## Laser

### 1. หนังสืออ้างอิงสำหรับเขียนทฤษฎีและเพื่อการค้นคว้าทั่วไป

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# SAFETY NOTES

Lasers are valuable sources of light for exciting demonstrations and laboratory experiments in schools. Although the powerful pulsed lasers are used for welding and are capable of drilling holes in metal, the low-powered Metrologic helium-neon lasers are incapable of such destruction and may even be aimed at clothing or skin tissue with no damage. However, just as people are cautioned not to look directly into the sun, they should also be cautioned not to look directly into the laser while it is operating. If a student stares directly into the laser at close range for an extended period of time, the ultra-violet radiations from the plasma tube may result in damage to the conjunctiva and cornea of the eye that is very similar to sunburn. Similarly, although high-powered lasers are being used to, weld detached retinas and for other surgery of the eye, the eyes of many animals and humans have been exposed to direct beams of low-powered lasers without apparent damage for short periods of time. To ensure absolute safety, however, the following precautions are recommended :

1. Laser light should be treated like a beam of light from an arc lamp projector - *it should not be viewed by looking into the laser or into the reflection of the beam from a mirrored surface.*

2. Careless shining of the laser near others' eyes is to be prohibited.

3. A three wire grounded plug is provided on all Metrologic lasers. The plug should be inserted in a three hole wall outlet or the laser case should be grounded prior to operation.

4. A high voltage at lethal current levels is present inside the laser chassis. Do not open the chassis with the laser plugged in.

5. All Metrologic lasers are manufactured in accordance with the safety requirements of the U.S. government. Do not open the laser housing.

# INTRODUCTION TO EXPERIMENT MANUAL

In the relatively short time that has elapsed since 1958 when Arthur L. Schawlow and Charles H. Townes published their ideas for a proposed laser, it has evolved from an expensive laboratory curiosity into an economical tool used in industry, medicine, navigation, communications, and now in science education as well. The helium-neon gas laser is now a low cost dependable source of intense monochromatic light. Laser light is valuable in lecture demonstrations and in the student laboratory from elementary school science to graduate physics at the university level.

This manual contains experiments which have been developed by active teachers and have been thoroughly tested under typical classroom conditions. Additional experiments may be added as techniques are improved and the uses of a laser as a teaching tool are perfected in the field. Write to Metrologic for the latest information available.

Although the experiments described in this manual may be performed using mirrors, lenses, and filters already in the school laboratory, it is recommended that the accessories in the Metrologic Optics Education Kits used whenever possible. These accessories have been specifically manufactured and selected for their compatibility with the low cost Metrologic lasers.

Each of the experiments start with a short introduction and the minimum amount of theory which must be known before starting the experiment. The underlying concepts are then developed as the experiment proceeds and data is analyzed. It is hoped that this will whet the appetite of the student to delve more deeply into textbooks and journals for more complete details as he progresses. The manual also contains many suggestions for open-ended experiments whose scope is only limited by the interest of the students and the time available.

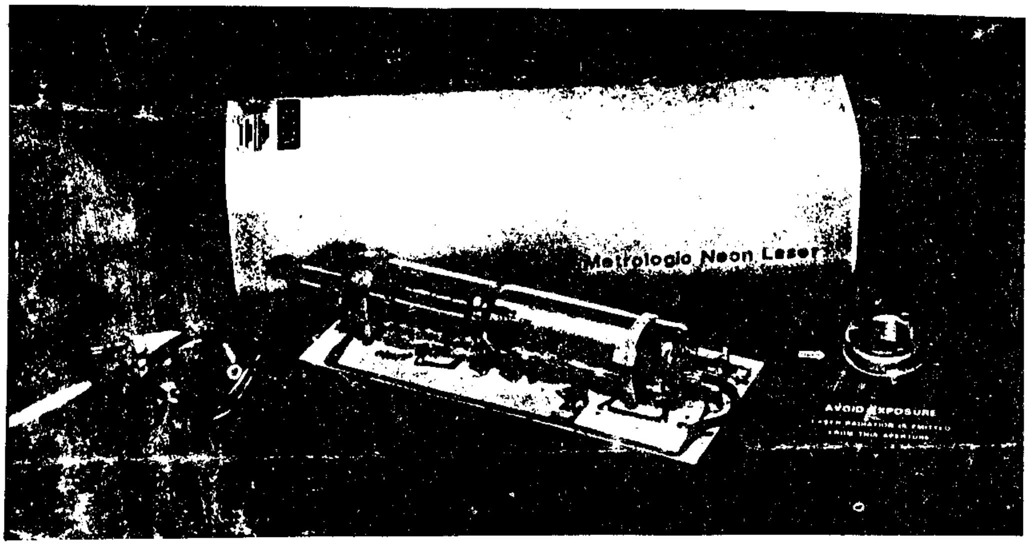
It is recommended that the experiments be performed in the sequence given in this manual. The first four experments are exploratory exercises in which the student becomes familiar with the basic characteristics and capabilities of his laser while learning several of the more important principles of optics.

The experiments in reflection and refraction of light, which follow the introductory exercises, are adaptions of well known experiments which have been improved to take advantage of the laser's narrow intense beam. They incorporate long distance measuring techniques which enable the student to obtain precise data with comparatively crude and inexpensive measuring instruments.

The latter half of this experiment manual describes experiments in modern physics which are difficult or impossible to perform using ordinary sources of light in the typical school laboratory. It is in this area that the laser shows its greatest promise as an indispensable instrument for science education.

It should be noted that the exercises herein are intended to involve groups of students - the experiments may be seen by several or many students at the same time.

# THEORY OF LASER OPERATION




Laser disassembled to show major components

The low cost Metrologic helium-neon lasers have been especially developed for educational purposes. Although it is not necessary to understand the theory of laser operation to perform most of the experiments in this manual, the principles of operation which are described below are interesting applications of electronics, optics, and quantum mechanics.

## General Characteristics of Laser Light

Laser light is quite different from light normally encountered in daily life. The difference is in four characteristics :

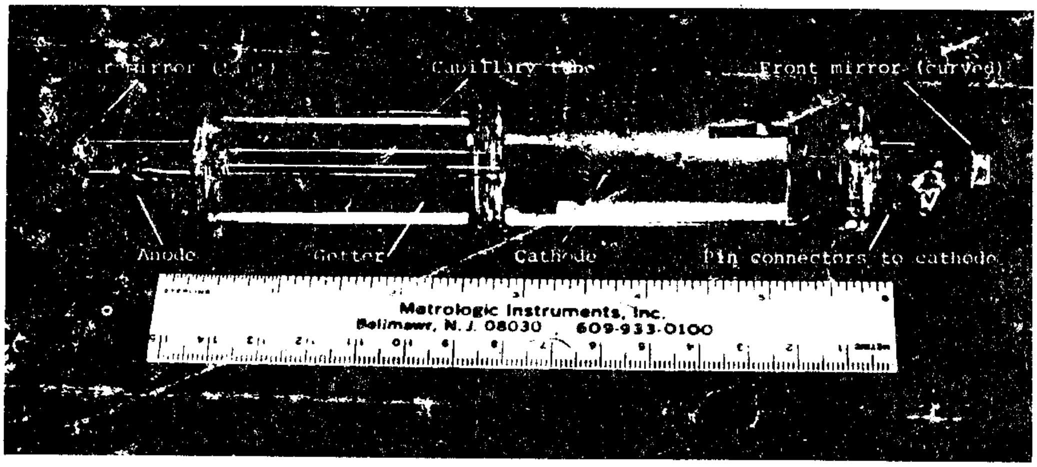
1. Brightness ; high energy concentration.
2. Monochromaticity ; single coloredness.
3. Collimation; narrow divergence of the beam.
4. Coherence in time and space.

To see how these characteristics arise, let us see.how a laser works.

## General Theory of Operation

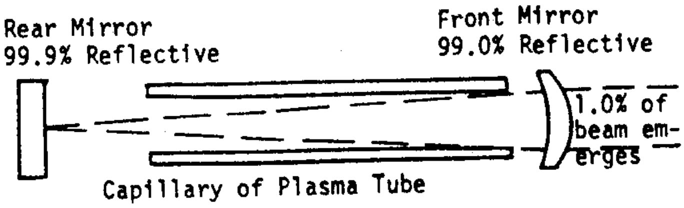
The laser is essentially a long glass tube filled with a mixture of helium and neon gases under low pressure. Beneath the laser tube is a solid state power supply which converts 110 volts AC from the linecord into 1100 volts DC. This high voltage is applied to a set of electrodes in the laser tube setting up a strong electric field. Under the influence of this field, the gases are activated and a beam of intense red light is emitted from the front of the laser. The light is monochromatic with a wavelength of $632.8 \times 10^{-9}$ m (6328 Å or 632.8 nanometers) and has other characteristics that are associated with laser light.

