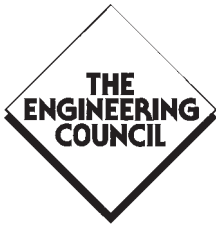


OPTICAL SYSTEMS

VERSION 1



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Text by John Cave

Layout by Diane Gliddon

Line illustrations by James Wilkinson

Series Editor

John Cave
Middlesex University

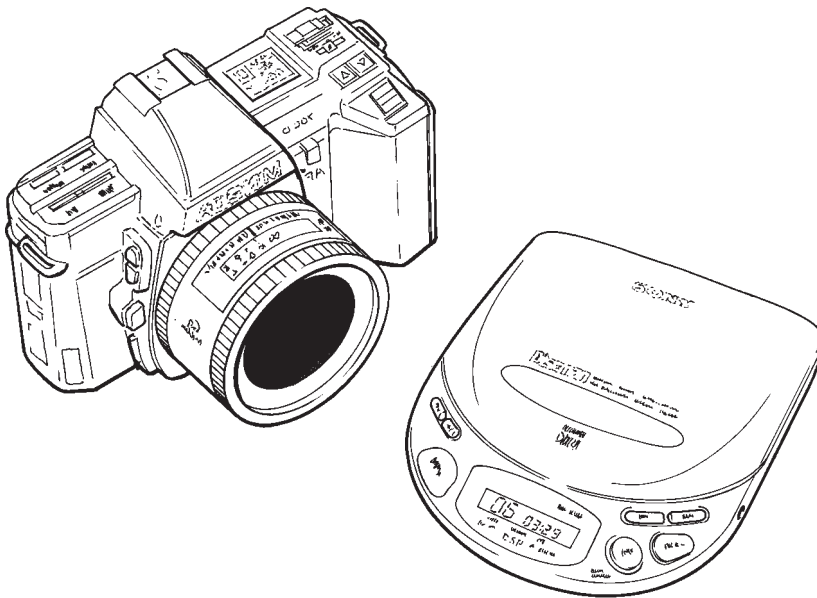
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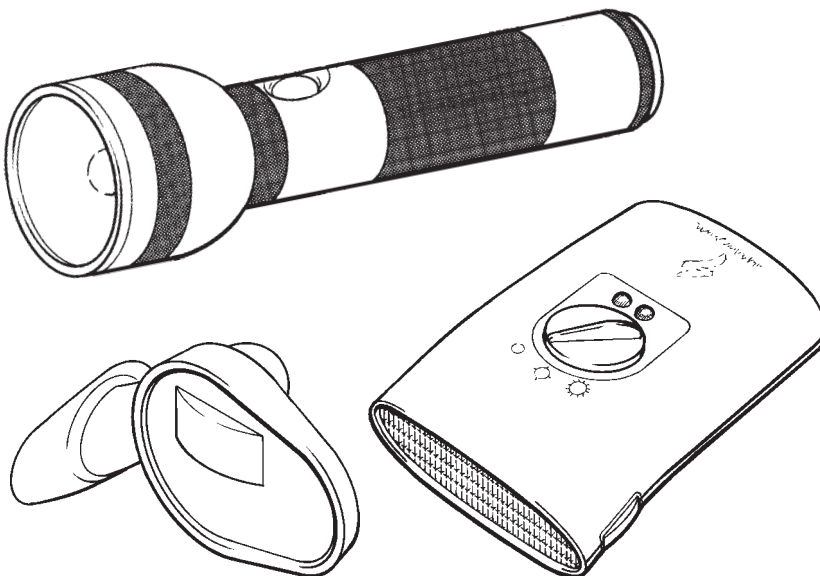
OPTICAL SYSTEMS

INTRODUCTION

“Optics” is an important branch of physics and optical principles are used in a wide-range of products and systems. These include, for example, measuring instruments, cameras, machine tools, video cameras, CD players - as well as entire advanced communication systems.



A whole range of much simpler consumer products such as hand magnifiers, bicycle lamps, torches, mirrors and even party toys also use optical components. And if these are to work properly, their designers need to know something about basic optical principles.

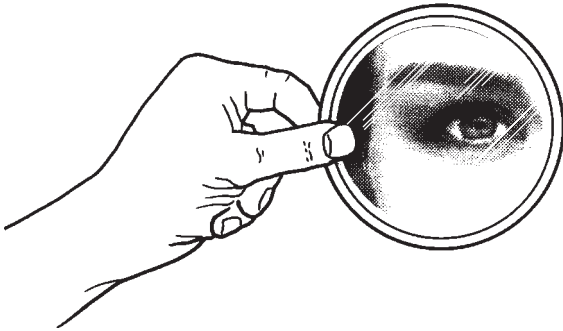


This book is divided into four sections each of which opens with a brief explanation of how optical devices “work”. Each section then goes on to examine possible applications for them and to suggest design and make opportunities for optical products and systems.

SECTION 1

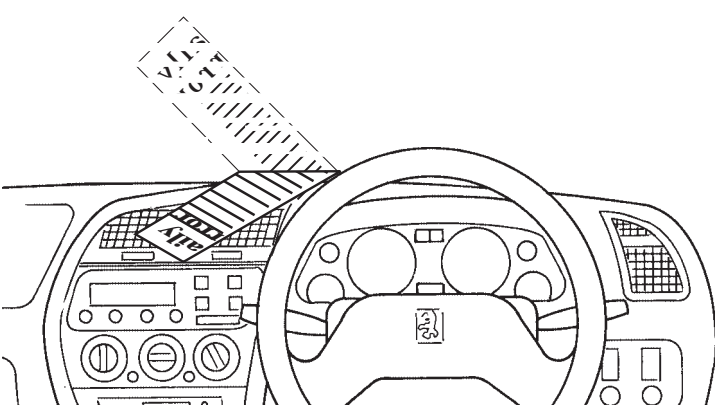
Mirrors & reflectors

Mirrors are probably the most familiar optical devices because they are used by most people everyday. Mirrors are also employed, for example, in astronomy as components of very complex and precise telescopes and in high temperature furnaces where the sun’s energy is focused onto a very small area. We also have the common expression “its all done with mirrors” because mirrors can be used for so many special effects..



Mirrors and reflected light

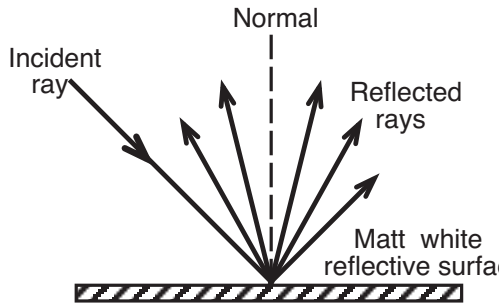
When light falls on a surface, some of it will be reflected. The amount of reflected light depends on the surface. Hardly any light will be reflected from a matt black surface. (For this reason, the inside of optical instruments is painted matt black to avoid unwanted reflections.)



Technical fact
Plain glass is sometimes used to see through and reflect at the same time. Something left on the dashboard of a car can often be seen as an unwanted reflection in the windscreen. Although a nuisance in cars, this principle is used in aircraft to project information to a canopy or visor so that the pilot does not have to look away. This kind of projection is called a head-up display.

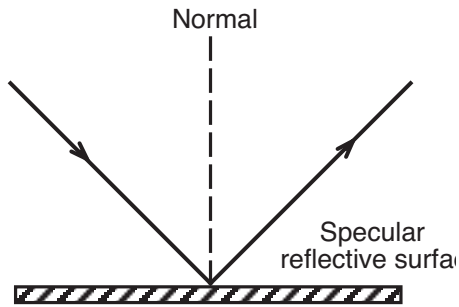
Diffuse reflection

A white non-shiny surface reflects light but will *scatter* it in different directions. Ordinary blotting paper or paper tissues are good examples of *diffuse* reflectors.



Specular reflection

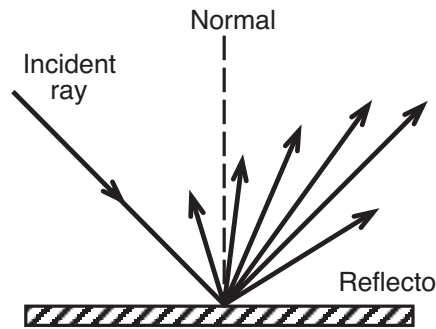
A polished shiny surface is described as a *specular reflector* when it reflects light without scattering. Common mirrors are specular reflectors. A plastic mirror with a shiny aluminium surface reflects up to 95% of the light falling on it. This can be compared with other shiny materials in the table.



Material	Finish	Reflectance
Aluminium	Anodised and polished	0.70
Aluminised plastic	Specular	0.94
Stainless steel	Polished	0.60
Chromium	Plated	0.66

Mixed reflection

Sometimes a surface will reflect like a mirror as well as scatter some of the light. The polished paintwork on a car will do this. Although you may be able to see your face in it, it does not make a very good mirror. Sometimes surfaces that offer mixed reflection are a nuisance because they give unwanted *glare*.



Curious Fact:

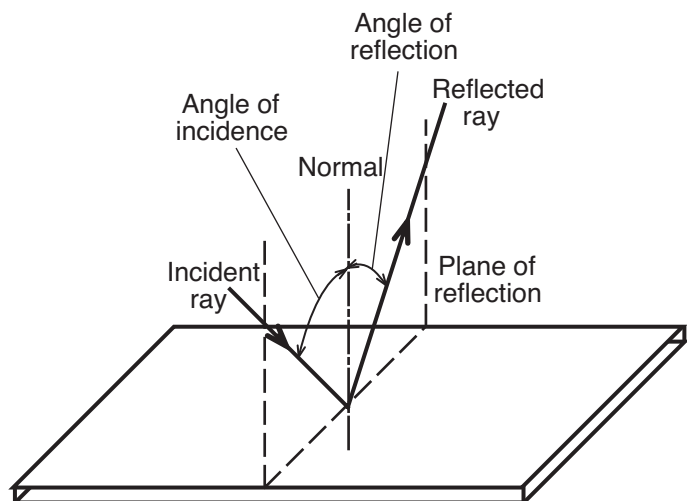
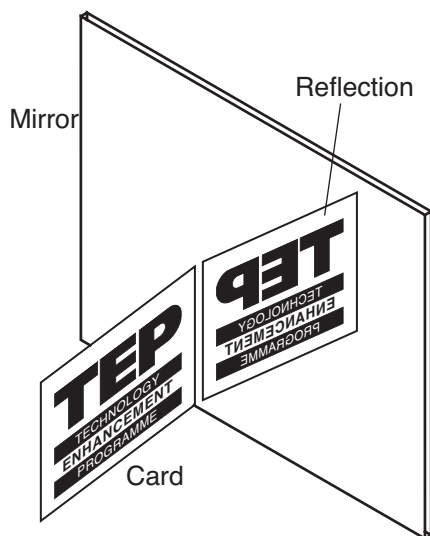
The French painter Claude sometimes painted from the image seen in a small black glass mirror. This is like viewing the reflection off a shiny black car. It helped Claude to concentrate on the main details in a scene and compose his picture. This type of mirror has since become known as a Claude glass.

Laws of reflection

For a specular reflector or mirror, there are two basic laws of reflection:

- 1. The angle of incidence of a ray is the same as the angle of reflection.**

Explanation: An imaginary line drawn at 90° to the surface of a mirror is called the *normal*. A ray of light falling on the mirror is called the *incident ray*. The angle between this incident ray and the normal is the same as the angle between the reflected ray and the normal. You can demonstrate this by holding the edge of a card or ticket against a mirror and moving it.

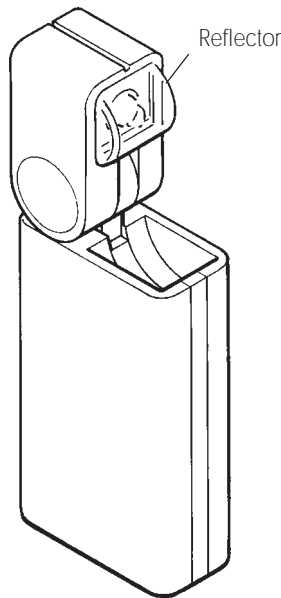


This law enables you to predict where reflected light from a mirror will fall.

2. The incident ray and the reflected ray lie in the same plane.

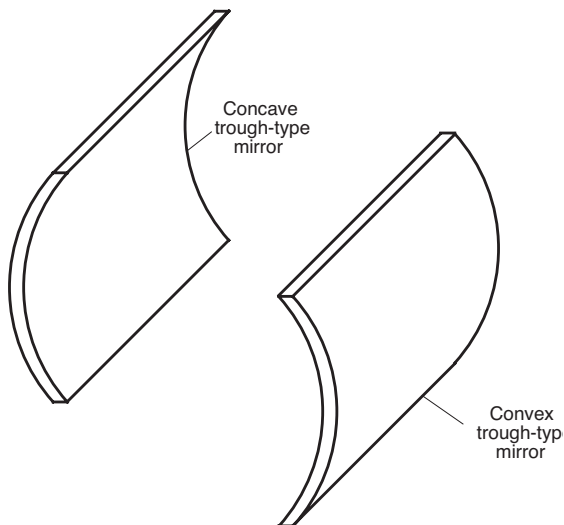
Explanation: A plane can be thought of as an imaginary flat sheet. An incident ray and its reflection lie on this flat sheet without twisting off to one side.

Most of the mirrors we use are flat but some are curved so that we can view things over a wide angle. Other non-flat mirrors are designed to reflect light in torches and other lamps

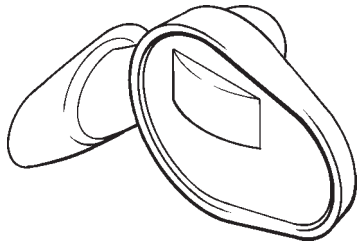


Convex and concave mirrors.

Mirrors which are bent inwards (*concave*) or outwards (*convex*) distort the reflected image and make it appear narrower or wider.



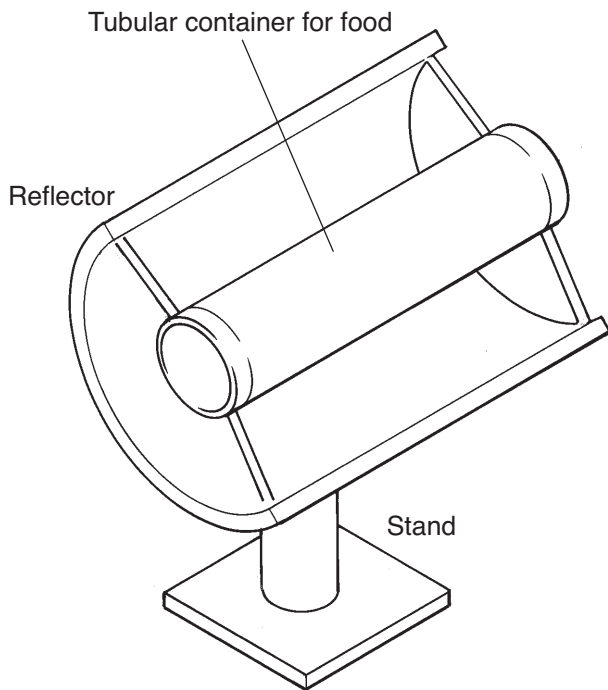
Cheaper plastic mirrors sometimes produce unwanted *distortions* for this reason. Although they distort the image, convex mirrors are widely used to give a *wide angle* of vision; examples include shop security and car mirrors. Convex mirrors give a magnified image.



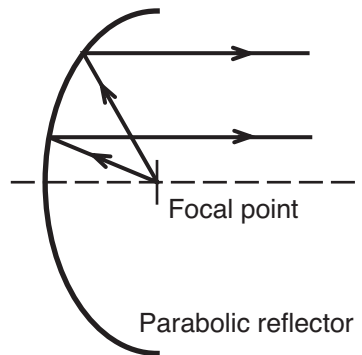
Car mirror with convex insert

Parabolic reflectors

When a light source is placed at the *focal point* of a parabolic reflector, the light is reflected back in parallel rays. This type of reflector is used in searchlights and some lighthouses to send out a powerful beam of light over a long distance. The parabolic reflector is also used, for example, in telescopes for magnifying and for concentrating the sun's rays onto a very small area to produce intense heat. Solar furnaces and solar cookers use this principle.

