Semiconductor Laser Experiments

This section contains descriptions and explanations of a number of standard experiments which can be performed using the IPC Semiconductor Laser. These cover the experimental determination of the velocity of light, the use of fibre optics and classic experiments with a double slit and diffraction grating to accurately determine the wavelength of light.

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Overview.

A laser emits light which is monochromatic and coherent. This means it generates light at one particular wavelength only and all emitted light waves are in phase with each other. The name is an acronym to describe the process used to produce the laser light, it is derived from the first letters of **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser can be considered as a source of 'pure' light waves. A normal white light source (eg. the filament bulb used in a traditional raybox) emits light over a large range of wavelengths and even when used in conjunction with a high quality coloured filter, a band of wavelengths are transmitted. A laser allows optical experiments to be performed in a clear and highly visible manner and allows high quality results to be obtained.

The first lasers available for use in schools were of the Helium-Neon type producing a beam at 632.8nm. In this type of laser the lasing action took place in a gas filled tube making the instrument fragile. This type of gas filled laser also required a period of warming up after switch on before the laser was ready to use. The resulting beam was also difficult to modulate easily.

Modern lasers are based around semiconductor laser diodes and the associated control is done electronically. This makes the laser robust, reliable, longer lasting and safer to use as no high tension power supply is needed. The only power supply required is a PP3 alkaline battery (which will give approximately 10 hours of continuous use), or a suitable 8-12VDC smoothed and regulated power supply able to supply up to 100mA. A semiconductor laser is also ready for use at switch on and requires no warm up. The beam can be easily modulated and produces an output at approximately 630nm, making the beam highly visible to the human eye.

Detection of the laser can be done using any suitable phototransistor but the best results will be produced using a Modulated Laser Receiver. The receiver uses a high speed phototransistor and a wide band amplifier to produce an output suitable for connecting directly to an oscilloscope. Any modulation in the audible range will be heard via the internal loudspeaker. When using the Modulated Laser Receiver, care must be taken to ensure the phototransistor does not become saturated by too much laser light falling on it. If saturation occurs and the output signal becomes unstable or noisy, defocus the beam slightly or direct the beam partially away from the detector.

Safety.

This laser operates in Class 2 mode and as such produces an optical power output below 1mW. Damage to the eye at such low power outputs is unlikely as the blinking reflex of the eye will protect the retina. For this reason laser safety goggles are not necessary when using this laser but the following safety precautions should be observed:

1. The laser should not be viewed by looking directly into the beam or a regularly reflected beam.

2. Have the laboratory brightly lit. This will ensure that the pupils of your eyes will be as small as possible, so reducing the chance of the laser accidentally entering the eye.

3. Observe all warning notices displayed in the laboratory.

4. Don't place yourself in a position along the path of the laser beam.

5. Replace the lens cap when the laser is not being used.

Attention is drawn to the Department of Education and Science Administrative Memorandum No. 7/70 on the use of lasers in schools and other educational establishments. Although this is an old document and refers to Helium-Neon lasers, the safety content is applicable to the semiconductor laser.

Geometrical Optics.

1. Introduction.

All of the experiments in this section can be adequately performed using a conventional filament bulb and raybox as the light source. However, much clearer results will be seen with a laser due to the use of an intense and narrow beam of light.

2. Objective.

To demonstrate the nature of propagation of light and simple reflections and refraction using mirrors, lenses and prisms. All these experiments can be performed with the minimum of equipment on a single bench without the need for blackout conditions.

3. Equipment.

i.   Right angled prisms
ii.   Plane mirrors
iii.   Glass or transparent plastic tank
iv.   Screen

4. Method.

Propagation

An object can be seen when light from the object enters the eye, is focussed on the retina and interpreted accordingly by the brain. Basically there are three ways in which light can travel from the object to the eye:

1. The object being viewed can directly emit light energy, eg. a filament lamp or laser. Directly viewing a laser beam can be damaging to the eye so this method is not applicable in this case.