## The Plasma Tube




The plasma tube consists of a long capillary tube, two millimeters in diameter, which is surrounded by a hermetically sealed glass outer tube. The laser action which produces the beam occurs in the central capillary tube as the high voltage DC is applied to a mixture of gases, approximately 85% helium and 15% neon, which are at a pressure of about 1/300 of an atmosphere. As the electric energy is applied, the electrons of each atom respond by changing their orbits from the normal ground level configuration to the larger or more complex orbits that are associated with higher energy levels. After a short time in the energized state, the electrons spontaneously revert to their original ground state conditions, giving off their recently acquired energy as photons of light. They are emitted in many different directions making the entire laser tube glow with the characteristic blue color of helium and the red color of neon. Some photons are likely to be emitted in a direction along the axis of the capillary tube where they will encounter other energized atoms. Each such encounter stimulates the gas atoms to produce additional photons which join the original one like a rolling snowball coming down a snow covered hill, getting/larger and gaining energy as it travels. The phenomenon is called stimulated emission of radiation. The stimulated emission results in a combined wave of increasing amplitude. Upon reaching the end of the laser tube, the wave encounters a mirror which sends it back through the tube to stimulate more energized atoms and increase its amplitude by a factor of 1.02 with each pass. With a flat mirror at each end of the laser tube, perfectly aligned waves of high amplitude are generated in a very short time.

These waves are coherent in time because only those waves with an integral number of half wavelengths from mirror to mirror can sustain oscillation. The situation is similar to the standing waves in a jump rope.




To produce an external laser beam the mirror at the front of the laser tube is a partial reflector which reflects 99% of the light and transmits approximately 1%. The mirror at the back of the laser tube has a higher reflectivity and reflects about 99.9% of the light while transmitting less than 0.1%. Neon radiates several different wavelengths of light as its electrons fall from higher energy levels to the ground state, one of the strongest radiations in the visible light range (6328 Å) is produced when the orbital electrons fall from the $3S_2$ to the $2P_4$ level

During the manufacturing process, the coatings of the two mirrors are carefully adjusted so that the laser will resonate the 6328 Å emission at the expense of other radiations produced by the neon gas.

A "semi-confocal" mirror arrangement is used in the Metrologic lasers. This consists of a flat mirror at the back of the laser tube and a concave mirror at the front where the beam comes out. Although a greater power output could be obtained with two flat mirrors (or long radius curved mirrors) flat mirrors are very difficult to align; it is even more difficult to maintain their alignment when the laser is subjected to minor mechanical stresses during operation. With the semi-confocal arrangement, some power is sacrificed, but the laser is so stable that it can withstand the vibration and stress which occurs in a typical student laboratory. Furthermore, the curvature of the front mirror is calculated to focus the beam at the surface of the distant flat mirror. This curve-flat arrangement produces a laser beam which is cone shaped between the mirrors, the point being at the flat end, and diverging at the curved end. To compensate for this divergence, an additional converging lens surface is placed on the laser output mirror to produce a beam whose edges are very close to parallel.

Because of the internal geometry of individual laser tubes, it is found that the beam tends to vibrate more strongly in a particular plane than at any of the other possibilities. That is, the beam tends to be elliptically polarized. It is also observed that there is sometimes a secondary beam, polarized at right angles to the favored direction of vibration. In a short laser tube, one will find that the output beam is polarized at a given instant and that this plane of polarization appears to shift between two favored directions at right angles to each other in a somewhat unpredictable manner. This interesting effect may be observed by passing the laser beam through a polaroid filter and observing the changes in beam intensity.

The capillary tube in which the laser action occurs is surrounded by a second tube about one inch in diameter. This outer tube has two purposes: 1) it supports the inner capillary and the two end mirrors in a rigid permanent alignment; 2) it provides a large reservoir of neon gas which replenishes the supply in the laser cavity as it is slowly absorbed by the cathode during laser operation.

Helium gas is included in the laser because it has been found to enhance the output of the neon gas by a factor as high as 200 X. As the helium atoms are energized by the high voltage direct current, they collide with nearby neon atoms in a most efficient energy transfer process. Although it has been found that the neon gas alone will provide laser action, the output is about 200 times as great when helium and neon are mixed in proportions of about 6 to 1 (i.e. about 85% helium, 15% neon).

## The D.C. Power Supply

The D.C. power supply receives 110 volts A.C. from the linecord and produces a D.C. voltage of 2000 volts. To do this, a transformer steps up the 110 volts to 630 volts A.C. A 630-volt (rms) A.C. signal has peak voltage excursions of about 1000 volts positive and 1000 volts negative. Solid state rectifiers act upon the positive and negative excursions of the transformer output separately to produce two independent outputs of 1000 volts. These voltages are then added in series using a voltage multiplier circuit to produce a combined output of approximately 2000 volts. This is reduced to the required 1100 volts with the aid of a string of ballast resistors. To start the initial laser action and ionize the gas in the tube, a separate circuit provides a pulse of about 2000 volts which is automatically removed once the laser action starts.

## WHAT IS A LASER?

The term "laser" is an acronym. It stands for "Light Amplification by Stimulated Emission of Radiation". Thus the laser is a device which produces and amplifies light. **The mechanism by which this is accomplished, stimulated emission, was postulated by Einstein in 1917 but has only recently been applied.** The light which the laser produces is unique, for it is characterized by properties which are very desirable but almost impossible to obtain by any means other than the laser.

To gain a better understanding of what a laser is and what it can do, we shall start with a short review of some of the phenomena involved in laser action. A good subject with which to start is light.

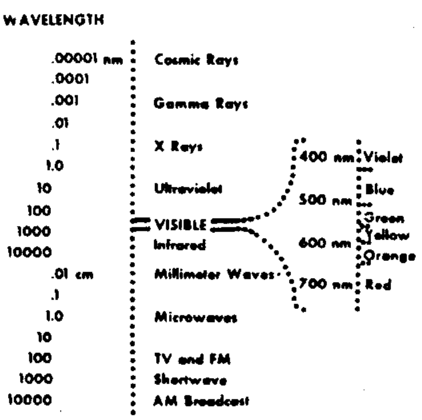
## A. Light

Light is a form of electromagnetic energy. It occupies that portion of the electromagnetic spectrum with which man first dealt because it was visible to the human eye.

Originally the term "light" included only the visible frequencies. About 1800, however, the British-German actronomer, W. Herschel, placed a thermometer just beyond the blue portion of a spectrum produced by a prism using sunlight and found its temperature was raised. Later, invisible light was found on the other side of the visible spectrum. Thus it was that frequencies outside the visible range were lumped with the visible frequencies under the term **light.**

Later, when X-rays, radio waves, and other discoveries were made, light was found to be part of a spectrum of electromagnetic radiations. The distinction between the various radiations is primarily energy which is proportional to frequency. Light is considered to be that portion of the electromagnetic spectrum having wavelengths between 100 and 10,000 nanometers (nm = $10^{-9}$ meters) as shown in Figure 1.

Figure 1




ELECTROMAGNETIC SPECTRUM

From a classical point of view, electromagnetic radiations simultaneously display two seemingly contradictory properties. Electromagnetic radiations.

1. Propagate through space as **waves**; and

2. Possess a definite **particulate nature** since a discrete energy and momentum are associated with them.

Each of these properties is important to the complete understanding of the behavior of all electromagnetic radiation. Both properties are combined in the current concept of light as described by quantum mechanics.

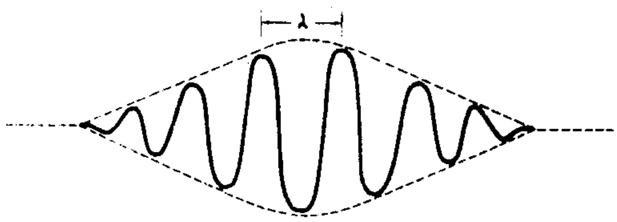
Frequently, for aid in visualizing wave behavior, light is said to move in much the same fashion as waves on a body of water. While this is not entirely true, certain characteristics are common to both types of wave motions.

The fact that a definite energy is associated with the radiation is often considered a particulate property. It is therefore difficult to visualize electromagnetic radiations as continuous waves, propagating continuously through space. One means of partially relieving this conceptual difficulty is thinking of the radiations as consisting of a limited "wave packet" which we call a "photon" (See Figure 2). The packet or photon is thought to move through space, thus satisfying a human need to visualize what truly cannot be visualized.

## B. Electron Energy Levels

Light can be produced by atomic processes, and it is these processes which are responsible for the generation of laser light. Let's look first at atomic energy levels and then see how changes in these energy levels can lead to the production of laser light.