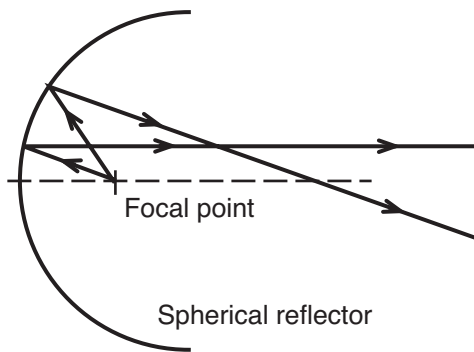


Simple solar cooker



Spherical and other curved reflectors

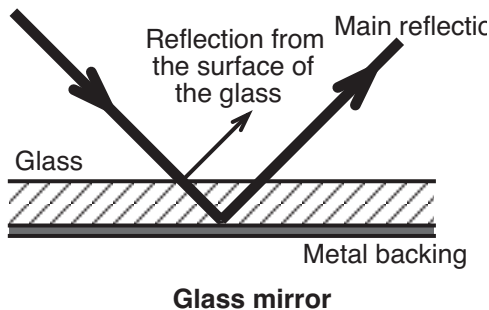
The light from a source at the focal point of a curved reflector other than a parabola will normally produce a *diverging* beam. This means the beam will open out into a form of cone. The shape of the beam will be determined by the shape of the reflector. The reflectors in cheap torches are made practically any shape that produces a conical beam. In some more expensive torches, the reflector can be moved to change the shape of the beam.



Mirror materials

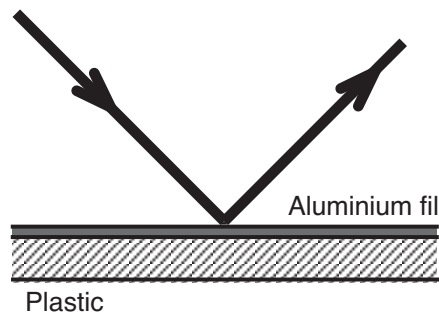
1. Glass

Most larger mirrors are made from glass with a reflective metal backing. Glass mirrors have the advantage of being very flat but they also produce two reflections - a strong one from the metal backing and a weaker one (depending on the angle of viewing) from the surface. This makes them unsuitable for many applications. Glass mirrors cannot be easily heat formed and they are usually quite fragile.



2. Metallised plastic

Rigid plastic mirrors are usually *acrylic* or *polystyrene* sheet with a thin film of *bright aluminium* deposited on the surface. Plastic mirrors are cheap and less fragile but are not always as flat as glass mirrors. A very small curve in a mirror has a large effect on the reflected image - as you can demonstrate by looking at your own face in one. Plastic mirrors are *surface* reflectors and do not give rise to double reflections like glass mirrors. Plastic mirrors are also generally cheaper.



Metallised plastic mirror

Flexible plastic mirror material is available in different gauges, but has to be bonded to a flat surface to produce a normal mirror. It is often used for special lighting or decorative effects as well as for curved reflectors in cheaper torches.

3. Metallised card.

This is card sheet with a metallised aluminium surface. It is sometimes used as a mirror in games and toys but the surface texture of the card usually shows through and distorts any reflections.

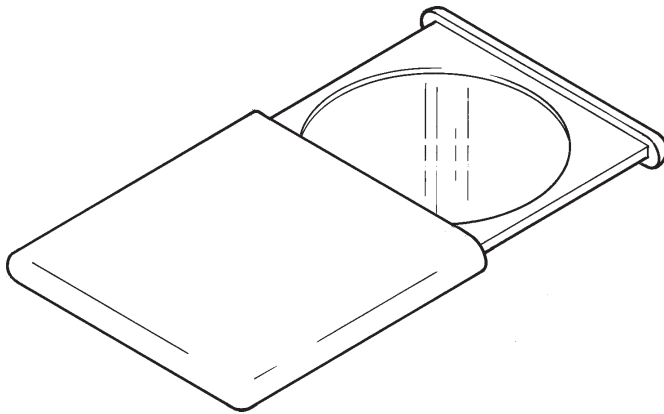
OPPORTUNITIES FOR DESIGNING AND MAKING WITH MIRRORS

Single mirror projects

There are many different uses for single mirrors enabling us to see ourselves, something behind us, or something which cannot otherwise be seen.

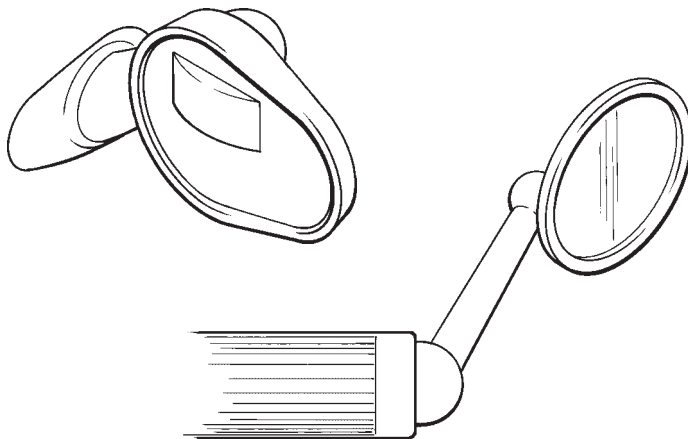
Vanity mirror

A *vanity* mirror is for personal use. Plastic mirrors normally require a container or housing to prevent the surface being scratched when not in use. Some mirrors have a hinged lid; others fit into a wallet.



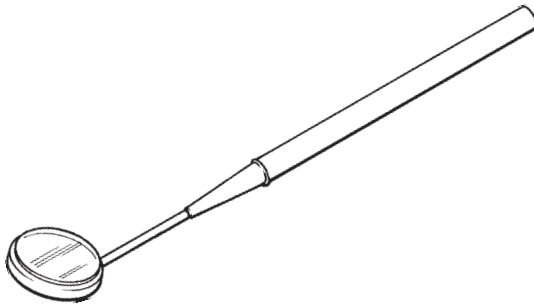
Rear-view mirror

A rear-view mirror usually needs adjustment. On cycles, there is normally a ball joint or other flexible joint that attaches the mirror to the cycle handlebars. On cars, external mirrors are often electrically driven; this could also be a useful facility for a disabled person. Some rear-view mirrors are wide-angle types which, although they distort the image, enable the viewer to see much more.



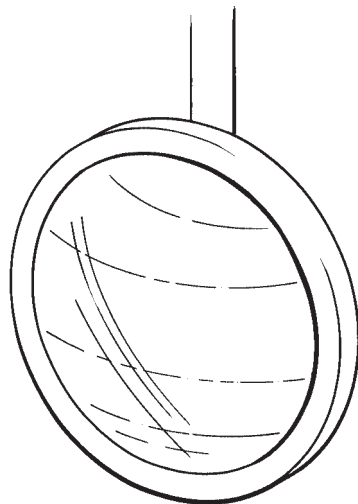
Inspection mirror

To see behind teeth, dentists use a small inspection mirror on a handle. This type of mirror is also used by those who maintain equipment such as cars or photocopiers to see into difficult places. The mirror is normally small and attached to a handle via a flexible joint.



“Spy” mirrors

Mirrors are often used in retail security to make all parts of a shop or store visible to supervisors. Mirrors are sometimes even built into spectacles to give the wearer rear vision !



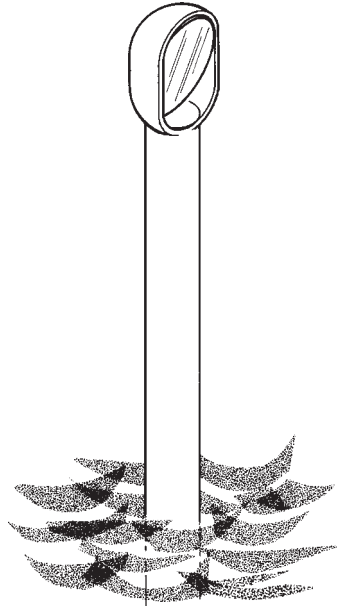
Photography and video

Mirrors are sometimes used in photography and video work to enhance lighting. Generally, though, white diffuse reflectors are used rather than specular reflectors.

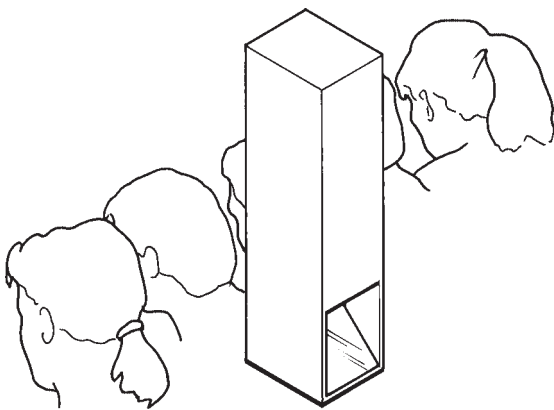
PROJECTS WITH MULTIPLE MIRRORS

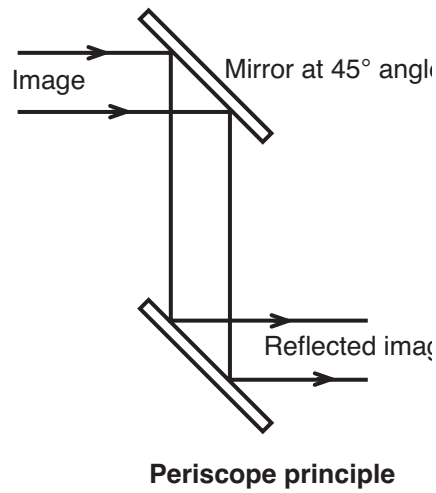
Periscope

A periscope enables you to see things over an obstacle without necessarily being seen at the same time. Periscopes used in submarines provide a view of the surface while the craft is several metres below the surface.



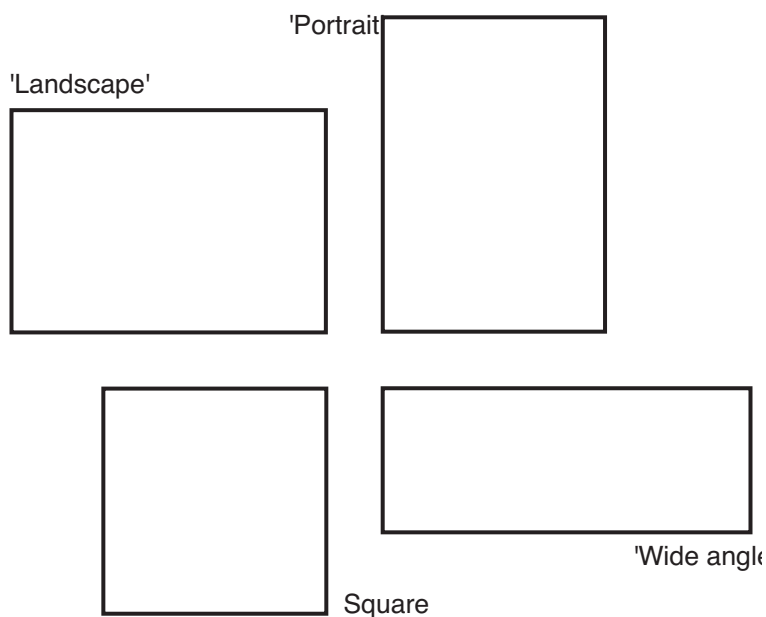
Periscopes have become popular recently for viewing public events from within a crowd of people - or for children's games. A simple periscope uses two mirrors placed at 45° to the horizontal and parallel to each other. If the angles are exactly 45° , the image in the second mirror will be exactly what would have been seen from a greater height. This is what gives rise to the very powerful illusion of seeing through solid objects when a periscope is used.





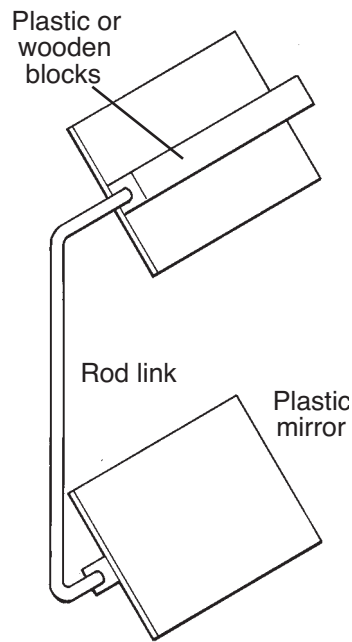
The first steps in designing and making a periscope are deciding on:

- the height advantage needed;
- the size and *aspect ratio* of the mirrors. (The aspect ratio is the proportion of width to height);
- the means of holding the mirrors. Normally, a periscope consists of a tube or box with the mirrors held at top and bottom. The inside of the tube or box is painted matt black to prevent unwanted reflections.



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Once these basic decisions are taken, a tube, frame or box construction must be designed, manufactured and the mirrors fitted accurately. Some card-construction periscopes fold flat for transit, and can be both challenging and interesting to design and make. A simple permanent rectangular box (e.g. MDF and plywood) can be easy to build but must not be too heavy. An open-frame type periscope of the type illustrated can be constructed very quickly, can be folded flat or taken apart - but may suffer from unwanted reflections.

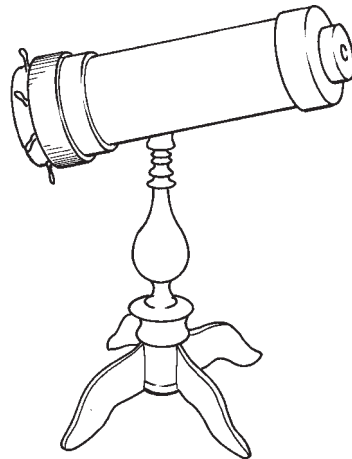


Open frame periscope

Kaleidoscope

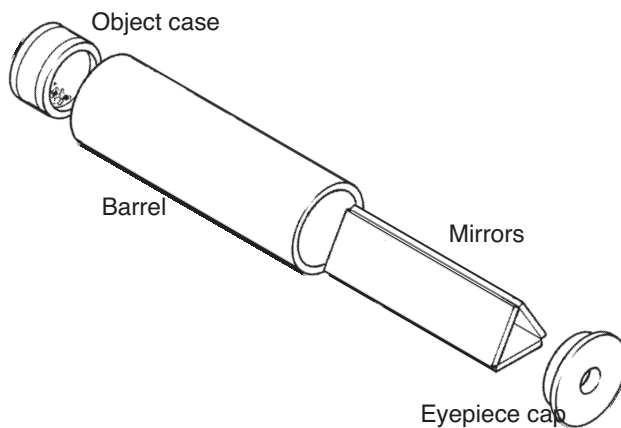
The kaleidoscope is an optical instrument which uses two or more mirrors to produce interesting and entertaining *symmetrical* patterns. It was invented by David Brewster in 1816 and caused a sensation. It was reported in 1818 that:

“.....no invention, and no work....ever produced such an effect. A universal mania for the instrument seized all classes...and every person felt that a new pleasure had been added to their existence.....”

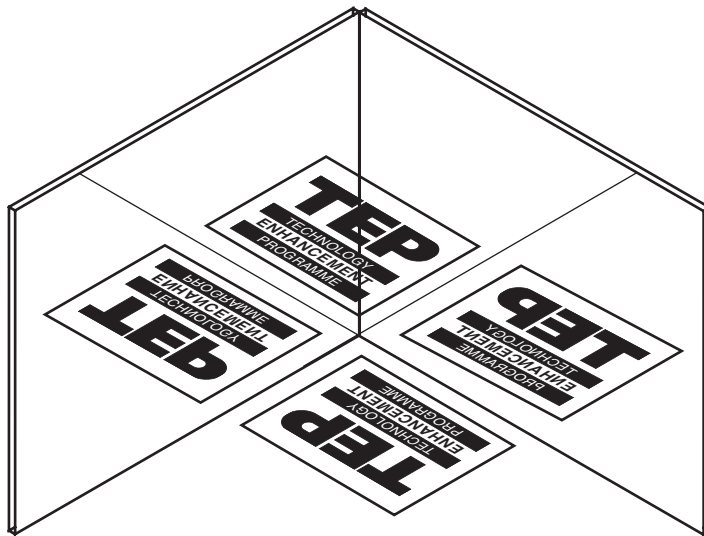


Although, kaleidoscopes fell out of fashion during the 19th century, they have been produced in vast numbers ever since as childrens' toys. Recently, however, interest in designing and making kaleidoscopes has taken off once again and there are books and societies devoted to the subject. Kaleidoscopes are once again becoming fashion accessories - sometimes very expensive ones. *With modern materials, there are unlimited opportunities for designing and making entirely original kaleidoscopes.*

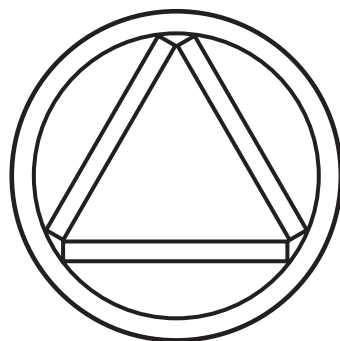
A simple kaleidoscope consists of a tube containing 2 or 3 mirrors positioned along its length. Opposite to the viewing end is an *object-case* containing small coloured objects that move around when the tube is rotated. Alternatively, the kaleidoscope is left open or has a lens at this end to project an external view into the instrument.