2. Light energy from another source (or sources) is reflected off the object. This is how we see the moon, in this case light from the sun is reflected and seen by us. This method can easily be used to show the propagation path of a laser. The beam will show up in air very clearly if it is allowed to pass through a region of reflective particles. Smoke or dust can be used to good effect. In water a few drops of milk can be added.

3. Light energy is absorbed by the object and is then emitted at a different wavelength. This is the case in fluorescence and phosphorescence. Fluorescein can be used to demonstrate this method but as this works best with white light, the results with a laser may be unsatisfactory.

Reflection

Set up the laser, a plane mirror and a screen and investigate how the light can be reflected. Care should be taken to ensure the reflected beam is not in danger of entering a person's eye. Repeat the experiment using a right angled prism and see how the reflected image changes. The image reflected by the mirror should be of a poorer quality due to dispersion effects on the beam caused by multiple reflections from the surface of the glass and the reflective backing. See fig. 1 below. In the prism, total internal reflection takes place purely at the boundary between the glass and the air leading to little or no beam dispersion.
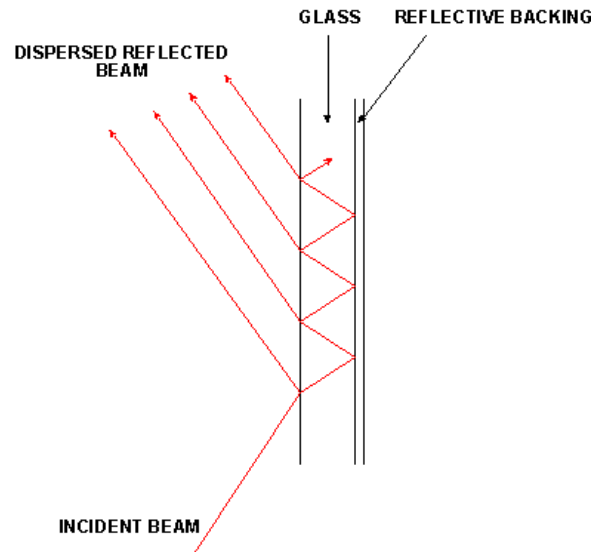
Figure No1 – Beam Dispersion at Mirror

Refraction

Fill the tank with water and add a few drops of milk to make the laser visible.

Aim the laser through the tank at different angles and note how the beam is refracted at the boundaries. Notice how altering the angle of incidence around the critical angle causes the method of propagation to alter from refraction to total internal reflection. By setting up a refracted path and measuring the incident and refracted angles it is possible to calculate an approximation of the refractive index of water. See fig. 2 below. The measurements can be tricky to take and so will not yield an accurate result.
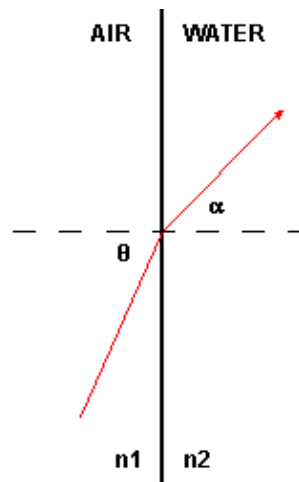
Figure No 2 –

Determination of the Refractive Index of Water.

Measure the incident and refracted angles θ and α, the refractive index of water (n2) can then be determined using:

$$n1\sin\theta = n2\sin\alpha$$

where:- n1 is the refractive index of air.

Fibre Optics & Data Transmission.

1. Introduction.

The laser can be used as an effective demonstration of the way light can be made to travel in optical fibres. By modulating the laser and using the modulated laser receiver, data transmission using light can be achieved.

2. Objective.

To investigate the structure and properties of optical fibres and the use of lasers as a means of transmitting information.