Figure 2




REPRESENTATION OF PHOTON

A number of simplifications can be made regarding the concept of the atom. We can assume, for purposes of this discussion, that the atom consists of a small dense nucleus and one or more electrons in motion about the nucleus.

The relationship between the electrons and the nucleus is described in terms of energy levels. Quantum mechanics predict that these energy levels are discrete. A simplified energy level diagram for a one electron atom is shown in Figure 3.

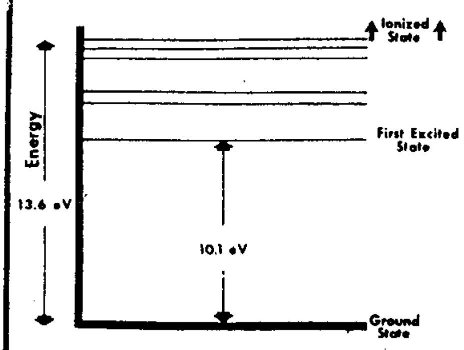
## C. Radiative Transitions

The electrons normally occupy the lowest available energy levels. When this is the case, the atom is said to be in its ground state. However, electrons can occupy higher energy levels, leaving some of the lower levels vacant. The electrons change from one energy level to another by the absorption or emission of energy. One of the ways in which an atom can change its energy state is through what is called a radiative transition.

There are three types of radiative transitions. Two of these, absorption and spontaneous emission, are quite familiar, but the third, stimulated emission, is relatively unfamiliar. It is this third type of radiative transition that forms the basis for laser action. Each form of transition is described below.

**1. Absorption.** An electron can absorb energy from a variety of external sources. From the point of view of laser action, two modes of supplying energy to the electrons are of prime importance. The first of these is the transfer of all of the energy of a photon to an orbital electron. The increase in the energy of the electron causes it to "jump" to a higher energy level; the atom is then said to be in an "excited" state. It is important to note that an electron accepts only the precise amount of energy that will move it from one allowable energy level to another. Hence only those photons of the energy or wavelength acceptable to the electron will be absorbed.

Figure 3




TYPICAL ENERGY LEVEL DIAGRAM

The second means often used to excite electronics is an electrical discharge. In this technique the energy is supplied by collisions with electrons accelerated by the electric field. The result of either type of excitation is that through the absorption of energy, an electron has been placed in a higher energy level than that in which it had been residing, and the atom of which it is a part is also said to be excited.

**2. Spontaneous Emission.** The entire atomic structure tends to exist in the lowest energy state possible. An excited electron in a higher energy level will thus attempt to "de-excite" itself by any of several means. Some of the energy may be converted to heat. Another means of de-excitation is the spontaneous emission of a photon. The photon released by an atom as it is de-excited will have a total energy exactly equal to the difference in energy between the excited and lower energy levels. This release of a photon is called spontaneous emission. One example of spontaneous emission (and absorption) is seen in phosphorescent materials. The atoms are excited by photons of appropriate energy from the sun or a lamp. Later, in the dark, they de-excite themselves by spontaneously emitting photons of visible light. A second example is the common neon sign. Atoms of neon are excited by an electrical discharge through the tube. The de-excite themselves by the emission of photons of visible light. Note that in both of these examples the exciting force is not of a unique energy, so that the electrons may be excited to any one of several energy levels. The photons released in de-excitation may have any of these several discrete frequencies. If enough discrete frequencies are present in the appropriate distribution the emission may appear to the eye as "white" light.

Now, let us look at the third, and probably the least familiar, type of radiative transition.

**3. Stimulated Emission.** In 1917 Einstein postulated that a photon released from an excited atom could, upon interacting with a second, similarly excited atom, trigger the second atom into de-exciting itself with the release of a photon. The photon released by the second atom would be identical in frequency, energy, direction, and phase with the triggering photon, **AND** the triggering photon would continue on its way, unchanged. Where there was one, now there are two. This is illustrated in Figure 4. These two photons could then proceed to trigger more atoms through stimulated emission.

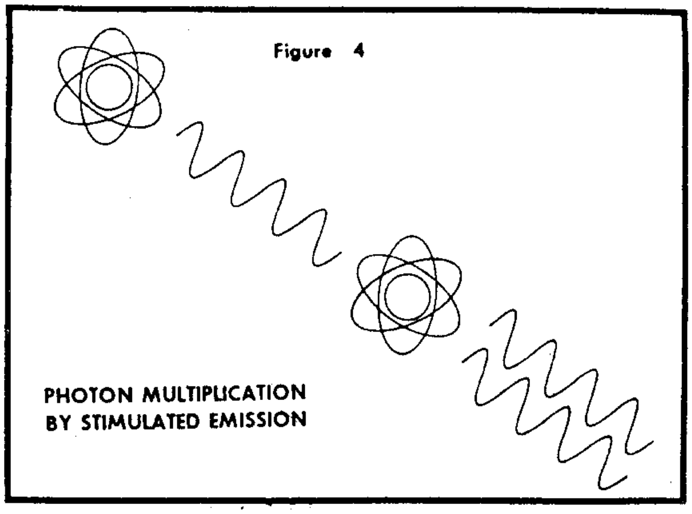
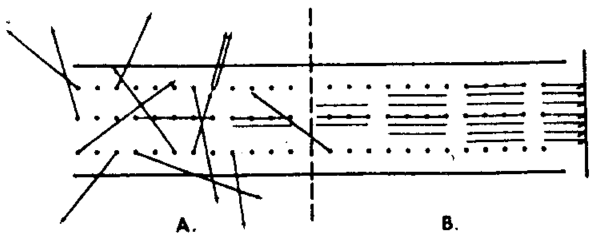


Figure 4

PHOTON MULTIPLICATION BY STIMULATED EMISSION

If an appropriate medium contains a great many excited atoms and de-excitation occurs **only** by spontaneous emission, the light output will be random and approximately equal in all directions as shown in Figure 5A. The process of stimulated emission however, can cause an amplification of the number of photons traveling in a particular direction--a photon cascase--as illustrated in Figure 5B. A preferential direction is established by placing mirrors at the end of an optical cavity. Photons not normal (perpendicular) to the mirrors will escape. Thus the number of photons travelling along the axis of the two mirrors increases greatly and light amplification by the stimulated emission of radiation occurs.

Figure 5




PHOTON CASCADE

## D. Population Inversion.

Practically speaking, the process of stimulated emission will not produce a very efficient or even noticeable amplification of light unless a condition called "population in version" occurs. If only two of several million atoms are in an excited state, the chances of stimulated emission occurring are infinitely small. The greater the percentage of atoms in an excited state, the greater the probability of stimulated emission. In the normal state of matter, the population of electrons will be such that most of the electrons reside in the ground or lowest energy levels, leaving the upper levels somewhat depopulated. When electrons are excited and fill these upper levels to the extent that there are more atoms excited than not excited, the population is said to be inverted. This is illustrated in Figure 6.

Figure 6

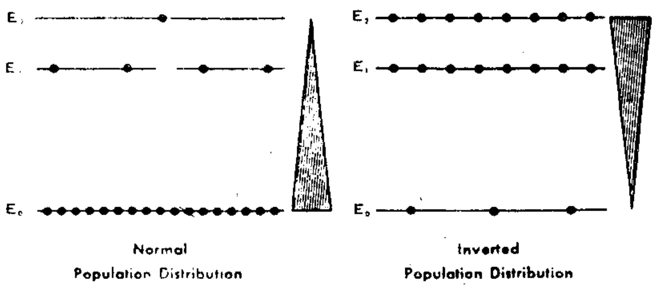



ILLUSTRATION OF POPULATION INVERSION

# HOW DOES THE LASER OPERATE?

Now that some of the phenomena have been discussed, let us see how a laser is constructed and how it operates. Three components are necessary : (1) An active lasing medium, (2) an input energy source (called the "Pump"); and (3) an optical cavity.

**(1) The Lasing Medium.** Lasers can be classified according to the state of their lasing media. Four common families of lasers are presently recognized.

**A. Solid State Lasers** employ a lasing material distributed in a solid matrix. One example is the ruby laser, using a precise amount of chromium impurity distributed uniformly in a rod of crystalline aluminum oxide. The output of the ruby is primarily at a wavelength of 694.3 nm, which is deep red in color.

**B. Gas Lasers** use a gas or a mixture of gases within a glass tube. Common gas lasers include the Helium-Neon laser with a primary output of 632.8 nm and the $CO_2$ laser, with outputs in the blue and green regions are becoming quite common. Even water vapor can be made to yield a laser output in the infrared.

