

LASER EXPERIMENTS FOR THE CLASSROOM*

SOME GENERAL REMARKS

Throughout this book I have said things like “Measure this”, “Mark that”, and so on as though it is very simple and straightforward. Not so! Some measurements are not easy to make, and also some are more important than others, so if you want to get consistent and accurate results, the more care you take with even the simplest measurement, the better in the long run. In general, I have not specified which measurements are going to be easy, and which you will have to work for!

** Many of the activities described in this book revolve around known laws of optics, and so can not be considered as “research”. However, this is the first time you have come across them, and so they are research for you. I have written this book with that in mind. Many of the quantities you are measuring are unique to your lab and so I have refrained as much as possible from even suggesting what kind of answers you should be getting. “How do I know if my answers are right?” I hear you cry. There are two good ways.

First, repeat your readings while trying to forget what the first ones were (not easy). How many times should you repeat? I don’t know. With one reading there is not much on which to base confidence. Two readings are better, but they will probably not be exactly the same. A third reading will probably be closer to one than the other. Four will start firming things up, and I think I would stop at five total readings. By this time your technique would be getting quite good too. Never underestimate improving technique (skill) in doing any task. Every task, when you first encounter it, looks virtually impossible, but you would soon become a world expert at it if you were to stick with it.

Second, always compare your results with those of other people in your class.

*** In this book you will see that I have included sections labeled “Other things to try or think about” This is to bring your attention to the strong possibility of extending the matters being discussed to new, innovative, novel — call them what you will — activities or projects..

**** The laser supplied in the Laser LightLab kit is a semiconductor visible diode laser. It has a power in the range of 1 to 3 mW (1 to 3×10^{-3} W). This doesn’t sound very powerful, but the beam is very concentrated, and if directed straight into your eye, it will be like looking at the Sun. **PLEASE READ, BEFORE STARTING, THE SECTION ON LASER SAFETY.** If you look at the laser you are using, you will see on it a label indicating CAUTION or DANGER, the power of the laser, and its class.

Lasers are divided into different classes according to their potential for eye or other tissue damage.

Class 1. 10^{-6} W. Usually this refers to the permissible leakage of light from a higher class laser contained within an enclosure. Quite safe.

Class 2. Up to 1 mW ($=10^{-3}$ W). Marked with a “Caution” warning... See the safety precautions on the lid of the box and Topic 1.

Class 3a. 1mW to 5mW. Marked with “Caution” or “Danger”. See the safety precautions again.

Class 3b. **5mW to 50mW. Marked “Danger”.** Only to be used by trained personnel. Capable of blinding.

Class4. **Extremely dangerous.** Capable of cutting metals. Only to be used by trained personnel.

The lasers used by Laser LightLab are either Class 2 or 3a.

The term irradiance used frequently in this book refers to the illumination falling on a surface. It is a measure of energy per second per unit area. Joules per second per square meter are the units. This may also be stated as Watts per square meter.

TOPIC 1. Laser Safety.

USE YOUR LASER SAFELY.

This science kit was designed for classroom use only. The Class 2 or 3a laser diode it contains is of low power and because of normal eye aversion response (i.e. blinking, eye movement, etc), will not normally present a hazard, but may present some potential for hazard if viewed **directly and repeatedly** (like viewing the sun).

SIX SAFETY PRECAUTIONS WHEN OPERATING THE LASER.

1. **DO NOT SHINE THE LASER BEAM DIRECTLY INTO YOUR OR ANYONE ELSE'S EYE.**
2. **WATCH OUT FOR REFLECTIONS OF THE BEAM OFF SHINY OBJECTS (LENSES, MIRRORS, ETC) .**
3. **WORK IN AREAS WELL MARKED AS THOSE DESIGNATED FOR LASER USE. IF YOU DO NOT HAVE ANY OFFICIAL SIGNS, COPY AND ENLARGE FOLLOWING ONE..**
4. **SWITCH OFF YOUR LASER WHEN NOT IN USE.**
5. **DO NOT TRACK PEOPLE OR VEHICLES WITH A LASER BEAM. IT IS AGAINST THE LAW. EVEN THOUGH IT MIGHT SEEM LIKE FUN, A LASER, ESPECIALLY AT NIGHT, CAN LOOK VERY BRIGHT AND ALARM PEOPLE ENOUGH TO CAUSE AN ACCIDENT.**

TOPIC 2. Building your own laser.

Introduction.

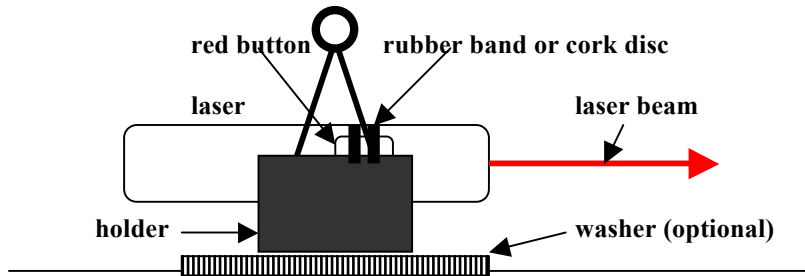
The visible diode laser provided in the kit operates on 3volts provided by two AAA or C or D batteries. The AAA's fit inside the laser case; the C's or D's fit into a holder and have to be connected to the laser using two alligator clip jumper leads.

Safety.

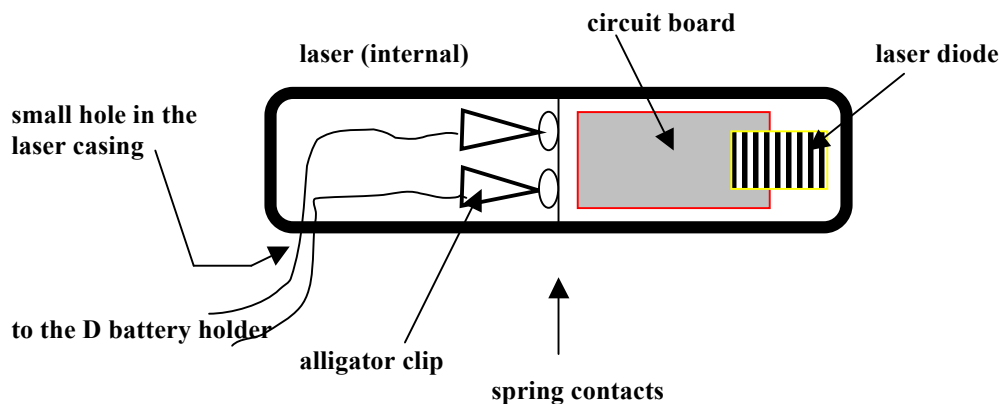
Block the beam with a small piece of masking tape over the end of the laser for this 'operational test'.

What to do.

The laser is operated by depressing the **red button** in both cases. **Make sure the batteries are connected before depressing the button.** To avoid having to hold the laser by hand while performing experiments, it may be slipped into a **large clip holder** which will press on an elastic band or **small cork pad** placed against the button. For extra stability the clip may be stuck onto a washer using a small amount of putty.



When using the C or D batteries, red and black leads should be connected to the positive and negative wires or tabs of the 3 volt battery pack provided. (You should buy alkaline batteries as these have a longer operating life than some others). If you mistakenly connect the red to the negative and the black to the positive you will not damage the laser. It will just not light up.



The laser has a small **lens** through which the beam emerges. The circuit board and laser unit may be gently raised above its housing, and the lens moved in or out by twisting the end section of the brass housing containing it and the laser diode. This has the effect of narrowing or broadening the beam.

TOPIC 3. Measuring the height of a room by laser beam surveying..

Introduction.

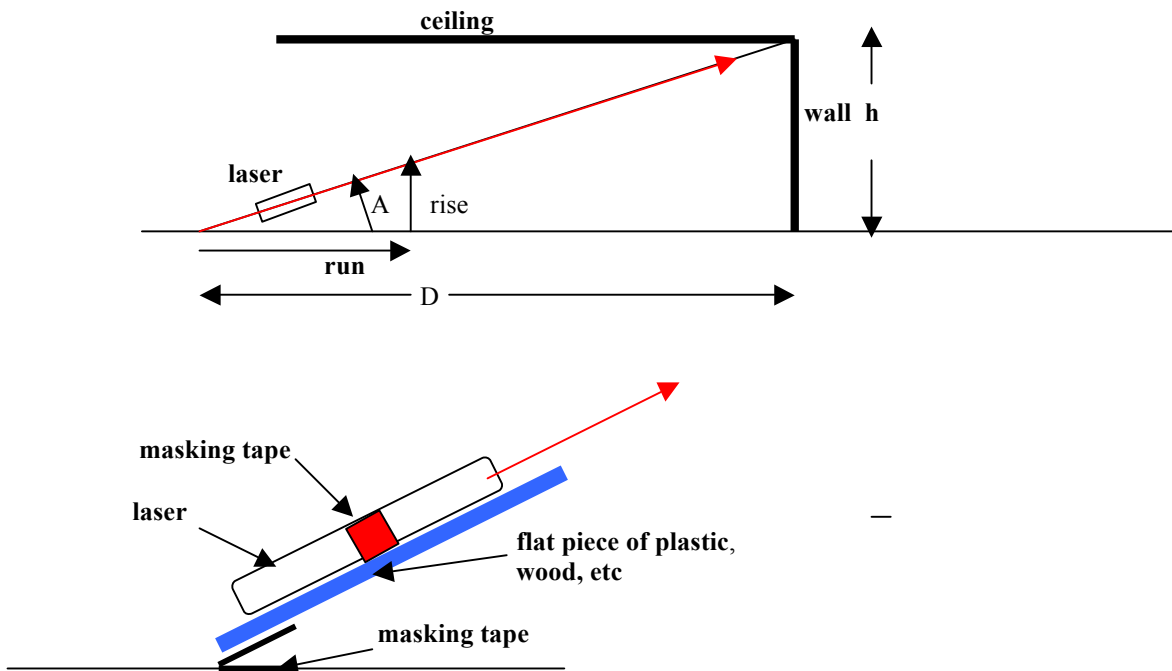
To a very good approximation a laser beam can be considered as a ‘pencil’ of intense parallel light which can run over large distances without diverging (much better than a flashlight), and so can be used very effectively as a lightweight ‘pointer’. (In fact you might have seen one used this way by a lecturer to point to things on a screen, by surveyors, and (in the movies I hope) by policemen as ‘gun sights’ when lining up on criminals). We shall use this property of a laser beam in a surveying exercise to measure the height of the room (this can be extended to measuring the height of a building— or anything).

Safety

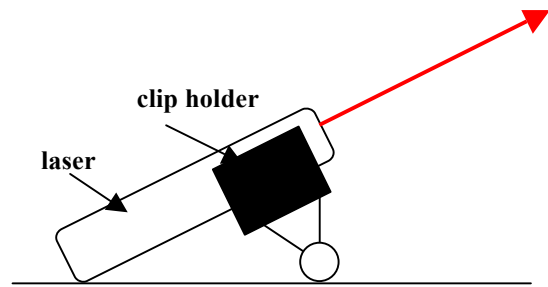
The chance of someone walking into the beam is very great in this activity. Work along a wall, if you can, to reduce the risk of this happening. Also, warn all present of what you are doing for them to be aware of the section of the lab you intend using. Also, watch out for reflections off shiny surfaces on the wall whose height you are measuring.

What to do.

1. Tape your laser to a ruler or some similar ‘base’ and make a ‘hinge’ with some masking tape as illustrated below so that the laser beam may be angled upward by sliding a clip under it.
2. Angle the laser upward so that the spot hits the top of the wall (where it meets the ceiling) whose height you are measuring. When the spot has reached its mark, secure the clip ‘wedge’ with some masking tape.



Alternative ways of holding the laser



3. Measure the angle A, either using a protractor or measuring the “rise” of the beam for a given “run”.

Notice the ratio rise/run is $\tan A$, so if you divide the rise (say 73 cm) by the run (say 115 cm) on your calculator, you will get 0.6348. Hitting the \tan^{-1} button will give the angle A ($=32.4^\circ$ in this case). Try both the protractor method for measuring the angle, and the rise/run method. Discuss the relative accuracy of these methods

4. Measure D and then calculate h using the relation $h/D = \tan A$.

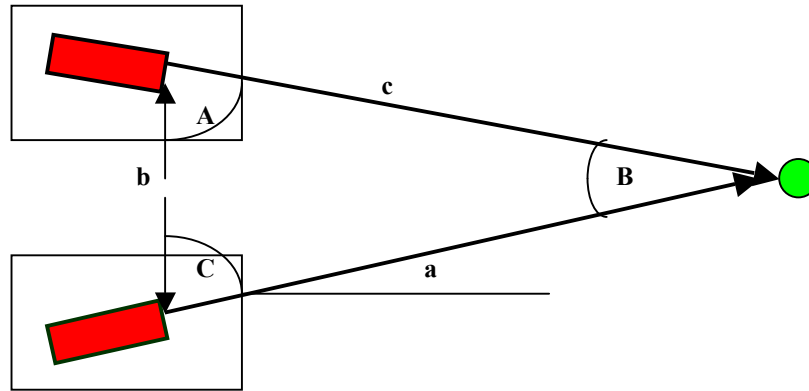
Instead of using trig you may use “similar triangle” ratios. That is $h/d = \text{rise/run}$.

TOPIC 4. Baseline distance measurements.

Introduction

If the a baseline is established and the angles measured between it and the lines of sight from its ends to a distance object, then the laws of trigonometry can be used to find the distance to that object. Referring to the diagram, if angles A and C are measured with a protractor, then B calculated from $B = 180^\circ - (A + C)$. The law of sines then gives the side c or a via $\sin A/a = \sin B/b = \sin C/c$.

ALTERNATIVELY, ANGLE A CAN BE SET AT 90° AND $\tan C = c/b$ USED INSTEAD TO FIND c.



Safety

The chance of someone walking into the beam is very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces on the object whose distance you are trying to measure.

What to do:

1. Tape sheets of paper at each end of your table and mark a line along the table and across the sheets.
2. Shine your laser beam across one of the sheets onto a distant object, and then trace its path across the paper. Holding a pencil, or something thinner, vertically in the beam is one way of doing this.
3. Repeat the tracing on the other sheet
5. The angles A and C can now be measured with a protractor, and the base line length **b** with a ruler. Calculate 'a' using the equations given in the introduction.

