



Experiments in Photonics

Section 2 Photonics & Optics



Setting up the spectrometer.

2.1 Lenses and Chromatic Dispersion

Introduction

This section will concentrate on using convex lenses to produce images and look at some of the problems when optical devices are constructed.

Light bends as it passes through a lens and the amount and direction of the bending depends on the shape of the lens.

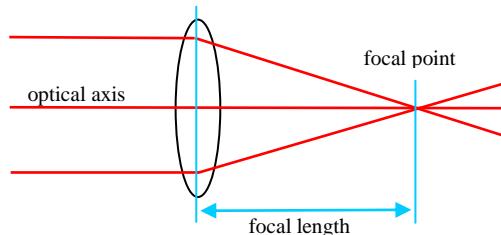


Figure 2.1.1 Convex Lens

All rays parallel to the optic axis of the lens always cross at the focal point of the lens.

All rays passing through the centre of the lens travel in straight lines.

Aims

Calculate the focal length of a convex lens
Relate image and object size to magnification
Distinguish between real and virtual images
Understand how optical instruments work
Identify distortion effects in lenses.

Equipment

	Minilab II		Screen
	Optical Mounts		Coarse Grid
	White LED		Convex lenses

Activity

Select a lens from those provided. A quick way get an idea of the focal lengths of the convex lenses is to focus a window or overhead light onto a sheet of paper.

Make a rough measurement of the focal length of the lenses.

Investigate the properties of the glass lenses using a Light Emitting Diode light source on the top of the optical bench with the magnetic holders.

Insert the LED into a holder and plug the LED into the correct socket.

Set up the components as shown in figure 2.1.2 using the **thickest** lens.

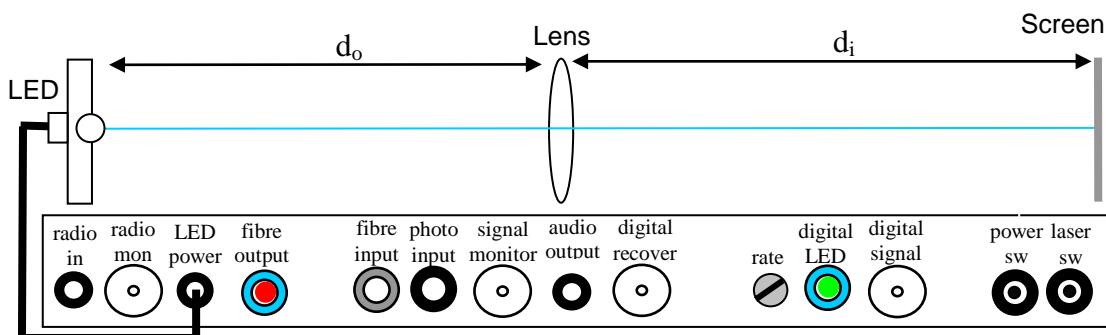


Figure 2.1.2 Properties of a convex lens

Adjust the lens until a sharp image of the grid is seen on the screen. Note that d_o object distance and d_i image distance must both be greater than the focal length for a real image to be formed and seen.

Measure d_i the distance from the lens to the image and d_o the distance from the lens to the object (screen). Draw and fill in the table.

The thin lens formula allows the focal length to be accurately calculated using your measurements

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

d_o	d_i	f

Is the focal length the same as your earlier estimate? Complete the results in tabular form.

Move the lens and repeat the calculation with two more images.

What happens if the lens is placed too close to the object slide?

Which way up is the image produced by a convex lens?

A convex lens produces a real image that means it can be formed on a screen.

Lenses also produce magnification m that is the ratio of the image size h_i to object size h_o . It is also related to the distances d_i and d_o by the following equation.

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

Use the 150mm focal length lens to produce a magnified image. Do your measurements confirm the relationship in the above equation?

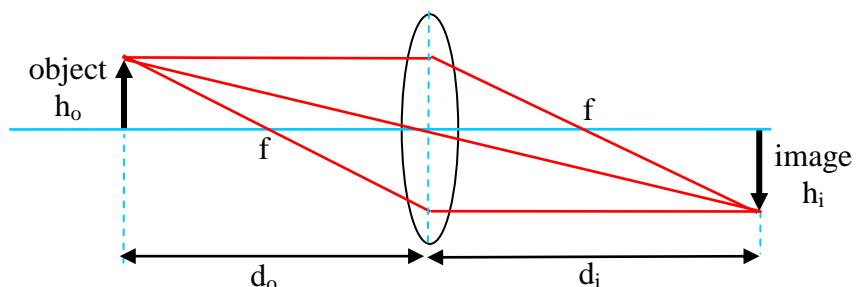


Figure 2.1.3 Object distance, image distance, focal length and magnification

Light coming from objects some distance away is considered to be approximately parallel. Our eye focuses these parallel beams onto the retina to form an image. Any optical instrument that we use needs to produce similar parallel rays so that the eye or a camera can focus them.

Real images are produced by optics when light rays are focussed to a point. This occurs inside the eye. If an imaging screen is placed at this point then an image will be seen on it.

Virtual images cannot be seen on a screen. Additional optics of the eye, camera or lens is needed to see them.

Activity

Magnifying Glass

Try out the lenses on their own as magnifying glasses. The eye focuses the virtual image produced by the lens.

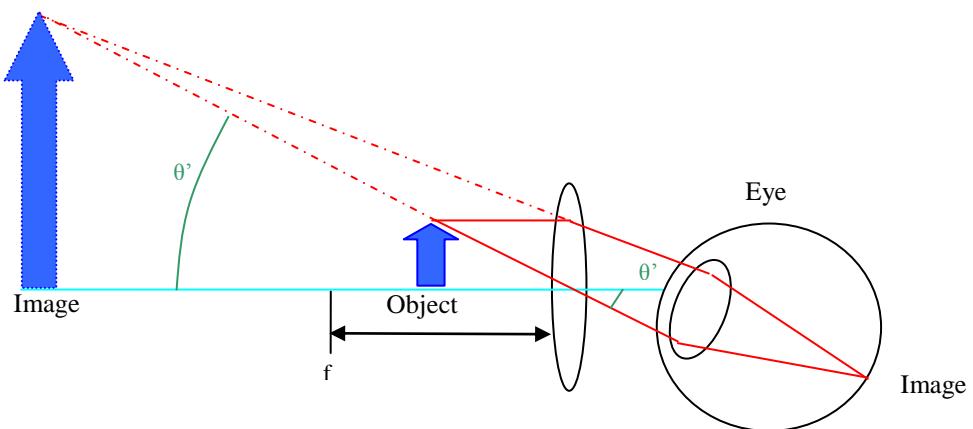


Figure 2.1.4 Magnifying glass

Investigate the magnifying ability of some of the lenses available. Sketch a diagram to illustrate the magnification of each lens. Use a piece of print or grid. What position should the eye take?

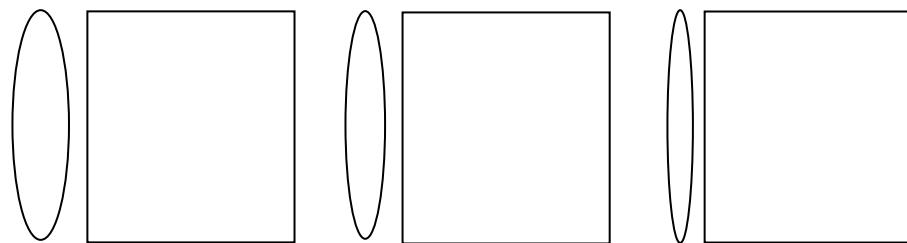


Figure 2.1.5 Magnification results

Telescopes

Refer to Figure 2.1.6 and construct an astronomical telescope on the optical bench. Focus on a (distant) object at least three metres away.

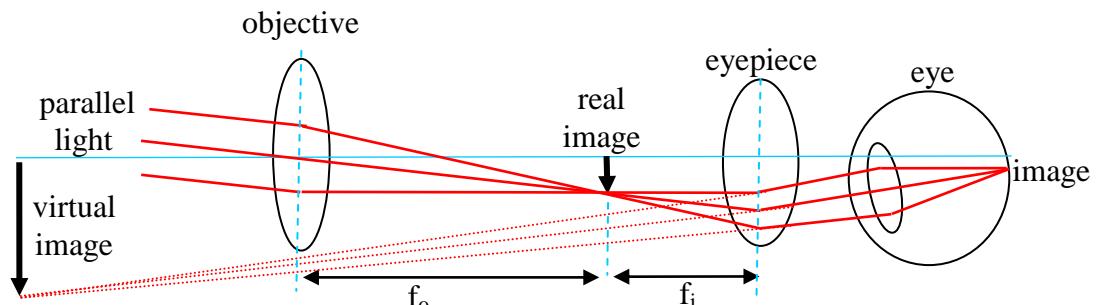


Figure 2.1.6 Astronomical Telescope

Look through the telescope and describe the image. Try different combinations of lenses and note the significance of focal lengths.

The Galilean telescope or opera glass has certain advantages over an astronomical telescope

Refer to Figure 2.1.7 to build a Galilean telescope.

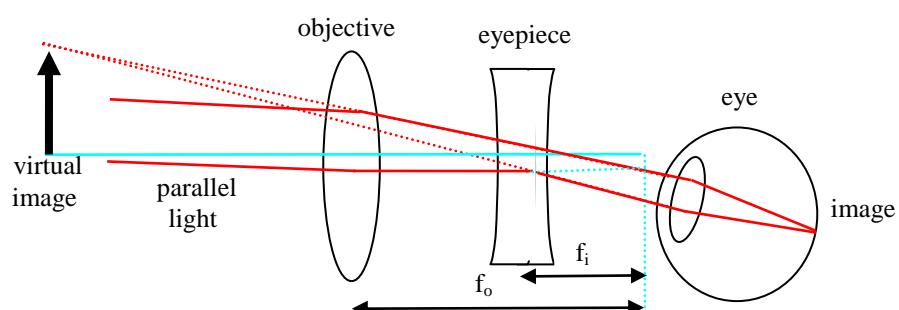


Figure 2.1.7 Galilean Telescope

Additional Activity

Calculate the magnification m of the telescopes with different lens combinations.

f_o = focal length of objective and f_e = focal length of eyepiece

$$m = \frac{f_o}{f_e}$$

Devise a method using the eye to estimate the magnification and compare these to calculated values.

Image quality is important in optical instruments. The experimental arrangement used earlier to measure focal lengths is used once again, but this time to demonstrate and measure distortion and colour dispersion.

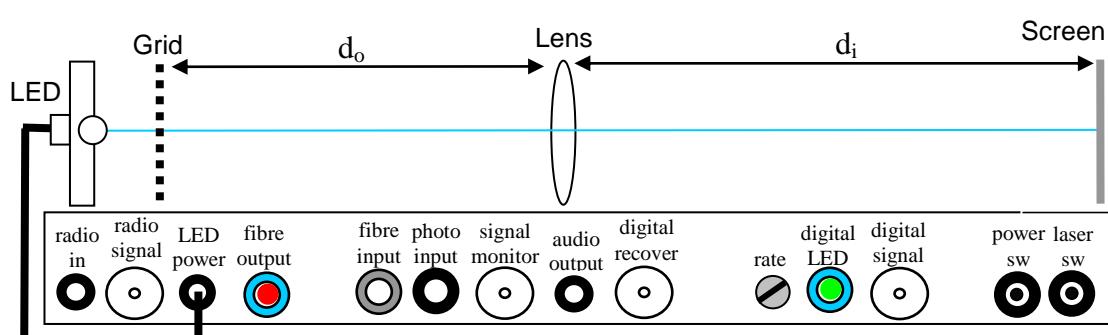
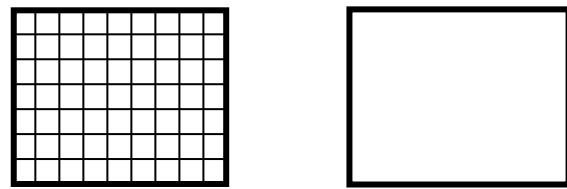


Figure 2.1.8 Measuring distortion and dispersion

Use the LED and place the coarse grid close to the source.

Focus the grid on the screen and sketch or record the image. How does it compare to the original grid? This exercise requires a dark area.



Place the red filter in front of the grid and try to adjust the screen to give the sharpest possible image. Measure the distance from the screen to the lens.

Replace the red filter with the blue filter and adjust the screen once again to give a sharp image. Measure the distance from the screen to the lens.

