Waves and Optics Activities

Bent Pencil

Apparatus

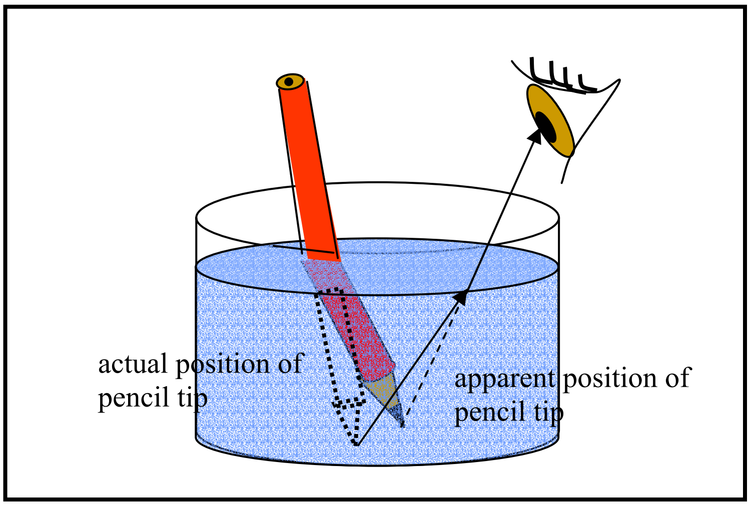
transparent container of water, for example a glass beaker, pencil

Action

The students observe the pencil through side of the container. They should note that the pencil appears to bend at the air-water interface, and explain this apparent bending. By removing the pencil from the water, they can easily see that the pencil is not in fact bent.

The Physics

The light from the pencil is refracted when it passes from the water into air, bending away from the normal as it moves from high to low refractive index. The light coming from the pencil tip appears to be coming from the apparent pencil tip as shown.



Accompanying sheet

Bent Pencil Observe the pencil. What do you notice about it? Pull it out of the water. Is the pencil actually bent? Why does the pencil appear to bend where it enters the water? Can you tell by the direction of the bend whether the air or water has the higher refractive index?

CD

Apparatus

compact discs

Action

The students observe the light reflected from the CDs. They should be able to see colours in the reflections, and explain why they see these colours.

The Physics

Compact discs behave like diffraction gratings. This because the data is stored on a CD using pits, and each pit is around 500 nm wide – within the wavelength range of visible light. When light is incident on the CD it is reflected from the pits and interferes. The intensity of the resultant light depends on the path difference, which is a function of wavelength. Different wavelengths hence give constructive or destructive interference at a given point, giving a particular colour – the colour with a wavelength that interfered constructively.

Accompanying sheet

CD

Hold the CD in your hand and angle it towards and away from the light.

What do you observe?
Explain your observations.

Change the Colour of Your Fruit

Apparatus

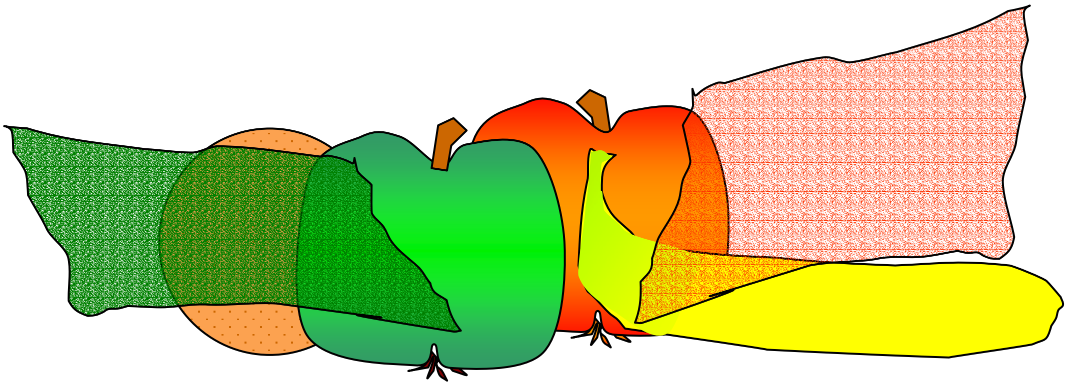
some brightly coloured fruit, eg ripe bananas, oranges, red and green apples, coloured cellophane or glasses with coloured lenses

Action

The students observe the fruit through the different coloured lenses or cellophane. They should try to explain why the fruit look different through different lenses.