Other things to try or think about.

The accuracy of this method depends upon the size of your base line. Have different student groups work with different size base lines in measuring the distance to a given object. Have them compare results, and in particular, the experimental spread of their results.

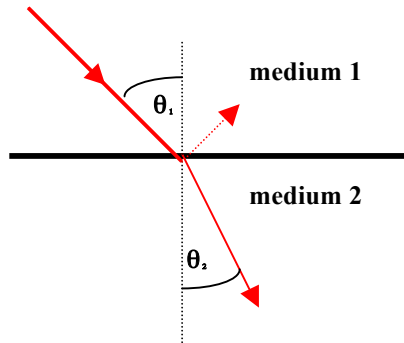
TOPIC 5. Measuring refractive index.

Introduction.

When light travels from one medium to another, it either speeds up or slows down. This causes wavefronts to change direction (see the next diagram) as they cross the boundary separating the two media (unless the angle of incidence is zero, in which case the angle of refraction is also zero). The angles of incidence θ_1 and refraction θ_2 are shown in the figure. Even though it shows the 'top' medium as air, it does not have to be. Also, with some media combinations, the beam will bend the other way. The vertical line in the diagram is called the normal (the perpendicular to the surface) and we say the refracted ray is bent either towards or away from the normal. As the angle of incidence increases, so too does the angle of refraction (which can also be called the transmission angle, if you prefer). However, the relation is not a linear one. Rather, the *sine* of one angle bears a linear relation to the *sine* of the other. In fact, for a given interface, $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ no matter what the value of the incident angle. (The transmission angle will always adjust itself to make the equation come out). The n 's are constants for the media and are called the refractive indices of the media.

It turns out that n is actually the ratio of the speed of light in a vacuum (its fastest) divided by the speed of light in the medium. In other words, the speed in the medium = $(3 \times 10^8 \text{ m/s}) / (n \text{ of the medium})$. Since n is always greater than 1, this means that light, due to its interaction with the substance it travels through, always travels slower through transparent materials than through a vacuum.

Refractive index is an important optical property that comes up all the time in optics.

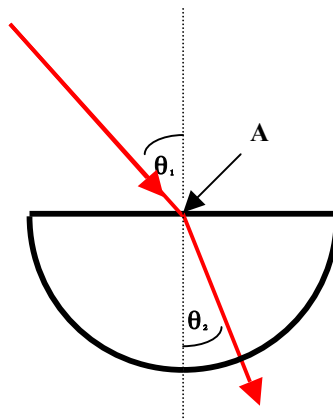


Safety

This experiment again has the beam going all over the place. Try to block it as much as possible and be cautious when placing items, such as the prism, in the beam.

What to do:

1. The 'usual' way of measuring n of a liquid is to use a plastic semicircular dish filled with the liquid.

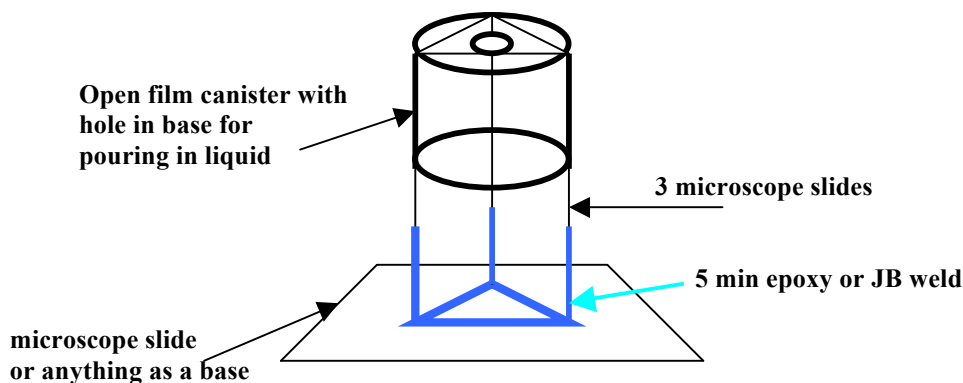


Care should be taken to direct the laser beam directly at the center A of the flat surface of the dish.

2. Measure the angles. This is made easier if the dish is placed on polar graph paper. Otherwise, the beam should be traced on a sheet of paper (on both sides of the dish) and measured after removing the dish.

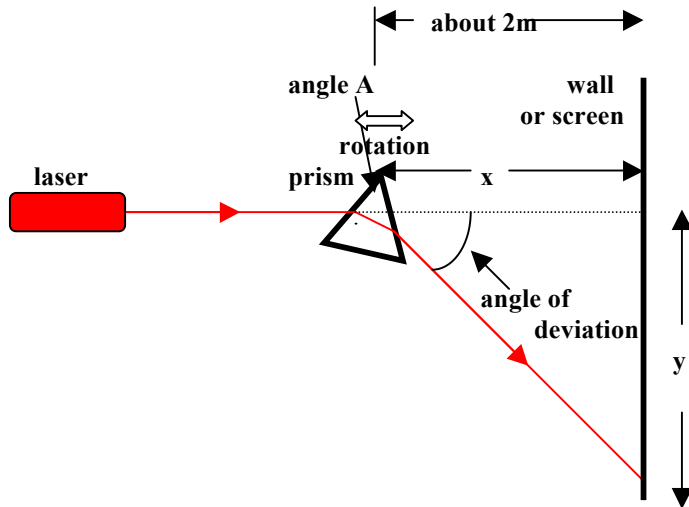
Other things to try or think about.

1. For greater accuracy and speed a hollow triangular cross-section prism can be used in this activity, and the refractive index of the liquid poured into it will be measured using the “minimum deviation” method. This involves triangulation techniques again which, if long distances are utilized, are very accurate. The directions for constructing the hollow prism is illustrated in this diagram



Refer to the diagrams which follow for use of the liquid-filled prism.

- a). Direct your laser beam at a wall or flat surface about 2m away so that it hits the surface at right angles (important to form a right triangle for triangulation). A microscope slide placed flush on the surface will give a reflected beam right back into the laser if you are hitting the surface perpendicularly.
- b). Rotating the hollow prism, filled with water, back and forth in the laser beam, will fairly quickly show that the angle through which the beam is deviated by the prism (the angle of deviation), after refraction through just two adjacent faces, can be varied by turning the prism, *but has a minimum value* (the angle of minimum deviation) below which you just can't reduce it.



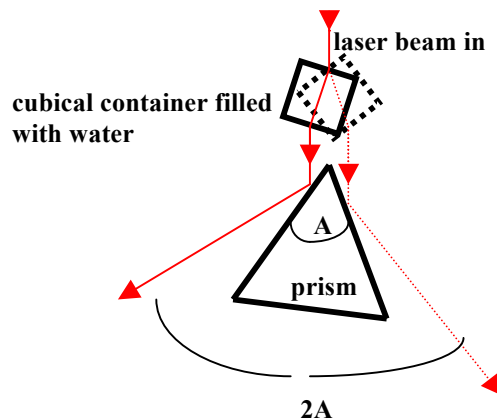
- c). This angle can be obtained very accurately by triangulation..by measuring x and y in the diagram
The refractive index of the prism is given by the equation.

$$n = \sin[(A + \text{amd})/2] / \sin[A/2]$$

where A is the angle shown and “amd” stands for the measured “angle of minimum deviation”.

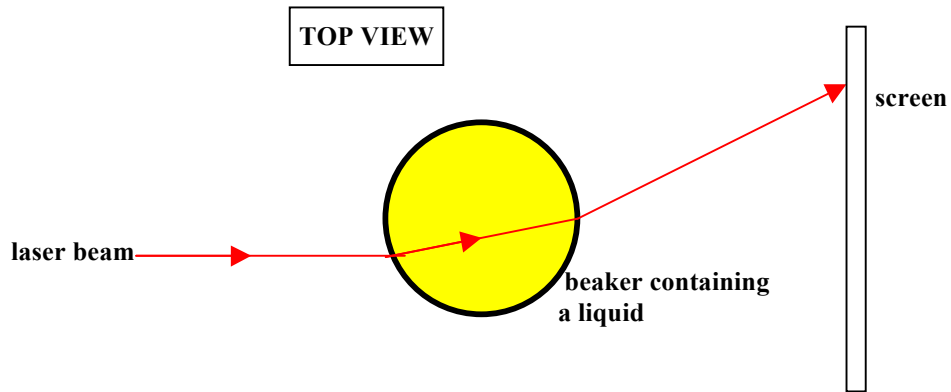
Hollow prisms can be used to measure the refractive indices of different materials which fill them. For instance, water, jello, cow’s eye humor, sugar solution, and so on. If you use water, or sugared water (with various sugar concentrations) the corresponding refractive indices can be found in lab handbooks or textbooks for comparison.

2. Measure the n of Jello before and after it has set.
3. Measure the n of the solid glass prism in the kit.
4. The angle A of the prism should be measured accurately. We have assumed it to be 60° for the hollow microscope slide prism, or 45° for the glass prism. The diagram below shows how to use the hollow cubical container filled with water to move the beam off one of the prism’s faces onto the other in order to measure the angle.



Notice that the beam emerging from the container is always parallel to the incoming beam, but with a sideways displacement.

5. A beaker filled with a liquid will act as a lens and bend a laser beam, as shown in the next diagram, in proportion to the refractive index of the liquid.

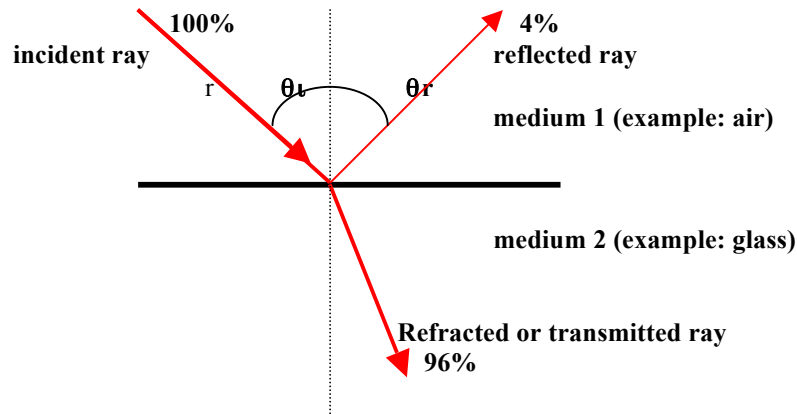


A simple 400 ml glass beaker can be used and sugar added in measured amounts. The beam will be seen to move across the viewing screen as the concentration changes. The system can be calibrated and used later to determine unknown sugar concentrations.

TOPIC 6. Beam steering by reflection.

Introduction.

Whenever light strikes a boundary, some of it is transmitted (refracted) and some reflected. For an air/glass boundary about 4% is reflected. For specially prepared mirrors, however, up to about 80% can be reflected. In all cases the law of reflection is at work and this predicts that the angle of reflection (θ_r) always adjusts itself to equal the angle of incidence (θ_i). The diagram illustrates this. The objective here is to compare angles of incidence to corresponding angles of reflection. Also, double mirrors will be studied.



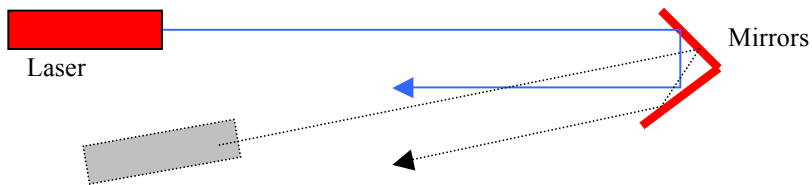
Safety

The chance of someone walking into the beam is very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces and block your beam path when doing calculations.

What to do:

1. Stand a “front-surface” mirror with its face vertical at the center of a piece of paper. Shine the laser beam onto the mirror and trace the incident and reflected beams (the cylindrical lens mentioned in Topic 4 works well here). Repeat another five times for different sets of angles. (Use angles like 20, 30, 40, 50, 60, and 70^o as opposed to 20, 21, 23, 25, 26, and 29^o). Record in the table and then plot angle of reflection vs angle of incidence. Draw the “best straight line” through your points, and don’t forget to give the graph a title; also mark your data points with sharp dots and surround them with, say, circles to show that they are indeed data and not just accidental marks on your paper. This way you can put the whole class’s data on one graph sheet using different shapes (squares, triangles, and so on) to indicate which data belongs to which group.

2. Stick two mirrors to the halves of a door hinge (or use masking tape on the back of the mirrors to form your own hinge) so that a laser beam after reflecting off one mirror reflects off the other. The deviation of the beam independent of the orientation the mirror pair, depending only on the angle between the mirrors. (If this angle is 90° then the deviation of the beam is 180°. This arrangement is called a retroreflector, and it pretty well sends the beam back the way it came except for a minor lateral displacement.)



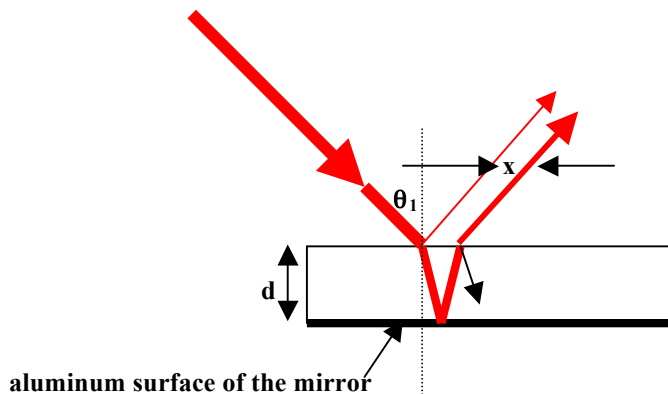
Other things to try out or think about.

1. If you place three mirrors in the corner of a shoe box you will have a three dimensional “corner reflector”. No matter the direction the incoming laser impinges upon the mirror pair, it will be retroreflected (so long as the beam hits all three mirrors). The Apollo astronauts took an array of such mirrors to the Moon the first time they landed there. It meant they could just place the array on the ground ;no need for adjusting its position. Ruby laser pulses were directed to it from Lick Observatory in California and from Goddard Space Center, and the round-trip time for the pulses to arrive back at Earth was measured. Accurate timing gave the distance from the Earth to the Moon. Approximately how long would it take for light to make such a round trip?