Are they the same and do your results correspond with Figure 2.1.9

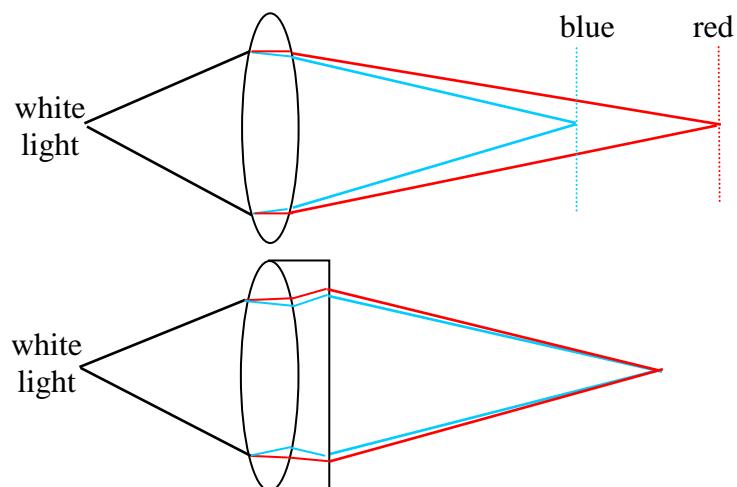


Figure 2.1.9 Colour dispersion and use of an achromat lens to correct the effect

2.2 Diffraction: An Introduction

Introduction

When light passes an edge it spreads out causing diffraction. This effect is particularly important in the design of optical instruments.

The shape of an aperture or object determines the shape of the diffraction pattern. For example a circular aperture will produce a diffuse circular pattern known as Airy's disc:

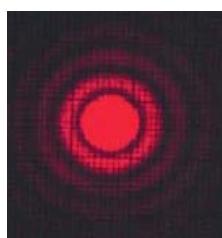


Figure 2.2.1 Diffraction pattern formed by a laser shining through a small hole

When you look at a distant street lamp there may be a corona surrounding it. This is actually a diffraction pattern determined by the aperture of your eye. Occasionally the moon exhibits a corona due to diffraction from the small water droplets or ice crystals in the air above us.

The dimensions of the interference pattern observed can be calculated if we know the wavelength (λ) of the light, the size of the aperture (d) and the distance from the aperture to the screen (L). W is the width of the central maximum.

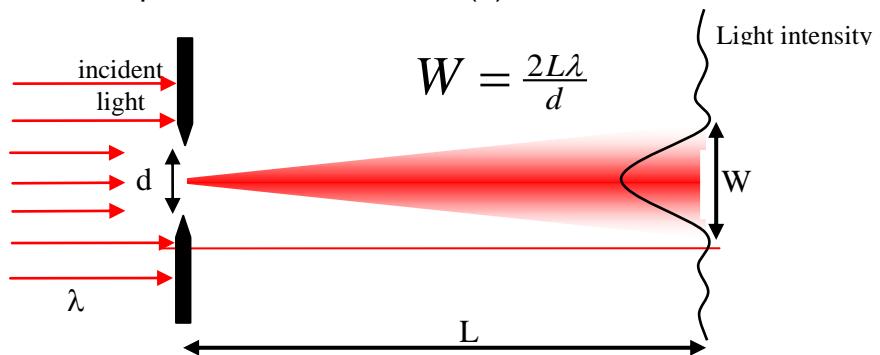


Figure 2.2.2 Diffraction and light intensity through a slit

In general terms the smaller the aperture the greater the effect of diffraction and interference. This knowledge is useful because many optical instruments have small circular apertures.

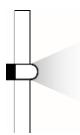
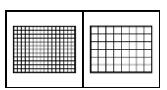
Usually for an optical instrument it is desirable to limit the diffraction. This means W must be as small as possible. By inspection of the equation above we can see that we need to make d as large as possible. Microscope objective lenses provide an example, with the better lenses having the larger apertures.

This experiment will demonstrate some of the qualitative effects of diffraction.

Aims

- To view and recognise diffraction effects
- Relate diffraction effects to the wavelength of light
- Use a diffraction grating

Equipment

	Minilab II		Diffraction Grating		Optical Mounts
	LED Light Sources				Grids

Activity

As a simple demonstration hold a forefinger as close as possible to the thumb without touching. Place an eye close to the gap and look out of the window.

What do you observe?



Diffraction phenomena are quite common for instance when we look through a flyscreen at a distant lamp or when a TV camera points towards the lights during a sporting event and a cross like effect occurs.

Activity

Set up the white LED in a magnetic holder on top of the optical bench and plug it into the correct socket.

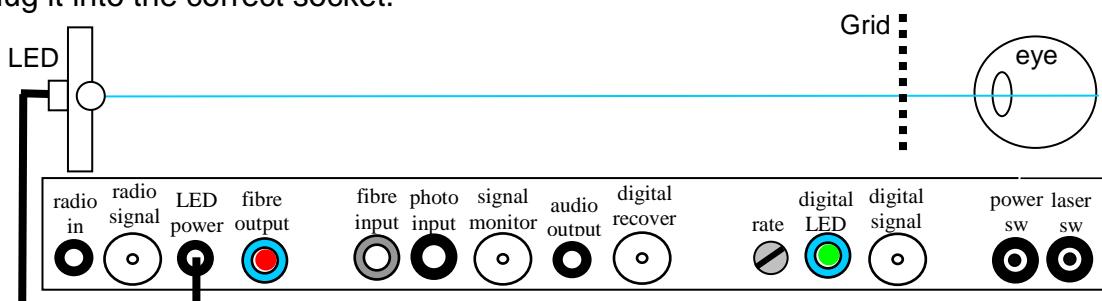


Figure 2.2.3 Viewing diffraction effects

Stand some distance away and look at the LED through the grids, diffraction grating and rainbow glasses.

Sketch and describe the visible patterns.

Coarse Grid	Fine Grid	Diffraction Grating	Rainbow Glasses

Although these slides diffract the light around the wire or lines the colours appear because of light interference that removes and enhances colours in a similar way to the patterns seen on a soap bubble.

How do you think the rainbow glasses are made?

A diffraction grating is a slide that contains thousands of tiny parallel lines etched into a piece of film. Typically a grating has 600 lines per millimetre or the spacing between lines is about 1.6 microns or 0.0016mm.

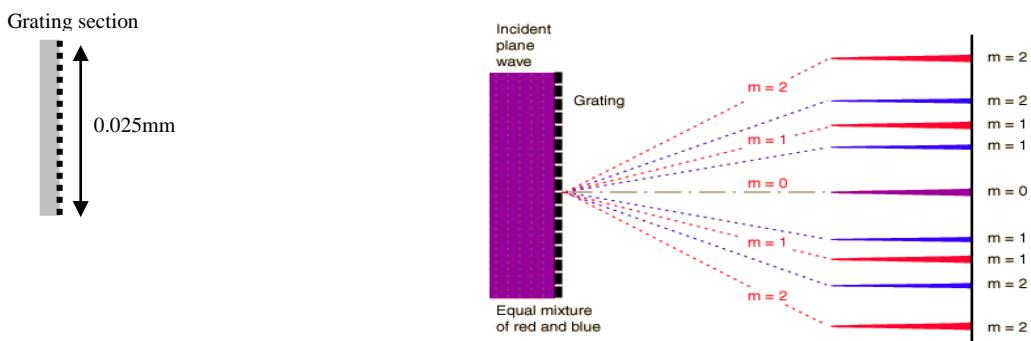


Figure 2.2.4 Diffraction grating. Line spacing is about 1.6 microns.

Activity

Look at the blue, green, red and white LEDs through the finest mesh slide. Sketch and record your results.

Blue LED	Green LED	Red LED	White LED

Which colours are bent the most and do your observations of the white light LED support these findings?

2.3 Emission and Absorption Spectra

Introduction

Light from the sun contains a continuous distribution of wavelengths, from the energetic ultra-violet (UV) at around 100nm to the deep infrared at over 2000nm. The wavelengths associated with a light source are its spectrum.

The sun's spectrum is thus very broad, whereas light from a source such as a sodium street lamp has a discrete spectrum of only a few different wavelengths. The reason for this is that the sun is very hot, and takes on the spectrum of a blackbody radiator. The street lamp emits wavelengths dependent upon the sodium atoms in the tube.

A blackbody radiator is a hot object that emits radiation according to quantum theory. The radiation curves for any hot body depends solely on the temperature:

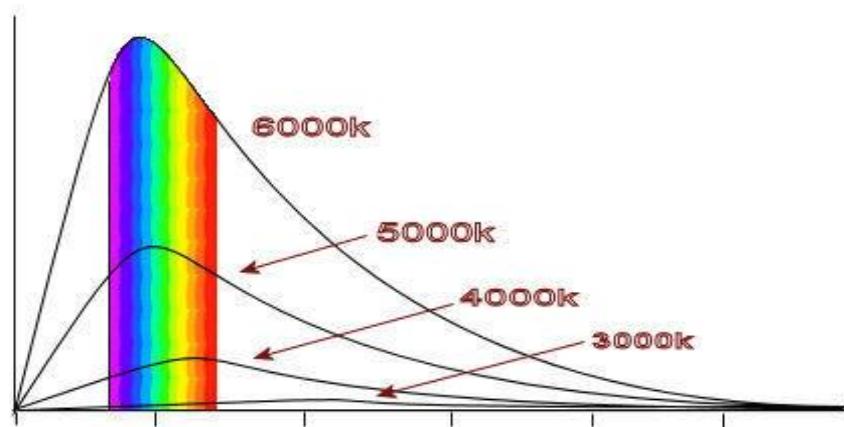


Figure 2.3.1 Black body curves

Light emitting objects such as the sun or normal tungsten lamps have a colour temperature. This means the colour of light is dependent on how hot the lamp is.

The spectrum of the sun closely matches the spectrum of a blackbody radiator at 5780°K. A typical halogen bulb operates at a temperature of around 3500°K. For objects much colder than this, the curve tends to have its peak output further into the infrared.

Fluorescent tubes and "neon" light displays operate on a different principle. These lights contain mercury, argon or neon for example. The electrons associated with the atom are excited by the electrical supply and each electron emits a photon of light as it drops back to its non-excited state.

The wavelength emitted depends on how much energy the electrons give up in dropping back to the ground state. Since electrons can only exist in well-defined energy levels this limits the number of different wavelengths that can be emitted from any given atom. For these types of light a discrete number of wavelengths are emitted, depending on the atoms excited.

Working the other way, we can determine the composition of a gas by the photons emitted and absorbed by it. This is how we determine the composition of atmospheres on distant planets and nebulous clouds and stars light years away.

In this experiment a diffraction grating spectrometer is constructed and used to examine the emission spectra from a range of light sources and a filter is used to demonstrate an absorption spectrum.

A light has been supplied that produces some spectral lines. The experiment can also be extended if (high voltage) discharge lamps are locally available.

Aims

To observe emission and absorption spectra

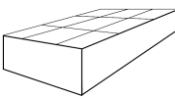
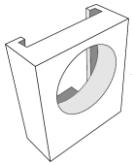
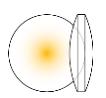
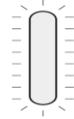
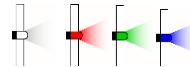
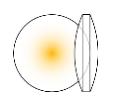
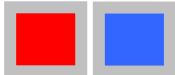
To build a spectrometer

Understand how spectra are produced

Calculate the wavelength of different colours of light

Calculate energy and frequency of light

Equipment

	Optical Bench		Optical Mounts		Biconvex Lens (f=150)
	Spectral tube			LED light sources	
	Diffraction Grating		Imaging screen		Slit Slide
	Parallel line slides			Coloured Filters	

The spectrometer is a widely used instrument that can be used to investigate the spectra of light sources and measure the wavelengths of light. Spectrometers use diffraction gratings or prisms to produce spectra.

A diffraction grating consists of thousands of microscopic lines etched into a film. When light hits the edges of the lines diffraction or bending of light occurs.

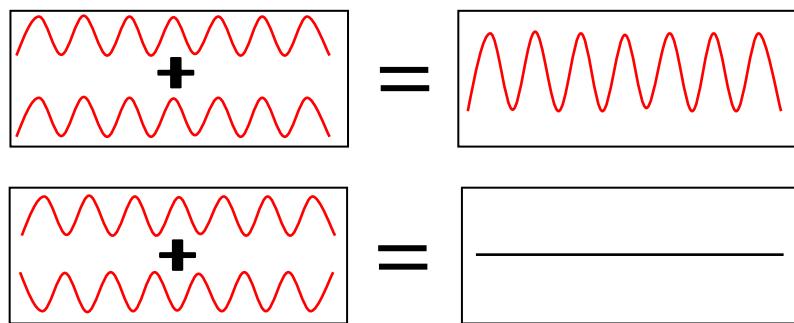


Figure 2.3.2 Constructive and destructive interference of light waves

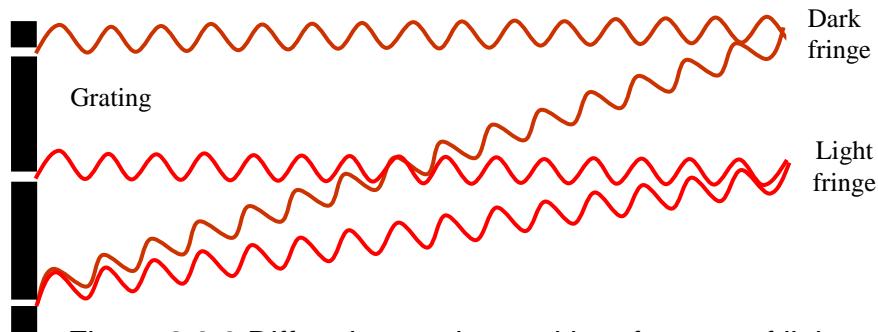


Figure 2.3.3 Diffraction grating and interference of light

The amount of bending depends on the wavelength or colour of the light. The light can constructively or destructively interfere to leave areas of darkness and colour.