The Physics

When we look at a coloured object using reflected light from the sun or room lights, we are seeing the light which is reflected from that object. The sun and most room lighting, eg fluorescent lights, contains light of many wavelengths and hence colours, and is approximately white light. The light we see reflected from an object is this white light, minus the light which is absorbed. Colours due to pigments, such as in paint or fruit skins, are called subtractive colours, because what we see is due to the subtraction of some wavelengths from the incident white light. When you look at a yellow banana through a yellow piece of cellophane or yellow lens it looks the same as when viewed in sunlight, because the yellow light from the banana is transmitted through the lens. When you look at the banana through a blue lens it looks very dark, because it reflects very little blue light, which is the only light that passes through a blue lens. In general, you will see white light, minus what is absorbed by the fruit, minus the wavelengths not transmitted by the lens.



Accompanying sheet

Change the Colour of Your Fruit

Look at the fruit just under normal light.
Why are the fruit different colours? What produces these colours?

Now look at the fruit through the different coloured lenses.
What do you see now?
Explain why you see these colours now.

Charting Pendulum Motion

Apparatus

a pendulum with a felt tip pen or pencil attached, chart recorder or some other means of pulling paper along beneath the pendulum at steady rate

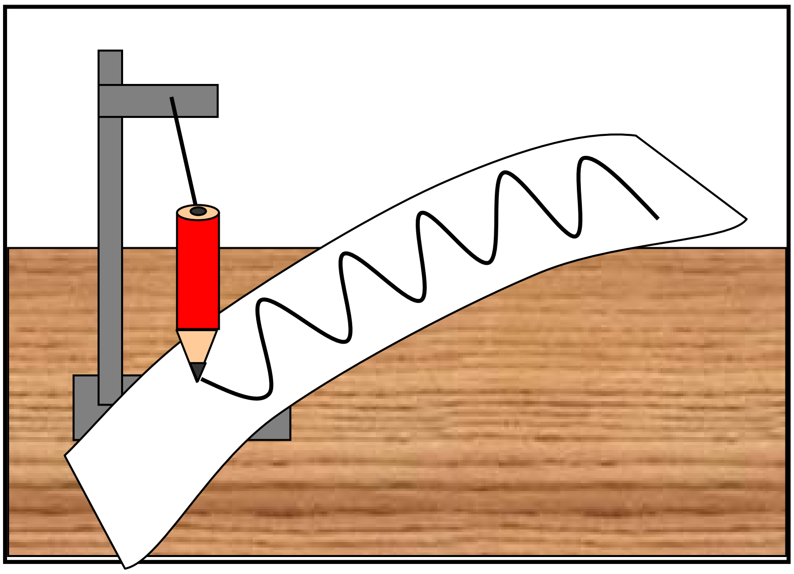
Note: the pendulum should only just touch the paper, so it is not pulled by it. A fairly heavy pendulum bob may be necessary.

Action

The students set the chart recorder going, or one of them carefully rolls the paper along so that it moves at constant rate below the pendulum. They then set the pendulum going and observe the trace left by the pendulum bob. They should be able to identify the resulting curve as a sinusoid.

The Physics

The pendulum undergoes simple harmonic motion (which is slightly damped). The line drawn is sinusoidal, and can be described by the equation $x = A\cos\omega t$, where A is the initial, and maximum, displacement, ω is the angular frequency of the motion and is equal to $2\pi f$ where f is the frequency of oscillation, t is the time, and x is the displacement at that time t. Note that due to damping the curve decays gradually in time.