2. Attach a mirror, using some sticky putty, double sided tape, or glue, to the platform on the shaft of one of the motors. Give the mirror a slit tilt as you do this so that the laser beam reflecting off it goes around in a circle when the motor is connected to a 1.5v battery. Place a similar motor-with-mirror close to the first one and arrange for the beam from the first to immediately strike the second. Connect this motor to the same battery. Look for interesting resulting patterns on the wall. Explore new patterns by varying the speed of one of the motors, using a potentiometer (variable resistor) in its circuit, and by changing the + and – connections to one of the motors.

3. People who work with window glass frequently need to determine the thickness of the glass, and if a double pane, the separation of the sheets. All these parameters can be found by studying the reflections of a laser beam off the glass surfaces involved. The following diagram illustrates this point. The separation x of the reflections off surfaces 1 and 2 can be measured, and if the angle of incidence, θ_1 , is measured, then d the thickness of the glass can be calculated . This assumes that the refractive index of the glass is known (usually 1.50).

Use the thick mirror for this.



TOPIC 7. Fiber Optics .

Introduction.

The basic principles behind optical fibers are relatively simple to understand, and really just involve refraction at a surface. I would like you to ‘revisit’ Snell’s law to study something called “total internal reflection (TIR)”, and to work with fibers in this activity.

As you are aware, fiber optics are “big” these days in the fields of medicine, in industry for getting into difficult to reach spots, and in telecommunications. In the first case single fibers are used to channel light into various parts of the body for illumination, and fiber bundles used for viewing what goes on there. In telecommunications, single fibers only are used since all signals, including TV, can ride on a single laser beam traveling along them. In fact, since modern fibers are quite capable of carrying telephone messages and TV signals at the same time, you can see why the telephone and TV companies are fighting over the control of the ‘delivery system’.

You should first use semicircular dishes to learn about “total internal reflection” (TIR), which is the controlling idea behind fiber operation, and then to work with actual fibers.

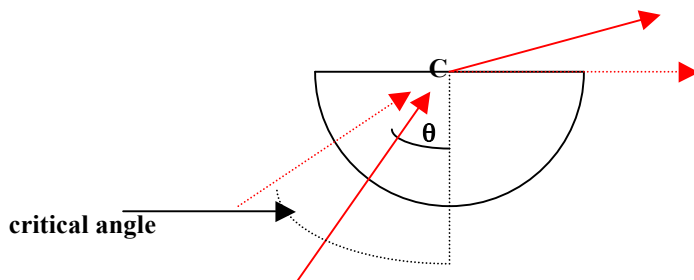
Safety

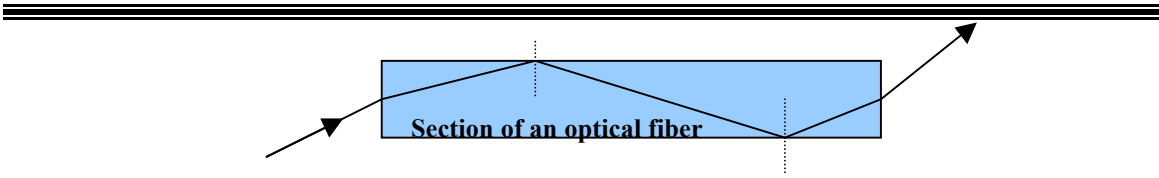
In this experiment the beam is contained very well inside the fiber, once things are set up properly, and this is one very good reason for using them.

What to do:

- 1 First demonstrate to your own satisfaction that there is such a thing as TIR, and then actually make some measurements, in order to determine the refractive index of water (oh no, not again!!). Take a semicircular dish and place it on a piece of polar graph paper as shown in the next diagram. Fill it about 3/4 full of water.
- 2 Shine your laser beam in so that it hits the center point, C, of the dish. This way it’s easy to read the angle θ . If the beam is emerging from the dish at C, then increase θ until the beam comes down onto the surface and JUST reflects back into the water. The value of θ when this occurs is called the critical angle. Measure this angle, and then calculate the refractive index, n , of the water from $\sin \theta = 1/n$ (Snell’s law but with the angle of refraction equal to 90° . Whenever θ is greater than the critical angle light glances off the outer surface back into the first medium with the angle of reflection equal θ .

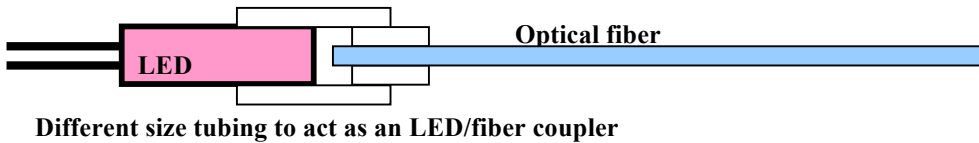
Optical fibers are so narrow that the “angle θ ” at which the beam always hits the outer surface is always greater than the critical angle and so the light always glances off the surface back into the fiber. In this way it is trapped in the fiber even if the fiber has slight bends in it.



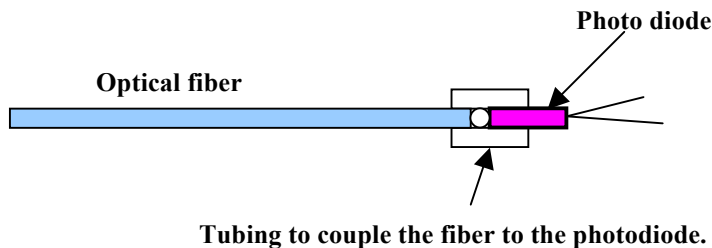


Working with fibers.

3. To show how light is transmitted along the fiber in the kit, connect the blinking LED (light emitting diode) to the 3V-battery pack and get it to blink. If it does not do so right away, you probably have the LED leads connected to the wrong battery terminals. Reconnecting the other way will solve the problem. Like all diodes (including the laser diode) it acts as a closed gate to current flow if connected up “the wrong way around”, and as an open gate when connected the other way. Blinking is caused by an additional timing circuit built into the LED.



The other end of the fiber can now be connected to the photo detector *photo-diode of the photo detector supplied* with the kit (further described in Topic 9), and the output of the photo detector connected to the speaker/amplifier unit which requires a 9V battery to work.

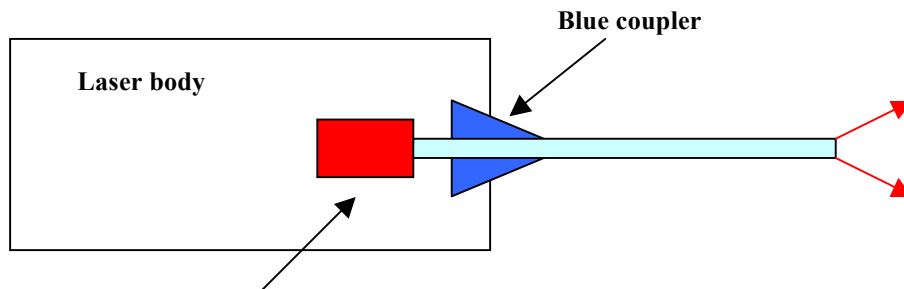


OR



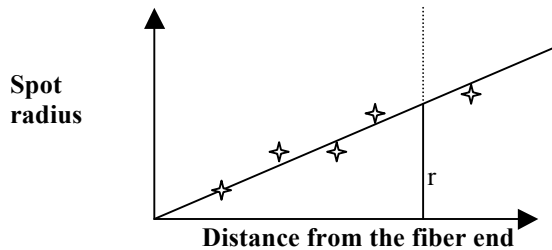
You should hear the clicks of the light pulses generated by the blinking LED coming through on the speaker. In the second case explore how the intensity of the clicks varies with d

4. The following diagram illustrates how to connect the fiber to the laser.



Laser diode module

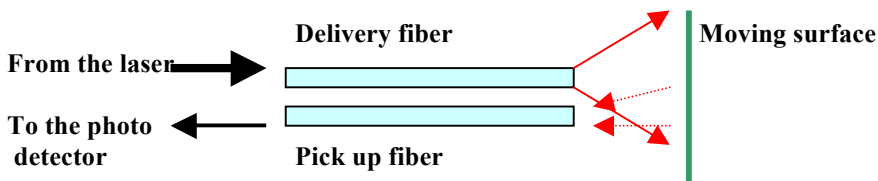
You will notice that the light emerging from the fiber spreads out quite rapidly. Scientists and engineers who work with fibers are quite familiar with this and call it the numerical aperture of the fiber. It is officially defined as $1/\sin \alpha$ where α is half the angle of the cone of the light emerging from the fiber. The cone is very fuzzy and it is difficult to measure the angle accurately with one reading. A good way of coming up with the angle is to draw a graph of spot radius (r) vs distance (d) from the fiber end. This should be a straight line and the ratio r/d will be $\tan \alpha$. This approach is used a lot in science and in effect averages out inaccuracies in your data.



You may also use the multi-meter set on volts to explore how the light irradiance (intensity) varies as d is changed. In particular, plot a graph of irradiance (in volts) against d .

Other things to try or think about.

1. Two fibers are frequently used to measure small displacements as an alternative to number 4 above. One fiber delivers the beam, and the other picks up its reflection off a surface.

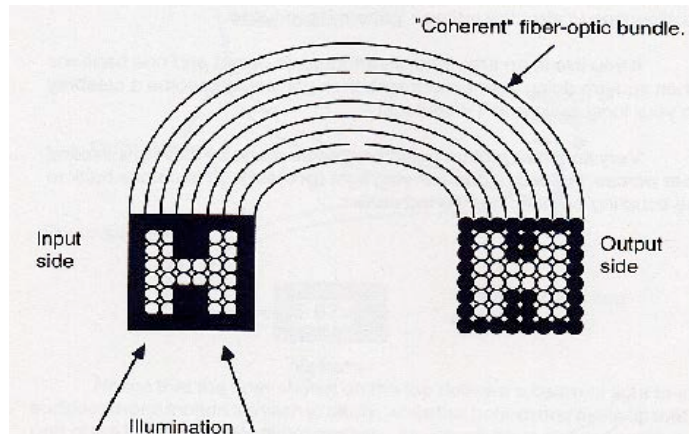


Notice that the fiber shown on the top delivers a beam of light to a surface whose motion we wish to study, while the bottom one picks up that part of the light reflected off that surface. As you will have already noticed, the beam emerging from the fiber rapidly increases in size (so its irradiance drops off rapidly) as it travels away from the end of the fiber, and it now further spreads very rapidly after reflecting off the “diffusely reflecting” surface. This means that if you keep the fibers firmly anchored and meter (using a photo detector and voltmeter) the light coming out of the bottom one, then this will change as the surface is moved. Of course, you’ll need the photo detector described in Topic 7 for this. A nice would be to calibrate your system by measuring the detector output for known positions of the surface. Professionals in industry are always interested in this. A graph of the data will probably not show a straight line, but who knows. If it isn’t a straight line, perhaps you could find an equation which best fits it.

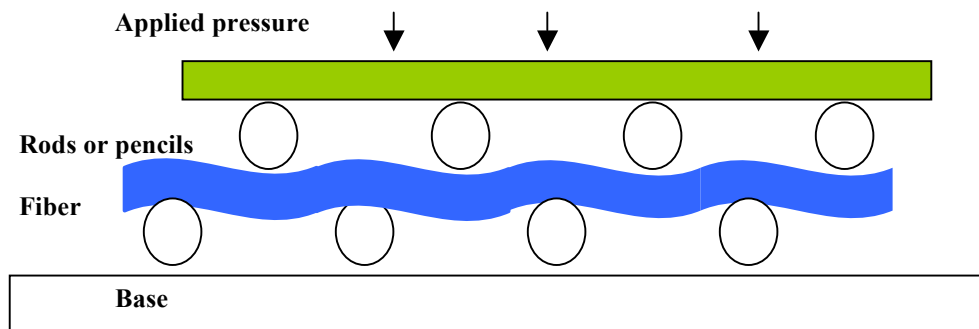
Other interesting surfaces to work with are ones which vibrate. Tuning forks, and hacksaw blades (held firmly at one end) are two things which come to mind, but I bet you can think of others. Why not try looking at the surface of a loudspeaker! Of course, for all the vibrating stuff you will need an oscilloscope to view the voltage ‘patterns’ produced.

If you live in an area where earthquakes occur, and one happens when you are doing your experiment, then you could become a celebrity on your local radio and TV stations!

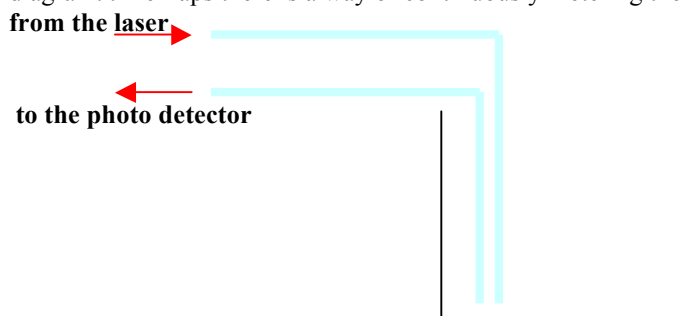
2. A word about “optical fiber bundles”. The diagram shows a “coherent bundle” meaning that each individual fiber has its ends in the same location on the ‘input’ and ‘output’ side. At the input side, a lens forms an image of, say, the lining of your stomach on the input end, and this is transferred to the output end (each fiber passing more or less light, according to what its input end sees, to its output end). For simplicity, the diagram shows the transfer of a simple letter. The output end is then viewed with a magnifier by, say, a surgeon. You have probably seen movies of them looking through their viewing magnifiers in the operating room.