The kaleidoscope exploits the fact that when mirrors are positioned against each other at certain angles, reflections from the object-case or outside are passed backwards and forwards between the mirrors. This creates a fascinating symmetrical image that moves and changes as the kaleidoscope is turned. The kaleidoscope effect can be seen by holding the edges of two mirrors on a patterned surface, and changing the angle between them. (What is the best angle ?)



A kaleidoscope needs perfectly flat surface mirrors and so cheap kaleidoscopes using polished metal or flexible metallised plastic, do not work very well. Rigid plastic mirrors are very effective and three mirrors can be assembled at the correct angle of 60° by cutting them to the right width and press fitting them into a tube.



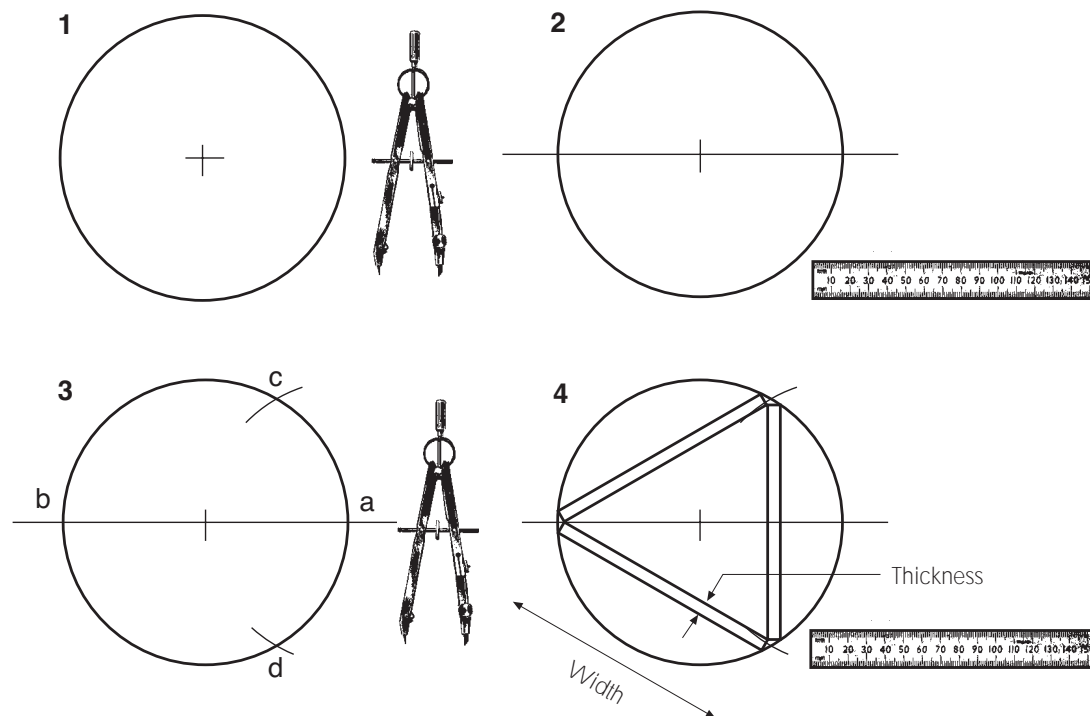
Arrangement of mirrors in kaleidoscope tube

The first steps in designing and making a kaleidoscope are deciding on:

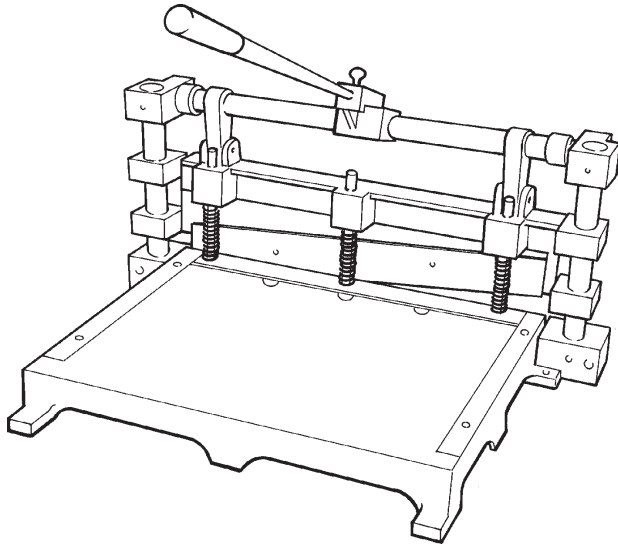
- the length and diameter of the tube. This will determine the size of the mirrors. *Although there are no hard and fast rules, most kaleidoscopes use a round-section tube whose length is between 4 to 6 times its diameter.*
- the means of generating an image - object-case, open end, lens system, or other method ?

For convenience, most kaleidoscopes use round tubing to house the mirrors. Many types of metal or plastic tubing, including plastic waste tubing, can be used. To fit a given size of tubing, the width of each of the three mirrors can be obtained using a ruler and pair of compasses.

- Step 1** Draw a circle the diameter of the inside of the tube.
- Step 2** Draw a diameter line through this circle.
- Step 3** Keeping the compasses at the same setting as for step 1, place the point at (a) and strike off two marks (c) (d).
- Step 4** Join up points (b) (c) (d).
- Step 5** Measure one side of the triangle to give the mirror width.
- Step 6** To allow the mirrors to actually fit into the tube, it is necessary as an approximate guide to subtract the thickness of each mirror from its width.



Ideally, the mirrors should be cut using a PCB guillotine. Alternatively, they can be scored and fractured. If the mirrors are found to be loose in the tube, they can be taped at the rear before insertion. Additional tape at the joins can be used as packing if necessary.



The eyepiece, which would normally be approximately 1cm in diameter, can be created by:

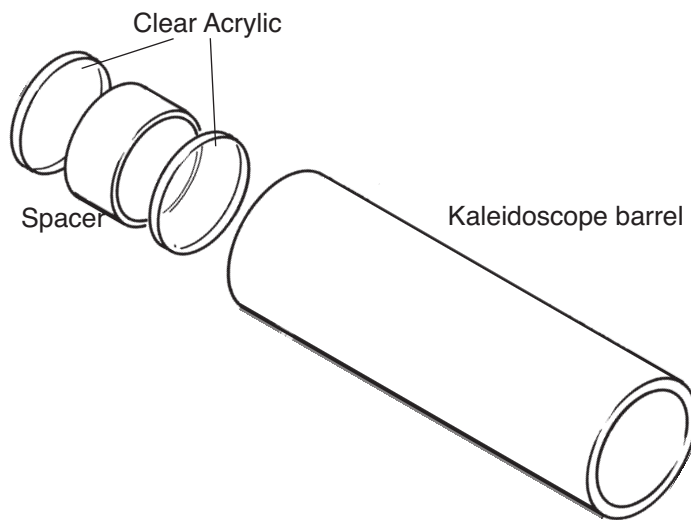
- drilling out an existing cap that fits the tubing (e.g. a cap for EMA tubing)
- turn and drill an internal or external fitting cap on the lathe



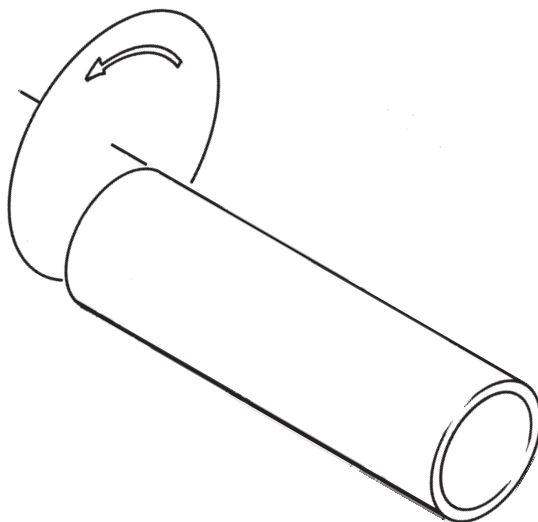
Eyepiece ca

An object case can be created in the end of the tube by:

- fitting two discs of clear acrylic or other material within the Kaleidoscope tube. These need to be separated by a spacer. The external acrylic disc should be given a frosted texture by lightly rubbing with abrasive cleaner or very fine abrasive paper.



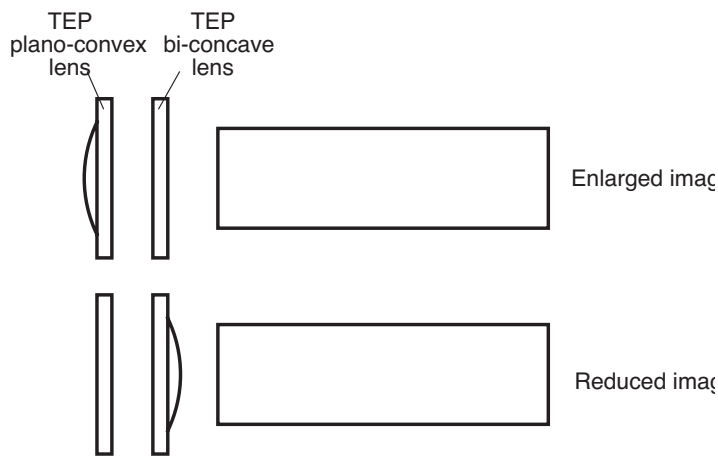
- fitting on a separate object case - which is turned from plastic or metal.



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An object case can in fact be larger than the tube and rotate independently of it. This might be manufactured from two pieces of acrylic separated by an “o” ring seal and joined together by a bolt on which they pivot.

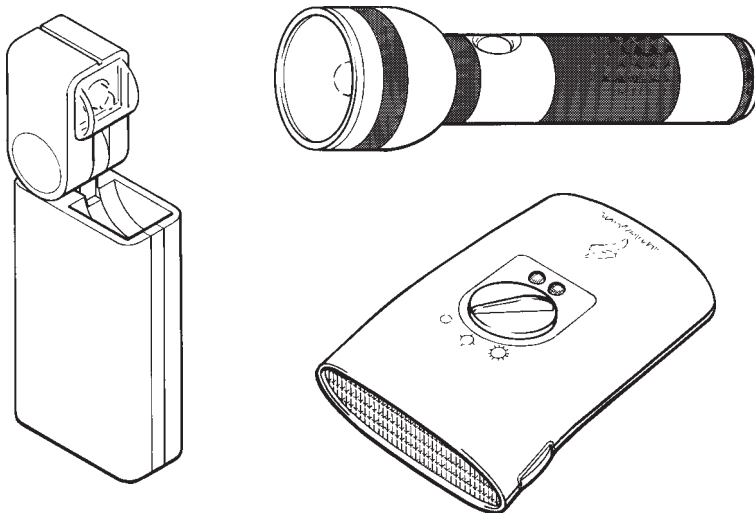
A translucent multi-coloured turning disc can also be substituted for an object case. To project an external image into the kaleidoscope, the object case end of the kaleidoscope can simply be left open. Alternatively, a lens system can be added.



Effect of positioning TEP lenses
in front of Kaleidoscope

Torches

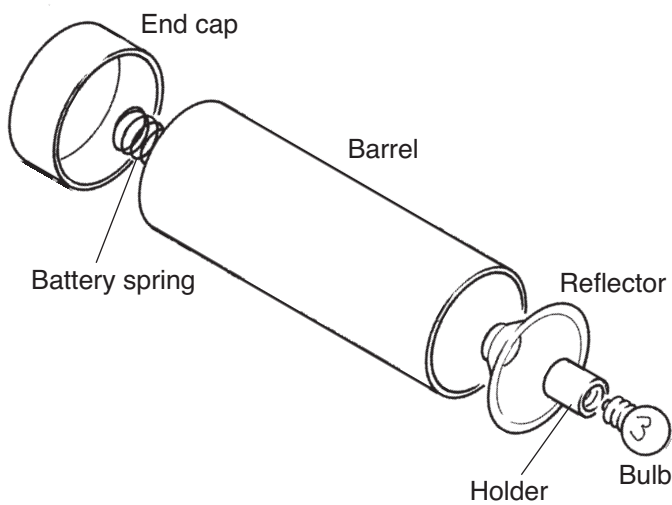
Torches are commercially available in an amazing variety of different shapes, sizes and materials. Basic constructional materials include aluminium, plastics, wood and - even paper. Styles include flip-top, swivel top, key-ring “micro” - and many more. The recent availability of new high-output miniature lamps such quartz halogen and xenon gas bulbs present many new design opportunities for the torch designer.



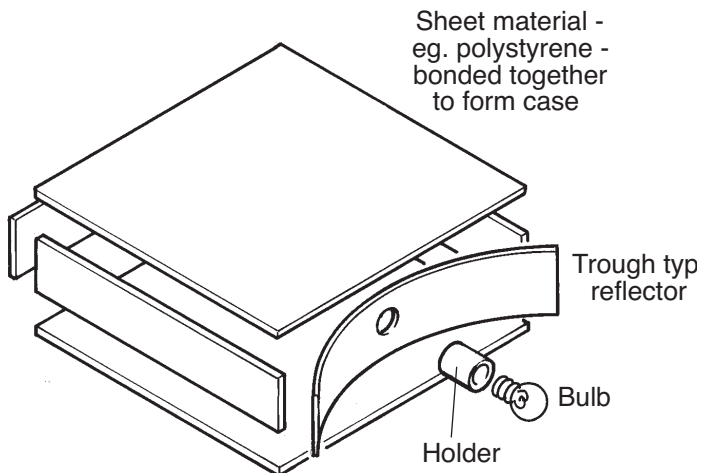
A torch has three main components. In a well designed torch these are integrated into a product that “handles” well and gives a good beam.

• **Case**

The design of the torch case will depend partly on the optical system and the size and type of batteries to be used. Beyond these constraints, there are very few limitations unless the torch is for a very special purpose (e.g. some torches are designed to be gas proof to reduce explosion hazards in gaseous environments). Two very simple construction methods are illustrated. In both examples, the torches can be given a very commercial appearance by attention to small details - not least surface finish.

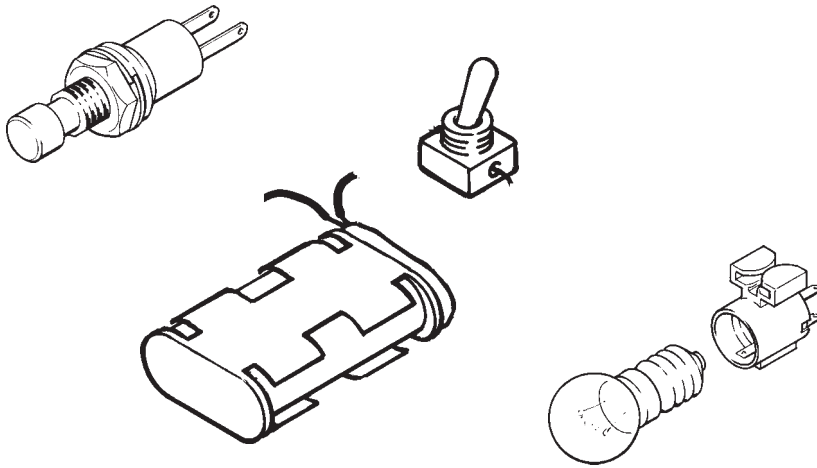


Basic parts of a cylindrical torch - metal, plastic, or a combination of both



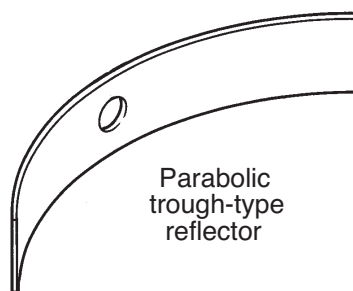
• **Power supply and switch**

Depending on the overall design, these components can be bought in as separate items or made as an *integral* part of a torch. An ultra-flat plastic torch, for example, might use a custom-made membrane panel switch. A metal tubular type might use the tube itself both to contain the batteries and act as a conductor.