Accompanying sheet

Charting Pendulum Motion

Set the paper moving along beneath the pendulum.

Now set the pendulum swinging **gently**.

What sort of curve does the pendulum draw?
Write an equation to describe this curve.
What sort of motion does the pendulum undergo?

Chladni's Plates

Apparatus

set of Chladni's plates (light metal plates held at the centre, in various shapes), violin bow or other bow, rosin for the bow, sand, salt shaker, tray, brush for clean up

The sand is kept in the salt shaker, so it is easy to shake evenly onto the plates.

Action

The students shake the sand into a thin (not solid) layer on the plates. Using the bow, they bow in long, even strokes, along the edge of a plate. A slow, steady stroke with the bow held almost vertical works well. This should produce standing wave patterns in the plate. The students can experiment with trying to find how many different patterns they can produce.

The students should also damp the plate while bowing. This is done by placing a finger firmly on the edge of the plate, while another student bows. This should change the pattern, drawing sand towards the finger.

The Physics

When you bow on the plate it will vibrate. The sand gathers in the nodes as it is shaken from the antinodes. The pattern depends on where you bow, and on the shape and size of the plate. The higher the harmonic, the more complex the pattern produced. Damping forces a node where you put your finger, changing the pattern.

Students at the Australian Catholic University producing patterns on a set of Chladni's plates.

Accompanying sheet

Chladni's Plates

Sprinkle some sand on one of the plates.

Bow firmly on the edge of a plate with long strokes.
What do you observe?
Explain what is happening here.

Use a finger to damp a spot on the edge of the plate while someone else bows.
Now what is happening, and why?

Curved Mirrors

Apparatus

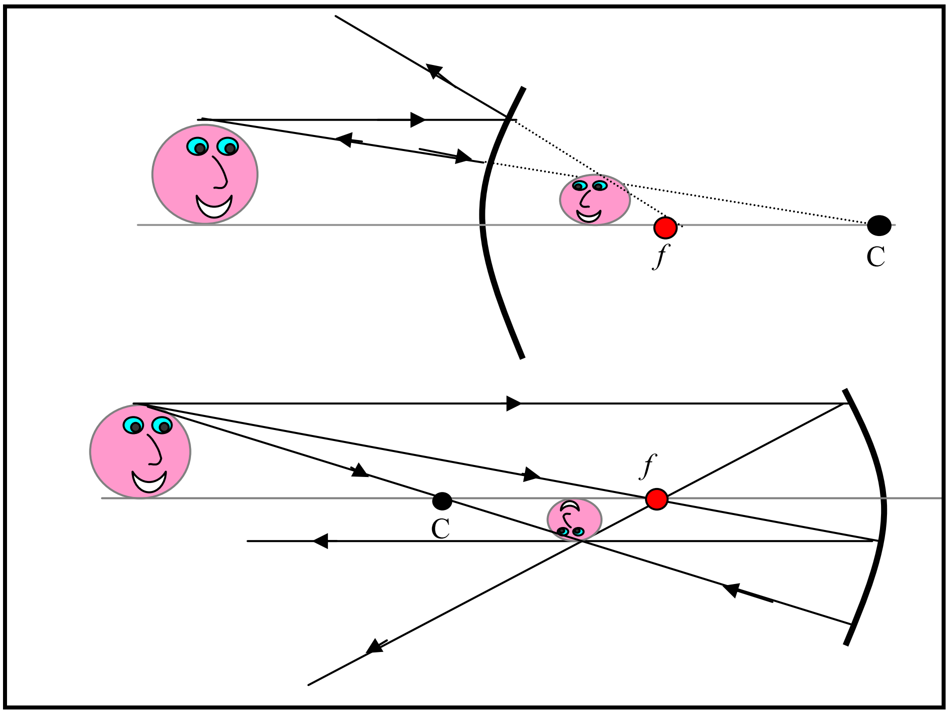
Curved mirrors, some concave and some convex

Action

The students observe the reflections in the mirrors. They should note whether the reflections are distorted, or magnified or reduced. They should deduce what sort of mirror they are looking into from this, and whether the image they see is real or virtual.