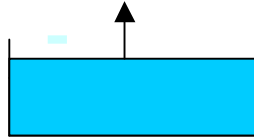


3. Professor John Rand of Kapiolani College, Honolulu, showed me a device made of our fibers, which I have called the Rand Honulu Bender pressure sensor. It has a single fiber placed over a row of circular rods (I think pencils would work) with another row of rods above it. Pressing down on the assembly causes small bends in the fiber which causes the critical angle to be exceeded in some areas which causes light to escape, resulting in a drop in the irradiance of the light emerging from the fiber end. It will be convenient to use the green LED as the light source here, coupled to the fiber as was the blinking LED mentioned earlier in this module, and to use the heavier fiber provided in the kit.. This principle is used in many pressure sensitive pads such as elevator buttons.



4. The fibers provided with the kit are quite tough and can be bent almost 180° without breaking and without losing too much light at the bend. However, if the bend is placed in water, this amount of light drops dramatically. This suggests using the fiber as a water level detector, as illustrated in the next diagram. . Perhaps there is a way of continuously metering the liquid level.





TOPIC 8. How quickly does a laser beam spread out

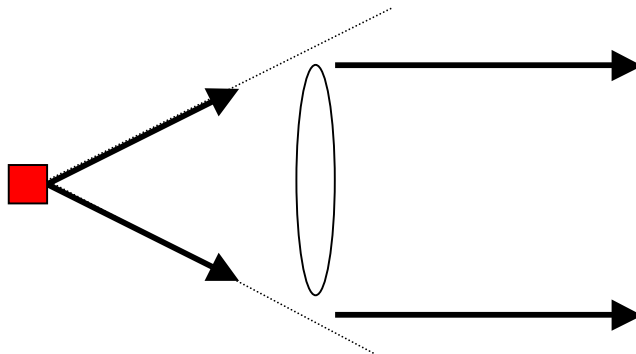
Introduction.

A laser beam is very directional but does diverge slightly as it travels away from the laser. (All laser people are very familiar with this so it's a good chatting point when you meet one of them). The divergence angle, or simply divergence as it is called, can be measured fairly well by measuring the size of the laser 'spot' at various distances from the laser and using some mathematics.

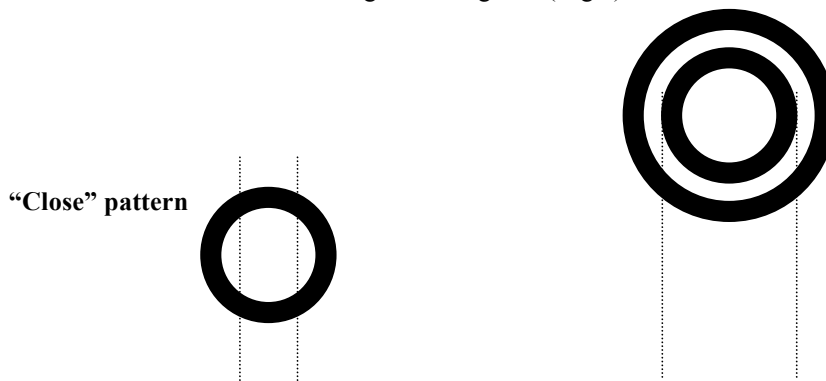
The spot diameter remains at about 2 to 5mm for about 1 to 2m from the laser, but then increases in size with distance. We ask you to find how it increases in size with distance beyond the 2 m mark; this is the important region for laser triangulation and surveying. (For table-top experiments, you can assume the beam does not diverge). Once known, this information can be used for distance measurement.

If you are using a HeNe laser, you will notice in doing this activity that the beam 'blob' is rather fuzzy; brightest at the center and trailing off at the edges. The profile is actually a Gaussian curve. If you are using the diode laser provided in the kit, the profile will be that due to diffraction through a circular aperture (the lens used to collimate the beam) and the circular 'blob' will be surrounded by rings. (See also number 7 of this Topic). The diameter of one of the rings will be measured at various distances from the laser during this activity. If the rings are not sharp enough, then see 2 under "Further things to do or think about".

The laser diodes provided in the kit basically have a huge divergence (60°) due to the beam emerging from a 1 or 2 micron area at the end of the chip upon which they are constructed. The reason the beam you see emerging from the laser is so directional is because it passes through a lens which collimates it (makes it parallel).



The lens is quite small (3mm diameter), and because it cuts off the edges of the beam, it imposes upon the beam a pattern of circles. The beam inevitably spreads, as does that of the HeNe laser, but now the pattern is easier to work with in terms of finding the divergence (angle) of the beam.





“Distant” pattern

Notice that a ‘calibration’ plot of beam diameter vs distance provides an great way of determining an unknown distance from a measurement of beam diameter

Since you will shining the beam all over the room to get large distances, be sure to warn people of what you are doing and where you will be directing the beam. If you use a mirror, first place it in the beam facing downward at an angle so when the beam hits it, the beam will be directed down onto the table-top. You can then slowly straighten up the mirror to direct the beam where you want it to go — in a controlled manner.

What to do:

1. Measure the beam diameter d (that of the smallest black ring) at a number of measured distances D from the front of the laser. Since these distances will have to be quite large, expect to work across the room or out into the corridor.

Get the ‘big picture’ first, before taking readings, to get a feel for how big the beam diameter is going to get for various distances. Once you have a feel for the full scope of your measurements—then go get them and use the table below for recording purposes.

2. Plot a graph of diameter (vertical axis) against distance. (You can start your distance axis at your first D value if you want to). This will give you the first indication, and illustrate the fact very nicely, of how the beam diameter changes with distance.

3. Use this ‘calibration curve’ to determine the length of a ‘test’ corridor or room. Don’t expect great accuracy here; just notice that this is an interesting idea, and exploring ways of improving the accuracy would be an interesting.

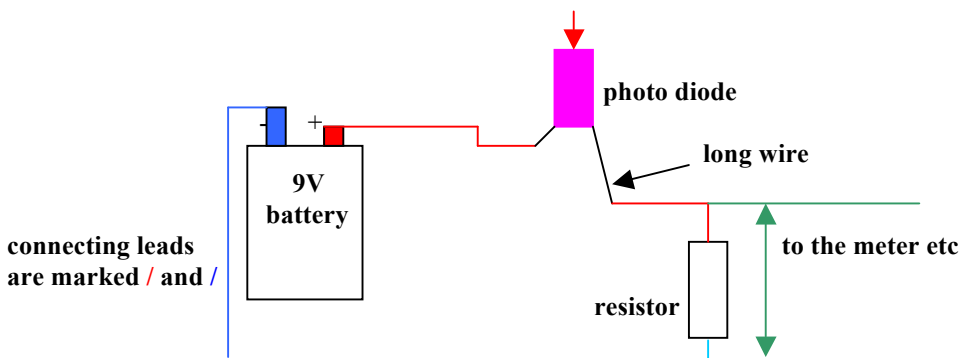
Further things to try or think about.

1. While you have a large spot size, try placing a match, candle, or even a hot soldering iron (maybe even your hand!) and a sharp edge (separately) in the beam. The hot air rising from the first group of objects should be observable (this is officially called a shadowgraph), while Fresnel diffraction patterns will be produced by the sharp edge.
2. If your particular laser spot has poorly defined rings, making it difficult to measure their diameters, then you should consider ‘improving’ their sharpness. To do this, push a pin through an index card, and place the resulting small hole over the end of your laser. This will reduce the brightness of the spot, but it should produce well defined rings. This is a diffraction phenomenon and will be discussed further in Topic 16.

TOPIC 9. Making a light detector for use with a laser.

Introduction.

In order to study the irradiance (intensity) profile of the beam, to look at information carried by it, and to determine exposure times for holography, some form of light detector is needed. Suitable photo detectors are silicon photo-diodes (n-p), reversed biased using a 9V battery, and connected in series with a large resistor. The circuit is shown below. With no light on the photo-diode, the reverse biasing means there is going to be no current in the circuit; the diode is acting as a closed gate. When a photon strikes the diode junction an electron/hole pair is created right in the middle of the 'gate', and these entities are swept through the circuit in opposite directions and constitute a current pulse. (If the pair were produced on either side of the 'gate' they would not get over the gate and would simply recombine). So, photons streaming into the junction cause a continuous current proportional to the number of photons arriving per second; the current is proportional to the light hitting the photo-diode. The current is 'translated' into voltage via the resistor ($V = Ri$) and this voltage is read by the multi meter or sensed by the speaker amplifier. The voltages may also be handled by analog to digital converters for automatic data acquisition or oscilloscopes. The latter two are particularly useful, indeed necessary, for time-varying signals.



One word of caution regarding the photo detector. This has nothing to do with safety, but with the interpretation of the signals you get from it.

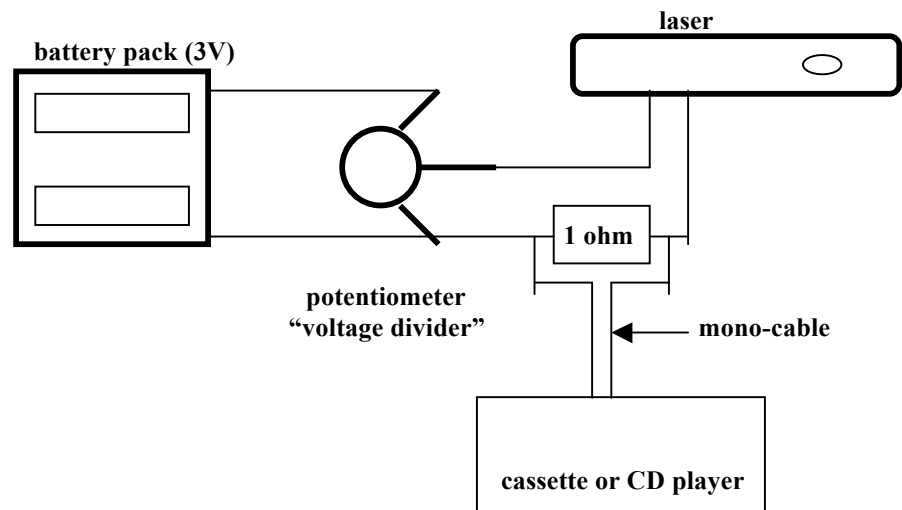
If a 'raw' 1mW beam shines onto the photo-diode, it becomes saturated and a solid 9V signal is obtained. If the beam power drops to, say, 0.8mW the photo-diode is still saturated and the signal is the same. This saturation persists until the power drops to about 0.3mW. If it falls further, the signal drops in a linear manner. This is a very nice part of the curve on which to work for many experiments. To get onto it some sort of filter will have to be placed in the beam or the current supplied to the laser reduced to drop the beam down to less than 0.3mW. **As a rule of thumb, if the voltmeter reads 6V or less, then you are on "the linear portion" of the detector sensitivity curve and safe to make relative readings.**

What to do:

1. Build the circuit ("breadboard") shown above using the alligator jumper leads to make the connections. A standard square 9V battery is used to power the circuit.
2. Connect the circuit to, first, the voltmeter; secondly, the speaker/amplifier (it requires an internal 9V battery); thirdly, an oscilloscope, if one is available. Shine a flashlight or laser onto the photo diode to observe how the various instruments respond..

The speaker/amplifier and oscilloscope are particularly useful if the light being sensed fluctuates. A good source for this, in the kit, is the red blinking LED. Connect it directly to 2 C or D-cells (3V) and watch it blink. You will be able to hear clicks from the speaker/amplifier, or see blips on the oscilloscope. Also, with the room fluorescent lights shining on the detector, you should hear a 120 Hz hum from the speaker/amplifier..

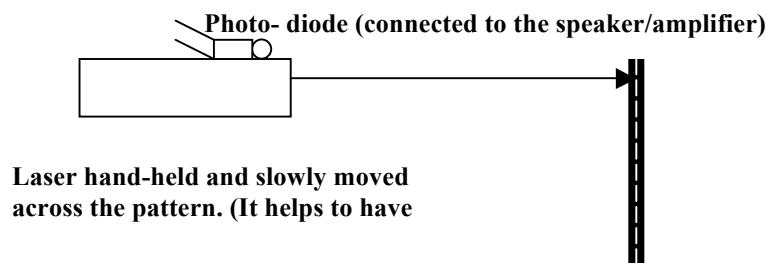
3. Shine the laser onto the photo detector connected to the speaker/amplifier, and run your fingers, and also a comb through the beam. Interesting? Hold a taut string in the beam and “twang” it. Increase and decrease the tension. Why not try this with a guitar string.
4. Connect the laser circuit shown next to transfer music or voice variations onto the beam. The 1 ohm resistor is already soldered to the mono-cable from the cassette or CD player.



The irradiance of the beam may be reduced by turning the shaft of the potentiometer to increase its resistance and hence the voltage applied to the laser. The beam can now be directed onto our photo-detector on the other side of the room, and the signal it picks up listened to on the speaker/amplifier.

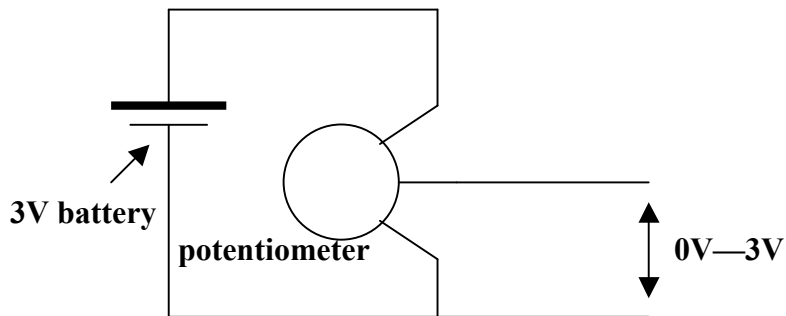
Other things to try or think about.

1. The photo detector (breadboard or prepared versions) is sensitive to the IR light emitted by a TV remote. Try this using the speaker amplifier connected to the photo detector, and observe how, distance, or the use of filters, affects the signal picked up by the detector.
2. With the breadboard version of the detector, strap the photo diode to the laser to receive light reflected from a bar code made of reflective tape. This is a simulation of a bar code reader.