3. Equipment.

i.   Semiconductor Laser
ii.   Signal Generator
iii.   Glass Rod
iv.   Fibre Optic Cable
v.   Bunsen Burner
vi.   Radio

4. Method

Experiment 1

When light is travelling in a transparent material and hits the surface of a material of a lower refractive index, above the critical angle, then total internal reflection will occur. This fact allows optical fibres to be manufactured in which the energy losses due to light 'leaking' out of the fibre are very small. This type of fibre is known as a stepped index fibre because there is a definite stepped transition between the refractive indices of the inner fibre and the cladding. A simplified cross-section and end view of a stepped index optical fibre are shown in fig. 3 below.
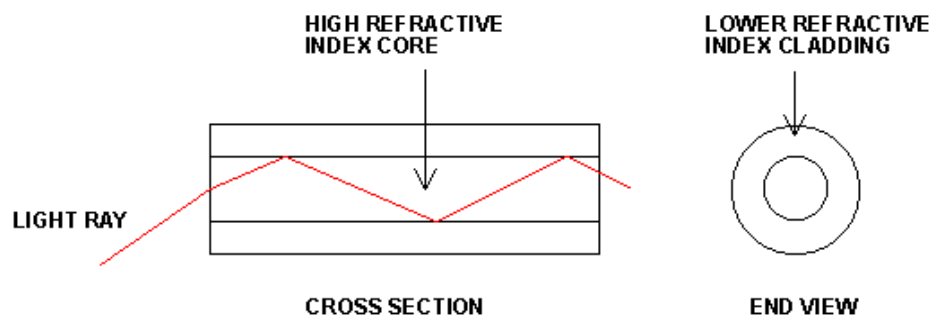

Figure No3 – Stepped Index of Optical Fibre.

Shine the laser beam at the end of the glass rod and examine how the light is emitted from the other end of the rod. Experiment with the angle that the beam falls on the rod end and see how this affects how the light is propagated.

Using a bunsen burner, gently warm the middle of the glass rod and bend it. Aim the laser at the end of the rod and see how the light is emitted from the other end. If the ends of the glass rod are flat it should be possible to pass the light through a quite complex set of curves (as long as the radius of curvature is not too small).

Experiment 2

Shine the laser at the end of a length of fibre optic cable. With that end fixed, light can be seen emitted from the other end irrespective of the placement of the cable. The fibres are delicate despite being very flexible. Do not bend the cable into a curve with a radius of curvature less than 5cm as this will cause the fibre to snap.

The main problems encountered when sending signals down long lengths of fibre optic cable are:

1. The glass or plastic used has to be very pure to reduce attenuation of the signal by partial absorption to an absolute minimum. Commercially this problem has been reduced by refining the methods of producing and drawing the fibre material so that the impurities and irregularities are reduced to a minimum. The typical level of attenuation now achievable is almost as low as is possible at about 0.2dB/km.

2. Scattering of the signal will occur due to chromatic aberration. This is caused by light containing different wavelengths taking different paths through the fibre due to refraction effects. As laser light is monochromatic (ie. it is emitted at a single wavelength) this problem is overcome by the use of a laser as the light source.

3. The time taken for a ray travelling down the centre of the fibre (a meridional ray) is less than that for a ray which takes a longer path (a skew ray). This can cause dispersion of the transmitted signal which results in degradation of overall signal quality. Commercially this problem is reduced by using very thin fibres and by using a fibre in which the refractive index of the fibre material varies across the diameter (as opposed to being stepped).

Experiment 3

In order to send information using a laser beam as the carrier, the information has to be impressed onto the beam. This is called modulation. There are three basic forms of modulation which can be applied to laser light.

1. Amplitude Modulation – this is where the intensity of the laser is varied in direct proportion to the modulating signal. This results in a light intensity which varies with time and is an analogue form of modulation.

2. Frequency Modulation – this is where the intensity of the laser remains constant but the wavelength is altered by the modulating signal. This method of modulation is not possible with this laser because the wavelength is fixed.

3. Pulse Code Modulation – this is where the analogue signal to be transmitted is regularly sampled and converted into a binary code. A train of binary codes is then modulated onto the laser beam by switching the beam on and off (eg. laser on = binary '1', laser off = binary '0'). This creates a signal which has a high immunity to noise caused by absorption and dispersion within the fibre. The information contained in even a greatly degraded signal can be easily recovered at the signal target.