The Physics

The angle of reflection is always equal to the angle of incidence, so a concave mirror is converging, while a convex mirror is diverging. A convex mirror produces a virtual, upright, reduced image. A concave mirror will give you a real, inverted and reduced image unless the object is within the focal length. In which case the image is virtual, upright and enlarged, as is the case with the shaving mirror. See diagrams below. C is the center of curvature of the mirror, *f* is the focal point.



Accompanying sheet

Curved Mirrors

Look at your reflection in the mirrors.

What do you see?
What sort of image does each mirror produce?
Can you tell whether the mirrors are concave or convex?
What might these mirrors be used for?

Damped Oscillations

Apparatus

mass on spring hanging vertically from stand, bucket of water, stopwatch

Action

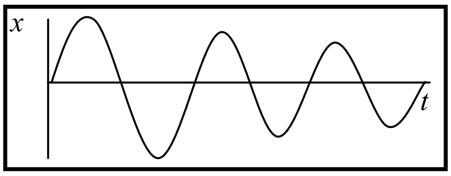
The students observe the oscillations of the mass on the spring in air. They should use the stop watch to time several periods and estimate a period from this. They then observe the oscillations when the mass is suspended in water. They should compare the periods of the oscillation in both cases, and how quickly the oscillations die out.

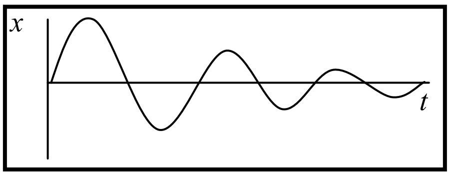
They can also experiment with their own joints, for example letting a knee swing freely.

The Physics

When the object is allowed to oscillate in air it takes a long time to stop, and the amplitude decreases very slowly. See top plot opposite. In water, the motion is strongly damped, and the oscillations decay and stop very quickly, as shown in the lower plot opposite. The damping makes little or no difference to the period.

Joints in the body are usually only slightly damped, and will swing freely for several oscillations. Muscles are heavily damped, and the lungs are close to critically damped.





The oscillations are quickly damped by the water.

Accompanying sheet

Damped Oscillations

Observe the oscillations of the spring-mass system in air.
Estimate the period of oscillation.

Now suspend the mass in the water.
Has the period of oscillation changed?
How has the motion changed?

Sketch amplitude vs time for the motion in air and the motion in water.

Diffraction Patterns

Apparatus

laser, piece of pantyhose material in a single layer.

Action

The students shine the laser light through the material and observe the resulting pattern. They then stretch the material and observe how the pattern changes.

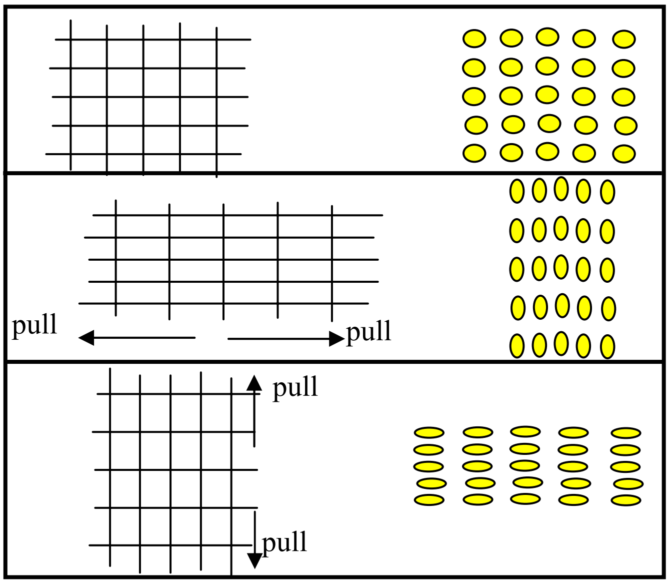
The Physics

The network of fine threads in the fabric forms a grating. When you shine the laser light through the fabric you see a diffraction pattern.