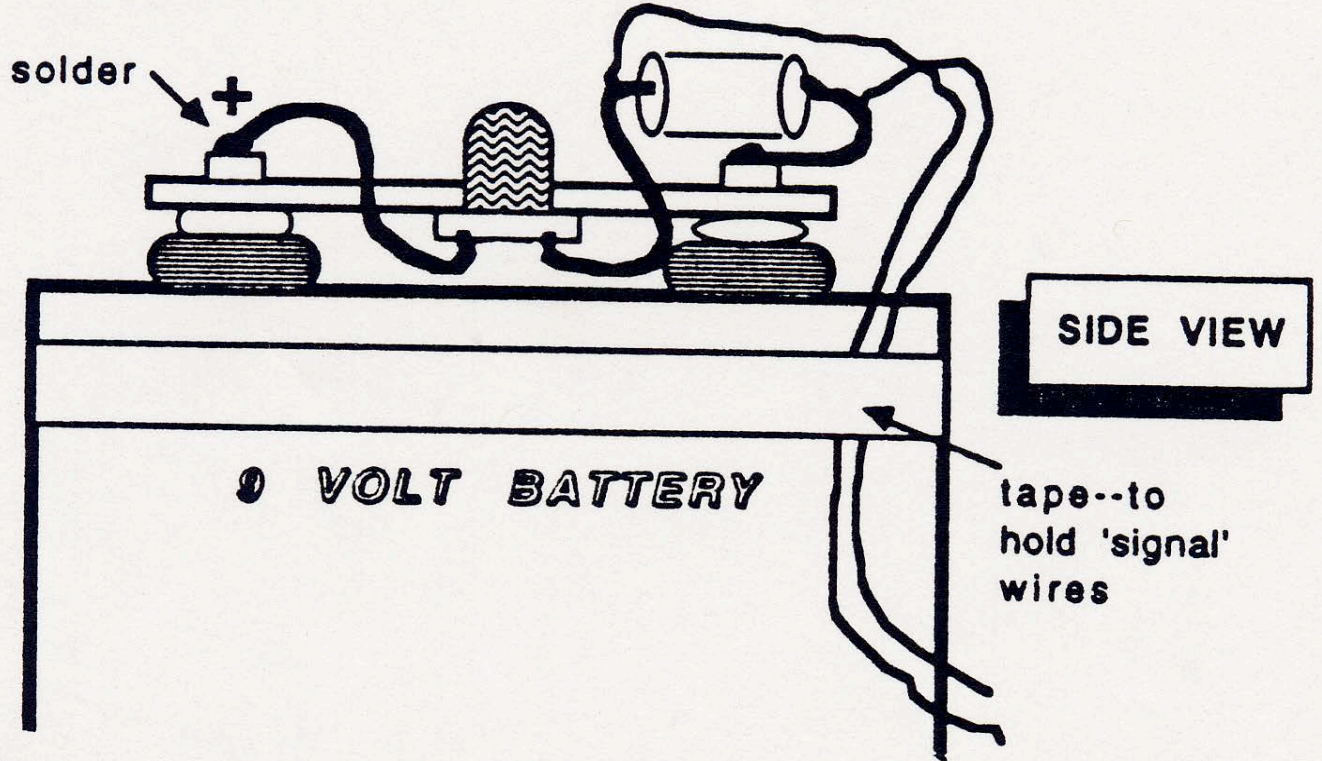
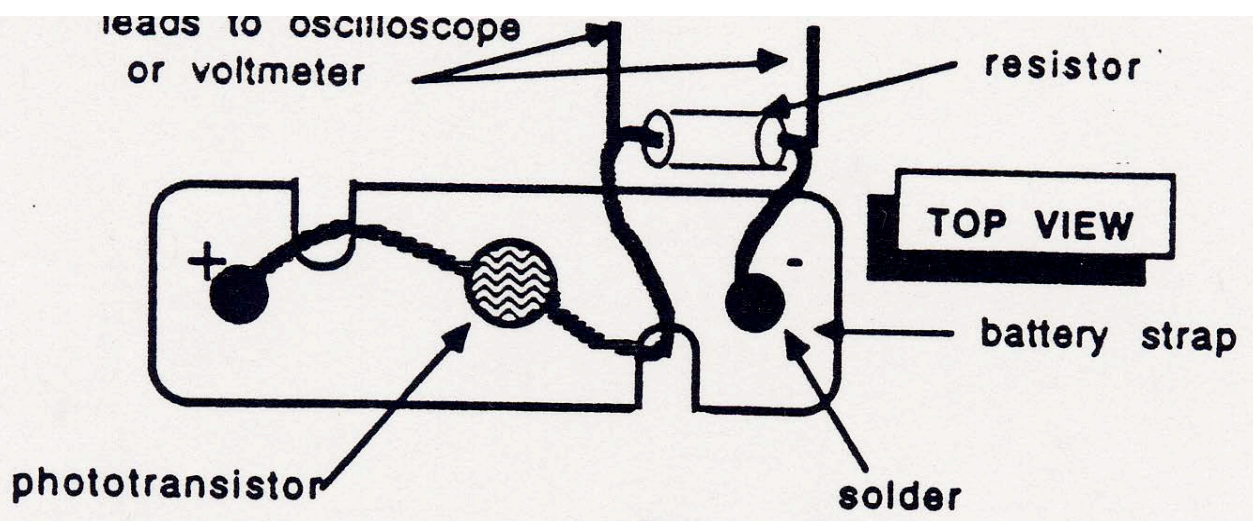
music 'playing on the beam').

3. Once familiar with the breadboard version of the photodetector, a more sophisticated one may be constructed for future use. This is shown on the next page.
4. Connect the green LED to the potentiometer using it as a **voltage divider**. As you increase the voltage to the LED it will glow more brightly. Using the photo detector to measure the light emitted by the LED as a function of voltage or current makes a very nice project.



5. As you increase the resistance, the current to the laser will drop and it will cease acting as a laser (stop lasing) and behave as a regular LED. The point where it suddenly starts lasing is called the "threshold". Measuring the beam irradiance (photo detector and voltmeter) as a function of current in the laser circuit (voltage across the 1 ohm resistor) is a nice project. **IF YOU WISH TO MEASURE THE CURRENT IN THIS OR ANY OTHER CIRCUIT WITHOUT INTERRUPTING THE CIRCUIT IN ANY WAY YOU SHOULD INCLUDE IN IT A KNOWN RESISTOR (R) WHEN YOU MAKE UP THE CIRCUIT, AND MEASURE THE VOLTAGE (V) ACROSS IT. THE CURRENT THROUGH IT AND THE REST OF THE CIRCUIT WILL BE GIVEN BY $I = V/R$ (OHM'S LAW). $R = 1\Omega$ WOULD BE A GOOD CHOICE.**
6. If you replace the 1Ω resistor shown in the diagram of #4 in "What to do" with the loudspeaker in the kit, and leave out the cassette or CD player, then as you speak into the speaker you will cause its cone to move the coil attached to it through the magnetic field of the speaker, generating a current which will add or subtract from that already in the laser circuit. The laser brightness will hence vary, and this will be in sympathy with the sound patterns from your mouth hitting the cone. You will actually be using the speaker as a microphone.

For this to work best, you should reduce the laser beam to as low an operational level as possible.



TOPIC 10. The beam intensity (irradiance) profile.

Introduction.

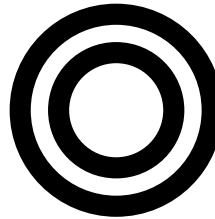
The most straightforward way of studying the beam profile is to measure the output of a photo detector as it is moved across the beam. If a HeNe laser is being used, It should show a Gaussian shape and the diameter, defined as the distance between the $1/e^2$ points, can be accurately measured. The diode lasers show a circular aperture diffraction pattern the exact profile of which can be obtained from optics texts.

Safety

The chance of someone walking into the beam might be very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces and block your beam path when doing calculations.

What to do:

1. Go a long way from the laser so that the beam is at least 2 cm in diameter. Then scan it with your photo detector and measure voltage vs position. A plot of your results should be the profile expected for a circular aperture. This can be obtained from almost any advanced optics text book.
2. If the pattern is not as ‘clean’ as the one shown here, you can improve it by placing on the front of the laser a round hole (in an index card, for example) for the beam to shine through. This will make the pattern fainter, but sharper. It will also diverge more rapidly..



“Distant” pattern

Other things to try out or think about.

1. The maximum irradiance (at the center of the pattern) will decrease as the distance from the laser increases (as the pattern spreads out). A calibration curve of irradiance vs distance can hence be generated, eventually leading to the determination of unknown distances from the laser from irradiance measurements and reference to the calibration curve.

TOPIC 11. Constructing the Wobbler scanner.

Introduction.

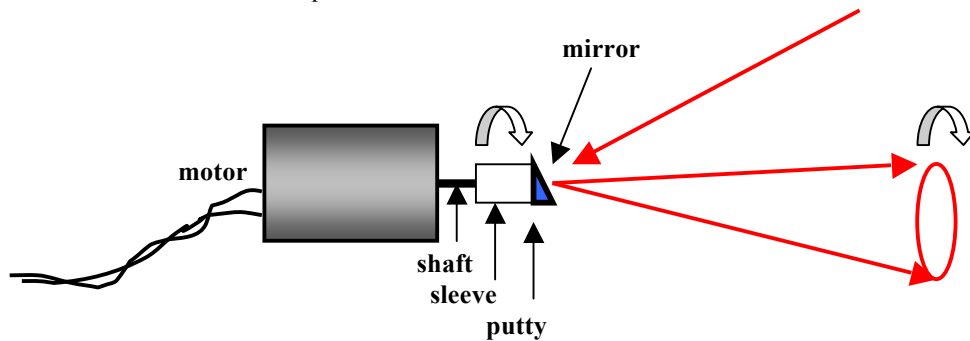
The wobbler is a mirror attached eccentrically to the shaft of a motor so that light reflected off it ‘wobbles’ around as the motor rotates. A laser beam reflecting off this mirror will scan around in a circle, and can be used for all sorts of experimentation. One particularly pretty arrangement involves the beam hitting two wobblers, one after the other, to create very interesting patterns on the wall. These patterns can be varied by changing the individual speeds of the motors. Set up the wobbler and become familiar with its operation.

Safety

The chance of someone walking into the beam is very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces.

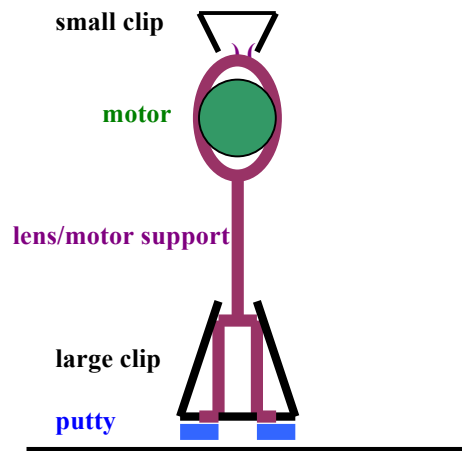
What to do.

1. Attach a small circular plane mirror to the sleeve on the shaft of a 1.5-3.0V dc motor with putty. The mirror should be slightly tilted so that when rotated it will cause a beam reflected from it to sweep around in a circle. The speed can be controlled by using the potentiometer again. Either use it as a voltage divider or as a variable resistor as in Topic 7.



The method for holding the motor is shown by the next diagram.

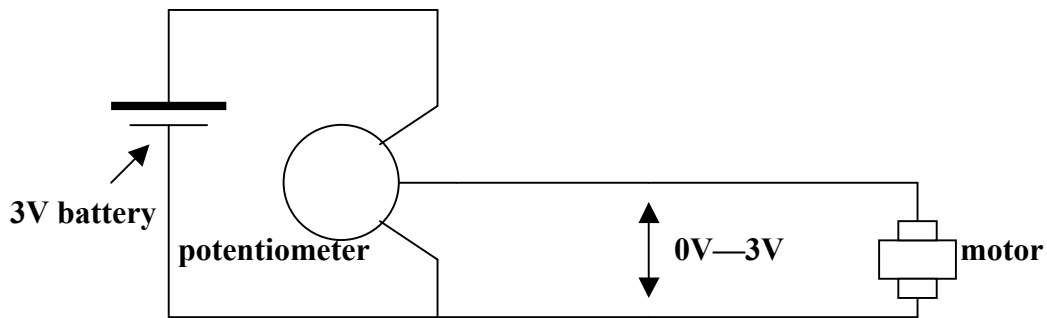
Notice that the ‘feet’ of the motor support have been bent at right angles for a firmer fit into the clip holder. Move an index card rapidly back and for in the beam, towards and away from the mirror. Pretty?



2. Combine your wobbler with that of a neighboring group's. That is, reflect the circulating beam from your wobbler off the spinning mirror of someone else's wobbler and allow the resulting beam to shine onto one of the walls of your classroom. You have the makings here of an interesting 'light show' with weird circulating patterns seen on the wall. If you increase the voltage to one of the motors, using two 1.5V batteries and also include a variable resistor ("potentiometer") in its circuit, then you will be able to vary the speed of this motor and so change the light patterns.

Other things to try or to think about.

1. Have the rotating beam pass over your photo-detector. If this is connected to the speaker amplifier, you will hear either clicks in rapid succession if the motor is rotating slowly or a note if it is rotating rapidly. The speed can be controlled using the potentiometer either in series with the motor as a variable resistor or as a voltage divider. Can you think of a way of doubling or tripling the frequency of the note?

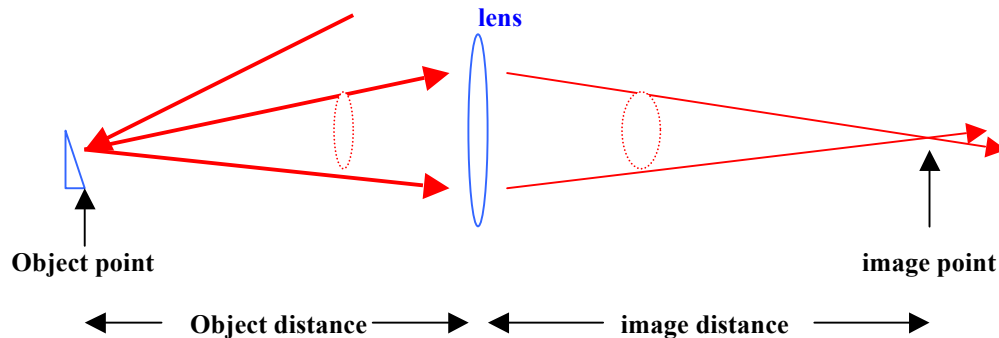


2. If the signal from the photo detector is displayed on an oscilloscope then a series of pulses will be seen on the screen. Observing the time between the pulses will give the time per revolution of the motor, and the inverse of this will give the number of revolutions per second (rev/s). This can be measured as a function of current to the motor if a resistor of known value is placed in the motor circuit and the voltage across it measured. (See Topic 9).