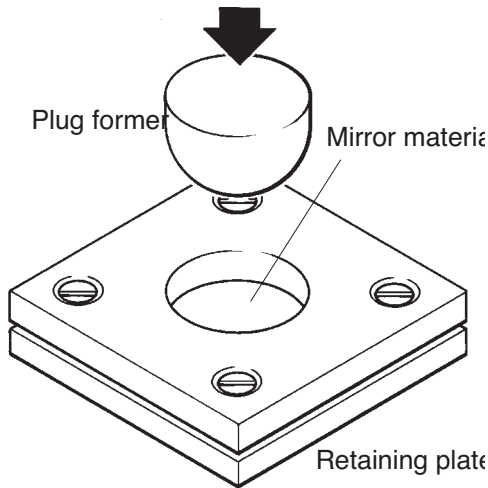


• **Optical system**

It is easier to make a *trough-type* reflector than one curved in three dimensions. Rigid plastic mirror material can be heated and bent over a former to give a parabolic or other curvature (see Study File 5).



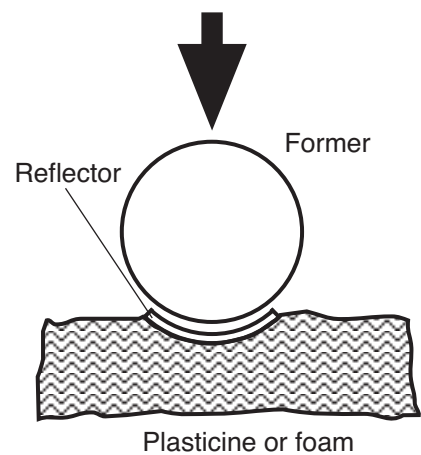
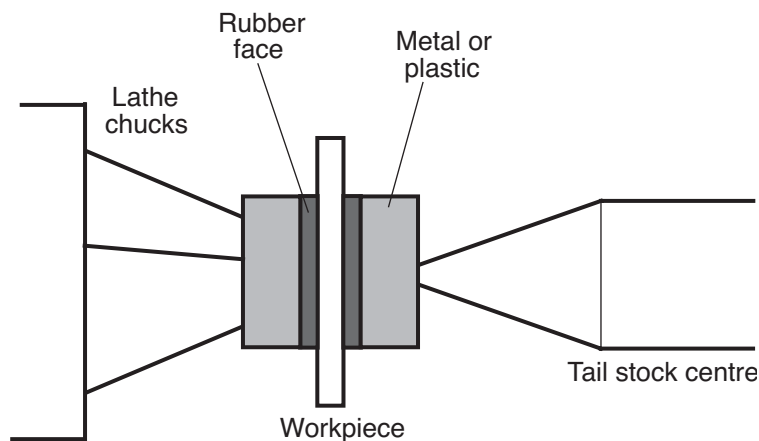
Alternatively, rigid mirror material can be vacuum formed or *press formed*. One method of press forming involves trapping the material between two wooden plates, heating to about 180°C and then pushing a profiled former against the softened material. It is essential that the plastic is not stretched too far otherwise the metallised reflector film will break up. This method leaves waste material to be trimmed off.



Stretch forming a small reflector

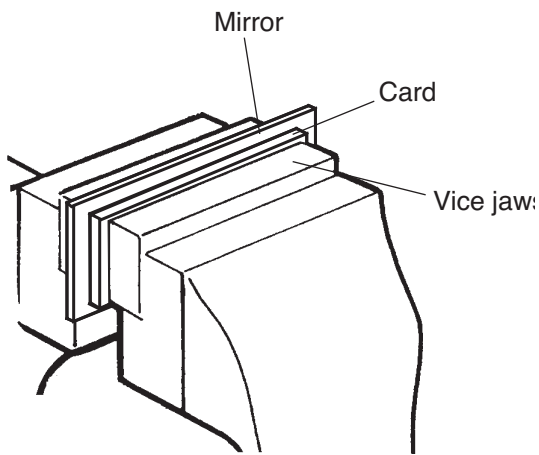
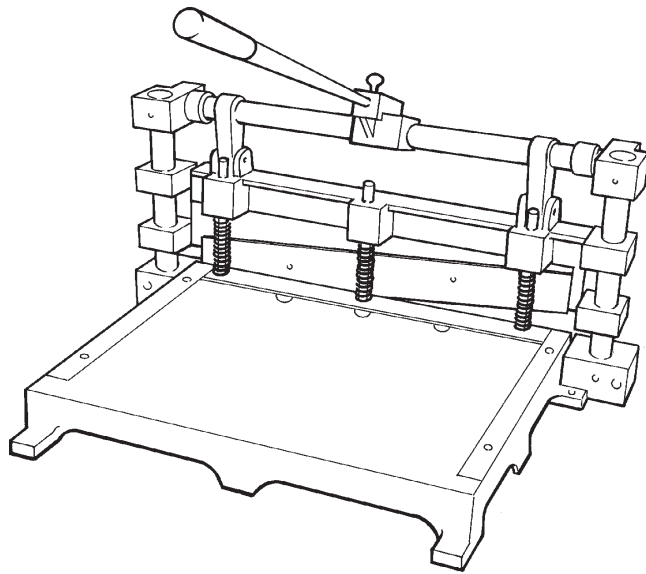
An easier and more efficient method is to produce a correctly shaped blank - e.g. by cutting out and turning on a lathe between pressure pads a blank - making some allowance for contraction during forming. The blank is heated, placed on a compliant material such as “Plasticine” and pressed into shape with a former such as a spherical ball. “Oasis”, the soft rigid foam used for flower arrangements, is an example of an alternative material for pressing into.

Warning: Suitable protective clothing and gloves must be worn when handling hot plastics.



Cutting and plastic mirror material

Rigid polystyrene mirror material is cut using a guillotine, saw or by scoring and breaking. The edges are finished by using a file or abrasive (wet and dry) paper. *The plastic film protecting the mirror surface should be left in place until all work is finished.* The mirror material must not be held in a vice unless it is placed between a protective layer of thick card or wood to prevent damage to the surface.

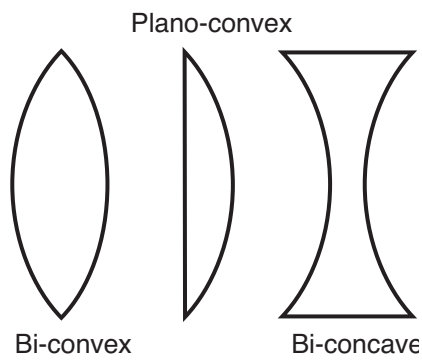


Protecting mirror material from vice-jaw damage

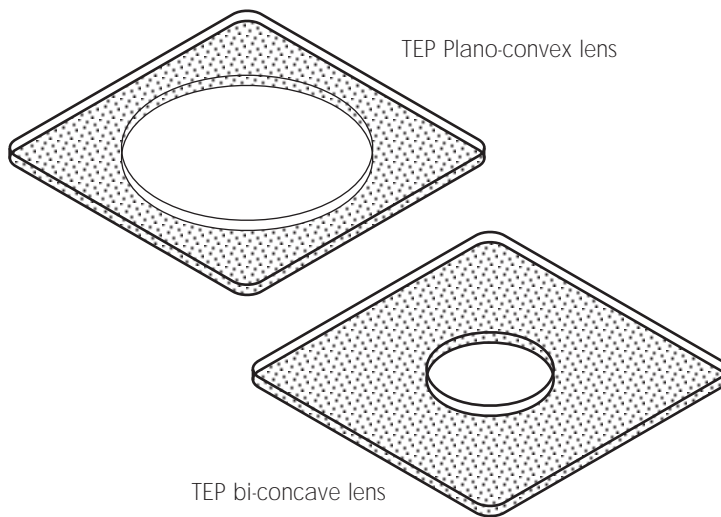
SECTION 2 - LENSES

Lens and how they work

A lens is a piece of clear plastic or glass (usually circular) which has a special *profile* or shape when viewed from the side. There are three common lenses : *bi-convex*, *plano-convex*, *bi-concave*. The “bi” in these names means “two” and the “plano” means flat; i.e., the term bi-convex means the lens has two convex faces, plano-convex means one flat face and one convex, and bi-concave means the lens has two concave faces. The TEP lens set contains a plano-convex and a bi-concave lens. Each lens has a square surround for ease of mounting or fastening.

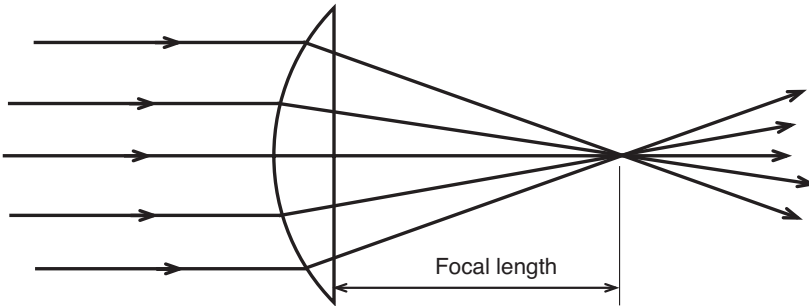


Lens types

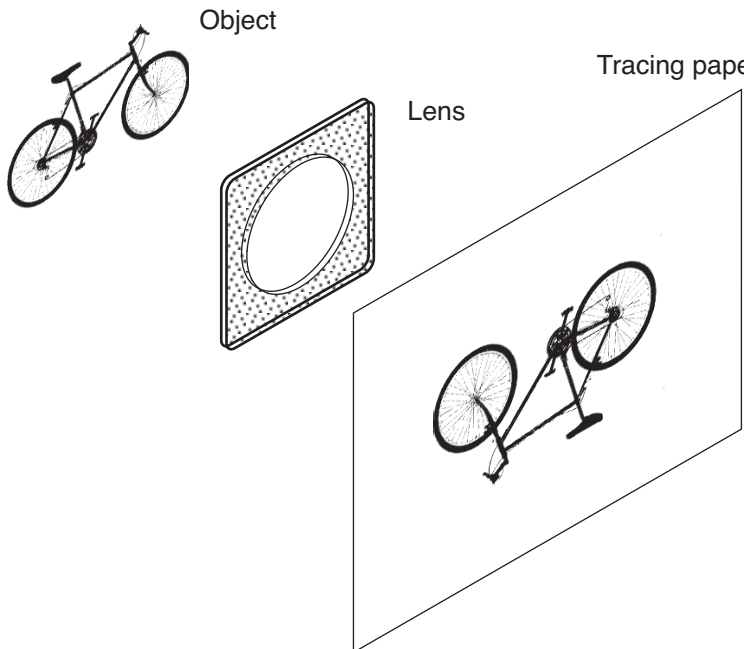


Plano-convex lens

When parallel rays of light pass through a plano-convex lens they are “bent” to *converge* at a point called the focal point. The distance between this point and the flat face of the lens is called the *focal length*. To determine the focal length of the lens, place it in front of a piece of tracing paper and move this closer and further away from it until a sharp image of what you are pointing the lens at appears through the tracing paper. The distance between the flat face and the tracing paper is the focal length.



Plano-convex converging lens



A plano-convex lens projects an inverted image on an opaque sheet or tracing paper

OPTICAL SYSTEMS

In this experiment, you will have discovered that the lens as well as focusing a distant image onto the tracing paper will have inverted it. This can be explained by following the path of light rays from the object as they pass through the lens. If the lens was placed in one side of a closed box and photographic film used in place of the tracing paper, you would have a simple camera.

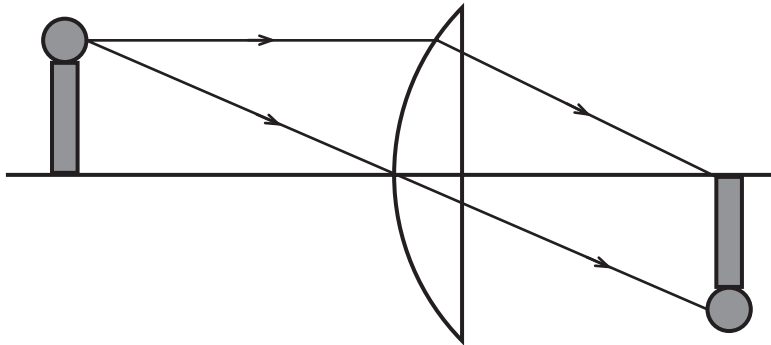
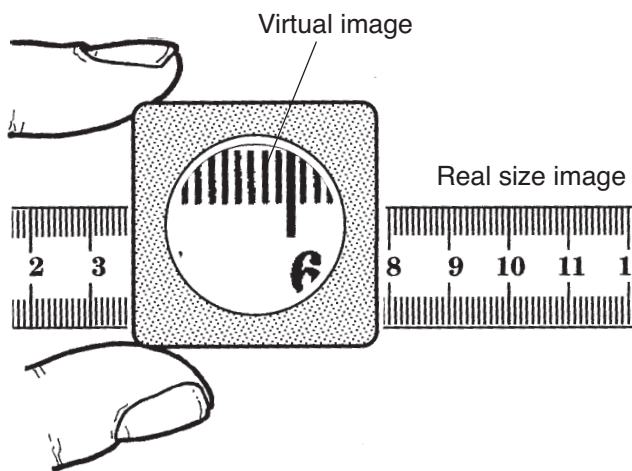


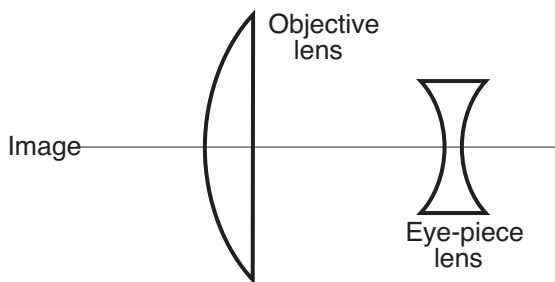
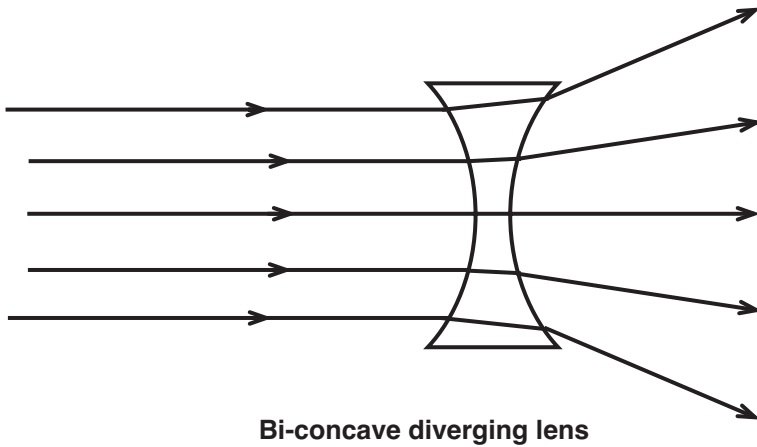
Image inverted by plano-convex lens

If the lens is brought closer to an object and closer to the eye, it has a *magnifying* effect. The enlarged image you see is called a *virtual image*. It seems to exist on the other side of the lens, but we know the object there is actually smaller. If we compare the size of the actual object with the virtual image, the magnification is about four times (written X4). This magnification is extremely useful for viewing small objects, manipulating things and measuring.



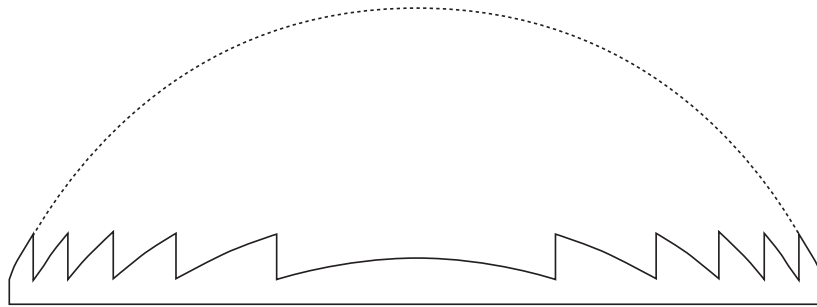
Bi-concave lens

When parallel rays of light pass through a bi-concave lens, they *diverge*. This type of lens produces a virtual image when you view an object through it, but the virtual image is always smaller than the actual object. A bi-concave lens is used, for example, in a simple telescope (or binoculars) as one of a pair of lenses. It corrects the inverted image that appears through the main *objective* lens.