The spacing between the maxima in the pattern (bright spots) is inversely proportional to the grid spacing; $d \sin\theta = m\lambda$, can be used to find the grid spacing, d, given the angular separation, θ, of the maxima.

The diagrams show the fabric to the left and the diffraction pattern to the right.

When you stretch the fabric horizontally it also squeezes in vertically, the pattern will do the reverse of this, squeezing in horizontally and stretching vertically. When you stretch it vertically it will squeeze in vertically and stretch horizontally.



A piece of panty-hose material is used to make a diffraction pattern.

Accompanying sheet:

Diffraction Patterns

Shine the laser light through the fabric.

What sort of pattern do you see?

How does the pattern change when you stretch the fabric horizontally?
What about when you stretch it vertically?

Half a Lens

Apparatus

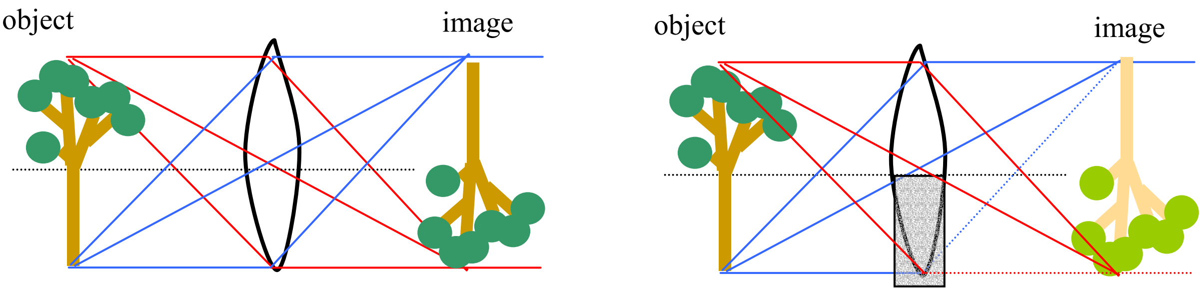
lens, light source, piece of paper

Action

The students use the lens to observe an image. They then predict what will happen to the image if the lens is partly covered by a piece of paper, giving only half a lens. *After* agreeing amongst themselves on their prediction, one student covers half the lens. They should compare their prediction to their observe, and attempt to explain any differences.

The Physics

When you cover half the lens you get a fainter image. Effectively you are cutting out half the light rays, but they still produce an entire image. In the diagram below you can see that rays from the top and bottom of the tree still pass through the top half of the lens to form. However half of the rays from all parts of the image are blocked, so that only half reach the image point, giving only half the intensity of the complete lens.
Note: it is particularly valuable to get students to predict what will happen in advance of doing the activity, as it is not an intuitive result for many people.



complete lens – bright image

half covered lens – faint image

Accompanying sheet

Half a Lens

Hold up the lens so that you create an image with it.

What do you think will happen to the image if you cover half the lens?
Discuss this in your group, and agree on your prediction.

Now cover half the lens.
What happens to the image?
Was your prediction right? Explain what has happened.