The amount of bending depends on the spacing and size of the lines on the diffraction grating.

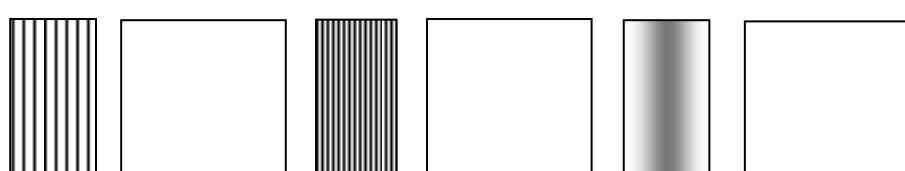
Activity

Set up the white LED on top of the optical bench, connecting it to the correct socket.



Figure 2.3.4 Viewing the LED with parallel line slides and diffraction grating

View the light source through the different size parallel lines and the diffraction grating. Sketch a diagram of what you see and describe how the spreading of the light or spectrum relates to the size and spacing of the parallel lines.



The amount of bending depends on the wavelength or colour of the light. The light can constructively or destructively interfere to leave areas of darkness and colour.

The amount of bending also depends on the spacing and size of the lines on the diffraction grating.

Activity

Build a spectrometer on the optical bench by reference to figure 2.3.5 using the white LED and the 150mm convex lens.

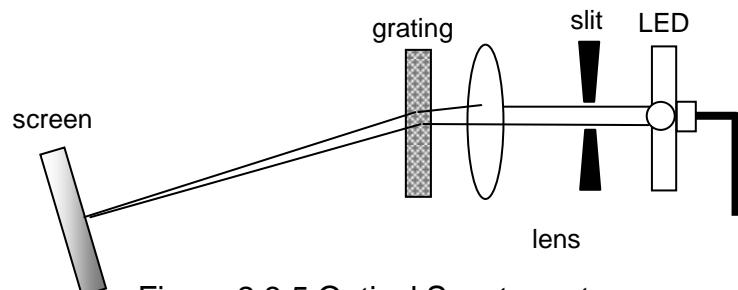


Figure 2.3.5 Optical Spectrometer

Move the lens and screen until a sharp image of the spectrum is observed.

Place a sheet of paper under the components and replace the white LED with the blue one.

Find the blue spectrum either side of the central axis drawn from the diffraction grating, Figure 2.3.6

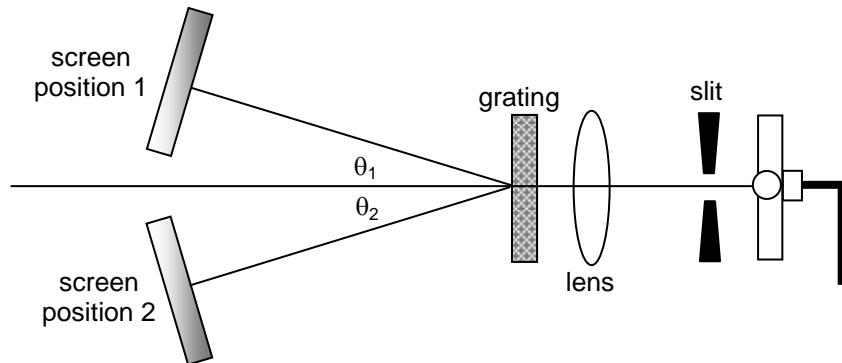


Figure 2.3.6 Wavelength measurements

Draw around the grating and mark the centre of the blue spectrum on each side. Construct lines from the spectrum to the grating and measure the angles θ_1 and θ_2 .

Take an average of these angles $\frac{\theta_1 + \theta_2}{2} = \theta$

The wavelength λ of the light can be calculated using $\lambda = d \sin \theta$

d is the line spacing on the diffraction grating. Check the number of lines per millimetre on the grating (600lines/mm) and work out the distance between the lines.

Calculate λ and convert your answer to nanometres the usual units for light wavelength. $1\text{nm} = 10^{-9}\text{metres}$ or 10^{-6}mm

Convert the wavelength measurement to frequency using $c = f\lambda$

c is the speed of light $3 \times 10^8 \text{ m/s}$ and λ should be in metres

Replace the blue LED with the red and green ones and make similar measurements.

Calculate photon energies using $\Delta E = hf$ where

$h = 6.626 \times 10^{-34}$ Joules/sec, Planck's constant.

E is in joules.

Fill in the table with wavelengths, frequencies and energies

	Wavelengths λ nm	Frequency f Hz	Energy J
Blue LED			
Green LED			
Red LED			

Minilab II is supplied with a Cold Cathode Fluorescent Tube CCFL. This can be powered with a 9 Volt battery in a dark room; or more effectively with a 12 Volt DC supply. This light source produces a line spectrum as it contains mercury. Measure some the main lines and compare them to the spectrum in figure 2.3.7. Remember the lamp has fluorescent properties so a continuous spectrum partially coexists with the lines.

Your laboratory may also have spectral light sources such as Hydrogen that can be viewed with the spectrometer. Line spectra relate to the atomic structure of the atoms in the lamps.



Figure 2.3.7 Line spectra of Mercury

To use the white light source use the electronic breadboard and note that the value of the resistor (10Ω - 100Ω) can be changed to vary the brightness of the light.

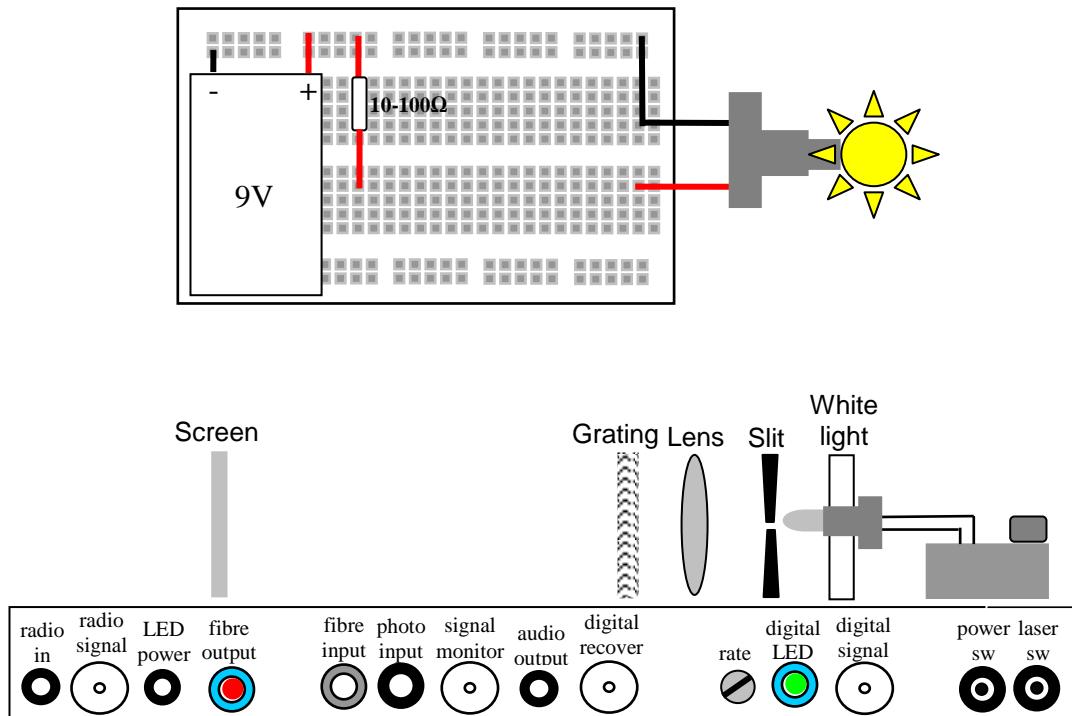


Figure 2.3.8 White light source on the Minilab

Absorption Spectrum

To demonstrate an absorption spectrum set up the white LED or lamp and display the spectrum. A continuous spectrum should be visible. Place the coloured filters in front of the light source and note how parts of the spectrum are missing.

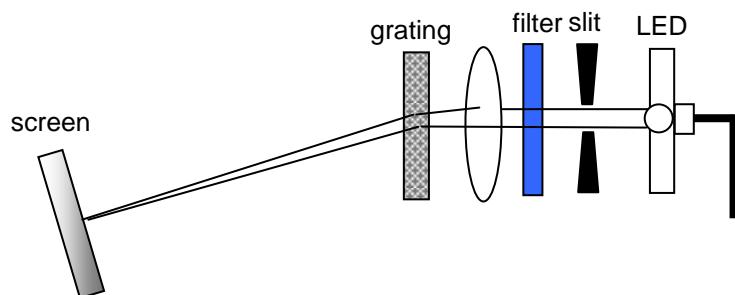


Figure 2.3.9 Absorption Spectrum

Many compounds or substances absorb light and can be identified from their absorption bands. Just as spectral lamps emit line spectra the same atomic vapours can absorb in a similar way. The sun produces one of the most spectacular absorption spectra.

2.4 Prism Spectrometer

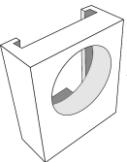
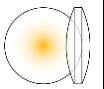
Aims

To construct a prism spectrometer

To observe diffraction by a prism

Compare the prism spectrum to a diffraction grating spectrum

Equipment

	Optical Bench		Optical Mounts		Biconvex Lens $f=150\text{mm}$
	Slit Slide & Screen		White LED and light sources		Prism

The spectrometer is a widely used instrument that can be used to investigate the spectra of light sources and measure the wavelengths of light. Spectrometers use diffraction gratings or prisms to produce spectra.

A prism produces a spectrum by dispersion. The refractive index of the glass depends on the wavelength or colour of the light.

The light is refracted as it enters and leaves the prism.

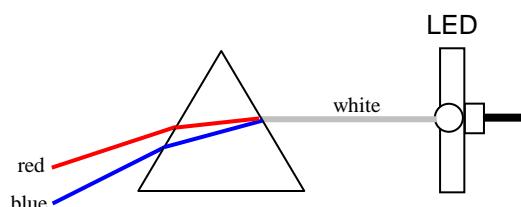


Figure 2.4.1 Dispersion by a prism

Try looking at light sources or windows through the prism. Careful as it is made of glass!!

Can you see dispersion of light into various colours?

Activity

Construct a spectrometer using a prism as shown in figure 2.4.2

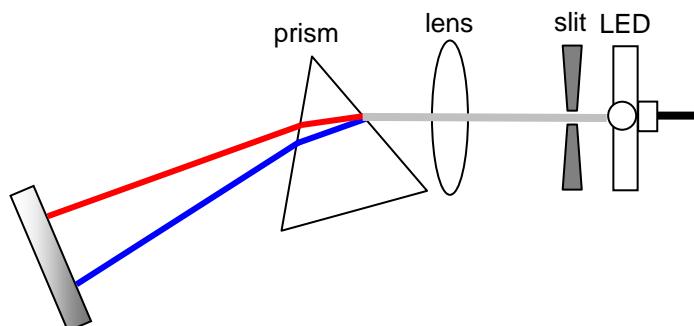


Figure 2.4.2 Prism Spectrometer

The light source should be placed next to the edge of the optical table and the slit placed vertically in a holder to provide a slit in front of the light source.

Rotate the prism to produce the best spectrum.

Use the white LED to produce a spectrum. Try the other light sources as well and compare the spectra produced by the diffraction grating and the prism. Note any differences.

2.5 Band Gap Energy and Spectrometry

Aims

To measure band gap energies

Construct a spectrometer

Understand the significance of band gaps

Introduction

Spectrometers are widely used instruments with applications ranging from astronomy to measuring the light output from lasers and light emitting diodes.

Spectrometers usually have a diffraction grating that consists of thousands of microscopic lines etched into a film. When light hits the edges of the lines diffraction or bending of light occurs.