The Fresnel lens (pronounced 'Fraynel')

This is a special type of flat lens that was originally invented for focusing the light source in lighthouses. It is a series of circular prisms that can bend light in the same way as a convex lens. It acts as a magnifying lens to produce a virtual image. Because the fresnel lens is very flat, it can be used in many applications where normal lenses are not suitable. It is used, for example, in overhead projectors.



Enlarged section through a Fresnel lens

Technical Fact

When a ray of light is deviated by a lens, all the deviation takes place at the two points where the light enters and leaves the lens. The glass between these two points plays no part in the deviation and can be removed without affecting the performance of the lens.

That is the principle of the Fresnel Lens. In the example shown, all the glass between the dotted profile of the original plano-convex lens and the solid profile of the equivalent Fresnel Lens has been removed.

Curious fact:
Spherical lenses
A small sphere acts as a very powerful magnifying lens when it is held close to the eye and close to the object being viewed. A plastic or glass sphere of 3mm diameter can give a magnification of between X50 to X100. This was the basis of early simple microscopes. If a hair, the edge of a piece of paper or other object is fastened in front of the TEP bead lens with "bluetack", it makes a simple microscope.

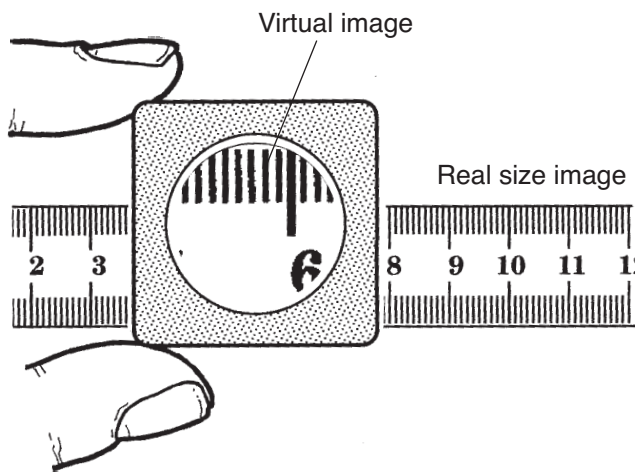
OPPORTUNITIES FOR DESIGNING AND MAKING WITH LENSES

Projects using single lenses

The TEP plano-convex lens gives useful magnification in a variety of situations. Some of these are:

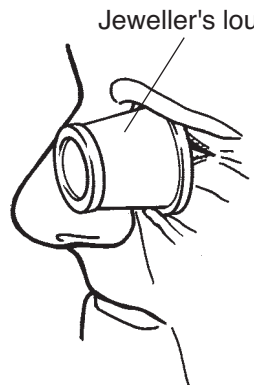
• **General purpose magnifying glass**

A magnifying lens is a small product that people might occasionally use. A plastic lens needs to be protected from scratching and from sunlight in case it is left lying around and becomes a fire risk.



• **Inspection magnifier**

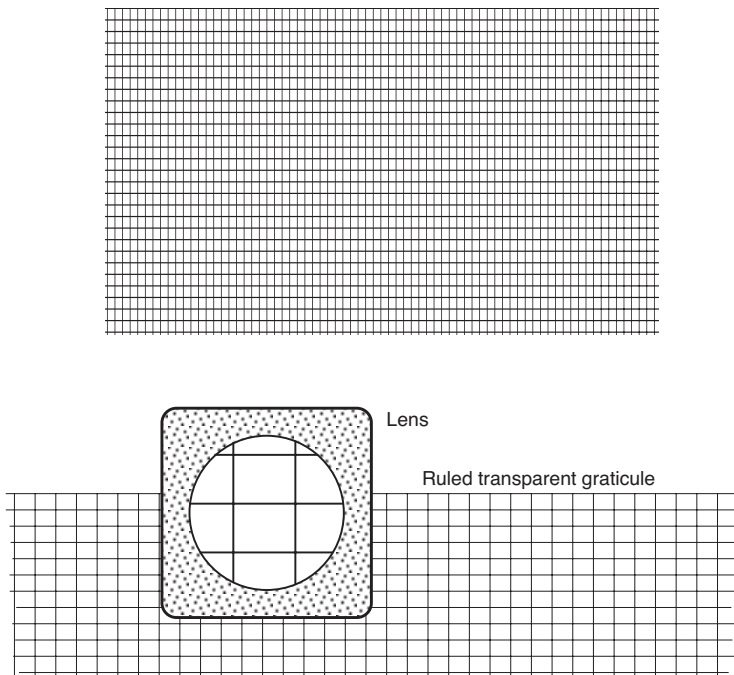
Magnifying lenses are used by people such as jewellers and watch repairers at work. Traditional watch repairers use a magnifying lens in a small tube called a loupe which fastens against the eye socket. Sometimes two lenses - one for each eye - are fitted into a form of visor.



• **Measuring tool**

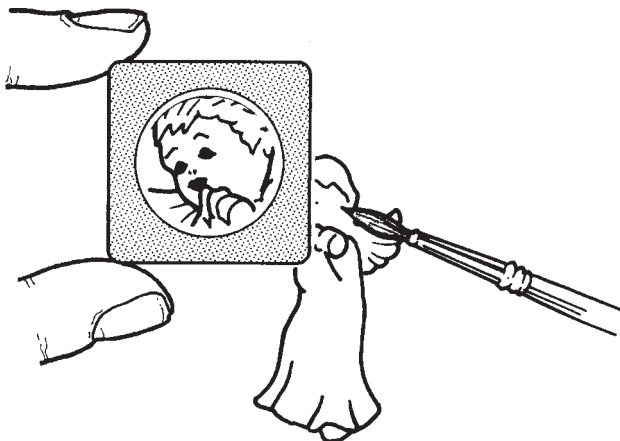
Small magnifying lenses are sometimes added to measuring instruments so that the operator can see very small graduations on a scale. It is possible to take very precise measurements by putting a finely ruled grid over something and then viewing it through a lens. This ruled grid is called a *graticule*.

See Study File 2 for a finely ruled grid that can be photocopied on paper or acetate sheet to make a ruled graticule.



• **Operational aid**

Many people require assistance with “fiddly” operations such as threading a needle, soldering or painting “fantasy” figures. If positioned correctly, a small magnifying lens can be of great assistance.

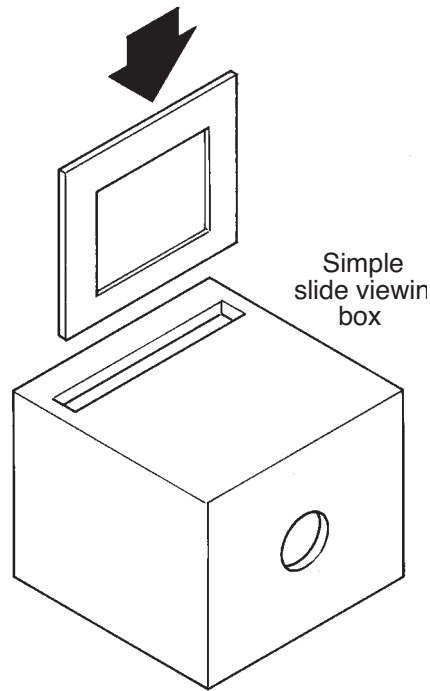


• **Promotional device**

A magnifier can be given away as a means of promoting a product - for example, a paper firm advertising an extra-smooth writing surface.

• **Slide viewer**

A single lens offers an inexpensive and portable means of viewing colour slides. The lens can be built into an enclosure that uses natural light for illumination - or a small bulb.



• **Educational toy/game**

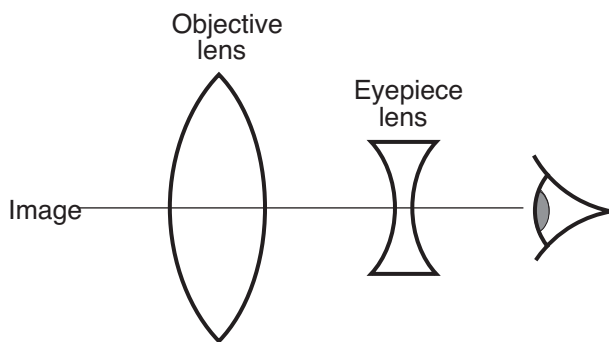
Lenses can be used in a variety of ways in educational toys and games - which younger children can learn from as well as enjoy. For example, it is possible to learn about fingerprints by devising a game that requires the players to identify other people from their fingerprints. A X4 magnification lens is ideal for this purpose.



Projects using combined lenses

A pair of bi-convex (or plano-convex) and bi-concave lenses can be used to build a small telescope or binoculars. The two lenses do not have to be in a closed tube, but this assists both viewing and concentration. The instrument may be of a fixed focus or adjustable; it may even be collapsible or disposable - or both !

Note: The TEP lenses are not specifically matched for this purpose, but can be used to demonstrate the principle, or make a low-performance instrument. If they are used, you will notice distortions known as *aberrations* around the edge of the image.



Lens arrangement for simple telescope

All of these design opportunities require research to arrive at a design specification. They also require you to know something about the lens being used; for example its focal length. Even a very simple product using a lens needs careful designing so that it can be held, protected and used effectively and safely.

The TEP lenses are supplied with a plastic surround to give you a wide choice of how to fix them in place. If a circular lens is required for fitting into a tube, the surrounding material can be trimmed off.

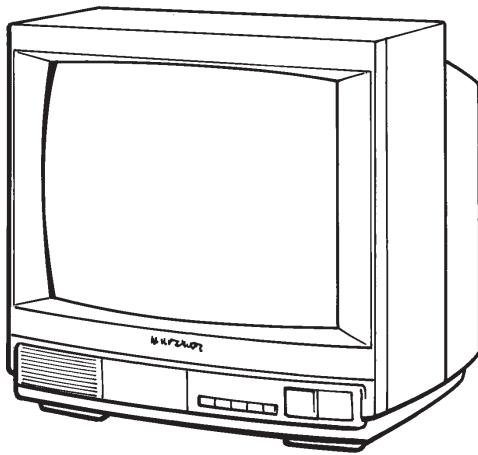
LENS SAFETY

- **Never look at the sun or a bright light through a lens**
- **Take care not to allow a lens to touch your eye**
- **Never leave a lens lying around; it is a fire risk**

SECTION 3

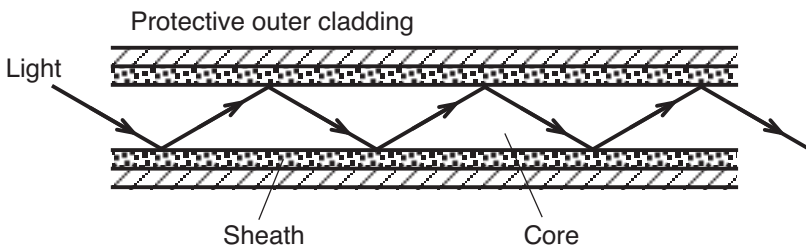
Fibre Optics

Fibre optics is a relatively new technology that provides the means for “piping” light, and information in the form of *encoded* signals, over very long distances. During the last few years *optical fibres* have become particularly important as a means of transmitting vast amounts of information - telephone conversations, television programmes and interactive services such as home shopping and banking. Because optical fibres can carry so much information, the UK is currently being cabled for the next step in the information revolution.



Optical fibres and how they work

An optical fibre is a small diameter glass or plastic rod which has an inner *core* and an outer *cladding* with different *refractive* properties. This means that when light enters at one end, it is *internally* reflected along the length of the core to the other end of the fibre - with very little escaping through the side walls.



Glass optical fibre is used for long distance communications work because it gives very little *attenuation* or loss of light over its length. Plastic optical fibre is much cheaper and easier to cut, but it offers greater attenuation and is typically used over distances of 10 metres. TEP offers two types of plastic optical fibre: a 1.00 mm diameter version with protective *sheath* and an unprotected 0.5mm type. Both types of fibre can be used in a variety of interesting applications.

OPPORTUNITIES FOR DESIGNING AND MAKING WITH OPTICAL FIBRES

Light pipes

A light pipe is a means of getting light to a particular place or concentrating it on a very small area. Light pipes are often used, for example:-

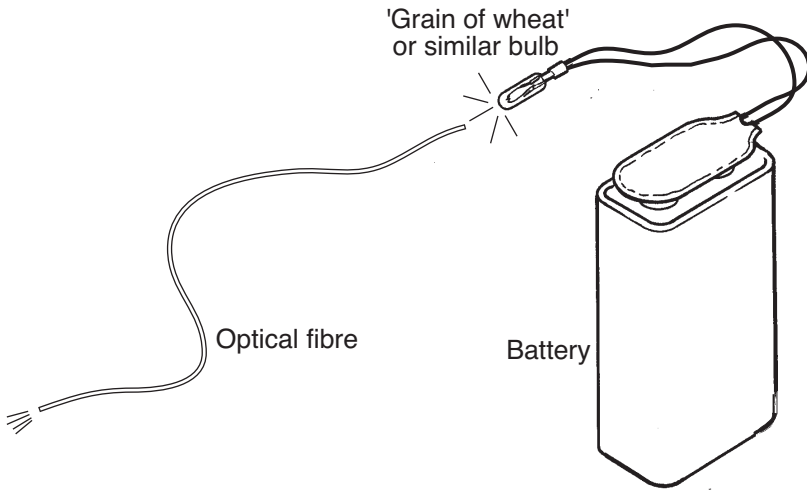
- to look at and examine dark places in complex equipment (often with the help of a small inspection mirror);
- to bring light to places where there is no room for a bulb - e.g. on architectural or other models, to illuminate a door-bell switch;
- to monitor the status of a light - e.g. the lights of a car or the rear light of a cycle.



Technical note:

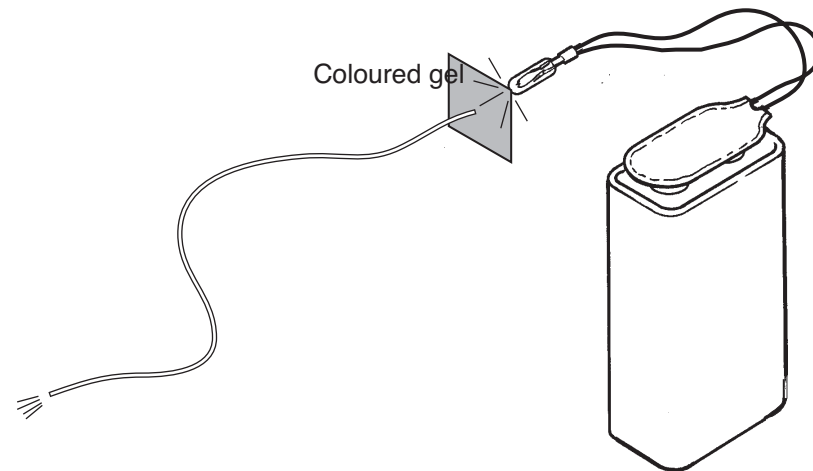
Some optical fibre cables are made up of a bundle of extremely small diameter optical fibres. In a coherent bundle of such fibres, where the position of each fibre is identical at both ends, images can be transmitted from one end to the other. This is the principle of the medical endoscope which enables a surgeon to see into a body cavity.

The basic parts of a torch-type light pipe, using a miniature “grain of wheat” bulb as the light source, are shown in the illustration. The lamp collar also acts as a holder for the optical fibre and can be machined, for example, from aluminium or brass and drilled on the lathe. The light “gathering” end of the optical fibre should be as flat and well polished as possible. It is normally cut with a scalpel and then smoothed on wet and dry abrasive paper - and finally *polished by rubbing on ordinary paper*.



Optical fibre used as a light pipe

When a light pipe is used to transmit light to different parts of models, colour filters at the gathering end of each optical fibre can be used to change the colour or transmitted light. (TEP offers a small pack of assorted colour filter offcuts for this.)