Interference

Apparatus

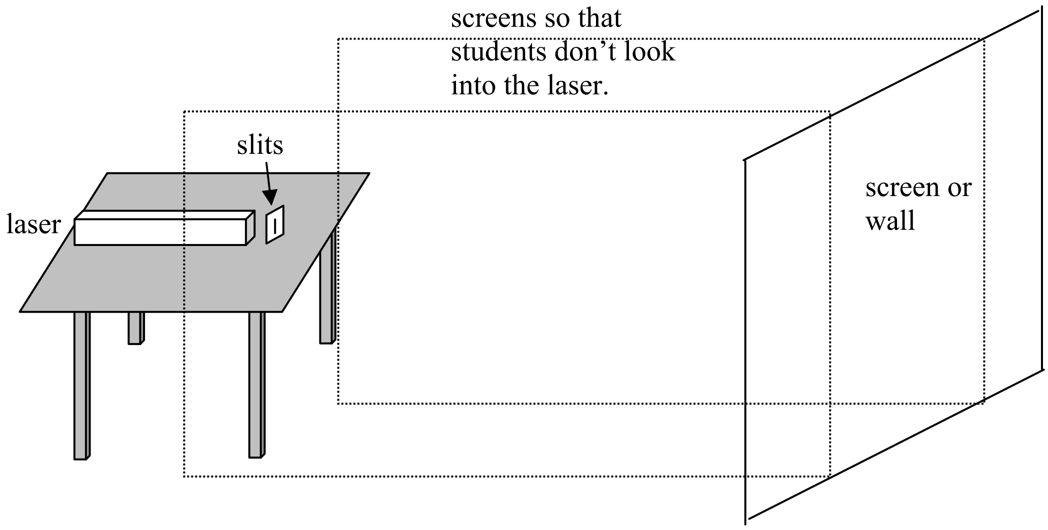
laser, slides with single and double slits

Action

The students use the laser to observe interference patterns.
The students are encouraged to draw diagrams showing why the interference pattern occurs.

The Physics

Waves passing through the two slits interfere to give a pattern of fringes, with spacing depending on wavelength and slit separation. The greater the slit separation, the closer together the fringes are. This shows the wave nature of light. Note that there are also diffraction effects visible.



Note: This is used with both the waves tutorials and the quantum tutorials.

Accompanying sheet

Interference

Observe the interference patterns with the laser and the double slits.

Sketch the pattern of intensity with position.

Why does this pattern occur?

Kaleidoscope

Apparatus

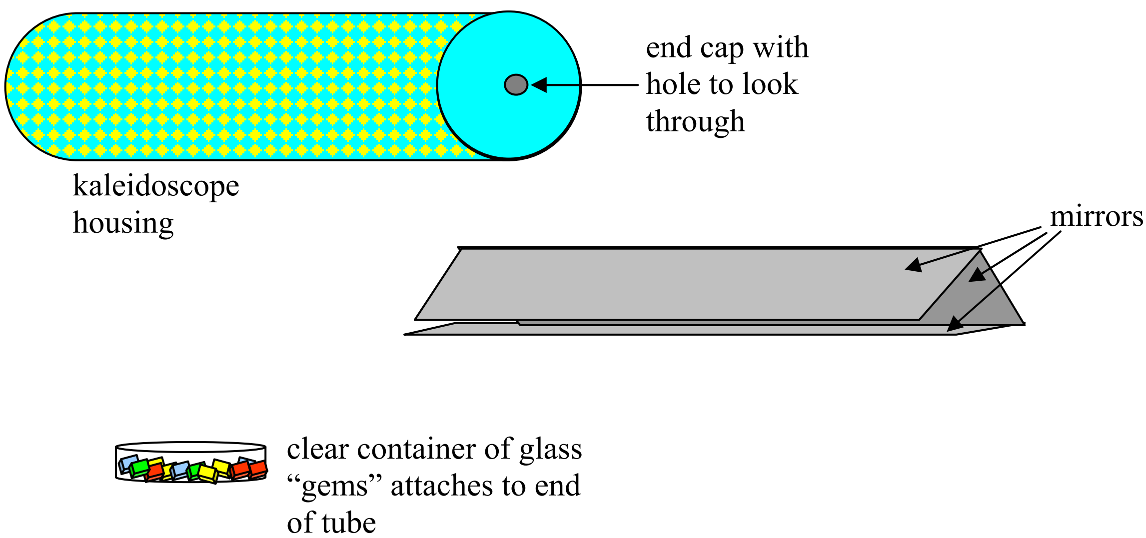
toy kaleidoscope from toy shop, light source, extra kaleidoscope, disassembled

Action

The students look though the kaleidoscope and attempt to explain how it works.

