wave interacts with a line of crystals as in a sheet of polaroid, any varying electric field in the direction parallel to the line of the crystals will cause a current to flow along this line. The electrons moving in this current will collide with other particles and re-emit the light backwards and forwards. This will cancel the incident wave causing little or no transmission through the sheet. The component of the electric field perpendicular to the line of crystals however can cause only small movements in the electrons as they can't move very much from side to side. This means there will be little change in the perpendicular component of the field leading to transmission of the part of the light wave polarized perpendicular to the crystals only, hence allowing the material to be used as a light polarizer.

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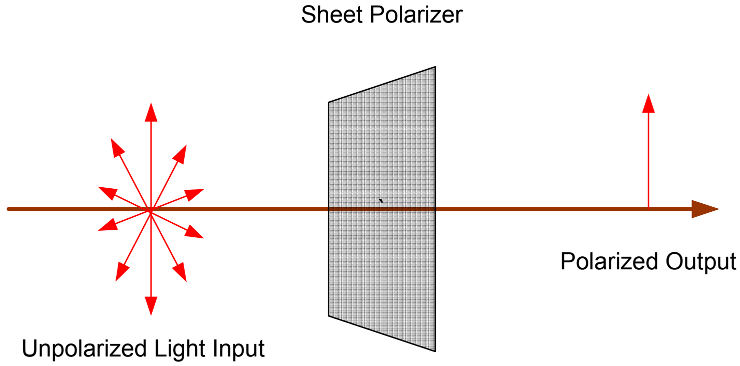
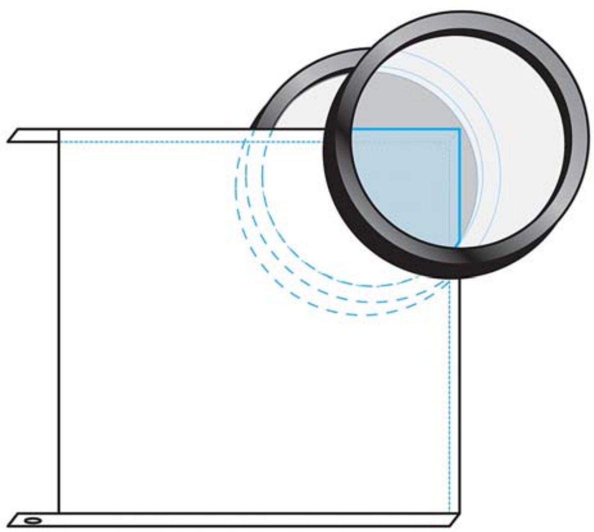
Objectives

In this experiment we will be looking a t the polarization properties of the output of the HeNe laser provided for the experiment. In order to measure the polarization properties we need some kind of polarizer. For our experiment we will use a sheet polarizer. Our sheet polarizer will be mounted in 1” rotating mount. We will need to find the orientation of the polarization. The direction in which needle-like crystals are aligned during manufacture of the film by stretching or by applying electric or magnetic fields.

Experimental Setup



Linear polarization effect on a sheet polarizer



Two linear sheet polarizers, acrylic plastic (CD Case), birefringence effect

Look through both polarizers placed over a light source. Turn one of them until they both look dark (crossed polarizers). Place the plastic (CD case top) between the two polarizers, as the illustration shows, and see how the plastic is transformed. Tilt the plastic or rotate it and see what happens. Use a folded and crumpled piece of cellophane and repeat the previous experiment.

Parts List

Qty	Description
1	HRR008 HeNe Laser (polarized
2	PM2 Clamp
1	C1503 Kinematic V-clamp
1	P8 Mounting Post
1	MB1224 Optical Breadboard
2	1” dia sheet polarizers - LPVISE100-A1**
2	RSP1 Rotational Mount
3	3” TR posts
2	2” PH Post Holders
2	BA2 base plates
1	UPH3 Utility Post Holder
1	DVM Digital Voltmeter*
1	DET36A Photo Detector
1	VT1 Variable in-line terminator
1	2249-C-36 36” BNC Cable
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