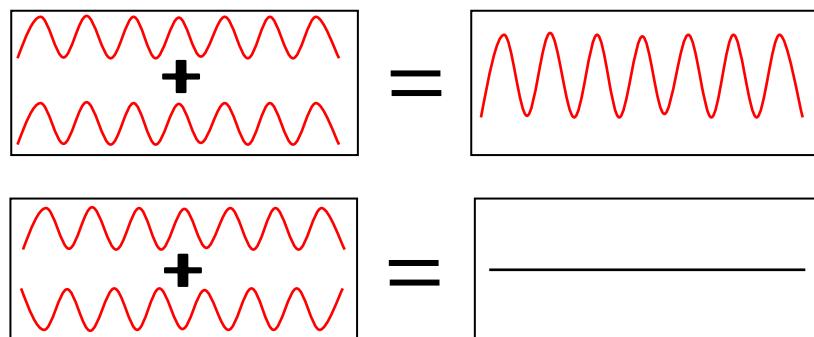


Figure 2.5.1 Constructive and destructive interference of light waves

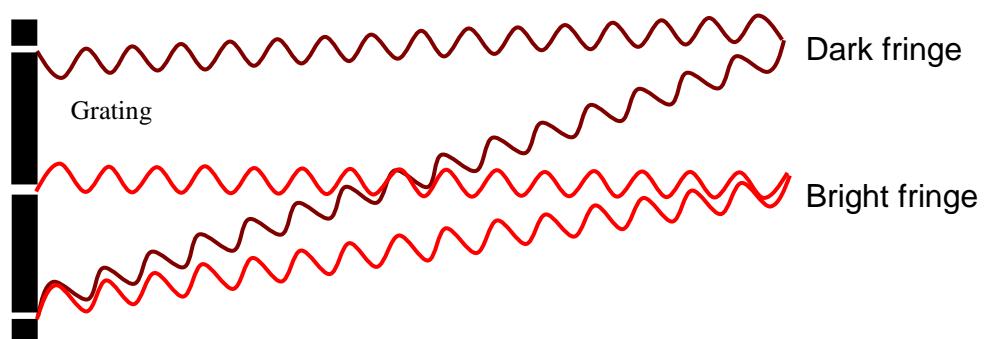


Figure 2.5.2 Diffraction grating and interference of light

The amount of bending depends on the wavelength or colour of the light. The light can constructively or destructively interfere to leave areas of darkness and colour.

The amount of bending depends on the spacing and size of the lines on the diffraction grating.

Light can be produced in a number of different ways. The filament of a light bulb is heated by passing a current through it. This heat is radiated as visible and non-visible light.

An LED or light emitting diode is different and works on the principle of band gap energies. A band gap is essentially the energy gap between the electron valence band and the conduction band. This gap is large for an insulator, small for a semiconductor and for a conductor these bands overlap, meaning that there are always electrons available in the conduction band.

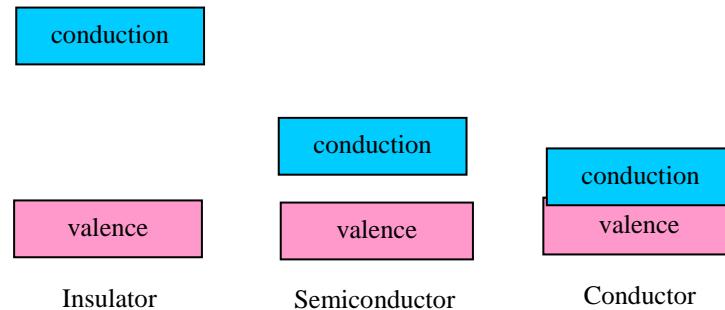


Figure 2.5.3 Relative positions of the valence and conduction bands in insulators, semiconductors and conductors

A diode is a device that allows current to flow only if it is in the right direction and is of high enough voltage. Diodes use a p-n junction. This is a term used for two pieces of semi-conducting material, one with positive holes (p) and another rich in electrons (n). When these materials are placed together, figure 2.5.4, the electrons and holes combine at the boundary to form a depletion zone that is electrically neutral and acts as an insulator.

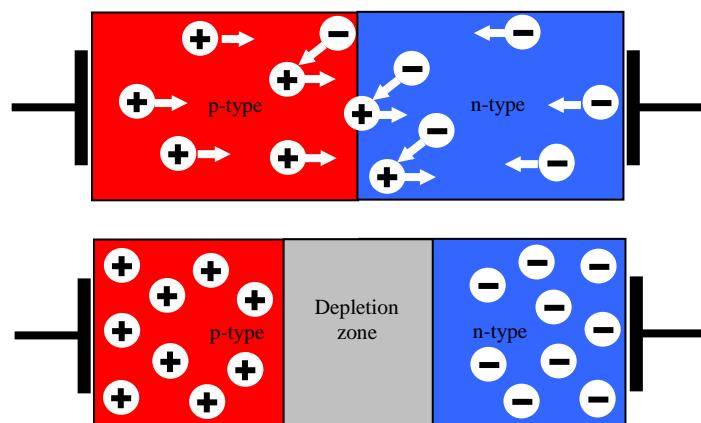


Figure 2.5.4 Holes and electrons in a p-n junction

If a high enough voltage is applied the electrons and holes migrate across the depletion zone. As the electrons drop into the holes they drop from the conduction band into the valence band and a photon of light is emitted.

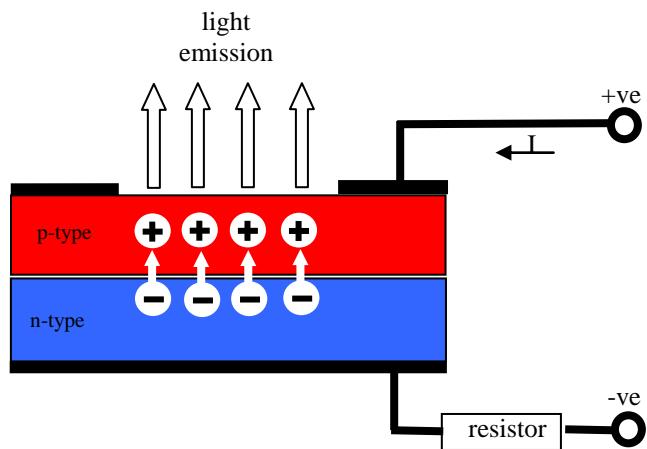


Figure 2.5.5 LED structure and circuit

LED's may be made from layers of Aluminium Gallium Arsenide (AlGaAs) in the form of a semiconductor chip encapsulated in epoxy resin. The composition of the LED can be altered to give different band gap energies. This controls the colour or frequency of emitted light.

Small band gaps give red light and larger band gaps give green and blue.

Equipment

	Optical Bench		Optical Mounts		Biconvex Lens (f=150)
	Parallel line slides		LED Light Sources		Spectral Light Sources [Optional]
	Diffraction Grating		Imaging screen		Slit Slide

Activity

Set up one of the LEDs on top of the optical bench, connecting it to the correct socket.

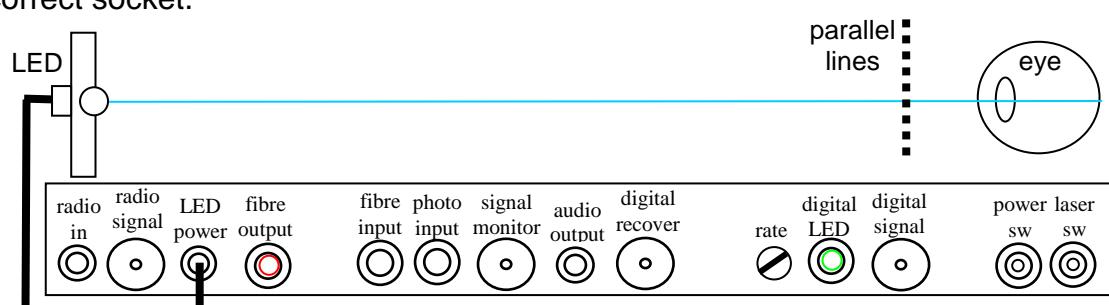
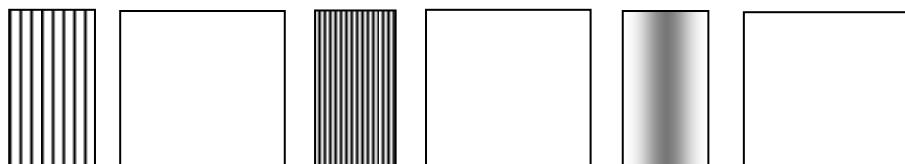


Figure 2.5.6 Viewing the LED with parallel line slides and diffraction grating

View the light source through the different size parallel lines and the diffraction grating. Describe how the spreading of the light or spectrum relates to the size and spacing of the parallel lines. Use the microscope to inspect the line separation.

Can you see any lines on the diffraction grating?



Build a spectrometer using the white LED and $f=150\text{mm}$ lens on the optical bench by reference to figure 2.5.7

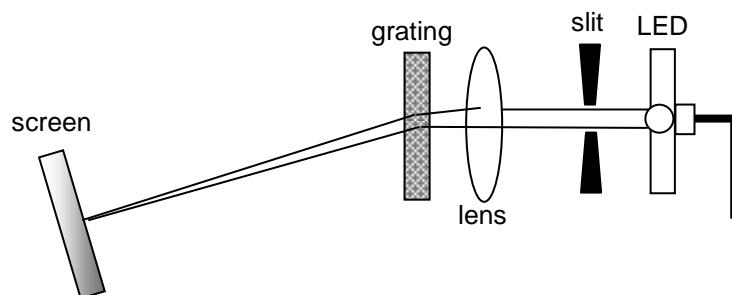


Figure 2.5.7 Optical Spectrometer

Move the lens and screen until a sharp image of the spectrum is observed.

Place a sheet of paper under the components and replace the white LED with the blue one.

Find the blue spectrum either side of the central axis drawn from the diffraction grating, Figure 2.5.8

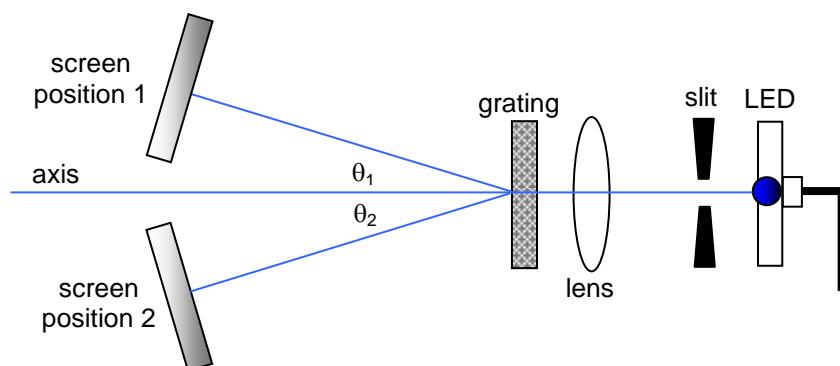


Figure 2.5.8 Wavelength measurements

Draw around the grating and mark the centre of the blue spectrum on each side. Construct lines from the spectrum to the grating and measure the angles θ_1 and θ_2 .

The wavelength λ of the light can be calculated using $\lambda = d \sin \theta$
d is the line spacing on the diffraction grating. Check the number of lines per millimetre on the grating (600lines/mm) and work out the distance between the lines.

Calculate λ and convert your answer to nanometres the usual units for light wavelength. $1\text{nm} = 10^{-9}\text{metres}$.

Convert the wavelength measurement to frequency using $c = f\lambda$

c is the speed of light $3 * 10^8 \text{ m/s}$ and λ should be in metres. Fill in the table.

Replace the blue LED with the red and green ones and make similar measurements.

Measurement of the wavelength of the light and use of the following equation allows the band gap energies to be calculated.

$$E = \frac{hc}{\lambda} \quad h = \text{Planck's Constant } 6.626 * 10^{-34} \text{ J.s}$$

The energy is calculated in Joules. Convert to eV using $1\text{eV} = 1.6 * 10^{-19} \text{ J}$

Complete the table and look up some values for the band gap energies for different coloured LEDs.

What other factor influences band gap energy?

	Wavelength λ	Frequency f	Energy J	Calculate eV	Typical eV
Blue LED					
Green LED					
Red LED					

2.6 Young's Double Slit Experiment

Aims

To reproduce Young's double slit experiment

To observe interference fringes

Relate their appearance to the wave theory of light and wavelength of light

Introduction

The double slit slide has several sets of slits. Use black tape to leave one set of slits only. Set up the white light or white LED source on the optical bench. Bring the slit up close to the eye and view the light source.

What do you see?

The interference pattern can only occur when the light diffracted by the two slits is coherent or in phase with each other. Coherence can be achieved with a laser, however Thomas Young performed this experiment in 1801 and did not have access to such a device.

Instead Young used the arrangement shown in Figure 2.6.1 in which single and double slits are employed to produce two coherent light sources. The light forms a spectrum from each slit and constructive or destructive interference occurs depending on the phase difference of the two paths for the light.