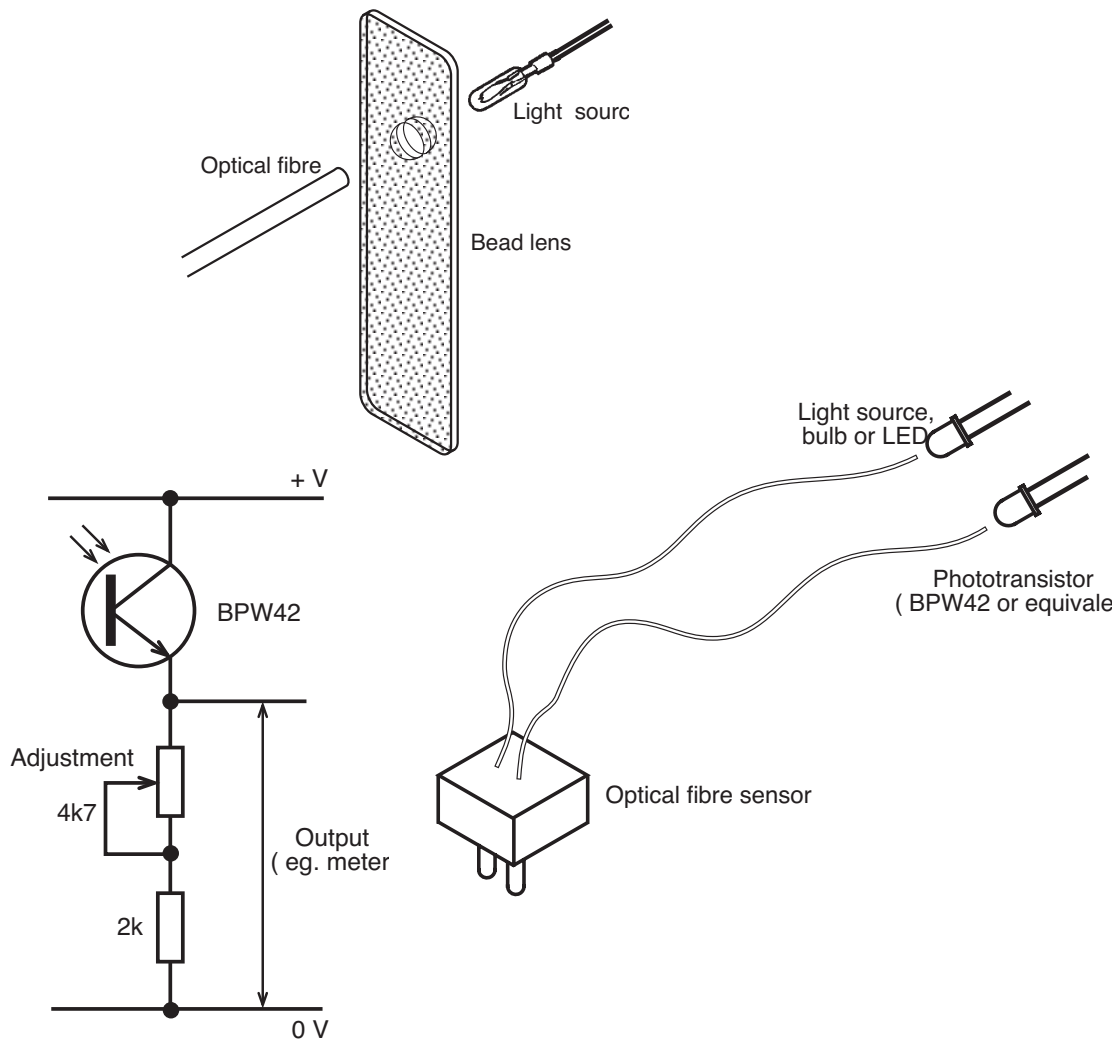


Technical note:
The light gathering efficiency of an optical fibre can be improved using a small lens such as the TEP bead lens. To determine the optimum distance (which is very short), light from an LED or filament bulb can be passed through the bead onto a paper screen.

Bead lens (spherical)

Optical sensors

Because an optical fibre can deliver light to a very small area, a pair of optical fibres can be used to sense and detect different reflective surfaces - for example, the difference between a black and white surface or even different colours. A simple sensor arrangement is shown. The actual light source and detecting circuit would depend on what is required of the sensor.



An example application is a simple instrument that enables an operator to distinguish between ripe and non-ripe tomatoes by colour difference. The transmitting and receiving optical fibres are contained in a tube which is lightly held against the fruit surface. The phototransistor circuit is connected to a voltmeter which will give different readings for levels of reflectivity from ripe (red) and non-ripe (greenish) fruit. Designing a practical instrument, however, involves experimenting with colour filters, circuit values and selecting the most appropriate meter.

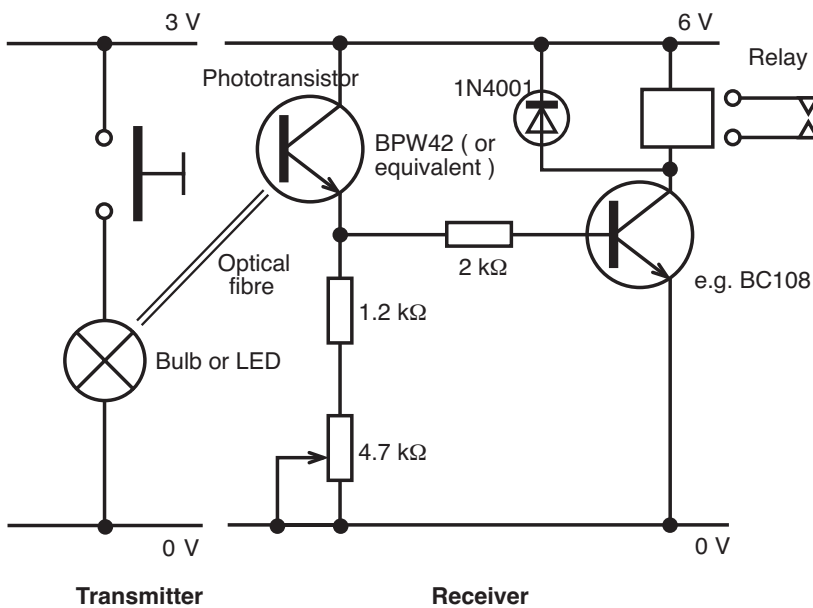
Optical communications

Communications is currently the most important and topical application for optical fibres. Unfortunately, it is also the most difficult because light has to be converted into a special signal to transmit any type of data. A typical optical communications system is *digital* which means that information is encoded as a stream of very high speed on/off laser-light pulses. A circuit at the receiving end of the optical fibre *decodes* the pulses and converts them back, for example, to speech or a television picture.

It is possible, however, to build a very simple fibre-optic link to turn something on or off. Two examples are given below:

- Optically isolated switch. A light source powered by a *local* battery can transmit light to a detector at the end of the fibre optic cable when a switch is operated. The detecting circuit operates a relay to turn another power supply on or off. This arrangement isolates the operator from the actual power supply being switched on and off.

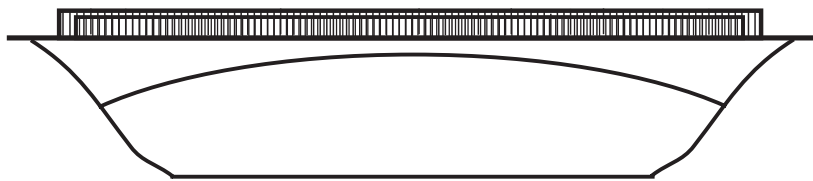
(SAFETY NOTE: Never experiment with or use mains voltages.)



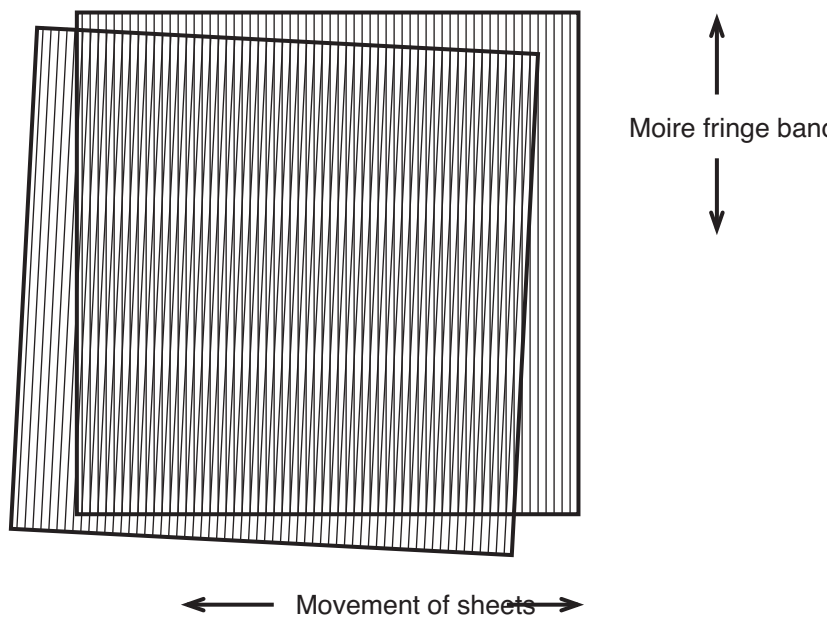
- Remote control for a toy. A motor-powered buggy or similar toy can be controlled via an “umbilical” fibre-optic cable. For example, if the buggy is driven by two motors, the fibre-optic link can be used to temporarily break the supply to one of them - causing the buggy to turn.

SECTION 4 - MOIRE FRINGES AND THEIR USES

A *moire fringe* is an optical effect that arises when two similar grid patterns are moved in relation to one another. Moire fringes sometimes appear when a motorist or cyclist passes under a bridge and looks through two sets of railings. Moire fringes can be created by passing a grid of lines printed on acetate sheet across an identical grid held at a slight angle. The effect is to see wider dark bands slowly passing down the sheet. (Study File 2 provides grid templates for copying on acetate sheet.)



Moire fringes sometimes appear when you look through two sets of railings



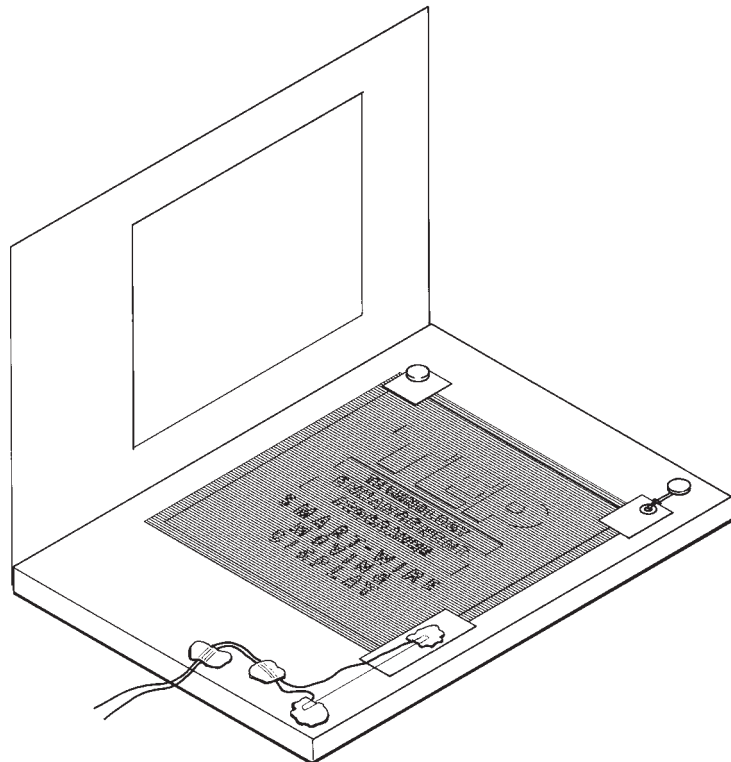
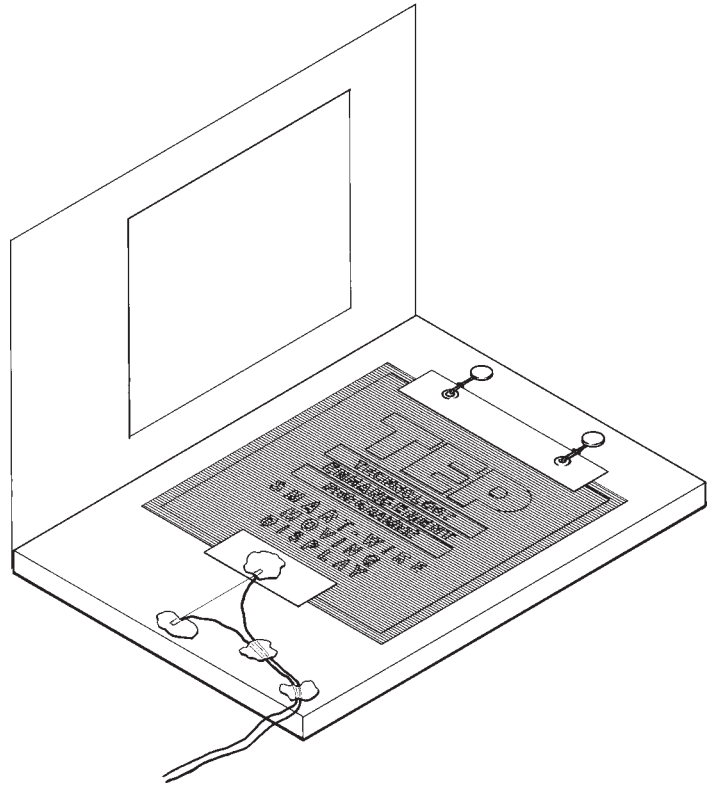
The dark moire fringe bands arise because at certain places the grid lines come together to block out all the light. A *very small movement of one sheet in relation to the other causes the larger dark bands to move quite rapidly*. Other moire fringe patterns appear whenever a pattern of closely spaced lines printed on clear material is moved in relation to an identical pattern or an image made up of closely spaced lines.

OPPORTUNITIES FOR USING MOIRE FRINGE EFFECTS

Moire-effect screens

Moire fringe patterns can be exploited for display screens that convey a message - e.g. for advertising. In this type of screen a printed acetate sheet is moved against a fixed sheet to create an eye-catching optical effect. This might draw attention, for example, to a printed message on the lower sheet.

The acetate sheet can be made to move by means of a short length of *smart wire*. This is a special alloy which contracts ("remembers" it should be shorter) when it is heated to about 70° C. Passing a small current through the wire heats it up and causes it to contract in about 0.1 second. When the current is switched off, the wire relaxes again to its original length in about 1 second. The contraction is only 5% of the length of the wire but this makes it ideal for the optical screen because only a tiny movement is called for.



Designing and making a moire-effect screen

You must first of all decide on what message the screen is conveying and how the moire fringe patterns can be used. You can then experiment with fringe effects by photocopying grids on acetate and then moving them against the originals - or other images. Words or additional images can be added to the lower grid by photocopying or pasting up. For example, a screen advertising sun tan blocker shows moving moire fringes as harmful rays falling on a beach scene.

The basic construction of a screen is very easy. Two examples are shown, but many others are possible. The important thing is that the top acetate registers properly with the lower image so that it returns to the same position each time after any movement.

In the simpler type of screen, the acetate is pivoted at one corner. A card tab bonded to the edge of the acetate with double-sided tape holds one end of the smart wire and an elastic band spring.

This type is made as follows:

- glue the lower image to a board (e.g. MDF); lay the acetate copy over and pin in one corner;
- attach a card tab to the acetate and fasten it to the board using an elastic band and drawing pin. (*When the acetate is in the correct position, the elastic band should be slightly taut.*) ;
- connect each end of a length of “smart wire” to connecting wires using crimps. These must be closed and folded to prevent the fine wire pulling through;
- place one end of “the smart wire” on the card tab and apply a small bead of hot-melt glue. Before the glue has cooled, press it flat with a scrap metal “stamp” whose end has been wiped with silicon grease or wax. This cools the glue quickly and gives a flat bond;
- The “smart wire” is pulled taut until the images come into line - and the other end is glued to the board;
- Cut out and fasten over a frame to conceal the outline of the screen. This can be taped to one side so that it hinges open. The frame is important because it finishes the product and creates the impression of an LCD screen of a lap-top computer. (See Study File 3 for a computer image that can be photocopied on card and used as a frame.)