**C. Liquid Lasers** are relatively new and the lasing medium is usually a complex organic dye. The most striking feature of the liquid lasers is their "tunability". Proper choice of the dye and its concentration allows light production at almost any wavelength in or near the visible spectrum.

**D. Semiconductor Lasers** are not to be confused with solid state lasers. Semiconductor devices consist of two layers of semiconductor material sandwiched together. One material consists of an element with a surplus of electrons, the other with an electron deficit. Two outstanding characteristics of the semiconductor laser are its high efficiency and small size. Typical semiconductor lasers produce light in the red and infrared regions.

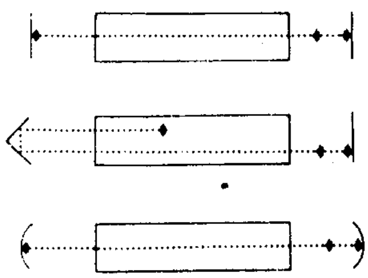
**(2) Pumping Methods.** Laser action can occur only when a population inversion has been established in the lasing medium. This population inversion can be established by pumping energy into the lasing medium. Several methods of pumping are commonly used. Optical pumping is employed in solid state and liquid lasers. A bright source of light is focused on the lasing medium. Those incident photons of correct energy are absorbed by the electrons of the lasing material and cause the latter to jump to a higher level. (enon flashtubes similar to strobe lights used in photography, but more powerful, are commonly used as optical pumps for solid state lasers. Liquid lasers are usually pumped by a beam from a solid state laser.

Electron collision pumping is utilized in gas lasers. An electrical discharge is sent through the gas filled tube. The electrons of the discharge lose energy through collisons with gas atoms or molecules and the atoms or molecules that receive energy are excited. Electron collision pumping can be done continuously and can therefore lead to continuous laser output.

**(3) Optical Cavities.** Once the lasing medium has been pumped and a population inversion obtained, lasing action may begin. If, however, no control were placed over the direction of beam propagation, photon beams would be produced in all directions. This is called superradiant lasing.

The direction of beam propagation can be controlled by placing the lasing medium in an optical cavity formed by two reflectors facing each other along a central axis (Figure 7) Photon beams which are produced a long the cavity axis are reflected 180° at each reflection and travel once more through the lasing medium causing more stimulated emission. Thus, the beam grows in magnitude with each traverse of the lasing medium.

Figure 7

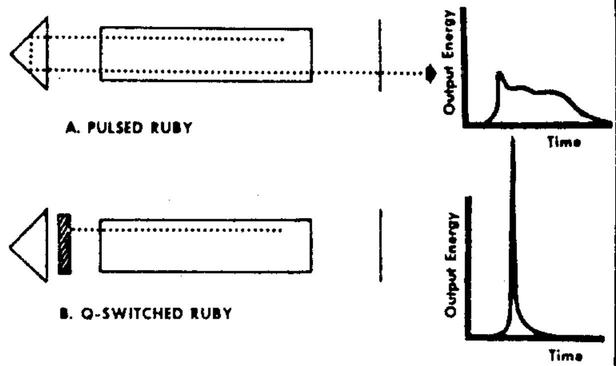


OPTICAL CAVITIES

Since the reflectors are not 100 percent reflective, some photons are lost by transmission through the mirrors with each passage. If the pumping is continuous, a state of equilibrium will soon be reached between the number of photons produced by atoms raised to the excited state and the number of photons emitted and lost. This results in a continuous laser output and is usually used only with low form power input levels. Higher power inputs usually are achieved in the form of a pulse, and the output is also in pulse form. One of the mirrors in the system is usually made more transparent than the other and the output, pulsed or continuous, is obtained through the reflector.

Q-switching (or Q-spoiling) is used to produce an exceptionally high-power output pulse. The term "Q" as applied to lasers is derived from the more familial Q of electrical circuits. Lasers are resonant cavities and in a similar way, many electrical devices are resonant. The Q is a numerical index of the ability of the resonant cavity to store energy at the output frequency. The higher the Q, the more effective the power concentration at the resonant frequency. Q-switching in lasers refers to the method of laser operation in which the power of the laser is concentrated into a short burst of coherent radiation. A Q-switch is a device which interrupts the optical cavity for a short period of time during pumping. A schematic of a Q-switched solid state laser is shown in Figure 8.

Figure 8




Q SWITCH AND PULSE OUTPUT DIAGRAM

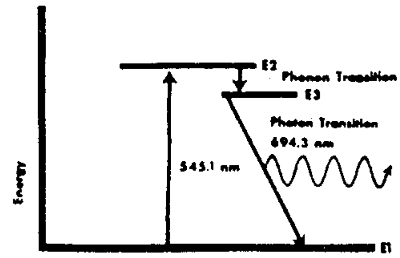
Lasing action normally begins as soon as a population inversion is achieved and continues as long as pumping action maintains the inversion. The Q-switch interrupts the optical cavity and reduces the losses due to lasing until pumping can achicve a greater population inversion, say 70% to 80%, the Q-switch then suddenly restores the cavity and the resulting pulse is much shorter and more powerful than would normally be achieved.

One example of a Q-switch is the Pockel's cell, made of a crystal of ammonium or potassium dihydrogen phosphate (ADP or KDP) sandwiched between two crossed polarizers. In its de-energized state, the crystal will not affect polarized light. When an electric field is applied across the crystal, however, the plane of polarization of the incident light is rotated by 90°, allowing it to pass the second crossed polarizer. This completes the optical cavity and results in a giant pulse.

Reflectors may consist of plane mirrors, curved mirrors, or prisms, as shown in Figures 7 and 8. The mirror coating may be of silver if laser output power is low, but higher powers may require dichroic material. A dichroic material is a crystalling substance in which two preferred states of polarization of light may be propagated with different velocities and, more important, with different absorption. By appropriate choice of material and thickness, the light impinging upon the dichroic coating may be either totally absorbed or totally reflected. The first ruby lasers were constructed with the crystal ends polished optically flat and silvered. Semi-conductor lasers use a similar technique. Gas lasers may use mirrors as seals for the ends of the gas tube or may utilize exterior mirrors. In the latter case, the tubes use end windows of glass or quartz set at Brewster's angle and the output is polarized light.

**(4) The Ruby Laser.** The laser first successfully operated was a ruby laser. It was constructed and operated by Dr. T.H. Maiman in 1960. Ruby is a crystal form of aluminum oxide with about 0.05% by weight chromium as an impurity. The chromium gives the ruby its red color and is responsible for the lasing. Chromium exhibits a 3-level energy system, as represented in Figure 9.

Figure 9




ENERGY LEVELS OF CHROMIUM

In a ruby laser, the electrons of chromium atoms are pumped to an excited energy level by means of an xenon flashlamp placed beside or around the ruby rod. The chromium electrons absorb photons in a band centered around 545.1 nm and are raised from their ground level to excited level E2. From here, they drop almost immediately to level E3 by means of a photon (radiationless) transition. The small amount of energy lost here is through heat and vibration. The electrons will reside in level E3 for a considerable length of time--much less than a second--but for an electron that is a relatively long time. Thus, since the flashlamp operates in a period of microseconds, a population inverstion can be obtained.

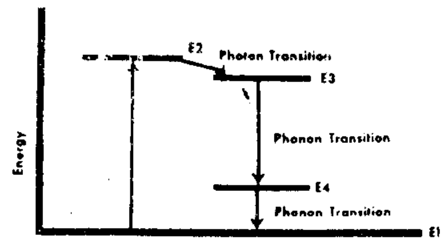
The excited atoms begin to de-excite spontaneously, dropping from level E3 to E1, and since a population inversion is in effect, stimulated emission may begin. In any lasing medium, stimulated emission may occur in all directions and no particular direction of propagation is favored. As stated earlier, to gain control of the emission direction and increase the amount of energy within the pulse, the lasing medium is placed within an optical cavity. Photons not emitted along the axis of the cavity will pass out of the system and be lost. If, however, a photon cascade is aligned with the cavity axis, it will encounter one of the mirrors and be reflected back upon itself, pass once more through the lasing medium and trigger more excited atoms to undergo stimulated emissions. The pulse thus grows in size and on each encounter with the less reflective mirror, part of it emerges from the laser as high intensity coherent light.

The pulse from a typical ruby laser lasts only a few microseconds, since the pumping is not continuous. The flashlamp is run by a charge stored in capacitor banks, and once the lamp has flashed, the capacitors must by recharged. Pumping occurs over few hundred microseconds and continues as long as the flashlamp is discharging.

**(5) The He-Ne Laser.** The most common laser used today in both industry and education is the helium-neon laser. It was first operated in 1961 by Ali Javan and has proved to be the forerunner of a whole family of gas lasers. Since gas lasers are all quite similar in construction and behavior, we shall discuss the He-Ne laser as representative of the group.