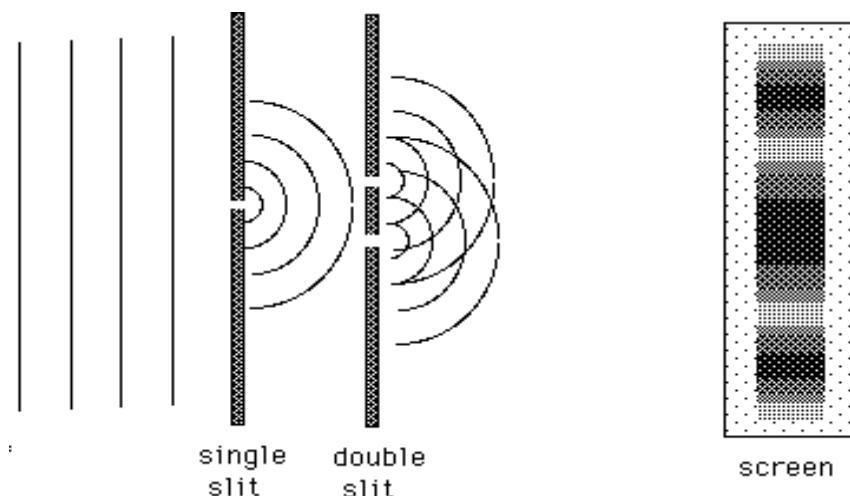
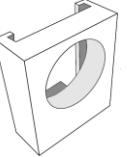
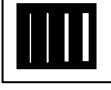


Figure 2.6.1 Young's double slit experiment

Young's experiment provided strong evidence for the wave nature of light and the measurement of wavelength. The formation of spectra and interference effects are exploited in the design and use of diffraction gratings.

Equipment

	Optical Bench		Optical Mounts		Double slit slide
	Slit slide			LED light sources	

Activity

The interference patterns or fringes can be investigated by using a single slit in front of the light source and placing your eye close to the double slit slide. Refer to figure 2.6.2

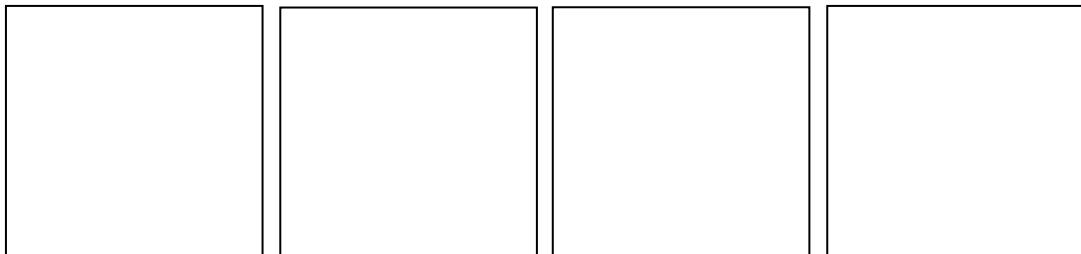


Figure 2.6.2 Observing double slit interference fringes

The single slit fits into one of the magnetic holders horizontally or vertically and can be held open using the screws. Try different double slits but block out the remainder.

Adjust the components and alignment to produce the best fringe pattern possible.

Sketch the fringe patterns from the different LEDs and note any differences.



Explain the interference patterns and results in terms of the wave like nature of light.

How are the colours and separation of fringes related to the wavelength of the light?

2.7 Polarization

Aims

To produce and investigate polarized light.

Measurement of the intensity of light passing through polarizers..

Visualisation of stress in rulers and protractors.

Introduction

Light is a wave that oscillates about a particular axis. Normally light consists of a random mixture of polarisation states where each wave oscillates at a different angle

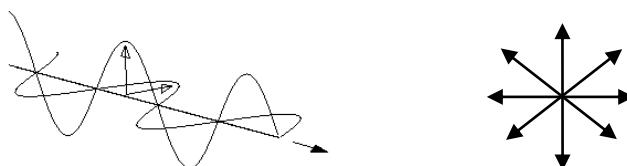


Figure 2.7.1 Transverse oscillations of light in random directions

Light is polarised if all the photons are oscillating in the same plane. The most common material for producing polarized light is made from aligned long chain polymers. This is Polaroid and is the material found in sunglasses.



Figure 2.7.2 Alignment of molecular polymers and polarization direction

A sheet of Polaroid will only allow transverse vibrations through in one direction

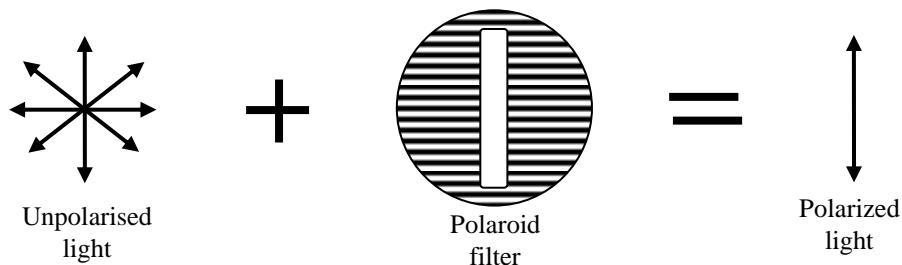
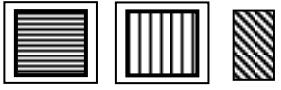
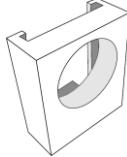
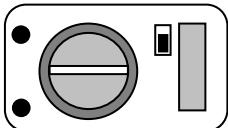
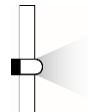


Figure 2.7.3 Producing polarized light

Equipment

	Optical Bench		Polaroids
	Optical Mounts		Meter
	White LED		Phototransistor
			
			BNC-4mm lead

Activity

Set up the optical bench so that there are two empty slide holders between the white LED and the phototransistor. The phototransistor output should be connected to the meter.

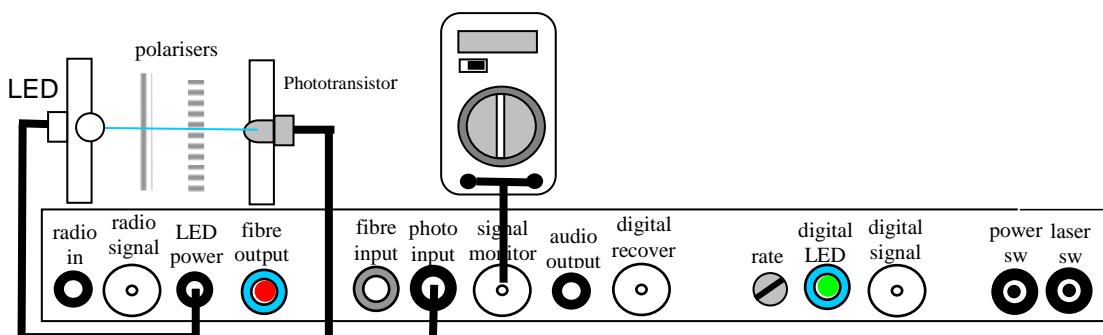


Figure 2.7.4 Polarization experiment

Set the meter to DC volts and measure the ambient light level on the phototransistor.

Switch on the LED and measure the new light level. If the phototransistor is saturated move the device away from the LED. The output should fall slightly.

Place one polarizer in the holder and record the new light level. Insert the other polarizer so light passes through to the phototransistor and record the level. Turn the second polarizer 90° and record the new light level.

Explain what has happened to the light levels.

The kit contains a third piece of unmounted polaroid. Rotate this piece of polaroid in between the other two crossed polarizers and note what happens to the light levels.

Crossed polarizers do not permit the transmission of any light. Placing a piece of polaroid at 45° between the crossed polarizers permits light to come through.

One way of looking at the phenomenon is that the first polarizer blocks 50% of the light, the second one another 50% and the third one yet another 50%. The total transmission is now 12,5% compared to 0% with crossed polarizers. Can you find an explanation for this using vectors?

Additional Activity

Many types of glass, plastic and chemical solutions affect polarized light.

Remove the pieces of polaroid and place them either side of a transparent plastic ruler or protractor. Slightly flex the plastic and observe the stress patterns. These patterns relate to flaws in the manufacturing process and stresses inherent in the design.

Identify areas of stress, weakness and uneven thickness.

Investigate how the light level changes as one of the polaroid slides is rotated through 360°. It will be necessary to find a way to orientate the slide or polaroid at different angles in front of the phototransistor.

2.8 Analog Modulation

Introduction

Analog modulation is a signal changing in level and frequency on a continual basis. This occurs when a microphone or telephone is used with sound waves being converted into electrical signals.

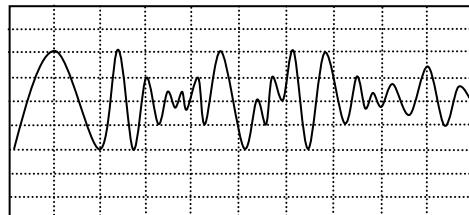


Figure 2.8.1 Analog modulation

The analog transmitter is a LED that emits an unchanging light intensity. A LED normally emits an unchanging light level or a steady signal. The signal has to be modulated by using the audio output from a radio to change the light levels slightly.

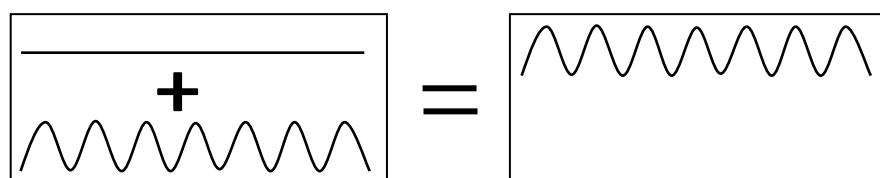


Figure 2.8.2 Audio signal added to the DC voltage driving the LED. The result is an analog signal with a DC offset.

The detector is a phototransistor that converts the light into electrical signals that can be seen on the oscilloscope and heard through the amplifier.

Figure 2.8.3 shows how the analog audio signal is added to the dc voltage of the LED through a transformer and induction.

The phototransistor converts the light into a current. When the current passes through the resistor it generates a voltage that can be seen on the oscilloscope or used as a source for the earphone or speaker.

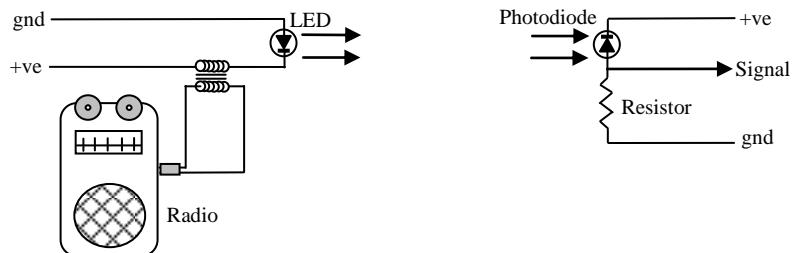


Figure 2.8.3 Modulating the LED and detecting the signal

Aims

To observe analog modulation
To build a free space audio link

Equipment

	Optical Bench		Optical Mounts		Biconvex Lenses
	Radio		LED		Phototransistor
	Oscilloscope & BNC leads		Speaker or earphone		3.5-3.5mm stereo lead

Activity

Construct a free space audio link based on analog modulation by reference to figure 2.8.4. Use one of the LEDs and the phototransistor. A lens can be used to increase the range of transmission.

If the light levels are too high the signal can saturate the phototransistor and prevent it from detecting the signal.

An oscilloscope is useful to visualise the waveforms and a speaker or earpiece can be used to listen to the transmitted signal.

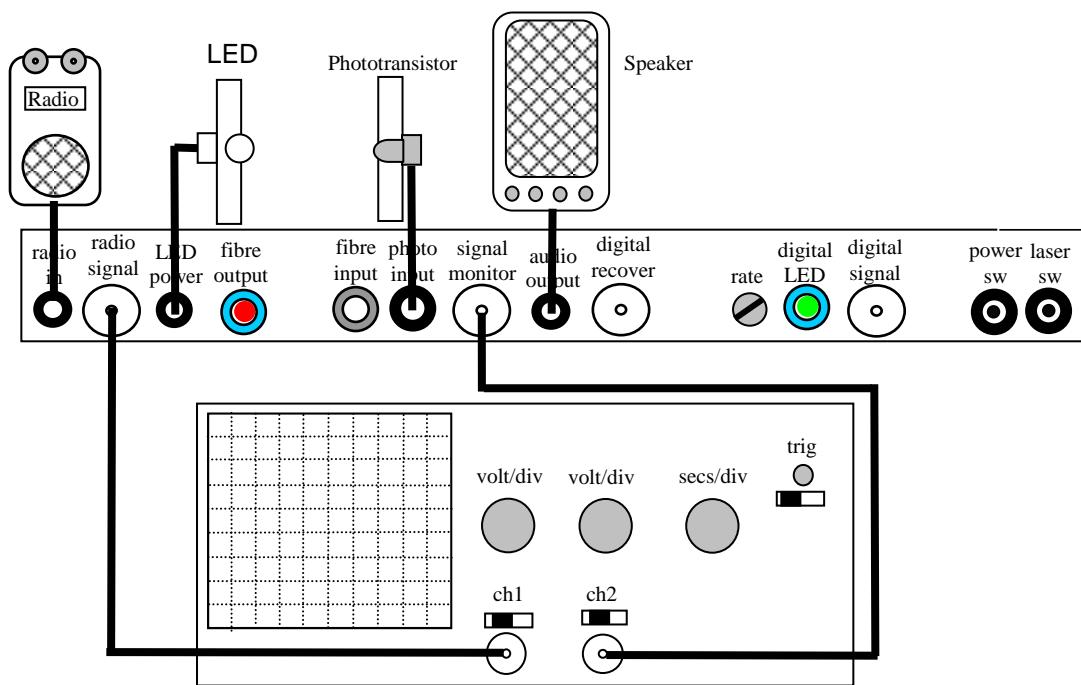


Figure 2.8.4 Analog free space modulation

Tune in the radio station and display the signal on the oscilloscope. Try VOLTS/DIV on 0.5volts/div and SECS/DIV on 5msecs/div.