The Physics

The three mirror kaleidoscope makes a repeating pattern, with the number of images depending on the angles between the three mirrors. The two mirror kaleidoscope makes a circular pattern. Kaleidoscopes with four mirrors produce a line of images. Pictured below is the construction of a three mirror kaleidoscope. The mirrors are arranged in to form a long triangular tube with open ends which sits inside the kaleidoscope housing. When an object is viewed through the tube many images are seen, forming a pattern. Many kaleidoscopes come with an object such as a clear container of glass beads ("gems") attached to end to form sparkling patterns.



Accompanying sheet

Kaleidoscope

Look through the kaleidoscope.
What do you see?

How many images do you see?
How many mirrors does it contain?

You can check your answer by pulling apart the other kaleidoscope.

Lenses – Concave and Convex

Apparatus

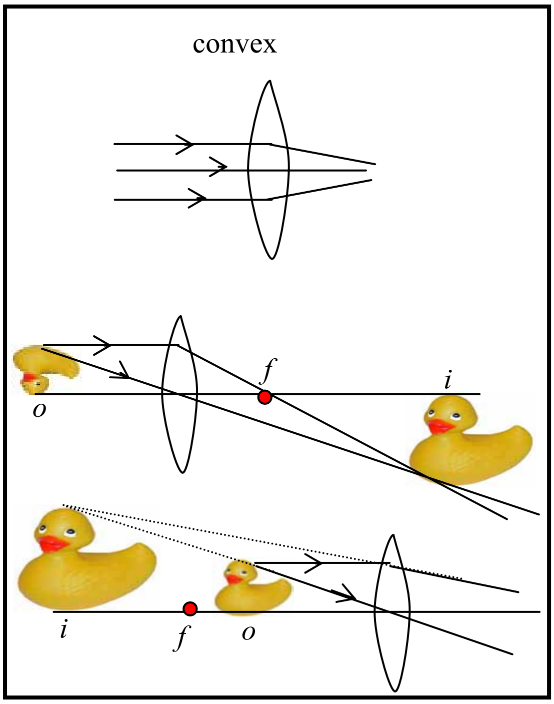
selection of lenses, collimated light source, e.g. light box or pencil torch

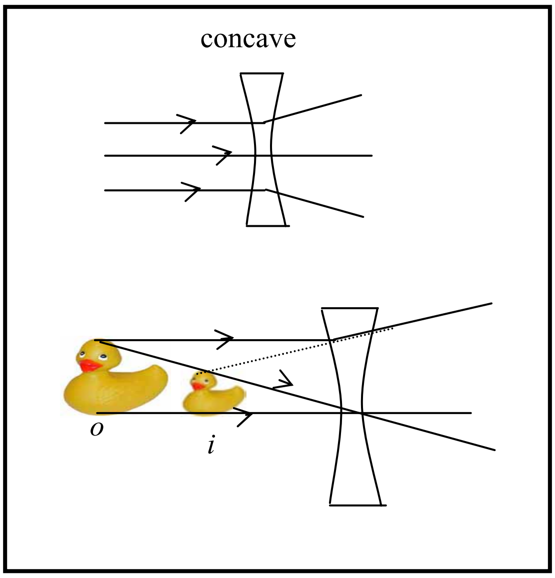
Action

The students observe the effect on light passing through the various lenses. They should try to describe any images they form in terms of magnification, upright or inverted, real or virtual. They should determine from the image produced whether a lens is concave or convex, and converging or diverging.

The Physics

Convex lenses are converging lenses, and concave lenses are diverging lenses. See diagram below. A convex lens gives a real, inverted image if the object is outside the focal length of the lens. It will give a virtual upright image if the object is within the focal length. A concave lens gives a virtual upright image.