TOPIC 12. Working with lenses.

Introduction.

With the arrangement shown in the next diagram, the converging lens is presented with a cone of light. The lens will focus it to a point. The cone originates at the wobbler or fiber optic end (object point) and spreads out to the lens at which point it is converged back to the (image) point. The lens equation will give the focal length of the lens. Different lenses and lens systems can be investigated this way. I suggest you use the wobbler method for this experiment.



Safety

The beam in this experiment will be confined to the vicinity of a section of your table. Try to block the beam path after it passes the end of the table.

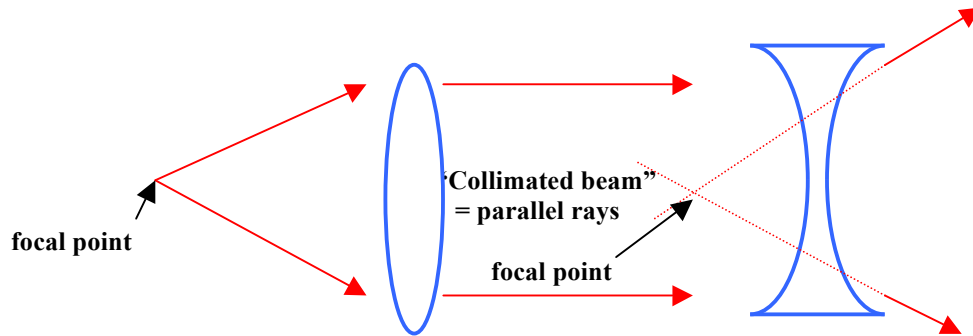
What to do:

1. Measure the focal lengths of two lenses using the lens formula $1/(\text{object distance}) + 1/(\text{image distance}) = 1/(\text{focal length})$ using the wobbler mirror as your object point.
2. Repeat using the fiber end as your object point.
3. Repeat using the green and (blinking) red LED, one on top of the other, as your object.

If you were asked to measure the focal length of a lens for a customer, which method would you choose and why?

Other things to try or think about.

1. Using the separation between the LED's as your object "size" and the separation of their images as the image "size", measure the magnification (image size/object size) for a variety of object distances. Plot magnification vs object distance. At what object distance is the magnification = 1?
2. Use one of the lenses to collimate the 'beam' coming from the mirror (see the next diagram) and place the other lens anywhere in this beam. Where the resulting converging cone comes to a point is the focal point of the second lens, and the distance of this point from that lens is its focal length. Compare with the focal length measured earlier.



(At one school, students found this method quite useful. Normally they used sunlight as collimated light for measuring the focal length, but on dull days they would set up this “collimated beam” arrangement on a side table for quick focal length determination).

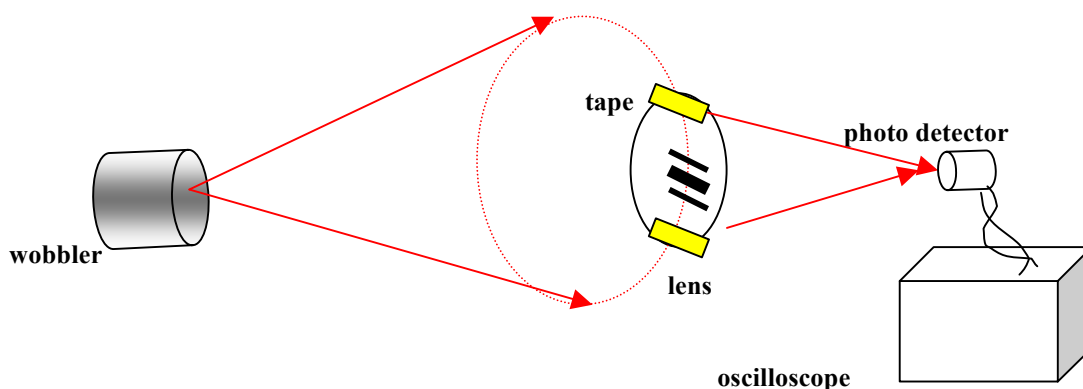
3. Place a diverging lens in the collimated beam as shown in the last diagram. Work with the resulting diverging cone to find the focal length of this lens. (Because it is on the ‘incoming beam’ side of the lens it is usual to assign a negative number to this quantity). Notice how easy it is to find the focal length of the negative lens. The distance from the lens to the point where the beam diameter doubles in size is numerically equal to the focal length of this lens.

TOPIC 13. Bar-code reading

(This is treated somewhat briefly since an oscilloscope is not available in all classrooms.)

Introduction

In this activity, we shall scan a stationary target with the moving ‘wobbler’ beam. The figure shows how the scanning will be achieved. It is best to start with a simple pattern—such as a plastic fork! The reason for using such a simple pattern is that our system is not quite as refined (or as expensive!) as the scanners found in supermarkets. Also, notice we are going for the stronger signal obtained by having the beam transmit through parts of the pattern as opposed to reflecting off the pattern as is the case in the stores. (If one were to try detecting the weaker signal due to reflection off ‘store’ patterns, then those on soft drink cans might be the ones to go for due to the reflective nature of their aluminum surface. Notice the cunning use of the lens to ‘collect’ the sweeping beam to bring it to a stationary point where the photo detector is then located.



Safety

A relatively safe experiment, but be sure the portion of the ‘scan’ which might not pass through the lens is blocked from spreading out across the lab.

What to do:

1. Get the wobbler working and capture the rotating beam with a lens to bring it back to a point — just as in the last Topic. Make sure that the lens is “square” or perpendicular to the cone of light coming from the wobbler. If this is not the case, the point will smear into a line. In fact, making sure the point is nice and sharp tells that the lens is correctly oriented.
2. Now increase the tilt of the wobbler mirror until the circle at the lens is about three times the size of the lens as shown in the last diagram. Turn the whole wobbler so a section of this circle falls on the lens. You will see this section, after passing through the lens, getting smaller and smaller until it hits the detector as a point. (When I did this first I got some funny reflection off the very edge of the lens. I got rid of these by sticking two pieces of masking tape [also shown on the last diagram] to the lens to ‘sharpen’ the actual lens aperture).
3. Place your photo detector at this point making sure the light is falling on the photosensitive area of the photo-diode you are using.

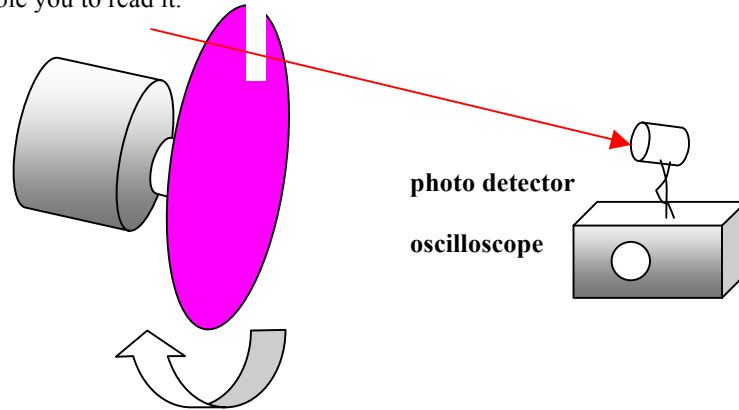
4. Connect up the oscilloscope to the detector. You should see pulses on the CRT, each pulse caused by light passing over the lens.
5. The top of each pulse should be quite flat if there is nothing interrupting the beam. I have found there is likely to be a lot of noise due to the beam not being exactly a sharp point (presumably due to lens aberrations causing distortions) causing it to move on and off the tiny photosensitive chip as it rotates. I have found that placing a piece of paper or masking tape over the photo-diode reduces this effect by scattering the light before it hits it.
6. Place a relatively simple pattern, such as the prongs of a fork, in the beam just in front or just behind the lens. You should see a corresponding pattern impressed on the oscilloscope trace. On the fork measure any of the 'bar' widths (in mm), and the corresponding pulse width (in seconds) off the oscilloscope. The ratio of corresponding bar width to pulse widths will give you the speed at which the beam is scanning the pattern at that particular point. Calculate the speed in mm/s.
7. Place strips of different color material. The pulses will again vary in height.

TOPIC 14. Pulses of light.

(This is treated somewhat briefly since an oscilloscope is not available in all classrooms.)

Introduction.

The same motor we used in the lens experiment can be used here. This time a card, with a slot cut out of it, is attached to the shaft, as shown in the diagram, and to see the effect on the beam of rapidly rotating the card, we shall use an oscilloscope connected to the photo detector. You will be able to see regular pulses on the oscilloscope and can time them to get the angular velocity (rev/s) of the card. If the slit is really narrow you will be able to reflect the beam back onto the spinning card, and if it has some writing on it, this self-strobing system will enable you to read it.



Safety

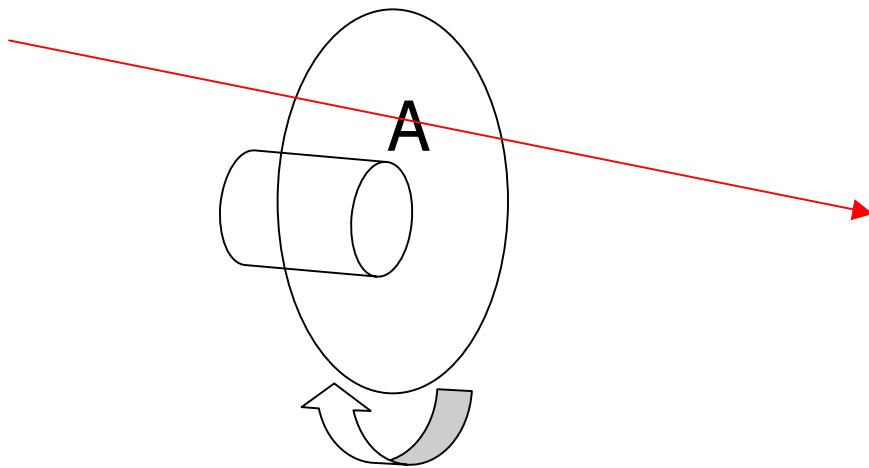
The beam in this experiment will be confined to a section of your table. Try to block the beam path after it passes the end of the table.

What to do:

1. The diagram shows the set-up. The slot you cut can be either rectangular or fan shaped. In the first case the 'pulse' of light let through will vary in duration (why?) as the rotating disc is raised and lowered in the beam; in the second case there will be no variation (why not?). Very interesting! Measure the rotational speed of the disc. For this, you will need to measure the time between the pulses (seconds per revolution) and invert it to find the number of revolutions per second.
2. If you darken the room and work with a very narrow slit (can you see why?) and reflect the pulses of light back onto the disc off a diverging or converging mirror (they both eventually give a diverging beam as discussed in Topic 10), the disc should look absolutely stationary (why?). Pasting a letter or pattern on the disc helps to see this. This is an example of self-strobing and is quite amazing to see.

Other things to try or think about.

1. After ‘calibrating’ the rectangular slot disc (position of the axis vs duration of the pulse) you can subsequently determine an ‘unknown’ position by measuring the pulse width.
2. Another example of character recognition is the following, and this is really cute! Stick *an opaque letter* onto a *transparent* plastic disc as shown in the diagram below and also an opaque ‘bar’ for triggering purposes (Why?). (What would you get if there were no bar?) Mount the disc onto your motor and spin it while observing the oscilloscope screen. By moving the spinning disc in the beam, you should be able to figure out what the letter is. Of course, you know already what it is—but the people next to you won’t (stick it on secretly!) and it will be their task later to find what it is by interpreting the patterns on the oscilloscope. Of course, you will have to do the same with theirs!



3. The speed of a drill, fan, or food processor can also be found. You might have to place a small ‘flag’ of masking tape to the rotating shafts for this.

TOPIC 15. Absorbing properties of different materials

Introduction.

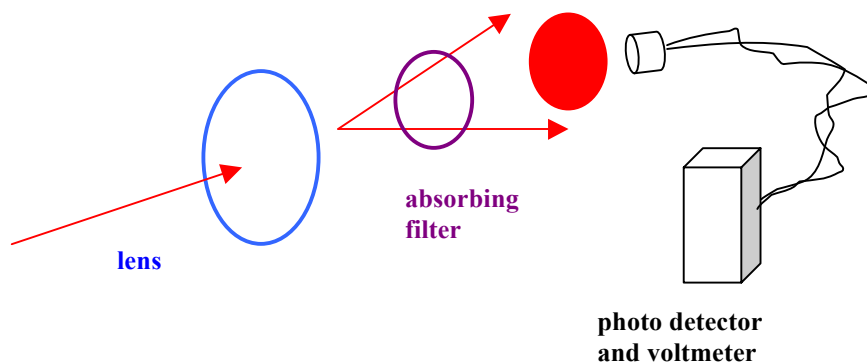
In general, when a laser beam travels through a medium, some of the energy is absorbed. The amount depends on how much medium it travels through and the absorbing ability of the medium. If you insert 1, then 2, then 3, and so on, identical lightly absorbing sheets in a laser beam you should get a characteristic exponentially decreasing curve. If the medium had an absorption >1 , then you would get an exponentially increasing curve! This is what happens in a laser; the active medium has an absorption >1 (called a gain) and so the beam traveling through it increases in strength.

Safety

The beam in this experiment will be confined to a small section of your table. Try to block the beam at the end of your table.