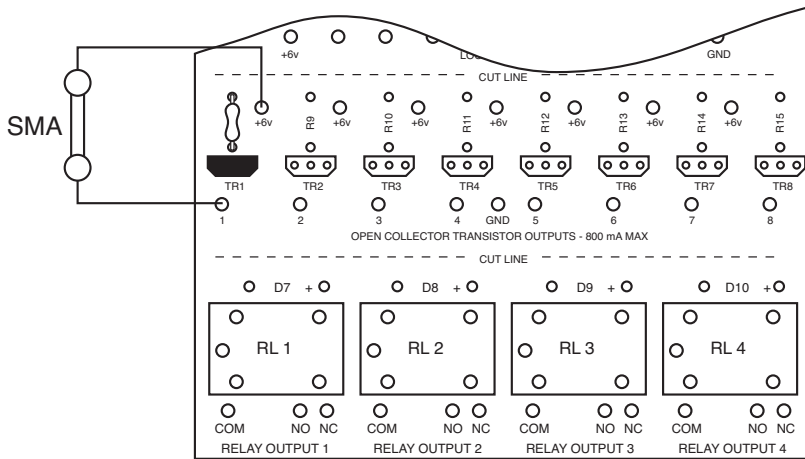
Full details of “smart wire” and its use are given in a separate TEP publication. However, as a rule of thumb, use 50mm of smart wire for each 1.5v of battery supply. For example, a 3v battery is suitable for 100mm of wire and 4.5v battery for 150 mm. If these figures are exceeded, the wire can be damaged.

Energising the “smart wire”

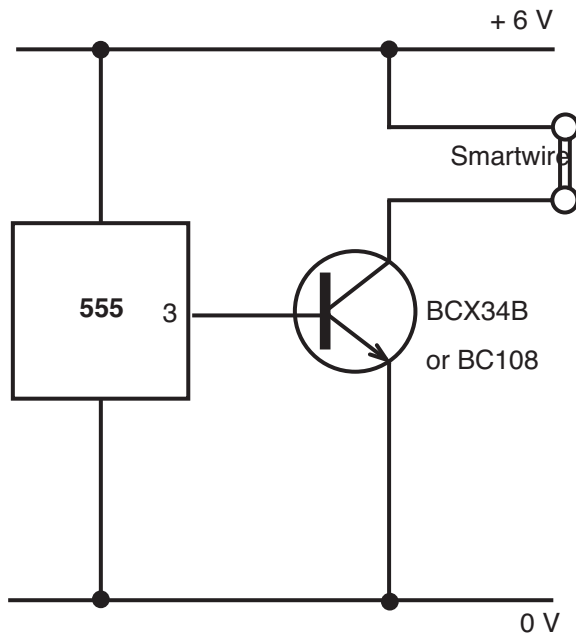
The wire can be energised by simply switching the current on and off. A press-button switch by the screen might invite people to press and release the button to see the effect.

To cycle the acetate up and down automatically, current can be switched on and off using TEP’s “Bit by bit” controller or a suitable dedicated circuit.

The “Bit by bit” controller has a handbook explaining how to program the board to switch an output on and off at any desired speed. The “smart wire” - which should be between 125 and 150 mm in length - is connected to one of the controller’s transistor outputs. *The speed of switching must not be too rapid because the wire takes up to 1 second to cool down after each contraction.*



A dedicated control circuit can be made from a 555 timer connected in its astable mode. A simplified circuit diagram is shown which uses the same output transistor as the “Bit by bit” controller. Other transistors can be used, however.

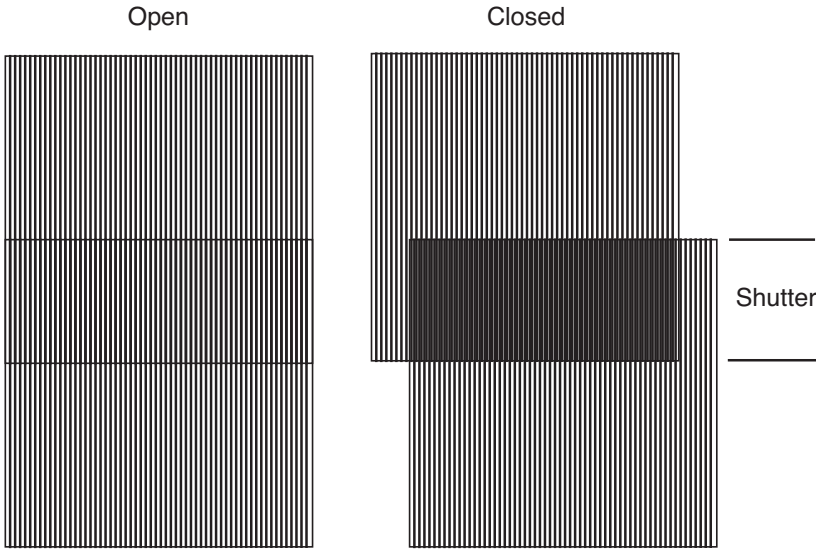


The moire-effect screen provides endless opportunities for experimenting with optical effects which can be combined with other graphics. It also invites you to design different mechanical methods of causing movement with or without “smart wire”. It is also an ideal opportunity to design and build a suitable control system.

Using moire patterns for measuring and counting

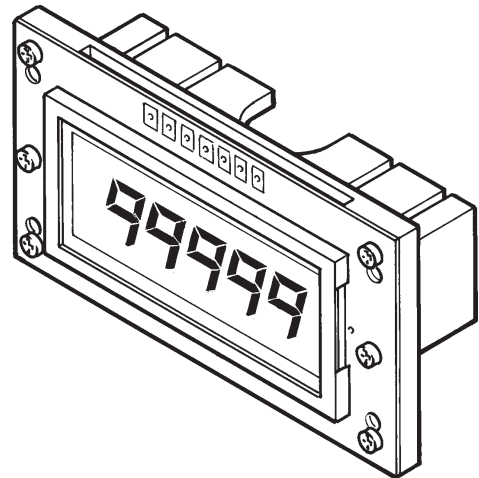
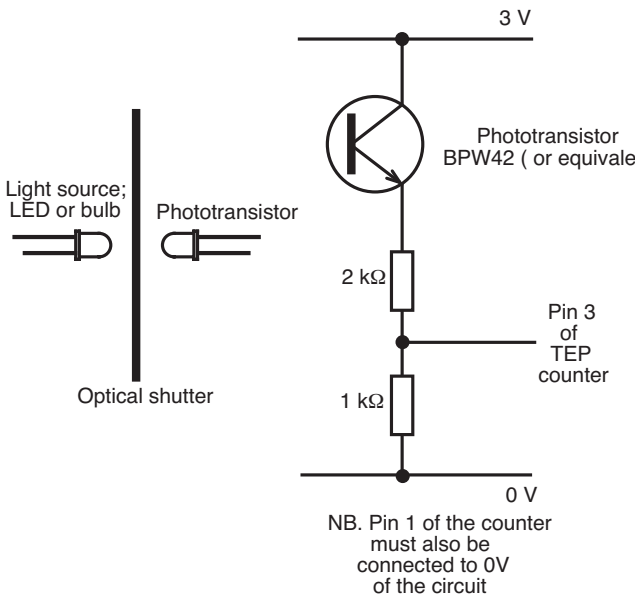
Optical systems for measuring and counting are very common. A simple method uses two clear plates printed with equally spaced lines. When the plates are moved past each other, these lines produce a *shutter* effect. In one position light passes through the shutter, but when one plate is moved by a width of one line, all light is shut out. *If the lines are narrow enough, full opening and closing of the shutter can occur within a movement of a fraction of 1mm.*

In a practical measuring instrument, the number of times the shutter opens and closes is counted and displayed as a number. This principle is known as *optical encoding*.



Shutter effect from two ruled grids

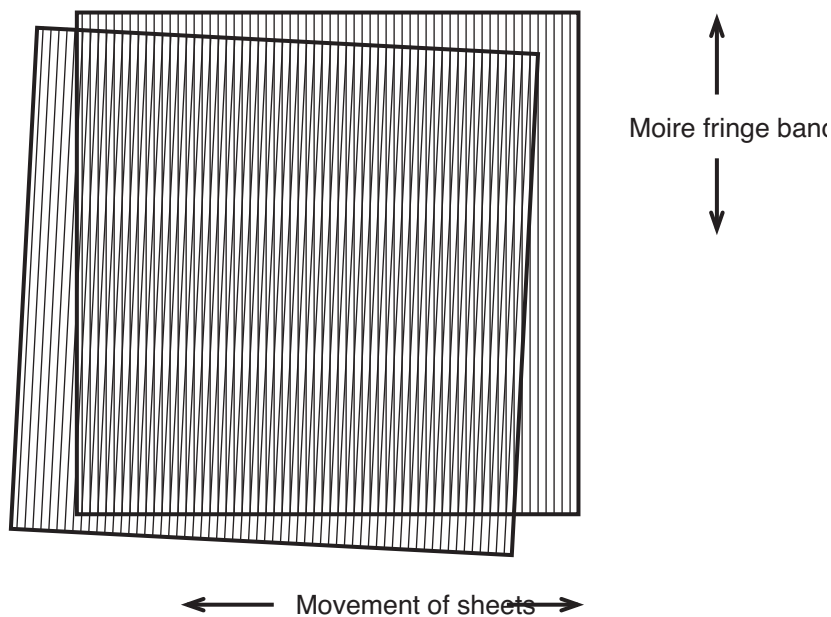
An accurate measuring device can be made by placing a light source and a phototransistor on either side of an *optical shutter* and connecting the transistor to a counter. When the shutter is closed, the transistor is switched off; when the shutter is open, it switches on and provides a signal to increment the counter by "1". The diagram shows a suitable circuit that can be connected to TEP's electronic counter.



A similar optical encoding principle is used to monitor the movement of rotating shafts. In this application the lines are printed on discs as radial “spokes”.

(Study File 2 contains photocopyable grids for linear and circular optical encoding.)

Another type of optical encoder uses the moire fringe effect. When a grid of parallel lines printed on acetate sheet is passed across an identical grid held at a slight angle, you see wider dark bands passing down the sheet. *The wider band, which shuts out all light, moves through a much greater distance than the actual movement of the two sheets.* If the light source and phototransistor are correctly positioned on either side of the sheets, the counter will show the number of times a moire fringe passes - with each pass representing a small *incremental* movement of the sheets.



This moire fringe principle is used in many measuring instruments - including the first all-electronic micrometer - and for monitoring very small mechanical movements.

Using either the shutter or moire fringe principle, it is possible to design and make:

- A *rolling-wheel measure* for (1) measuring large distances; (2) wallpaper lengths; (3) distances on maps.
- A *linear measurer* for (1) cloth; (2) wire supplied on a reel.
- An *electronic calliper tool* for (1) “go” and “no go” checking of dimensions; (2) checking thicknesses of stacks of paper or other materials.
- An *inclinometer* for measuring angles.

It is very straightforward to make optical encoders using images photocopied on acetate sheet. These can be generated by a computer or created, for example, by photocopying the images supplied in Study File 2. It is a good idea first to experiment with some of the grids to determine the relation of the moire fringe to the basic line spacing. The main problem is really one of mounting the light source and phototransistor and ensuring that the grids are properly supported and held together.

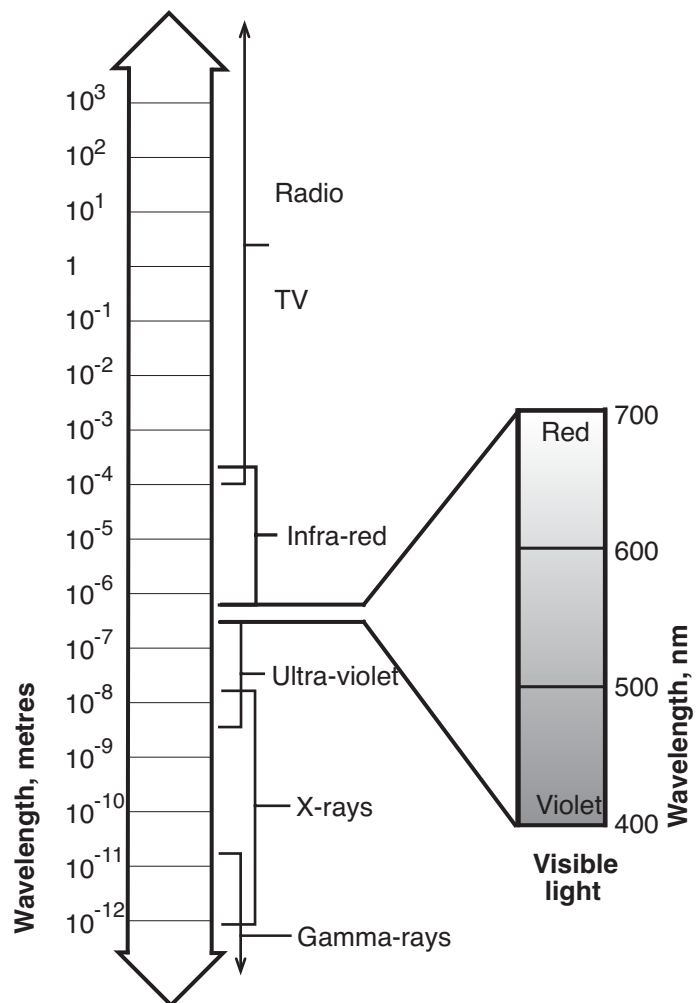
STUDY FILE 1 - WHAT IS LIGHT ?

Light is a form of energy called *electromagnetic* radiation. If you think of this radiation as a *wave*, visible light has a *wavelength* between 400 to 700 *nanometres* . A nanometre is 0.000000001 of a metre or 0.000001 of a millimetre ! The different visible wavelengths combine to make up white light. White light can be separated into its component wavelengths by means of a prism. This *refracts* or bends each colour of the visible spectrum by a slightly different amount. (A rainbow does this naturally.)

Different materials absorb different wavelengths to a greater or less extent and this gives rise to the fact that different materials appear to us to have different colours.

Visible light is just a small part of the larger electromagnetic *spectrum*. Just outside our vision, at one end of the visible spectrum is infrared radiation - used in TV remote control systems. At the other end, just outside our vision is ultraviolet radiation. Special ultraviolet lamps are used, for example, to illuminate security markings and signatures. The special inks absorb ultra-violet radiation and re-radiate it as visible light. (Special additives to washing powders also absorb ultra-violet light from the sun and re-radiate it as visible light to make garments look even whiter.)

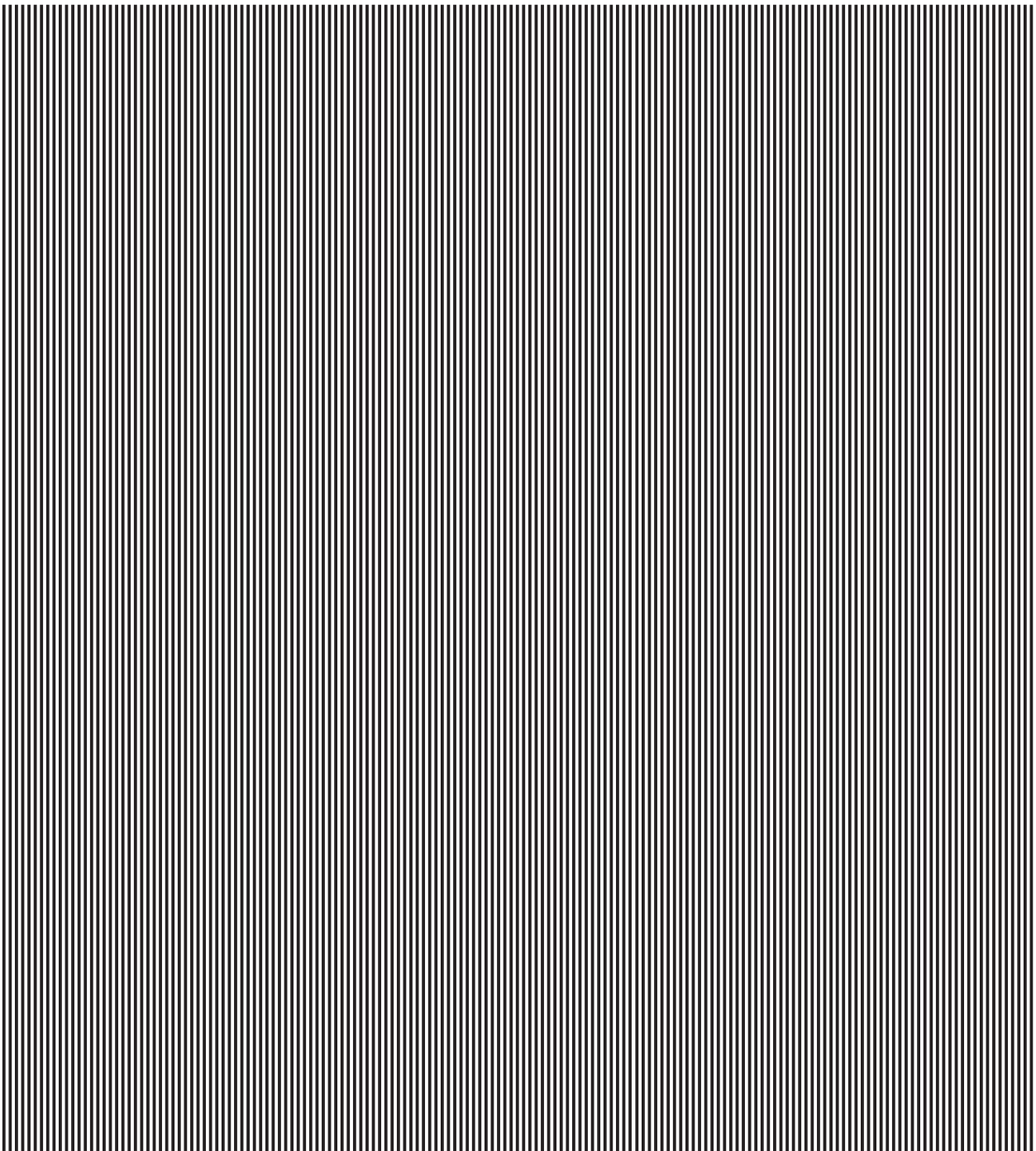
This process, in which a material absorbs short-wavelength radiation and emits longer-wavelength radiation (visible light), is called *fluorescence*.