To display the Phototransistor signal move the DC-GND-AC slider to AC. This blocks the DC voltage and allows the VOLTS/DIV setting to be increased to display the signal.

Use the lenses and mirrors to send the signal as far as possible. Describe how the link works. Occasionally free space laser communication links are used. What kind of problems would these links experience?

2.9 Optical Fibre Basics and Analog Modulation

Introduction

Analog modulation is a signal changing in level and frequency on a continual basis. This occurs when a microphone or telephone is used with sound waves being converted into electrical signals.

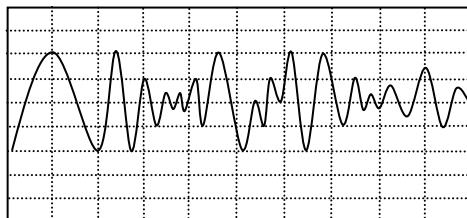


Figure 2.9.1 Analog modulation

The analog transmitter is a LED that emits an unchanging light intensity. A LED normally emits an unchanging light level or a steady signal. The signal has to be modulated by using the audio output from a radio to change the light levels slightly.

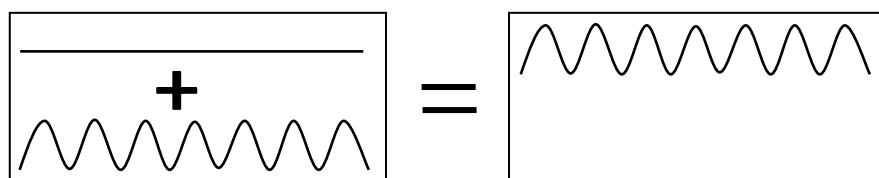


Figure 2.9.2 Audio signal added to the DC voltage driving the LED. The result is an analog signal with a DC offset.

The detector is a phototransistor that converts the light into electrical signals that can be seen on the oscilloscope and heard through the amplifier.

Optical fibres are the main links for global communications and formed the basis of the modern Photonics industry.

Optical fibre is now being used to provide direct links into households to carry broadband communications. These links can provide many direct and interactive digital video and data channels.

There are many types of optical fibre. This experiment uses polymer fibre with a core diameter of 1000 microns (1mm). Long distance communication grade fibre is made of very pure silica and has a core diameter of 5 microns or less, about the same size as a human hair.

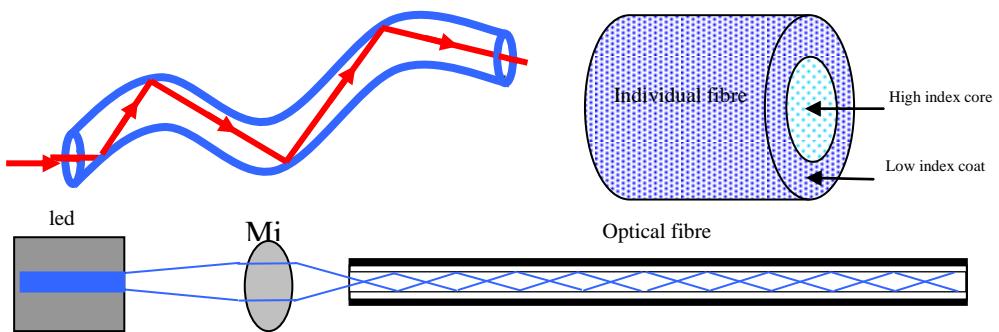


Figure 2.9.3 Optical fibre structure and total internal reflection

Light has to be launched into a fibre. Communication fibre uses lasers but for local networks light-emitting diodes may be used.

Light travels through the fibre by total internal reflection bouncing off the interface between the core and cladding. The cladding must have a lower refractive index compared to the core.

The light signal has to be detected by a sensor and a photodiode or phototransistor may be used to recover the original signal. These devices are similar to a solar cell and convert light into an electrical signal.

Aims

To demonstrate analog modulation
Transmission of an analog signal through a polymer optical fibre

Equipment

	Optical Bench		Radio		Optical Fibre
	Oscilloscope & BNC leads		Speaker or earphone		3.5-3.5mm stereo lead

Activity

Construct a fibre audio link based on analog modulation by reference to figure 2.9.4

An oscilloscope is useful to visualise the waveforms.

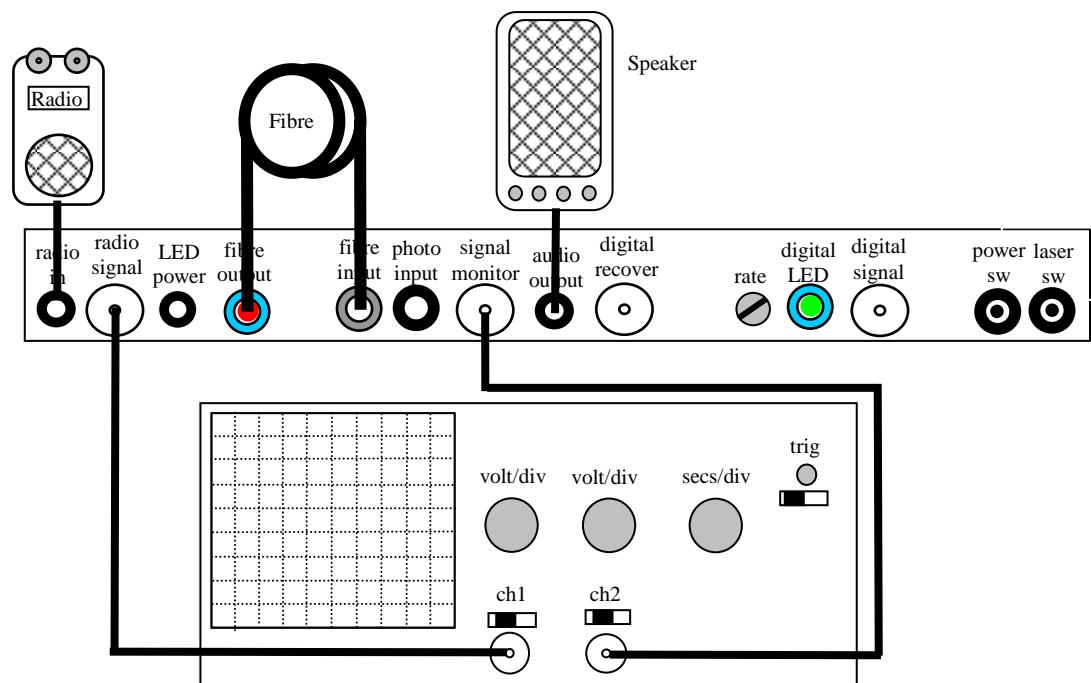


Figure 2.9.4 Analog modulation

Tune in the radio station and display the signal on the oscilloscope. Try VOLTS/DIV on 0.5volts/div and SECS/DIV on 5msecs/div.

To display the Phototransistor signal move the DC-GND-AC slider to AC. This blocks the DC voltage and allows the VOLTS/DIV setting to be increased to display the signal.

The phototransistor detector in the optical fibre receiver can be overloaded with light; causing the signal to break up.

Describe how this link works and try to think of the advantages in using optical fibre, rather than a free space link.

2.10 Optical Fibre Basics and Digital Modulation

Introduction

Fibre optic communication is usually based on digital signals.

Light travels through an optical fibre by total internal reflection. Digital pulses of light based on a binary code are normally used to send information through optical fibres. As the pulses of light travel through the fibre they tend to spread out and may eventually overlap. If this occurs the signal becomes corrupted and the information is lost.



Figure 2.10.1 Digital signal showing pulse spreading.

There are two main types of dispersion. Modal dispersion occurs because the light travels through the fibre by total internal reflection and can take different paths.



Figure 2.10.2 Modal dispersion in an optical fibre

Figure 2.10.2 shows the paths of two light rays through a length of fibre.

If each light ray travels at the same speed which one will arrive at the exit of the fibre first?

Aims

To demonstrate digital modulation
Calculation of bit rates
Observe digital signal restoration

Equipment

	Optical Bench		Oscilloscope & BNC leads		Optical Fibre
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Activity

Place a fibre in the digital LED socket and adjust the rate control, figure 2.10.3

Observe the light output from the end of the fibre.

Connect the other end of the fibre to the black fibre input socket and connect the oscilloscope to the BNC sockets near the digital LED fibre input socket.

As a guide oscilloscope settings should be VOLT/DIV 5Volts/div, SECS/DIV 10msecs/div, TRIGGER Auto and on channel 1, AC-GND-DC slider control on dc. It may be necessary to turn the Trigger Level control. Adjust the rate control and oscilloscope settings to display a digital waveform.

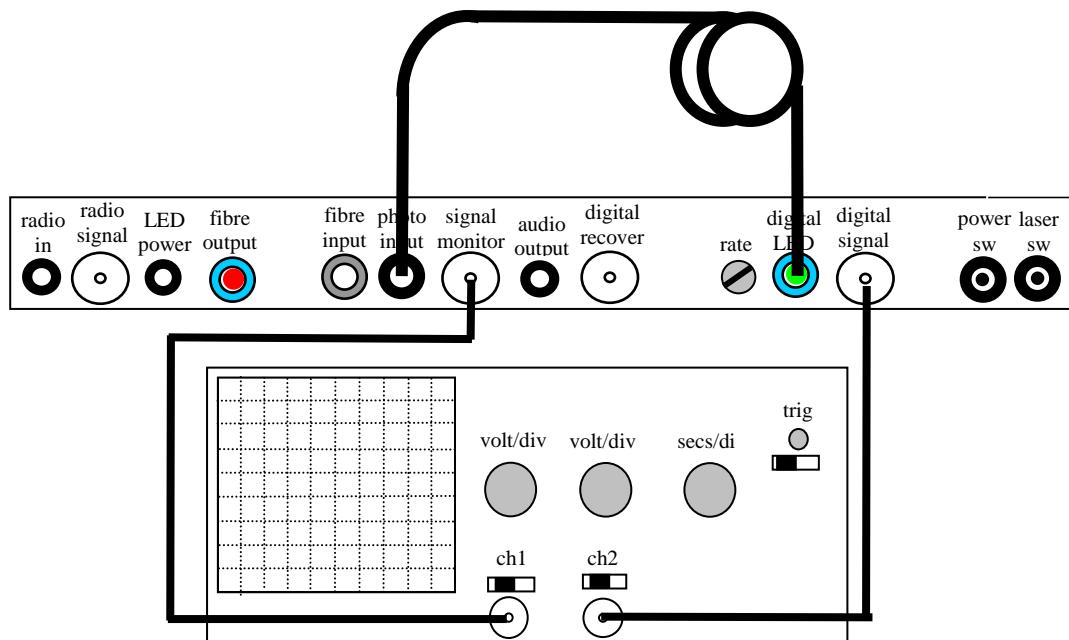


Figure 2.10.3 Connecting the oscilloscope

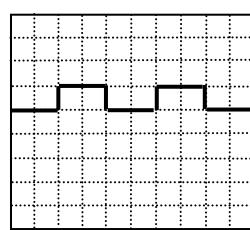


Figure 2.10.4 Calculating bit rate

Start with the rate control quite slow and calculate the number of bits per second from the screen. Note that each horizontal division on the screen corresponds to the setting on the secs/div control. On Off counts as two bits!

Turn the rate control to maximum. Adjust the sec/div control on the oscilloscope until the pulses appear.

Calculate the maximum bit rate available from the digital LED

Internet radio needs about 20,000 bits/sec and a CD player operates at 44,000 bits/sec

Which of these services could our transmitter support?

Try the longer lengths of fibre and investigate how the signal from the digital LED changes.

The pulses coming into photo-input are detected by a phototransistor without any amplification. Change the oscilloscope connection from signal monitor to digital recover. The circuit has an amplifier and a device to restore the shape of a digital pulse. Note how the signal changes.

The polymer fibre has many pathways available for the light to travel and is called multimode fibre. These fibres are only used for relatively short fibre links whereas especially designed single mode fibre with a very small core diameter (5 microns or less) is used for long distance communications.

Material or chromatic dispersion occurs because light of different wavelengths or colours travels at different velocities through the fibre. A white light source has a very broad range of wavelengths so would be most unsuitable for signal transmission in optical fibre.