The lasing medium in the He-Ne laser is a mixture of about 85% helium and 15% neon, with neon providing the lasing action. An energy level diagram for neon is shown in Figure 10.

Figure 10

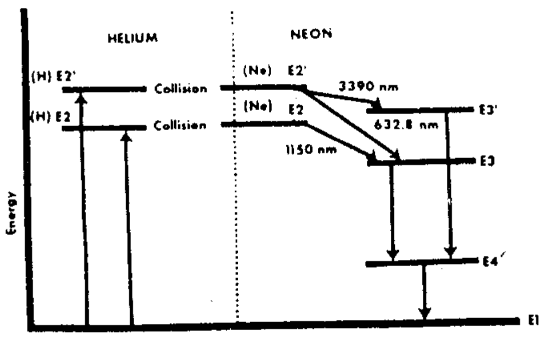



ENERGY LEVELS OF NEON

The four-level system of a gas laser differs from the three-level system of chromium in that the emission of a photon does not return the atom to a ground level. Transitions from level E3 to E4 and E4 to E1 are accomplished through a photon transition in which energy is transferred mainly through heat.

Pumping of neon to an excited state is not done directly by the energy source. Rather, indirect pumping is accomplished by exciting atoms of helium which then transfer energy to the new atoms by way of electron collision. These two gases are picked because they have electron excitation levels which are almost identical, thus facilitating the necessary energy transfer. Additionally, in the mixture of gases used, one does not need to affect a population inversion in helium in order to obtain a population inversion in neon. A more complete energy level scheme for He-Ne is shown in Figure 11.

Figure 11




ENERGY LEVELS OF GAS LASER (DETAIL)

The He-Ne gas mixture is contained in a sealed tube. Excitation of the helium is accomplished by a discharge of electricity through the tube, similar to a neon sign. The mirrors may be enclosed within the tube or may form the end caps of the tube containing the He-Ne mixture. This is a rather solid geometrical configuration and results in a stable light output.

Since the alignment of the mirrors is a delicate procedure, one common method is to mount the mirrors separate from the laser tube. When this is done, the ends of the laser tube are made of pyrex or quartz set at a Brewster's angle to the axis of the laser, and the output is polarized light.

**(6) Other Lasers.** Other lasers operate in similar but more complicated ways. Changes in molecular energy levels may be used rather than changes in electron energy levels, but output is still obtained through the stimulated emission of radiation.

# EXPERIMENT 1. SCATTERING OF LIGHT

## Purpose

Laser light, like any other light, is invisible to our eyes unless it is traveling in a direction which will permit it to enter the eye and fall on the retina. When small particles, such as dust, are in the laser path, much of the light will be transmitted but some of it will be scattered by the small particles. This scattered light enables us to "see" the laser beam. It will be observed that whenever scattering occurs there will also be some absorption of the laser beam, and it will weaken in intensity as a result. Try some of the suggestions for scattering experiments given below. At this point, you may wish to design your own scattering experiments. In either case, take careful notes as you proceed.

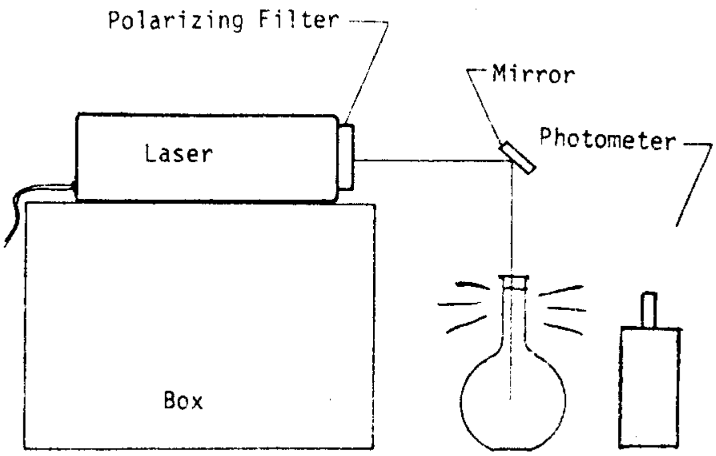
## Procedure

A. Shake chalk dust from a blackboard eraser front of the laser and record the scattering effects that are observed.

B. Pour some water into a container and shine a laser beam through the water before the air bubbles have had time to leave. Record the scattering effects that are observed as the air bubbles rise and finally disappear.

C. Hold some clear ice in front of the laser beam and observe the scattering effects that occur when the beam encounters any imperfections in the crystalline structure.

D. Shine the laser beam through a tank of clear water and place a photometer on the far side of the tank to measure the output of the laser beam. Place measured amounts of various chemicals which do not dissolve in the water and stir each time a small quantity of chemical is mixed with the water. Make graphs to show the relationship between the concentration of chemical mixed with the water versus the reading of the light meter.



E. When light it scattered, it is not scattered uniformly in all directions. Using a suitable liquid solution or suspension, place the base of a protractor along the laser beam and observe the amount of light that is scattered at various angles with respect to the beam. If a light meter or photometer is available, take quantitative data and on a graph, plot the meter reading versus the scattering angle.

F. Observe Rayleigh scattering using the setup shown above. Put a few drops of $AuNO_3$ in a florence flask full of water. Polarize the laser beam by placing a polaring filter over the front of the laser.

With the aid of a mirror, shine the laser beam along the axis of the flask neck and observe the intensity of the light scattered from the flask. With a photometer at a constant distance from the flask, move it in a 360” circle recording the intensity of the scattered light each 10° and plot the result on polar graph paper.

More complex scattering patterns result with a few drops of milk in the flask. Unlike $AuNO_3$, milk particles are much larger than the wavelength of laser light so the scattering pattern is not as simple as the Rayleigh, but it will be easy to observe by eye that the intensity of the scattered light is not uniform in intensity about the neck of the flask.

# EXPERIMENT 2. COLOR

## Purpose

The helium-neon laser not only generates an intense laser beam of red light having a wave length of 6328 Å, but it also produces a fairly strong output of blue light and green light. In this experiment, these colors will be examined and the transmission, absorption and reflection of the primary colors will be studied.

## Procedure

A. Darken the room or pull down the shades so that there is subdued lighting. Turn on the laser and observe the colors which emanate by holding a piece of white glossy paper about 25 centimeters in front of the laser.

B. There are four spectral color filters supplied with the optics kit. A color filter absorbs certain wavelengths of light and transmits the remainder. Hold each of the color filters in front of the laser aperture, in turn, and record the resulting colors of the laser beam on the paper.

C. Try combinations of two or more filters at the same time while trying to predict the resulting colors in advance. When all four filters are used simultaneously, they should absorb all of the laser light and none should be transmitted.

D. Use a variety of colored construction papers and allow the laser light to illuminate each in turn in a darkened room. Some of the papers will be found to be better absorbers, and some to be better reflectors for each of the three primary colors of light (red, blue, and green). When a color is absorbed by the paper, a black area will be observed where the laser light hits it. When a color is reflected, a color other than black appears on the paper. Using a piece of glossy white paper as a reference, record the relative absorption and reflection capabilities of each of the colored sheets.

# EXPERIMENT 3. BEAM INTENSITY

## Purpose

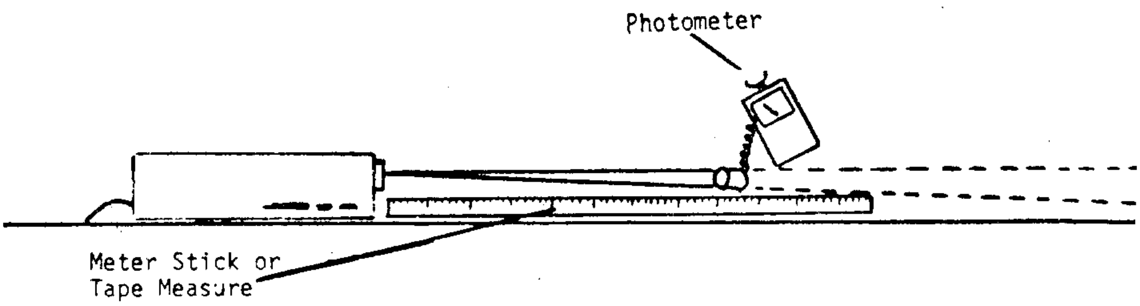
One of the chief advantages of a laser is that its primary beam is very intense and because the beam does not diverge much, the intensity does not fall off rapidly with distance. In this experiment, these characteristics of your laser will be measured.

## Procedure

A. Hold a sheet of glossy white paper in front of the laser and note the intensity of the red spot. Walk away from the laser for a distance of 100 meters or more while noting the beam intensity at one meter intervals.