Set up the laser and laser receiver on a bench. Connect the output of a signal generator to the external modulation socket on the laser. Set the signal generator to 0.5V peak to peak sine wave at approximately 1kHz. Connect a dual trace oscilloscope to the output of the signal generator and to the output of the laser receiver.

Aim the laser beam at the laser receiver detector. Adjust the oscilloscope controls to display the transmitted and received waveforms. The signal should be audible from the laser receiver internal loudspeaker. The laser beam is being amplitude modulated by the signal generator. Experiment with adjusting the amplitude and frequency of the modulating signal and note the results. Any signal deterioration visible at the received signal will be due to the electronics of the laser receiver.

Switch the signal generator to square wave output and experiment with different laser paths (eg reflect the laser using a mirror or pair of prisms or use the bent glass rod or a length of fibre optic cable). This shows how a digital signal can be used to modulate the laser.

Connect the headphone socket of the radio to the laser external modulation socket. Aim the laser at the laser receiver detector. The radio output will be audible at the laser receiver internal loudspeaker and the waveform will be visible on the oscilloscope display.

Determination of the Velocity of Light in Air.

1. Introduction.

The laser incorporates an internal 1MHz oscillator which is used to modulate the beam. The oscillator produces pulses of 0.1μs duration. When the laser beam is transmitted over a long enough distance, the time delay between the transmission and reception of a pulse can be measured, enabling the velocity of light to be accurately determined.

2. Objective.

To measure the velocity of light in air.

3. Equipment.

i.   Semiconductor Laser
ii.   Modulated Laser Receiver
iii.   Convex lens
iv.   Plane mirror (x3) or right angled prisms
v.   20MHz Dual Trace Oscilloscope (Single trace will do)

4. Method.

1. Set up the laser and laser receiver on a sturdy bench. Using a lead with a jack plug, connect the socket marked '1MHz INT. MODULATION' to channel 1 of the oscilloscope. Connect the output of the laser receiver to channel 2 of the oscilloscope. Set the oscilloscope timebase to 0.1µs/div.

2. Over a short distance (ie. 10-20cm) direct the laser beam onto the laser receiver detector. Adjust the oscilloscope vertical controls until two clear trains of pulses are displayed. (To avoid saturating the laser receiver detector it may be necessary to defocus the beam slightly).

3. On the oscilloscope, measure and note the time difference between a transmitted and a received pulse. This represents the time taken for the pulse to be propagated through the electronics of the laser receiver.

4. Set up the laser, laser receiver and a mirror (or prism) side by side on the bench. Switch on the laser and collimate the beam. At a distant point set up two mirrors (or prisms) side by side to provide a three reflection path from the laser to laser receiver as shown in fig. 4 below. Setting up this arrangement can be tricky and requires firm support of all the apparatus as any vibration will cause a variable output from the laser receiver and potential problems with beam misalignment. When using mirrors to perform this experiment, problems may be encountered caused by beam dispersion at the mirrors as discussed in the geometrical optics section earlier. If this occurs, it may be necessary to use a lens to focus the beam onto the detector of the modulated laser receiver. The best results will be obtained using high quality mirrors or prisms.
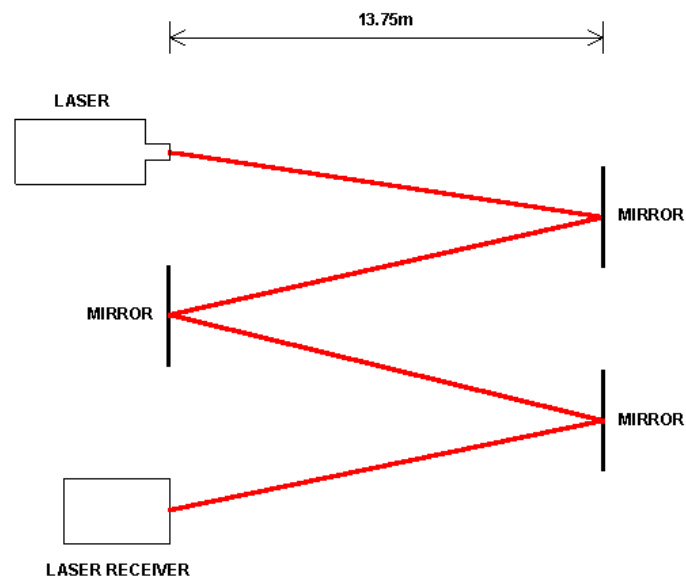
Figure No4 -

Velocity of Light Experiment.