Lasers have extremely narrow spectral widths and appear to have a single colour output and are ideally suited to data transmission. However chromatic dispersion still occurs with these devices.

How does dispersion affect the potential rate of signal transmission?

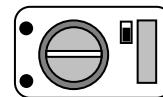
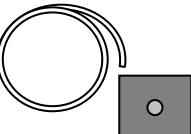
Why might it be important to restore the shape and strength of a digital pulse in a communication network?

2.11 The Inverse Square Law

Aims

To investigate the inverse square law and provide a calibration curve for the optical fibre detector.

Equipment

	Optical bench		Optical Mounts		BNC-4mm Lead
	Meter		Optical Fibre & Holder		Phototransistor

Activity

Set up the optical fibre and the Phototransistor on the optical bench as shown in figure 2.11.1. The Phototransistor is a device that converts light into an electrical signal. This signal is monitored and measured using a meter.

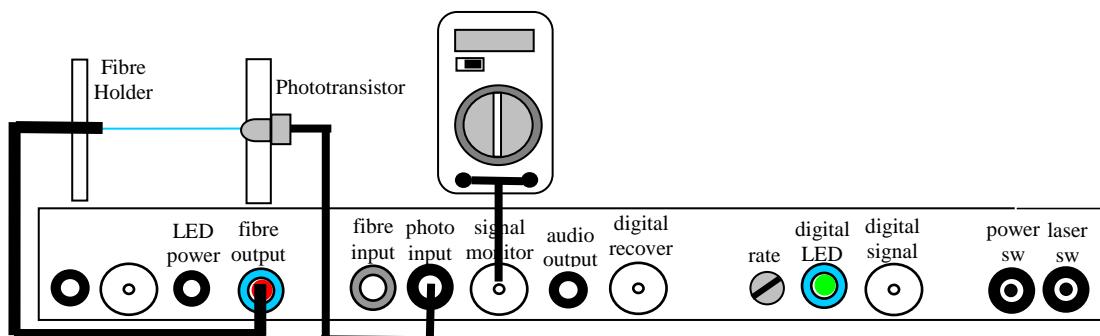


Figure 2.11.1 Measuring light intensity changes with distance

Connect the BNC socket for the Photodiode signal monitor to the meter. Set the meter to DC volts. Point the fibre towards the Photodiode and register a signal on the meter. Systematically measure how the light output of the fibre changes with distance.

The digital LED can also be used on a high flash rate.

Ideally measurements should be taken in a completely dark area to eliminate background light. The effect of background light can however be subtracted from the readings.

Plot the results on a graph with light intensity as the vertical axis and distance as the horizontal axis.

How does the light output from the fibre vary with distance?

The inverse square law states that the illumination of a surface by a point source is inversely proportional to the square of the distance between the source and surface.

$$I = \frac{I_s}{d^2} \quad I = \text{Measured Intensity} \quad d = \text{source-detector distance} \quad I_s = \text{Source Intensity}$$

Use the source intensity I_s to calculate and plot light intensities at distances similar to those measured earlier.

Compare this graph to measured results and explain the significance for the design of fibre optic sensors based on reflection.

2.12 Launching Light into Optical Fibre

Introduction

Light from a LED or a laser has to be guided or coupled into the fibre. A lens is often used and chosen to collect all the light from the LED and to focus it into the fibre at the correct launch angle so all the light can travel through the fibre as shown in Figure 2.12.1 If the angle is too sharp light will be lost into the cladding of the fibre.

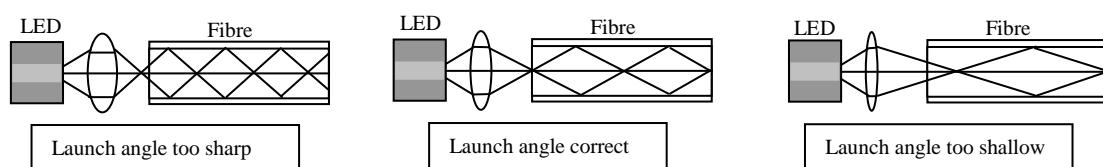


Figure 2.12.1 Light focused into a fibre.

This is known as coupling efficiency and is especially important in long distance fibres with core diameters less than 5 microns.

The Numerical Aperture (NA) is a measure of how much light can be collected by an optical system such as an optical fibre or a microscope lens.

The NA is related to the acceptance angle θ_a , which indicates the size of a cone of light that can be accepted by the fibre.

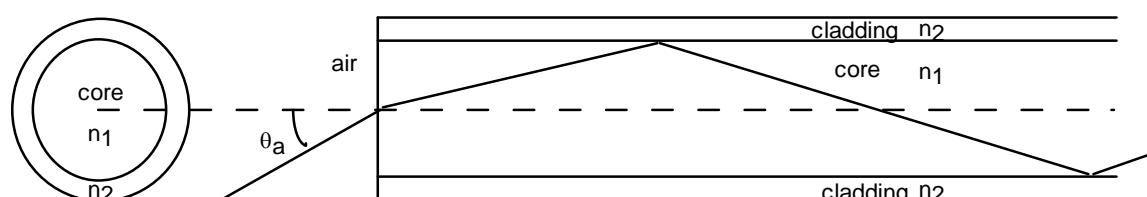


Figure 2.12.2 Acceptance angle of an optical fibre

Both numerical aperture and acceptance angle are linked to the refractive index via:

$$NA = n_a \sin \theta_a = (n_1^2 - n_2^2)^{1/2}$$

Where n_1 = refractive index of core
 n_2 = refractive index of cladding
 n_a = refractive index of air (1.00)

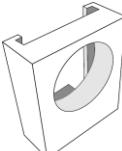
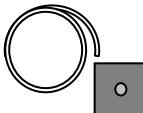
The Minilab II is supplied with polymer multimode fibre with a core diameter of 1000 microns or 1mm. One way of measuring the NA of this fibre is to fill the fibre with light and measure the characteristics of the light leaving the fibre.

Aims

To measure the acceptance angle of an optical fibre

Calculate the numerical aperture

Equipment

	Optical Bench		Optical Mounts	Ruler
	Optical fibre and holder		Imaging screen	Protractor

Activity

Plug the fibre into the fibre output or digital LED output and position the components on the optical bench as shown in figure 2.12.3

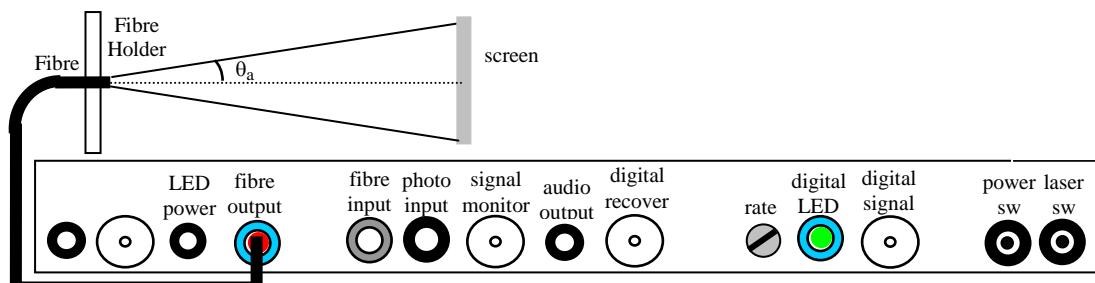


Figure 2.12.3 Measuring numerical aperture

The fibre output is a cone of light that spreads out wider as the distance from the fibre exit increases. The grid slide or screen and ruler can be used to measure diameters. The edges of the cone of light may appear fuzzy so there will be an error introduced into your measurements.

Measurement of the edges is an approximation to the notion of Full Width Half Maximum (FWHM). This is how light boundaries are characterised as shown in figure 2.12.4

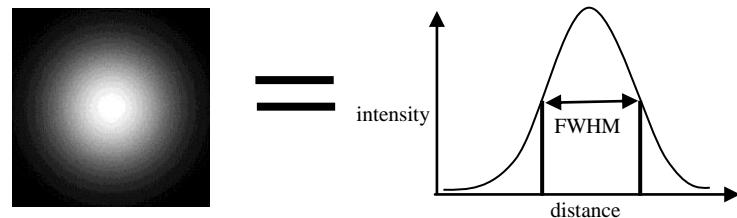


Figure 2.12.4 Optical pattern of a LED showing the FWHM points

Measure distance and spot diameter for several different distances and plot the results on graph paper to scale.

Measure the acceptance (emission) angle and calculate the numerical aperture.

The LED light source for the fibre has a lens incorporated into the design to match the numerical aperture of the fibre.

2.13 Optical Fibre Sensors

Introduction

Optical fibre sensors are extensively used in industry and have the advantage that the electronics can be housed well away from the sensor area.

One type of sensor uses an illuminating and receiver fibre bundled together. The receiver fibre needs to pick up light reflected or diffused from a surface.

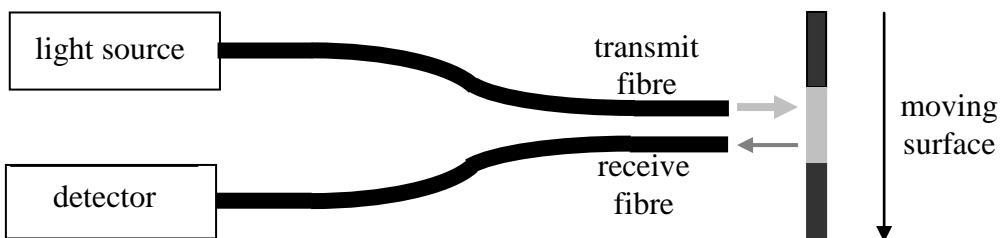


Figure 2.13.1 Sensor detecting changes in reflectivity of a moving surface

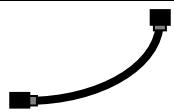
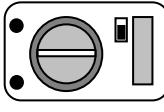
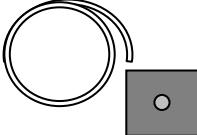
The sensor can be used in a digital way to detect objects travelling along a conveyor belt or the rotation of fan blades.

An alternative use is through the analog mode in which a change in light intensity is recorded. This could be in response to a changing level of fluid in a tank or a change in the turbidity of a liquid or gas.

Aims

To investigate how a simple optical fibre sensor works

Equipment

	Optical bench		Optical Mounts		BNC-4mm Lead
	Meter		Optical Fibres & Holders		Card

Activity

Set up the components as shown in figure 2.13.2 Use the analog or digital fibre input and output. Place a piece of white card near the end of the illuminating and receiver fibres and set the meter to DC volts

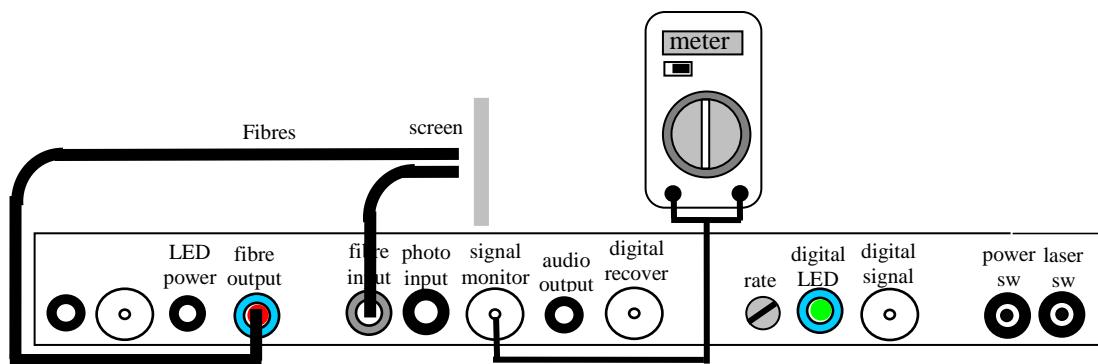


Figure 2.13.2 Simple reflective optical fibre sensor

Comment on the strength of the signal as the distance to the card and angle of the fibres is changed.

For a sensor used to detect the distance from a reflective surface a calibration curve is necessary. The output from any light source changes with distance.

2.14 Light Intensity in Fibres

Introduction

The power drops off with distance travelled by light in optical fibres. In this case signal loss or attenuation is measured in decibels. Decibels are based on a logarithmic scale and is the relationship between the input and output power.