CAUTION : Be careful not to look directly into the laser beam yourself and take precautions that the beam does not shine directly into the eyes of others in the immediate vicinity.

B. Measure the light intensity at various distances from the laser using a photometer.




Measure the light intensity at various distances from the laser using a photometer

C. Using a photometer, such as the one furnished with the Advanced Laser Optics Education Kit, measure the intensity of the beam at various distances from the aperture. Make sure that the opening which admits light into the photometer is the same width as the laser beam at its narrowest portion. For future reference, make a graph of the beam intensity versus distance. On the graph note the relevant experimental data such as the type and model light meter, the range setting, and the ambient light conditions.

# EXPERIMENT 4.-DIVERGENCE OF A LASER BEAM

## Purpose

One of the chief advantages of a laser is that it produces a beam of light whose edges are parallel. Any deviation form perfect parallelism will eventually cause the beam to diverge and spread out its energy, becoming weaker and weaker with distance. Perfect parallelism, however, is an unobtainable goal which is difficult or even impossible to achieve under practical conditions. Each instrument is guaranteed by the manufacturer to produce a beam that is somewhere between perfect parallelism and a specified amount of divergence. In this experiment, we shall measure the actual divergence of our laser beam.

## Procedure

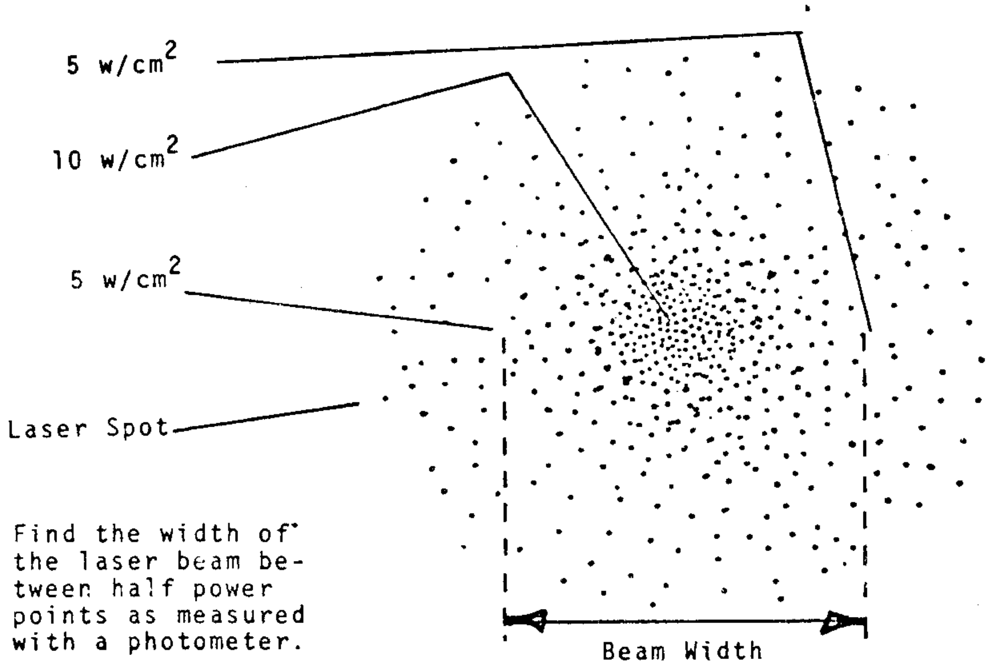
A. Measure the diameter of the laser beam by holding a sheet of millimeter graph paper in front of the laser. Record the diameter of the bright red spot on the graph paper.

B. At a distance of 10 meters in front of the laser, measure the diameter of the beam again using the same piece of graph paper. Using a long corridor, repeat this procedure at 10 meter intervals for the longest distance that is practical. Try this outdoors in broad daylight with the laser pointed along the ground in the general direction of the sun using a cardboard box to shield against the direct rays of the sun.

NOTE : The outer edge of the beam is fuzzy and it sometimes is difficult to tell where the beam ends. For consistency, use the half-power points for the edges of the beam. At these points, a photometer indicates that the beam is only one-half as intense as it is in the central portions of the beam.

C. Make a graph plotting the beam diameter versus distance and draw the best straight line connection to the points.

D. Calculate the angular divergence of the beam by dividing the change in beam diameter by the distance from the laser. The quotient will be the angle measured in radians. Multiply this value by 1000 to obtain the beam divergence angle in conventional units of milliradians.




# EXPERIMENT 5 - OPTHALMOLOGY

## Purpose

When an enlarged laser beam is aimed at a wall or at a piece of white paper, the illuminated area appears to have many small spots or grains. This granular appearance is caused by a complex interference pattern produced by the coherent light as the lens of our eye focuses it upon the retina. This phenomenon may be used to diagnose certain eye defects and illustrate how these defects may be corrected with the appropriate eyeglass lenses.

## Procedure

A. In a room with subdued lighting, aim the laser beam at a piece of white paper 2 or 3 meters away. Expand the laser beam using the +36mm lens supplied with the Optics Education Kit.

B. Observe the illuminated area and notice the very many small dots or grains that appear. Move your head very slowly from side to side while observing the spot. If you are farsighted or if your eyes are normal, the small spots will appear to move in the same direction as your head. On the other hand, if you are nearsighted, the spots will appear to move in a direction opposite from that of your head movement. In nearsighted persons, the eye tends to focus the pattern a short distance in front of the retina. Therefore, the parallax caused by the head movement results in an apparent motion of the spots to the opposite direction.

C. Demonstrate the parallax described above by holding your fingers apart and placing them a few inches in front of your eyes while looking at an object on a distant wall. When your head is moved from side to side while looking at the distant object which represents the illuminated area, your fingers, which represent the granular interference pattern, will appear to move in the opposite direction.

D. Simulate myopia (nearsightedness) by holding the +167mm lens in front of your eye. Observe the movement of the granulated spots as your head moves from side to side and record the results.

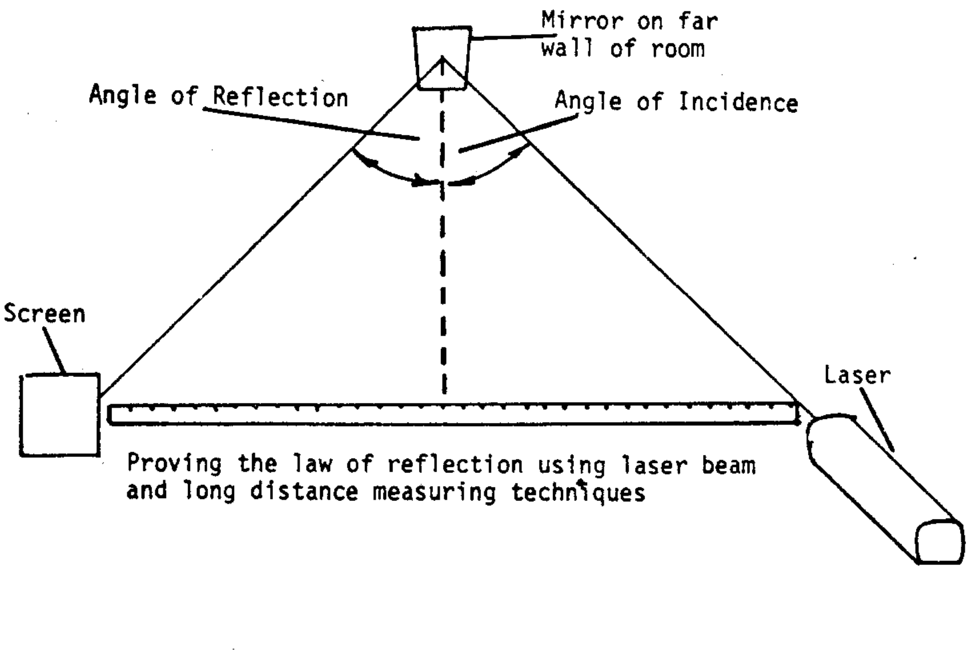
E. Simulate hyperopia (farsightedness) by observing the illuminated area on the wall through the −8mm lens. Observe the exaggerated movement of the granulations as they move in the same direction as your head from side to side.

F. If you normally wear eyeglasses, check your eyes in the manner described above with and without the corrective lenses recording your results.

**EXPERIMENT 6 - REFLECTION**

## Purpose

Whenever light comes to the boundary between two media having different optical densities, some or all of the energy will be reflected. In this investigation several types of laser beam reflection will be investigated.