STUDY FILE 2 - MOIRE FRINGE GRID

Photocopy the grid on plain paper and acetate sheet. Moving the acetate on top of the plain paper will produce moire fringes. Other grids can be generated on computer or purchased in the form of "Letraset" sheets. **Warning: only special photocopy-quality acetate sheet can be passed through a photocopier.**

1mm spacings

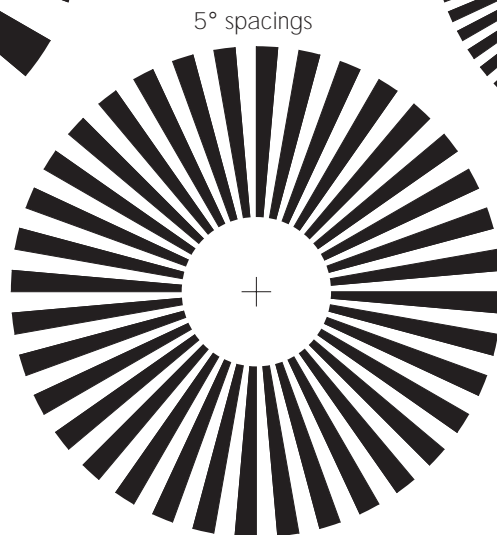




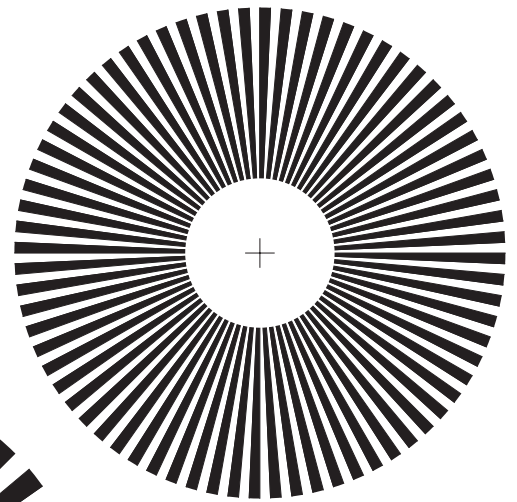
0.5mm spacings



10° spacings

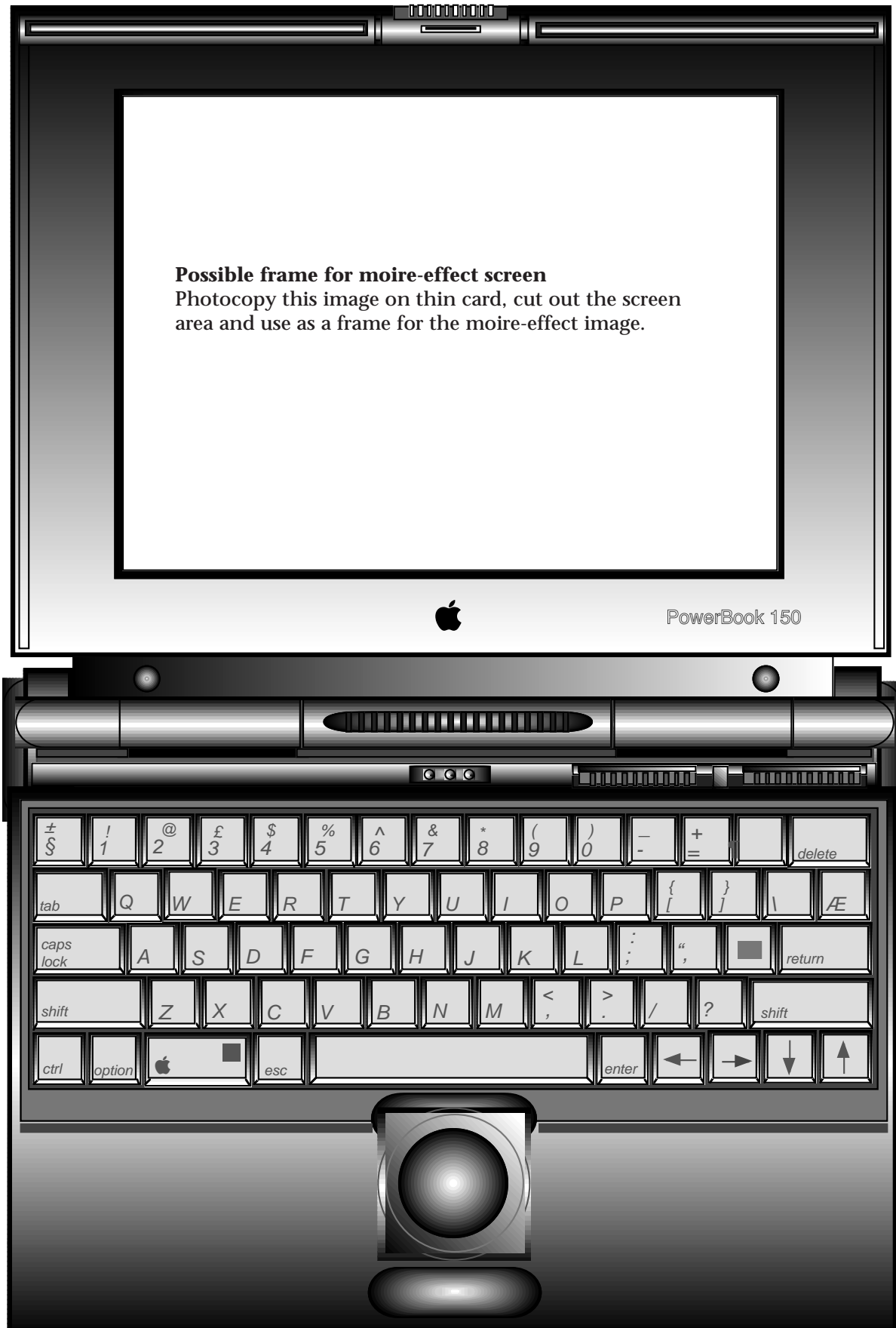


5° spacings



2.5° spacings

STUDY FILE 3 - MOIRE-EFFECT SCREEN



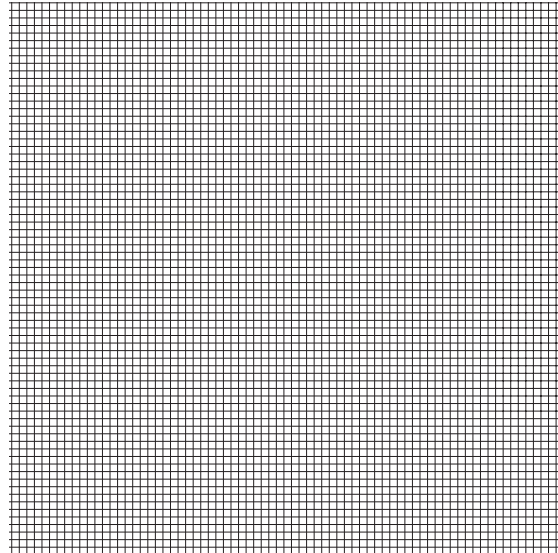
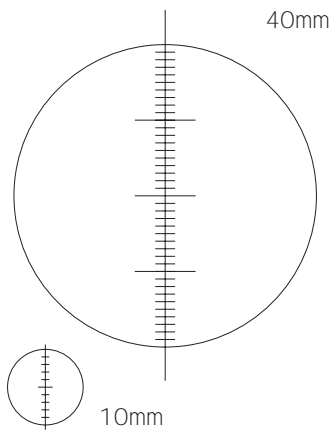
STUDY FILE 4 - MEASUREMENT GRATICULES

Graticules

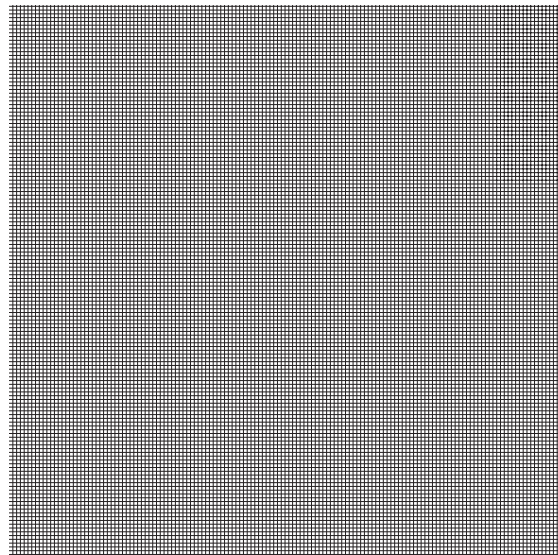
The following grids can be photocopied on paper or acetate for use as measurement graticules. There is an edge-type graticule, which is used like a ruler, or a squared graticule which is laid over the object to measure.

Technical Fact

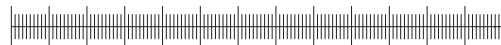
To illustrate the graticule principle, shown below is a full size graticule which is laid over faults on a car windscreen to see if they are within the MOT failure limit. An area of windscreen damage must not exceed 40mm diameter within the windscreen wiper area and in addition must not exceed 10mm in diameter within the wiper area bounded by two imaginary lines projected vertically from either side of the steering wheel.



1mm grid

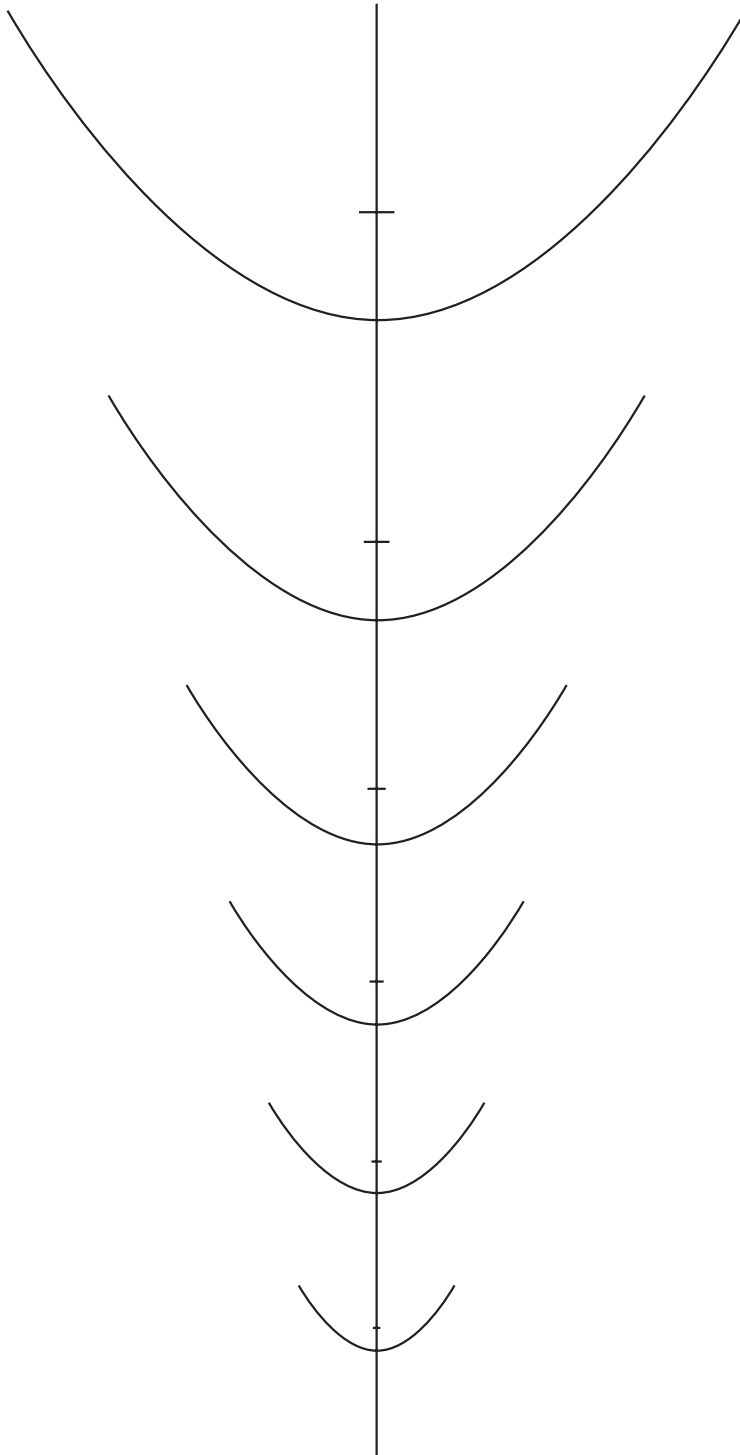


0.5mm grid



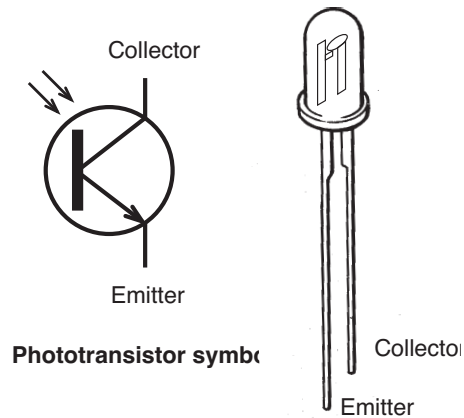
STUDY FILE 5 - PARABOLA PROFILES

This page provides a range of different size parabola profiles for use in making formers to create parabolic reflectors. The profiles can be reduced and enlarged using a photocopier.



STUDY FILE 6 - PHOTOTRANSISTORS

This type of transistor has an optically transparent case and usually just two legs: emitter and collector. The collector to emitter current depends on the amount of light falling on the phototransistor; in effect, light takes the place of base current to turn the transistor 'on' or 'off'.



A wide range of inexpensive phototransistors are optimised for use in the infra-red range of the spectrum and are supplied, for example, as the 'receiver' of an infra-red emitter-and-receiver pair. However, the spectral response of phototransistors is usually much wider than just the infra-red part of the spectrum and they are responsive, more or less, to light in the visible part of the spectrum too.

Examples of phototransistors for general purpose as well as infra-red use are:

BPW 42
SFH 309
ST8L
BP 103B

The phototransistor is used in a circuit in a similar way to an LDR such as ORP 12. The value of the variable resistor (e.g. 47k) will depend on conditions of use; it is important, however, to include a fixed value resistor in case the variable one is set to a very low value. A further simple transistor output stage, provides the possibility of driving buzzers, relays or small motors from a phototransistor.

It is also worth noting that an infra-red LED (the “emitter”) can be used at a distance to energise the phototransistor - and thus turn a load on or off.