What to do:

1. Set up your laser as shown in the diagram. The reason for using the lens is to reduce the amount of light hitting the detector so that you can be sure you are working in its linear range. **You can also attenuate the beam by passing it through a fiber, a diffusing screen, some other filters, or by reducing the current to it (see Topic 9).**



2. Place the red sheets in the beam (first one, then two together, then 3 together, and so on), and measure the detector output, with the voltmeter, for each combination of sheets. A graph of volts v number of sheets should give a nice curve. You should find that different colors absorb the red laser beam by different amounts. Also the transmission coefficient, defined as I_{out}/I_{in} can be calculated in each case. Here I_{in} can be taken as the reading with no filter in the beam.

One high school student I met dripped some blue bathroom cleaner into a glass cell and watched as the transmitted beam got weaker and weaker. Assuming the drips were coming at a constant rate, his transmission v time graph could be used for measuring time by looking at the voltage showing on a meter. We have been looking for something which changes concentration by itself over time such as a yeast or bacterial colony but haven't had much luck yet. Ask your chemistry colleagues.

Other things to try or think about.

1. There are many reflection measurements which follow the same pattern as absorption experiments. Measuring the reflectance of different surfaces is always very interesting, especially when you *compare* that of one with that of another. For instance, how much more laser light will a brand new penny reflect than a dirty one? How do the reflectances of a penny and a quarter compare? Reflectance is

defined as $R = (I_{\text{reflected}} / I_{\text{incident}}) \times 100\%$. Also how does reflectance vary with angle of incidence.

A very interesting project would be to measure the reflectance of teeth because the laser (argon) is being used now instead of the drill! Maybe you should get some dentures, and measure the reflectance for bright new ones and ones which have been soaking in tea or coffee for a while.

4. It is always useful to have a single filter which can be inserted into the beam to reduce it from 1 mW to 0.3mW. This can be a colored filter or a grey one. Grey filters are called neutral density (ND) filters and they "attenuate" the beam according to how dark they are. This is described by a "grey scale" defined as $ND = \log_{10} I_{\text{incident}} / I_{\text{transmitted}}$.

If $I_{\text{transmitted}} = I_{\text{incident}}$, then $ND = 0$ (Check this out on your calculator)

If $I_{\text{transmitted}} = (1/10) I_{\text{incident}}$, then $ND = 1$

If $I_{\text{transmitted}} = (1/100) I_{\text{incident}}$, then $ND = 2$

If $I_{\text{transmitted}} = (1/1000) I_{\text{incident}}$, then $ND = 3$

Why use logs? First, it compresses the scale; 1 to 1000 is compressed to 1 to 3. Secondly, if filters are placed on top of each other, and suppose they have ND's of 0.6 and 1.2, then the ND of the combination will be 1.8. See if you can show that this must be true.

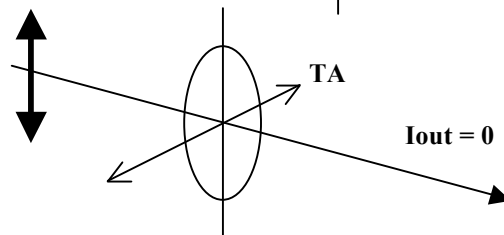
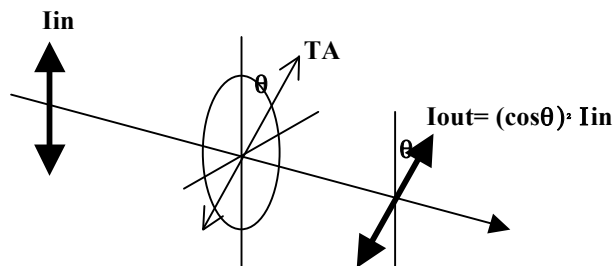
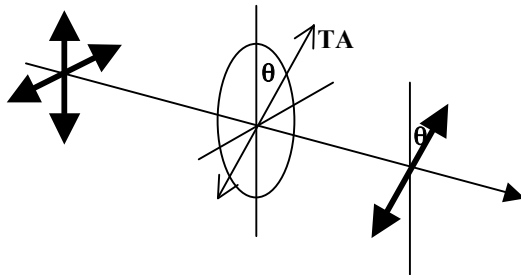
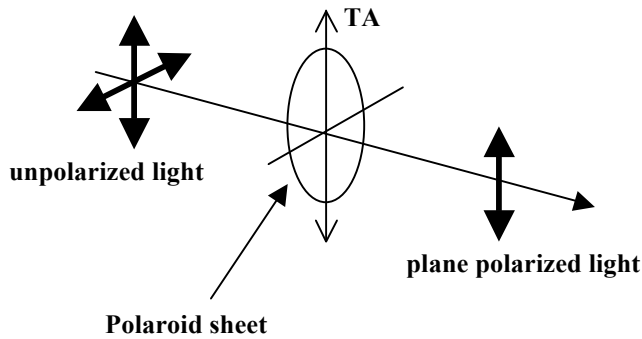
TOPIC 16. Polarization.

Introduction.

The laser provided in the kit has a beam which is highly, although not completely, plane polarized. In this Topic this will be established, and the plane of polarization identified. In addition the change of state of polarization after passing the laser beam through a fiber will be studied. Finally, the stability of the laser light, after passing through a polarizing sheet will be checked.

As a preliminary to polarization, please see the following diagrams illustrating the polarizing properties of polarizing sheets.

Some special cases. (TA= transmission axis)

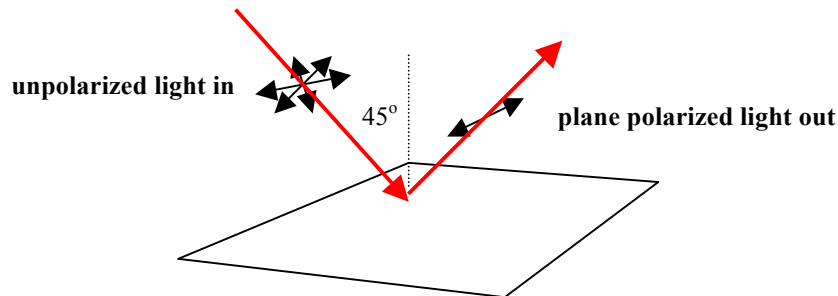


Safety

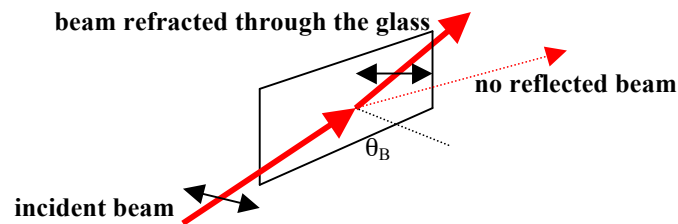
The beam in this experiment will be confined to the table. Try to block the beam at the end of the table.

What to do:

1. Take the polarizing sheet from the kit (thicker than all the other sheets) and rotate it in the beam. If the irradiance of the beam emerging from the sheet increases and decreases as you do this, then the beam is at least partially plane polarized. Measure the maximum and minimum irradiance with the photo detector and voltmeter to determine the ratio I_{\max}/I_{\min} . Call this the degree of plane polarization.
2. To establish the actual plane of polarization, look through the polarizing sheet at the reflection of sunlight or ceiling light off a waxed table top or a waxed floor. The reflection should be at about 45° to the reflecting surface. As the sheet is rotated the reflection should vary in brightness. When the brightness is a minimum, the transmission or polarization axis of the sheet is vertical since the polarized beam is horizontally polarized. (See other things to try). The polarization axis should be marked on a piece of tape attached to the polarizing sheet. Referring back to the polarization of the laser beam, when the light passing through the sheet is a maximum, its plane of polarization coincides with that of the sheet.



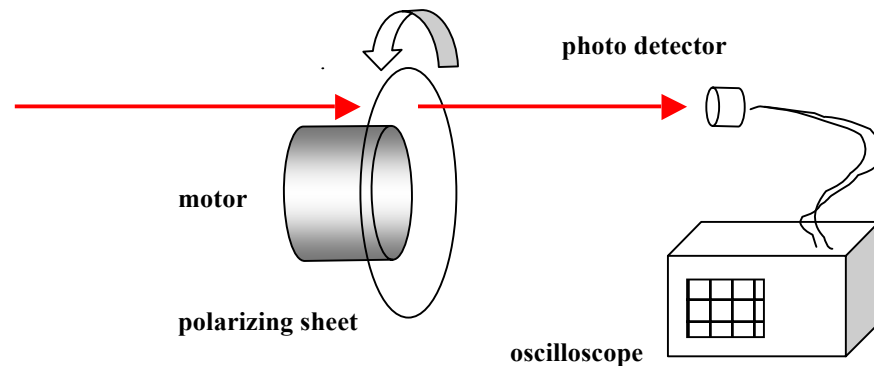
3. Making sure that the plane of polarization of the beam is horizontal, place a glass microscope slide vertically in the beam and vary the angle of incidence until the reflected beam dips to a minimum irradiance. This particular angle of incidence is called Brewster's angle (θ_B). He was the first person to observe this effect. Find the refractive index (n) of the glass using $\tan \theta_B = n$.



Other things to try or think about.

1. Check on the degree of polarization of the laser light emerging from an optical fiber. Compare this with the degree of polarization of the 'raw' laser beam. You might wish to cut your fiber into various lengths to see if the degree of polarization varies with the length of the fiber the beam travels through.

2. The following diagram shows how a spinning Polaroid sheet (together with a fixed one if your laser is not plane polarized) can result in a nice sinusoidal output from your photo detector. The frequency will be twice the number of revs per s of the disc (hmmmm...).



3. For this activity, two polarizing sheets are required. Place one against the laser with its polarizing axis parallel to the main polarization of the beam. This makes the beam highly plane polarized. Rotate the second polarizing sheet further along the beam until you get a minimum reading on the photo detector connected to the voltmeter. Now rotate the second sheet 90° in either direction at which time the reading will reach a maximum. From this point rotate the second sheet by various angles θ , each time recording the voltmeter reading. In general, the voltage (irradiance) should drop off as

$$I = I_{\max} \cos^2 (\theta).$$

This is called the Law of Malus. It is quite a challenge to come up with an accurate way of measuring θ , but even ‘eyeballing’ it with a protractor, and taking many different readings will give you good enough data to prove the law. Using two polarizing sheets like this is a good way of controlling the irradiance of a beam in a gradual or continuous manner. It gives photographers, for instance, a variable filter.

3. If two sound transmission systems are set up (see Topic 9), and the two laser beams are arranged so that their planes of polarization are at right angles to each other, and each shine onto the *same* photo detector and speaker amplifier, you should be able to select which tune is being played by correctly rotating a polarizing sheet in the beam! (If there is no sheet in the beam, both tunes will play together.)

TOPIC 17. The effect of one light beam on another

Introduction.

The necessary and sufficient condition for “interference fringes” is the presence of two coherent waves of the same wavelength impinging upon each other. The two waves are invariably produced from an original single wave. In this way the two are replicas of the original and so are replicas of each other. We say they are coherent with each other.

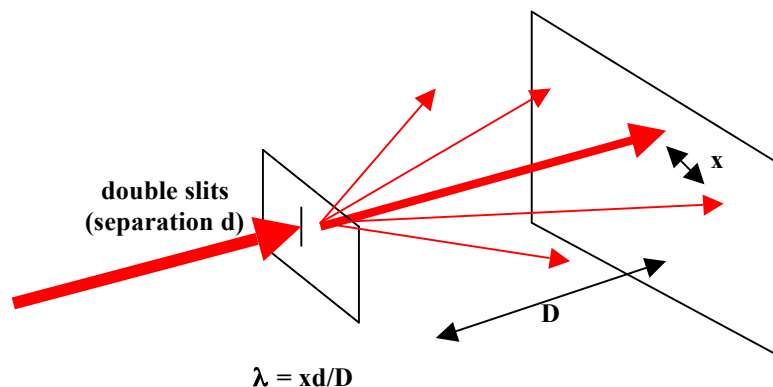
Using a laser as the original light source with its high irradiance and great purity of color, the two replica beams, when they combine, give very visible "fringes" (dark and bright bands). The beams can be produced in many ways, but in this activity we'll produce the fringes by passing our laser beam through two slits..

Safety

The chance of someone walking into the beam is very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces and block your beam path when doing calculations.

What to do:

1. Pass a microscope slide through a candle flame to get a good layer of soot on it. I think any candle will allow you to do this. Hold the slide with paper to avoid burning yourself because it might get hot.
2. Hold two ordinary pins side-by-side and touching, and run their points once through the soot. The lines you make don't have to be absolutely straight. It might help to tape together the two pins.
3. Placing the prepared slide in the laser beam will give a Young's double slit pattern (interference 'fringes'). Make sure you are far enough away from the laser so that the beam is big enough to cover both slits. The next diagram illustrates what has to be measured, and gives the formula to use to find the wavelength of the laser light. (The same formula holds for two or more slits). I have marked x between adjacent bright regions of the pattern. The separation between dark regions will also be x , and this is a little easier to measure. Also, measuring across, say, five x 's and then dividing this number by 5, gives a more accurate value for x . The actual slit separation can be determined by placing the slide containing the slits on an overhead projector and studying their greatly magnified image at the other end of the room. A knowledge of the magnification of the projected image will be required. Try placing a transparent ruler on the projector and measure its magnification. I like to use a piece of chalk which gives a very sharp image, and whose size can be accurately measured with a micrometer.



Other things to try or think about.

- 1 .Set up the laser and the concave mirror or diverging lens to give a 'blob' of light at the other end of the bench. Place a microscope slide or glass plate of similar thickness in the enlarged beam so that the beam covers a good portion of it at one end, and reflect the light back over the top of the laser onto a far wall. If you study the projected patch of light you will see that it is covered with a fine fringe pattern due to the 'interference' or superposition of the parts of the original laser beam reflected from the front and back surfaces of the microscope slide. The uniformity of the fringes is an indication of how optically 'good' the slide is.
- 2 Arrange a soldering iron to touch the center of the slide, on the back. When it is switched on, you can watch the changing distortion of the fringes.
- 3 The "speckle" pattern you see when looking at a laser 'blob', is due to the interference of the many beams reflecting off the relatively rough surface of the screen, or wall, upon which the blob is being projected. Here the fringe pattern is random. Look at the blob through a tiny pinhole in a card; the speckle will become much coarser. Also, project the blob onto a sheet of paper against the wall, and have your partner raise and lower the sheet. Do you see the pattern move with the paper, or in the opposite direction? This is a test for long and short sightedness. Test people in your class (without their corrective spectacles on) to see which way they see the speckles move.