Proving the law of reflection using laser beam and long distance measuring techniques

## Procedure

### A. Types of Reflection

1. Investigate the reflective abilities of several different types of materials that are included in the Optics Education Kit. Materials such as flat mirrors provide specular reflection which changes the direction of the beam without scattering or diffusing the light. Rough objects such as unpolished metal, paper, or wood reflect the light at the same time as they scatter it. Point the laser beam at a variety of solids and liquids, and observe the light that is reflected by holding a piece of glossy paper near the object to catch the reflected light. In each case, record the type of material tested and the appearance of the reflected laser light.

2. Using a microscope slide or the specially designed beam splitter, investigate the phenomenon of partial reflection as part of a laser beam is transmitted through the material and part of it is reflected at the surface. Observe the relative intensity of the transmitted and reflected portions of the beam as the glass is tilted at various angles with respect to the incident beam. Record your observations.

3. Shine the beam into a tank of water and observe that reflections will take place not only when the beam enters the water, but also when the beam is leaving the water from a different side of the tank. Reflections that tend to keep the laser beam inside of a medium are known as internal reflections. The intensity of the internal reflection depends on the angle that the beam makes with the surface. Set up an experiment to determine the relative amount of internal reflection as the angle between the laser beam and the surface is varied.

**B. Law of Reflection** The law of reflection states that the angle of incidence is equal to the angle of reflection and that the incident ray, normal and reflected ray all lie on the same plane. This may be verified with precision using the laser and the long distance techniques outlined below :

1. Place the laser on a table at the rear of a room and aim the beam at the center of the wall on the other side.

2. At the place on the wall where the beam appears, tape a flat mirror using masking or adhesive tape.

3. Mark around the point where the laser beam strikes the mirror using a fine felt tip pen.

4. Adjust the position of the laser so that the incident and reflected beams are superimposed and the reflected spot is as close to the laser aperture as possible. When this adjustment has been made, the laser beam coincides with the normal to the mirror surface. Mark the exact position of the laser at this time.

5. Move the laser three meters to the right of the original position in 50 cm steps. At each step, point the laser at the marked spot on the mirror at the far wall and see how far the reflected beam is to the left of the original laser position.

6. Examine the recorded data. According to the law of mirrors, the distance that the laser was moved to the right of its original position should be exactly the same as the distance that the reflected beam is to the left of that position.

7. Without touching the mirror on the far wall and with the laser slightly to the right of its original position, elevate the laser slightly by placing it on some books and point it at the marked spot on the mirror. Determine the relationship between the distance that the laser was elevated and the distance that the reflected beam is depressed.

# EXPERIMENT 7 – POLARIZATION EFFECTS

## Purpose

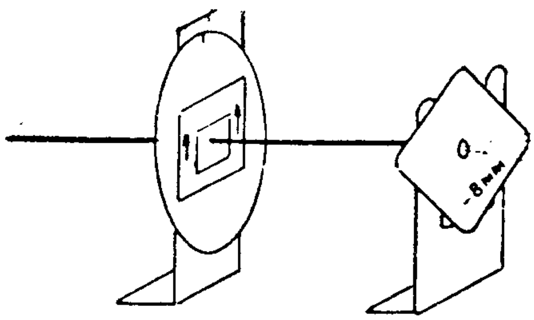
In this experiment, polarization effects of the laser beam will be investigated using the polarizing filters which are supplied with the Optics Education Kit. Theoretically, the laser beam should be like sunlight which contains light waves that vibrate in many different directions as the light travels straight ahead. In an actual helium-neon laser, however, polarization effects are observed as some planes of vibration are favored over others. These effects differ greatly from on individual laser to another and it is interesting to find out the characteristics of your own laser.

## Procedure

A. Fasten one of the polarizing filters to the rotating compass panel. Expand the beam which is transmitted through the filter with a diverging lens ( – 8 mm) and observe the spot which falls on a screen a short distance away. Rotate the filter slowly in a complete circle of 360° and record the effects of this rotation on the brightness of the laser beam.

B. On each of the two polarizing filters that are supplied with the Optics Education Kit, there is an arrow showing the direction of crystal alignment in the filter which permits maximum transmission of light. Measure the intensity of the laser beam which is transmitted through one filter, through two filters simultaneously with the arrows in the same direction, and with two filters simultaneously with the arrows at right angles to each other.

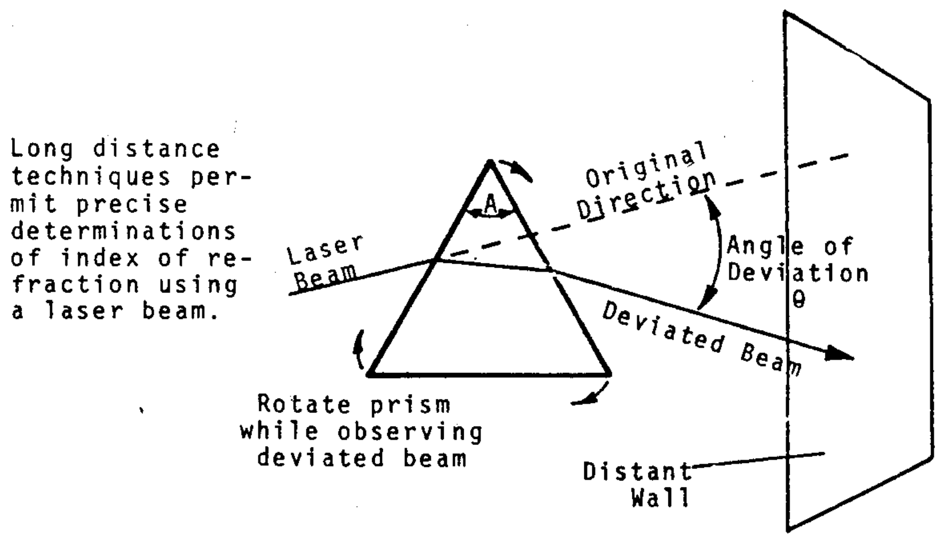
C. With a polarizing filter mounted on the compass panel, rotate the panel until the brightest beam is transmitted through the filter. At this position, the arrow on the filter shows the direction of polarization of the laser beam. Leave the filter in this position for a few minutes and observe the changes that take place in the brightness of the transmitted beam as the plane of polarization changes within the laser.



D. Find out how the plane of polarization of the laser changes over a time interval of several minutes. This interesting characteristic of laser operation differs from laser to laser because of differences in construction that occur during manufacturing process. With the laser beam go through the polarizing filter on the compass panel and then through a diverging lens for observation on a screen, rotate the compass panel until the brightest beam is observed. Record the setting of the compass panel at this time. After a few seconds, it will be found that the plane of polarization of the laser beam has shifted and a new position of the compass panel must be found to obtain the brightest transmitted beam. Over a period of several minutes, repeat the above procedure at 10 second intervals keeping a record of the compass setting and the elapsed time. Plot these data on a graph and determine whether or not there is any periodicity in the variations of the polarization planes. You may wish to refer back to the theory of laser operation at the beginning of this manual or to a textbook on laser operation for a more detailed explanation.

E. With a polarizing filter attached magnetically over the laser aperture, shine the beam into the photometer that is supplied with the Advanced Laser Optics Education Kit. As the plane of maximum polarization changes within the laser, the variation of beam intensity will be detected by the photometer Monitor the photometer for several minutes a record its reading at intervals of ten second a graph of beam intensity versus time. Compass shape of this graph with that observed in there above.

## EXPERIMENT 13 - INDEX OF REFRACTION OF A PRISM



## Purpose

When the laser beam is transmitted through a triangular prism, the beam will be refracted twice and emerge along a path that deviates from its original direction of propagation. By rotation the prism, the angle of deviation can be made larger or smaller. The smallest angle that it is possible to obtain is called the minimum angle of deviation for the particular prism. By measuring the apex angle of the prism (A) and the minimum angle of deviation ($\theta$), the index of refraction of the prism may be calculated:

$$n = \frac{\sin \frac{1}{2} (A + \theta)}{\sin \frac{1}{2} A}$$

## Procedure

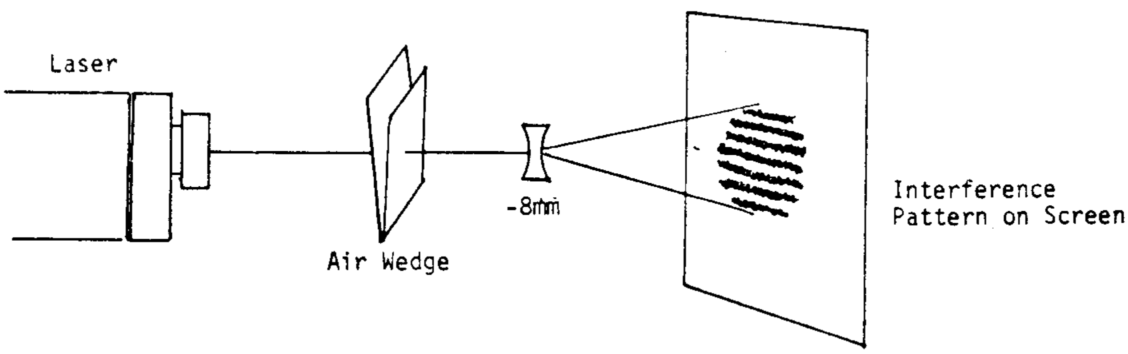
A. Mount the prism on the rotary compass panel in front of the laser.