5. On the oscilloscope, measure and record the time delay between a transmitted and a received pulse. The time taken for the light to travel from the laser to the laser receiver is then this measured time minus the time recorded in 3.

6. The velocity of light can then be calculated using the following formula:

velocity of light = distance travelled / time taken

where:
velocity is measured in metres per second.
distance travelled is measured in metres.
time taken is measured in seconds (this is the value found in 5 above).

6. Typical results and calculation.

Total distance between laser and receiver	=	55.0m
Time delay between pulses	=	0.19µs
Velocity of light 55.0/0.19µs	=	305000000 m/s

Young's 2-Slit Experiment.

1. Introduction.

This experiment demonstrates the effects caused by division of the wavefront which occurs when interference takes place between light from two coherent sources. The two coherent sources are derived using a laser and a double slit. Each slit acts as a source of circular waves. The two circular wavefronts then travel to the screen and if they arrive in phase they reinforce to create a fringe. If they arrive out of phase they cancel out. This experiment can be performed using a white light source but better results are obtained using a laser.

2. Objective.

To calculate the wavelength of the emitted light using the 2 slit method.

3. Equipment.

i.   Semiconductor Laser
ii.   Double Slit
iii.   Screen

4. Method.

1. This experiment should be performed in dull light. A full blackout is not necessary but darker conditions will make the fringes easier to see and more fringes will be visible.

2. Set up the laser on a bench and focus the beam on the screen a few metres away.

3. Place the double slit approximately 100mm from the laser, ensuring the beam falls squarely on both slits.

4. You will now see on the screen a central bright band which is the original path of the laser beam. This will be bordered on both sides by regular bright bands which become dimmer away from the central position (See Fig. 5 below). If the distance from the double slit to the screen is approximately 1m then bright fringes quite close together will be seen. If the slit-screen distance is as great as 5m then a good blackout will be required to adequately view the fringes.
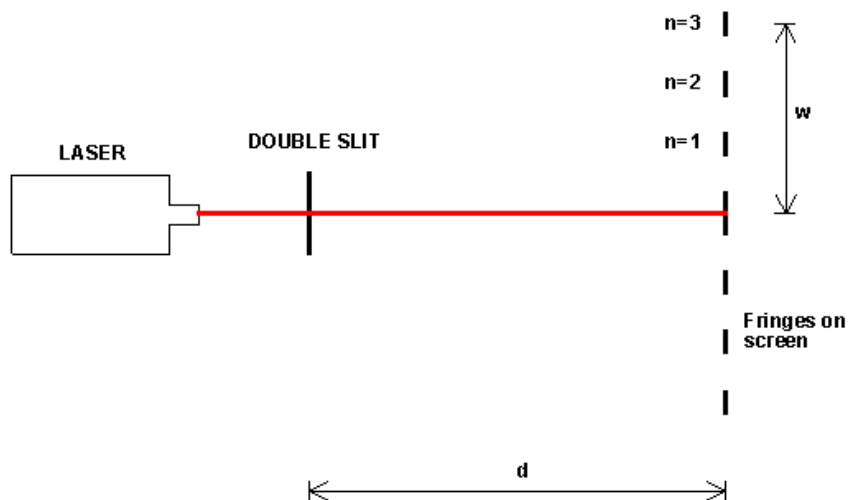
Figure No5 – Young's 2 Slit Experiment.

5. Pick a fringe and measure the distance on the screen between this fringe and the central band. Note the measurement and also the order of the fringe (ie. 1st order, 2nd order etc).

6. Measure and record the distance between the double slit and the screen.

7. Measure and record the distance between the two slits. This can be done using a travelling microscope or with an optical projection method.