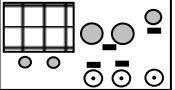
$$\text{Decibels} = 10 \log \left(\frac{\text{Power}_{\text{out}}}{\text{Power}_{\text{in}}} \right)$$

Loss in decibels	Fraction of power remaining	Physical comparison
0.2	0.95	Loss undetectable by the eye
1.0	0.79	Reflection from a light surface
3.0	0.5	50% loss of light
10	0.1	Reflection from a dark surface
20	0.01	1% of light left
30	0.001	0.1% of light left

Aims

To measure the loss of light power through a fibre

Equipment

	Optical bench		Optical Mounts
	Oscilloscope & BNC leads		Optical Fibres and Holders

Activity

Place the short piece of fibre to link the digital transmitter and detector and connect in the oscilloscope as shown in figure 2.14.1

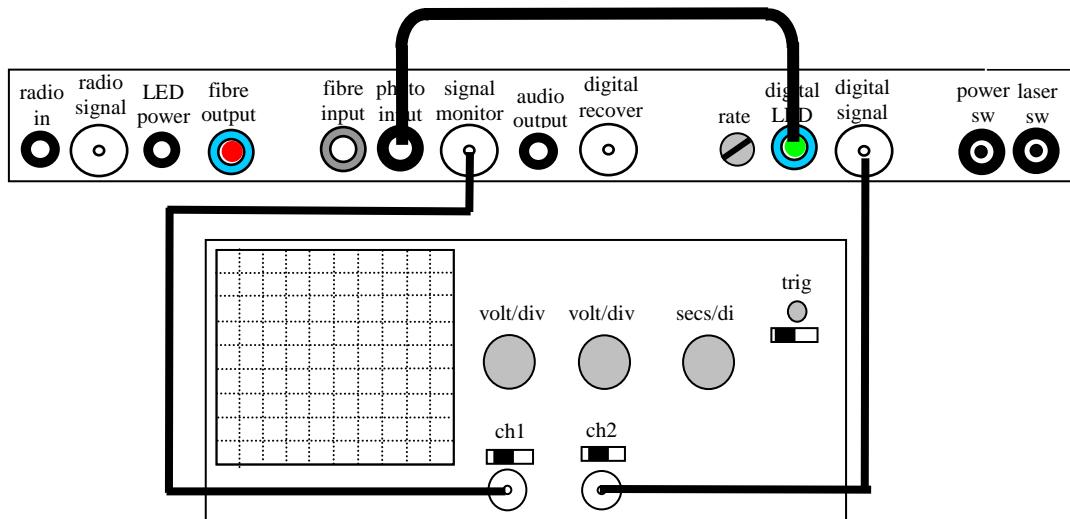


Figure 2.14.1 Measurement of light transmission through a fibre

Measure the voltage of the output signal. To do this turn up the volts/div control until the photodiode signal resembles figure 2.14.2 and fills the oscilloscope screen.



Figure 2.14.2 Voltage levels. Each vertical division corresponds to the volts/div setting.

Measure the length of the long piece of fibre. Connect up the long length of fibre and measure the new photodiode signal level.

Assume the signal level through the short length is the original power and so calculate signal loss in decibels per kilometre based on the measurement through the length of fibre.

Modern communication fibre has a loss approaching 0.2dB per kilometre

A 20dB loss in light levels in a fibre is acceptable but at this point the signal has to be amplified. Communication fibre with a 0.2dB loss per kilometre can carry a signal $20/0.2 = 200$ km before an amplifier is needed.

How far would the polymer fibre carry a signal before the 20dB loss level is reached?

Extra activity

If the oscilloscope is connected to digital recover the effect of signal restoration can be observed. The circuit contains an integrated circuit that can restore the signal to its original form or voltage level. This is one way to compensate for digital signal loss in a communications network.

2.15 Fibre Splices and Coupling

Introduction

Fibres often have to be joined together to connect different circuits, repair breaks or connect in optical amplifiers and lasers. This is known as splicing and various methods are available.

The best method is to weld the ends together using a device known as a fusion splicer. This machine melts, positions and welds the ends of fibre to each other.

A temporary splice is made by holding the fibre ends close together and surrounding the join with a special fluid to guide light from one fibre to the next.

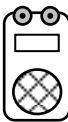
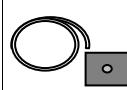
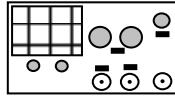
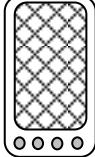
Polymer fibre and some thicker glass fibre fit into end plugs that clip together.

Aims

To produce a simple splice

To couple light between two fibres using convex lenses

Equipment

	Optical Bench		Radio		Lenses		Optical Fibre and holders
	Oscilloscope & BNC leads		Speaker or earphone		3.5-3.5mm lead		

Activity

To investigate the effect on the signal of splices obtain two lengths of fibre. Plug in a short length between a LED fibre emitter and fibre input and measure signal strength using the oscilloscope. To connect another fibre lay the ends next to each other and use a piece of adhesive tape as shown in figure 2.15.1



Figure 2.15.1 Spliced lengths of polymer fibre

Splice together two lengths of optical fibre and note any change in signal strength.

Figure 2.15.2 provides an additional exercise in transferring light between fibres. Use the two 150mm convex lenses and the fibre holders.

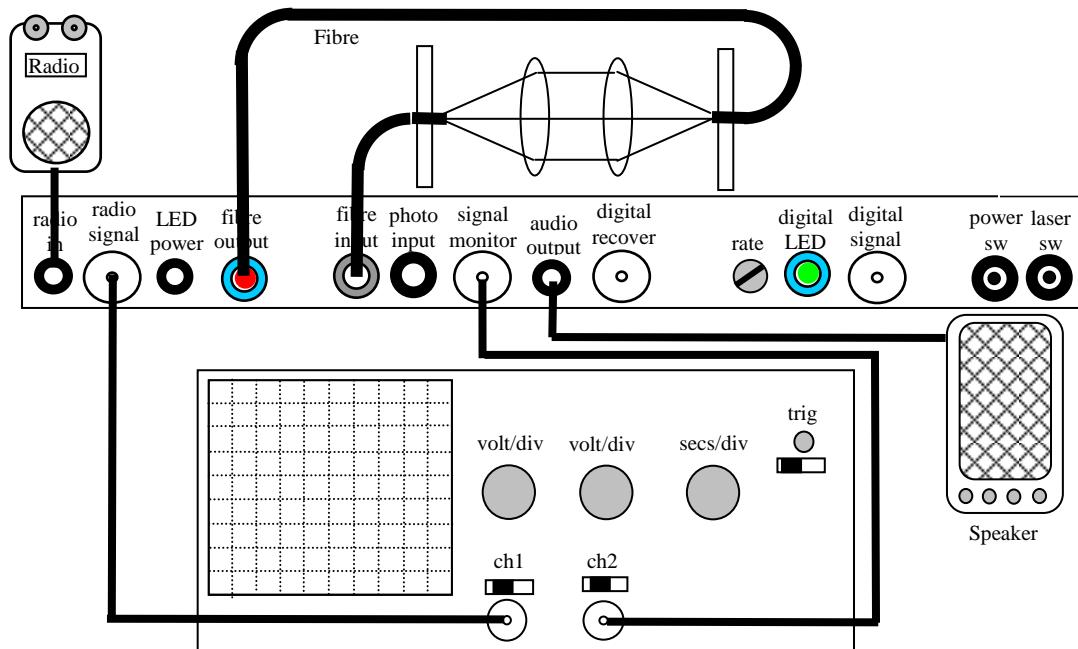


Figure 2.15.2 Building a fibre coupling link.

Explain how the distance between the fibres and lenses was determined for optimal response.

2.16 Signal Multiplexing

Introduction

Signal multiplexing is when more than one signal can be carried on an optical fibre (or wire). For optical fibres the correct term is Wavelength Division Multiplexing. Figure 2.16.1 shows three different wavelengths being combined and carried on the same fibre.

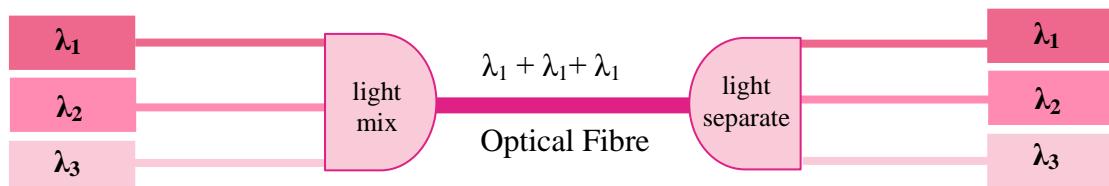


Figure 12.16.1 Wavelength Division Multiplexing WDM

The light is normally in the infrared and the wavelengths are very close to each other. This means that many light channels can be carried along the same fibre. The light signals do not interfere with each other and each wavelength can be separately recovered using filters 2.16.2 that only allow a single wavelength through.

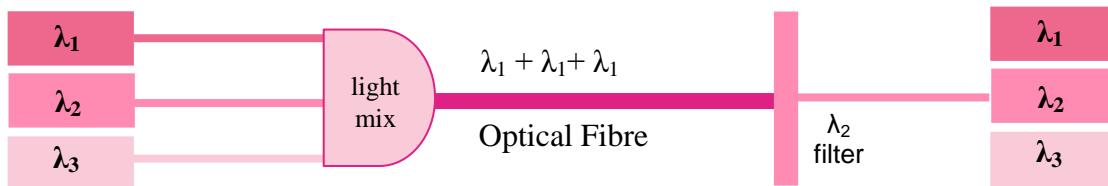


Figure 2.16.2 Optical filter only allows one wavelength through

A diffraction grating bends light according to its wavelength. Figure 2.16.3 shows the three different wavelengths being bent different amounts. A series of detectors can be placed to detect each signal. The gratings can be fabricated into a length of fibre; making it easier to extract the signals.

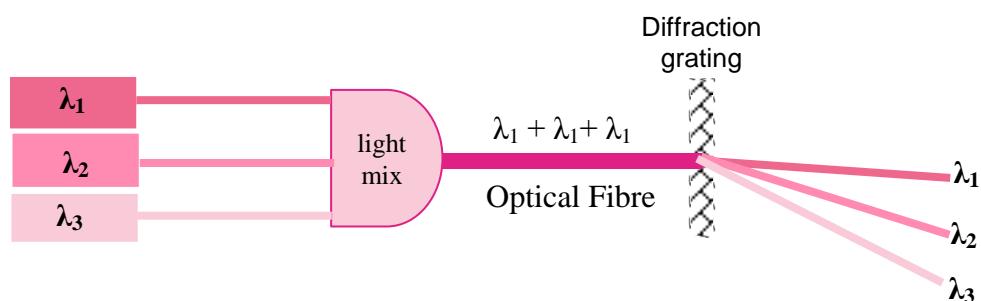


Figure 2.16.3 A diffraction grating separates different wavelengths of light

Aims

Demonstration of multiplexing using a polymer fibre and signal extraction using a filter.

Equipment

	Optical Bench		Radio		Lenses		Optical Fibre and holders
	Fibre Coupler Perspex & filters		Speaker or earphone		3.5- 3.5mm lead		

Activity

Connect the radio to its input. Use the coupler to connect the red LED output and the green LED (digital) output to each other. The light emerging from one of the arms should be a mixture of red and green.



Figure 2.16.4 Fibre coupler and splitter.

Connect the output of the coupler to the fibre input and adjust the frequency of the digital output to a suitable audio frequency.

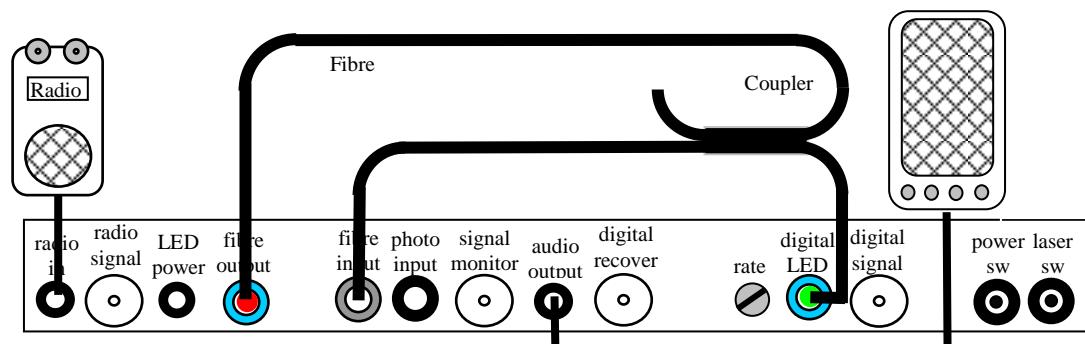


Figure 2.16.5 Listening to both multiplexed signals

Both signals should be audible. To select just one of the signals use the single fibre Perspex coupler and a red or green filter. Insert a small piece of filter into the slot as shown in figure 2.16.5. Another short length of fibre will be required to connect the Perspex coupler to the fibre input.

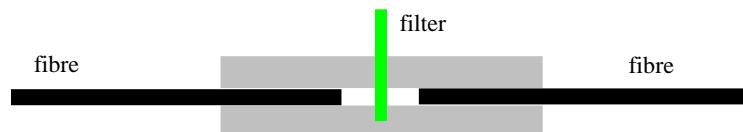


Figure 2.16.5 fibre coupler and filter

How effective are the red and green filters at selecting a signal?

Consider the results from the absorption spectroscopy to assist in the explanation.

Extra Activity

Work with another group and design a multiplex link carrying two audio and two digital channels between the two Minilabs.