B. Measure the apex angle of the prism and record this value. Slowly rotate the prism while observing the amount of deviation between the emerging laser beam and the original beam direction. Record the value of the minimum angle of deviation which was observed while rotating the prism.

C. Substitute the measured values of the apex angle and the minimum angle of deviation in the formula given above to calculated the index of refraction of the prism.

NOTE: To obtain greater precision in determining the minimum angle of deviation using a laser beam, the following procedure is suggested. Aim the laser beam across a room and mark the spot where it hits the wall. Place the triangular prism on the rotary compass panel is front of the laser beam and rotate it slowly while watching the deviation of the beam on the distant wall. Using this long distance technique, the magnitude of the minimum angle of deviation may be easily and precisely calculated by measuring the distances and using simple trigonometry.

EXPERIMENT 22 - THIN FILM INTERFERENCE USING AN AIR WEDGE



## Purpose

When two sheets of flat glass are separated by a thin film of air, multiple reflections of light occur at the air-glass interfaces. If the thickness of the film is adjusted so that it is 1/4 the wavelength of the incoming light (or odd multiples of 1/4 wavelength), none of the light will be transmitted, although both air and glass are perfectly transparent. In this experiment, the phenomenon of thin film interference will be investigated.

## Procedure

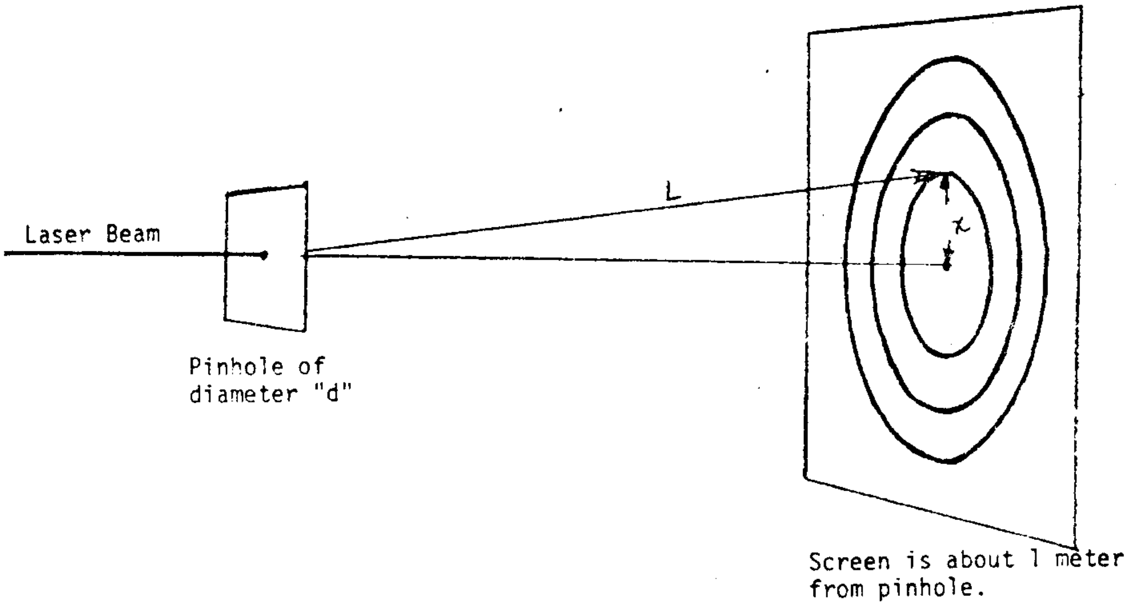
A. Mount the air film wedge on the maggie mount platform in front of the laser as shown on the diagram.

B. Enlarge the laser beam that is transmitted through the glass by mounting the diverging lens ( − 8 mm) on the maggie mount platform. Place a screen one or two meters in front of the laser to observe the patterns that are produced. As the screen is moved further from the laser, the size of the illuminated area will increase but its brightness will decrease proportionately.

C. Rotate the component carrier until it makes an angle of about 20° with the laser beam. As the carrier is rotated, the dark interference fringes will become more pronounced on the screen.

D. Vary the thickness of the air film wedge by squeezing the glass plates together with your fingers in different places around the edge. Observe the changes in the pattern on the screen as the glass is squeezed. Record your observations and explain them in a short paragraph.

NOTE: Observation of fine interference patterns is sometimes obscured by unavoidable clutter and random interference patterns which develop in the laser optics. To "clean" the laser output, use the + 36 mm converging lens and a pinhole as a spatial filter. The technique for arranging and adjusting such a spatial filter is described separately in this manual.




## Purpose

Diffraction of the laser beam by a small hole is similar to diffraction by a single slit, in principle. Because of the interference due to the diffraction fringes from the top and bottom of the hole, as well as the sides, the diffraction essentially occurs in two directions with interference in the area of overlap. Using the bright monochromatic light from a laser, these complex, well-defined patterns are easily reproduced for study and investigation.

## Procedure

A. Make a very small pinhole in a fresh piece of aluminum foil. To be sure that the hole is sufficiently small, just use enough pressure to make a needle point penetrate the foil. If the hole has been made properly, a bullseye pattern will be formed on a screen when the laser beam is passed through the hole. A perfectly round pattern on the screen indicates that the pinhole is also perfectly round. Experiment in making your pinholes smaller and smaller. The smaller the pinhole, the larger the bullseye.

B. Calculate the size of your pinhole by measuring the radius of the Airy disc on the screen. The Airy disc is the central bright disc in the bullseye pattern. Do this by using the ralationship:

$$d = \lambda \left( \frac{x}{L} \right)$$

where: d is the diameter of the pinhole,

x is the radius of the Airy disc,

L is the distance from the pinhole to the screen, and

$\lambda$ is the wavelength of the light ($6.328 \times 10^{-7}$ meter).

C. Small pinholes can also be made by using the spark produced by a Tesla coil. Adjust the coil to work at its lowest rate and make a series of small holes by passing a piece of fresh carbon paper across the spark gap between the Tesla coil and a grounded metal plate. Using the procedure of step B, measure the sizes of the pinholes and cut out and mount the better ones for future use.

D. Refer to a textbook on optics to learn more about the theory of the Airy disc and its practical use in astronomical observations.

# Binomial, Normal and Poisson Distributions[1]

## BINOMIAL DISTRIBUTION

We consider repeated and independent trials of an experiment with two outcomes; we call one of the outcomes *success* and the other outcome *failure*. Let $p$ be the probability of success, so that $q = 1 - p$ is the probability of failure. If we are interested in the number of successes and not in the order in which they occur, then the following theorem applies.

**Theorem 6.1:** The probability of exactly $k$ successes in $n$ repeated trials is denoted and given by

$$b(k; n, p) = \binom{n}{k} p^k q^{n-k}$$

Here $\binom{n}{k}$ is the binomial coefficient. Observe that the probability of no successes is $q^n$, and therefore the probability of at least one success is $1 - q^n$.

**Example 6.1:** A fair coin is tossed 6 times or, equivalently, six fair coins are tossed; call heads a success. Then $n = 6$ and $p = q = \frac{1}{2}$.

(i) The probability that exactly two heads occur (i.e. $k = 2$) is

$$b(2; 6, \tfrac{1}{2}) = \binom{6}{2}(\tfrac{1}{2})^2(\tfrac{1}{2})^4 = \frac{15}{64}$$

(ii) The probability of getting at least four heads (i.e. k = 4, 5 or 6) is

$$b(4; 6, \tfrac{1}{2}) + b(5; 6, \tfrac{1}{2}) + b(6; 6, \tfrac{1}{2}) = \binom{6}{4}(\tfrac{1}{2})^4(\tfrac{1}{2})^2 + \binom{6}{5}(\tfrac{1}{2})^5(\tfrac{1}{2}) + \binom{6}{6}(\tfrac{1}{2})^6$$

$$= \frac{15}{64} + \frac{6}{64} + \frac{1}{64} = \frac{11}{32}$$

1 Lipschutz, S., *Schaum's Outline of Theory and Problems of Probability,* 1st ed., New York : McGraw-Hill, Chapter 6.