8. The wavelength of light can then be calculated using the following formula:

$$n\lambda = (sw)/d$$

where:

n	=	order of fringe (an integer)
λ	=	wavelength of light in metres
s	=	Slit separation in metres
w	=	distance to the nth band from the central band in metres
d	=	distance from the double slit to the screen in metres

6. Typical Result and Calculation.

Fringe order	=	1
Slit–screen distance	=	1.5m
Slit separation	=	0.047mm
Distance from centre to 1st fringe	=	20cm
Wavelength of light	=	sw/dn = (0.000047) x (0.02) / (1.5) x 1 = 626.7nm

Determination of Wavelength Using a Diffraction Grating.

1. Introduction.

Using a diffraction grating produces a highly accurate determination of wavelength. If measurements are taken carefully, a value of wavelength to within 1% of the true value is possible.

2. Objective.

To accurately determine the wavelength of the laser.

3. Equipment.

i.   Laser
ii.   Diffraction grating
ii.   Screen

4. Method.

This experiment needs to be performed in an area of low ambient light. A total blackout is not necessary.

Set up the laser on a bench and focus the beam perpendicularly on the screen at a distance of approximately 2m from the laser.

Position the diffraction grating at right angles to the beam in the path of the beam so the laser falls in the centre of the grating. See fig. 6 below.
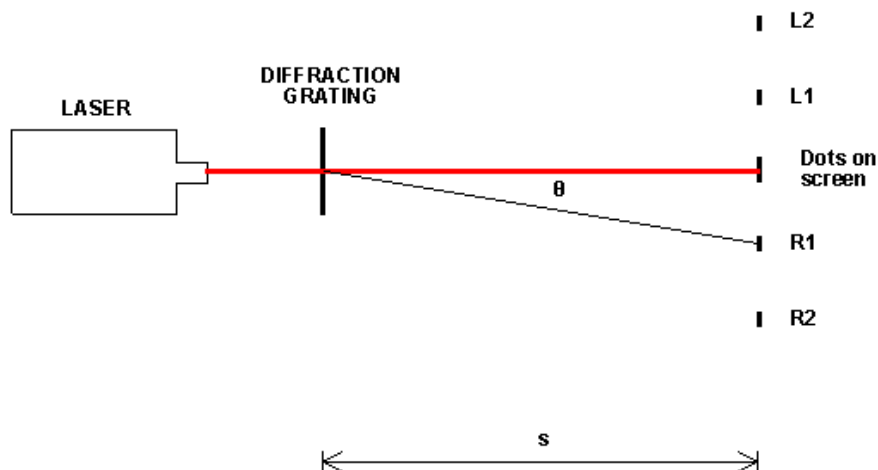

Figure No6 – Diffraction Grating Experiment.

There should now be at least 7 dots visible on the screen symmetrical about a bright centre dot. The intensity of the dots will diminish the further they are from the central bright spot. Additional focussing lenses should not be necessary due to the small angular dispersion of the laser beam. The dots will probably be brighter on one side than the other due to the way the diffraction grating has been manufactured.

On the screen, measure the distance between corresponding dots ie. L1 and R1 on the diagram above. Also measure the distance between the grating and the screen (s on the diagram above). If the diffraction grating is not labelled with the line spacing it will be necessary to measure the line separation using a microscope. Be careful to convert any stated line spacings given in lines/mm to a line separation in metres.

5. Typical Result and Calculation.

For constructive interference to take place at the screen:

$$d\sin\theta = n\lambda$$

where:

d   =   the line spacing of the diffraction grating in metres
θ   =   angle from central position to area of constructive interference
n   =   an integer
λ   =   the wavelength of the light in metres

Using algebra.

Tanq = L1R1/2S

Using this, θ and therefore sinq can be found.

Hence the wavelength can be determined from:

$$\lambda = d\sin\theta/n$$

By altering the experimental set up and taking and recording a number of measurements for the values of L1 to R1, q and s, it will be possible to arrive at an accurate value for the wavelength of the laser. Use of different diffraction gratings (if available) will also allow the experiment to be repeated to arrive at the same result.