TOPIC 18. Bending of light around obstacles and through slits.

Introduction.

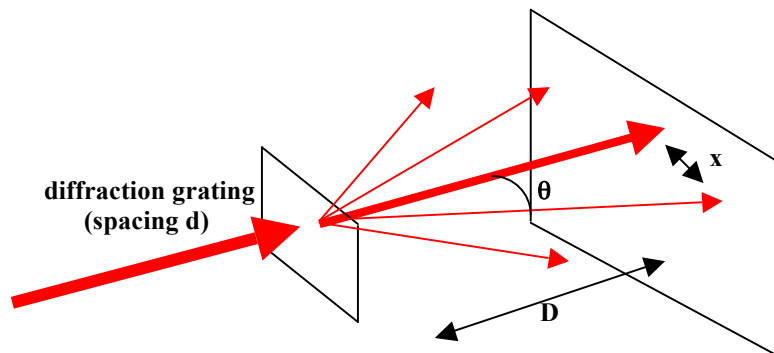
When obstacles are placed in a beam of light we have the condition for diffraction. ‘Neat’ diffraction patterns (caused by the superposition of many secondary light beams) are obtained only for simple obstacles- the simplest being a periodic structure such as a “diffraction grating”. We shall study gratings in this activity, and also diffraction around a single filament, like a human hair, in order to find its diameter.

Safety

The chance of someone walking into the beam is very great in this activity. Be extra careful and warn all present of what you are doing and which section of the lab you intend using. Also, watch out for reflections off shiny surfaces and block your beam path when doing calculations.

What to do:

1. Measure the spacing of your diffraction grating by probing it with your laser beam. Measure the distances x and y , shown on the diagram below, and knowing the wavelength λ to be 670nm, calculate d using the equation $d \sin \theta = n \lambda$.



$$X/D = \tan \theta \text{ to get } \theta \text{ and then } d = \lambda / \sin \theta \text{ to find } d$$

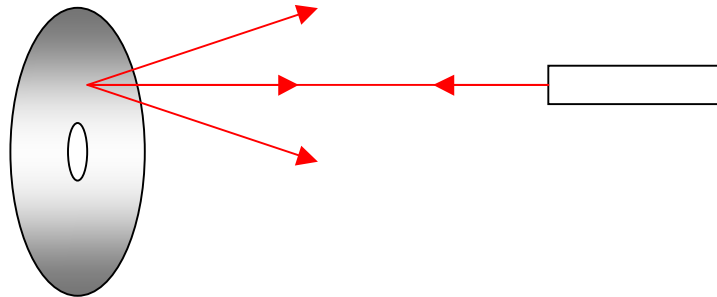
2. Now repeat the experiment but this time project the laser spot onto a white screen and view it (the spot) through your grating. You will see “orders” on each side. Measure an x and y and calculate d again. Compare this d to the one you found above. This is a very useful method for studying the spectra of non-directional sources such as fluorescent ceiling lights.

Other things to try or think about.

1. Study the fluorescent ceiling lights. As you do this you will see the bright green from the mercury vapor the tube contains, and also the continuous band of colors in the red/ yellow region due to fluorescence of the white-looking coating excited by the UV emitted by the mercury... Measure the angle θ again for the green and find this wavelength. See how close you came by comparing your result with one taken from a textbook or handbook. Searching for the handbook values is not easy. Look up spectroscopic data (the general field of studying the spectra of sources is officially called spectroscopy) and look for the strongest wavelengths emitted. Many will be quoted, but a

majority correspond to atomic transitions which are less likely to occur, and so are weaker than others.

2. Stick a strand of hair on a washer, or something, with tape and shine the raw laser beam onto it so that it is in the middle of the beam. Look at the diffraction pattern some way from them, on a wall maybe. If you measure the angle between the center of the central bright blob to the first dark band (center of) on either side, then the equation $\lambda = d \sin \theta$ will give d if λ is known.
3. Cross two gratings, project the beam through, and see what you get. Try the same with some stretched panty hose to determine the spacing of its mesh. Try different brands.
4. Find the spacing of the tracks on a CD by using it as a reflection diffraction grating. The same equations apply.



5. If you have some grating material to spare, cut out a disc of it and attach it to the shaft of your motor and spin it. A raw laser beam passing through it will generate circles which could be used for scanning as you did before. This is close to the holographic supermarket scanner developed by IBM a few years ago

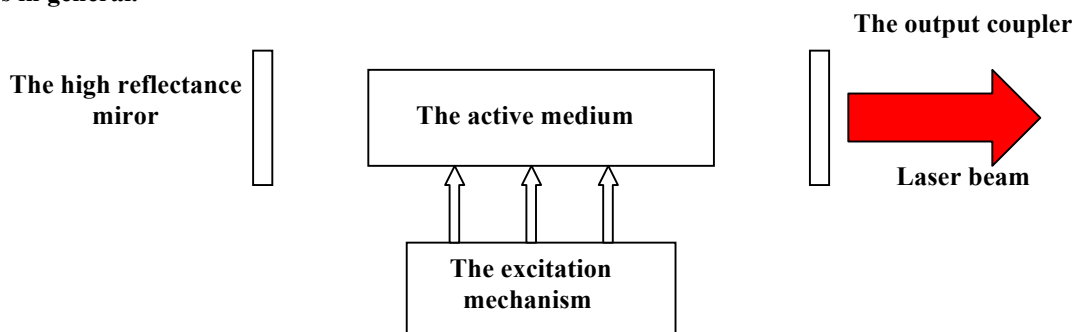
TOPIC 19. Lasers.

Introduction.

It might well be that this is the first chapter of this book you'll read, and it might have been a good idea to put it in as Topic 1. Maybe in the next edition.....

All lasers can be described in terms of their **four** basic “elements”, and laser light described in terms of its **four** “properties”. This generic approach avoids looking at the tremendous detail needed to describe individual lasers, but will put you in a good position to discuss them with optics professionals.

Lasers in general.



The active medium.

This is the material in the laser which “lases”. It can be either a gas (such as in helium-neon, helium-cadmium, carbon dioxide, argon, krypton, and nitrogen lasers), a liquid (as in fluorescent dye lasers), or a solid (as in ruby, titanium sapphire, neodymium;YAG, and diode lasers).

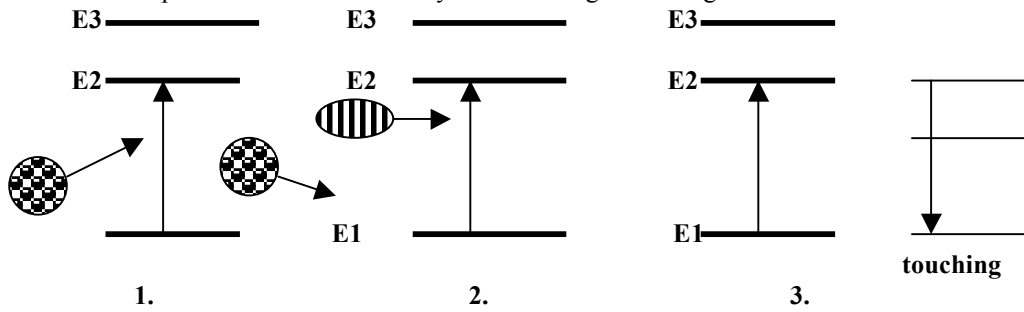
The key feature of lasing materials is that they are capable of undergoing “population inversion”. This is a feature of their atomic structure, and to understand this, one first has to look at how atoms can become “excited” (take up energy) and how they “relax” (shed energy). Luckily there are only three ways of them doing each, so they are easy to memorize.

Excitation.

1. An atom can be hit by another atom, electron, or proton, and absorb energy in the process. Let's call this ‘absorption of mechanical energy’.
2. An atom can absorb the energy of a passing photon if it has just the right * amount of energy. Let's call this ‘absorption of radiant energy’.
3. An atom can absorb the energy of another already excited atom, just by touching it.

* The energy of a photon is given by $E_{\text{photon}} = hc/\lambda$ where h is Planck's constant, c is the velocity of light in a vacuum, and λ is the wavelength of the light. The term ‘just right’ exposes another important fact about atoms. They are very picky in the amounts (“packets” or “quanta”) of energy they absorb, and atoms of different elements choose different amounts, while those of the same element always choose the same. Each atom has an internal ‘energy structure’, illustrated by the diagrams coming up, and normally sits at the lowest level (called the “ground state”). The energy structure is quantized, meaning that the atom can only be excited to one of a definite set of higher energy levels by corresponding definite energy inputs.

The three excitation processes are illustrated by the following set of diagrams.



Relaxation.

There are also three ways in which an atom can return to its ground state.

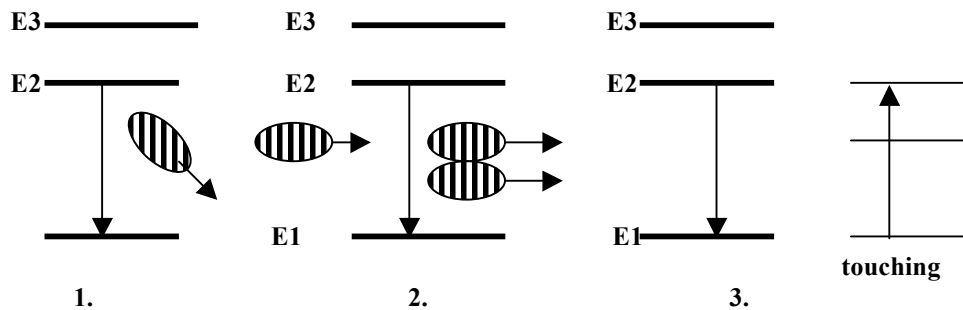
1. The atom can drop from an energy level to a lower one shedding the excess energy ($E2 - E1$, say) as a photon whose energy will be $E2 - E1$. So its wavelength will be $hc/(E2 - E1)$.

It does this randomly but always within about 10 ns (1ns = 1nanosecond = 10^{-9} s) and this is called spontaneous emission of a photon.

2. If a photon of the right energy comes close to the excited atom the photon can stimulate the atom to relax right then, and the released photon will fall into step with (be "coherent" with) and move away in the same direction as the stimulating photon. This process was predicted by Einstein about forty years before the first laser came into being and is called "stimulated emission of a photon." Notice in the process we have one photon coming in and two photons coming out. We have Light Amplification by Stimulated Emission of Radiation (laser).

3. The third relaxation process is touching again, just like number 3 before.

The three relaxation processes are illustrated below in the next diagram.



Now the picture becomes clear. For healthy laser action we want a majority of the atoms in a laser to be in the same excited state and to have them hit by photons whose energy corresponds to the difference between that state and a lower one. If this situation obtains then our photons will be more likely to hit excited atoms (because there are more of them) and be amplified in number, than to hit ground state atoms and be absorbed. Instead of "absorption" we have "gain" (see Topic 13.)

A majority of atoms in an excited state is not normal because the normal lifetime there (10ns) is so short, so population inversion, the term used for more excited than unexcited atoms, is not easy to achieve.

However, in the lasers listed at the beginning of this (rather long!) “Active Medium” section, metastable levels are found where the lifetime can go up to a microsecond (10^{-6}) or so.... not very long, but long enough to hold the atoms there to convert the population from its “normal” to an “inverted” state.

The excitation mechanism.

Each atom requires some energy from somewhere to excite it so that it can become part of the inverted population. In gas lasers, because the atoms are moving around so much, mechanical collision “pumping” is used. In solid state lasers, radiation pumping, usually using an electronic flash, or more commonly a diode laser, is used. The latter are semiconductors, and so allow enough current (electron flow) to be “mechanically” pumped. In any event, whatever system is used to provide the population inversion, it is called the excitation mechanism.

The feedback mechanism.

Since the excited atoms stay that way for such a short time, it is a good idea to have lots of photons flying around to hit them as soon as they get excited in order to get stimulated emission. If you don't do this many will relax spontaneously. It was decided early on in the game to put mirrors at the end of the active medium (to form a “resonant cavity”) to return photons, which miss atoms on the first run through, back into the medium. The build up in the number of photons increases the likelihood of stimulations, which produces lasing action. There was a temporary glitch in this plan, because in the early days the best mirrors were made of aluminum which has a limited reflectance of about 85% due to the electric field of light hitting them producing currents in the metal, which is a waste of energy as far as the overall process is concerned. This problem was solved by making (more expensive) “dielectric” mirrors of insulating material deposited as half wavelength thick layers. This way the reflection from the bottom of each layer (only about 4%) has traveled 2 x half- wavelength further (to the bottom and then back up to the top) than the reflection from the top. They hence fall into step with each other and push the total reflectance up to about 15%. This figure can be pushed up very close to 100% by stacking half wavelength thick layers on top of each other and it is not unusual to have about thirty layers in the stack. Of course, such mirrors work only for one wavelength, but then so do most lasers!

The output coupler.

Since we used some light to get out as the laser beam, one mirror is made with, say, just twenty five layer so that its reflectance is about 96%. This allows about 4% of the light to emerge as the laser beam

The four properties of laser light.

1. Directionality. Placing the small (because they are expensive) mirrors at the ends of the active medium makes all lasers rod-like, and the light bouncing back and fore between them makes for a strong axial flow of photons. This makes the emerging beam very directional.
2. Monochromatic. Atoms that lase are not all that easy to come by, and we are lucky to have two energy levels with which to manipulate a population inversion, although occasionally there are other 'lasing' levels in the same atom. The transitions between two well defined levels gives a well defined photon energy, and so a well defined wavelength. The selectively reflective nature of the mirrors helps too. Single wavelength light is called monochromatic light.
3. Coherence. Because the stimulated photons fall into step with the stimulating photons, as do the waves associated with them, we get a very regimented flow of photons or waves - all “marching in step” with each other. This is called a coherent beam.
4. High intensity. For the same reason as number 3, the “in step” nature of the beam causes the waves of individual photons to interfere constructively, or reinforce each other (if they fell out of step they would cancel). The resulting beam, both inside and outside the cavity, is hence very intense.