Accompanying sheet

Lenses – Concave and Convex

Observe how the different lenses change the direction of the light rays.

Feel the different shapes and relate the shapes to the effect of the lens.

Which ones are converging? Which ones are diverging?

Lenses – Finding the Focal Length of a Convex Lens

Apparatus

convex lens, piece of paper, window or light source at opposite end of room or corridor

Action

A student holds the lens up towards the window, and holds a piece of paper on the other side of the lens. They then move the piece of paper towards and away from the lens until a focused image of the outside or a distant object such as a tree is formed. From the distance between the lens and the paper they can then find the focal length of the lens.

The Physics

Hold the lens up to the window and hold a piece of paper behind it (on the other side of the lens from the window). Move the paper until you get a sharp image of the world outside the windows (or distant object such as a tree). When you have a sharp image, you measure the distance between the lens and the image (paper). This distance is the focal length of the lens.

(Using $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$, and $o = \infty$ so that $\frac{1}{o} = 0$, gives $f = i$)

When the paper is held at a distance from the lens equal to the lens's focal length, an image of the window forms on the paper.

Accompanying sheet

Lenses – Finding the Focal Length of a Convex Lens

Hold the lens up to the window and hold a piece of paper behind it (on the other side of the lens from the window).

Move the paper until you get a sharp image of the world outside the windows, or a distant object such as a tree.

What is the focal length of the lens?

Longitudinal Waves

Apparatus

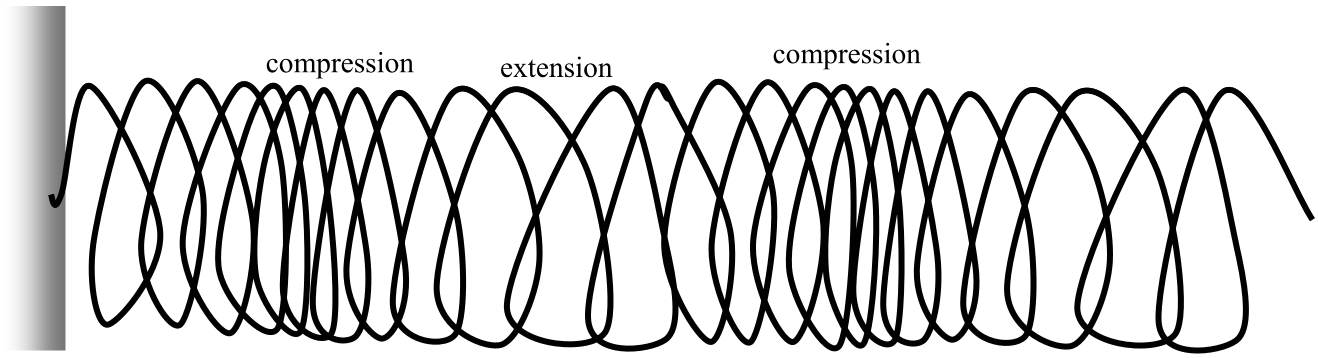
"slinky" or very large spring, fixed to the wall at one end

Action

The students hold the slinky taut and horizontal. They send a longitudinal wave along the spring by pulling at the free end, and allowing it move back again by a few centimetres. They should recognize that this is a longitudinal wave. They then experiment with changing the amplitude of the waves, and the wave speed by changing the tension of the slinky. The tension can be changed by stretching the slinky more or less.

The Physics

The amplitude of the wave does not effect the speed of the wave. The speed is determined by the medium it travels through, in particular it depends on the elastic and inertial properties of the medium, i.e. the tension and mass. You can change the wave speed on the slinky by stretching it more, and increasing the tension.



Accompanying sheet

Longitudinal Waves

Send a wave along the length of the slinky.

Does the amplitude of the wave affect the speed at which it moves?

How can you change the wave speed?

Caution: Please do not stretch the slinky too much!

Look and Listen

Apparatus

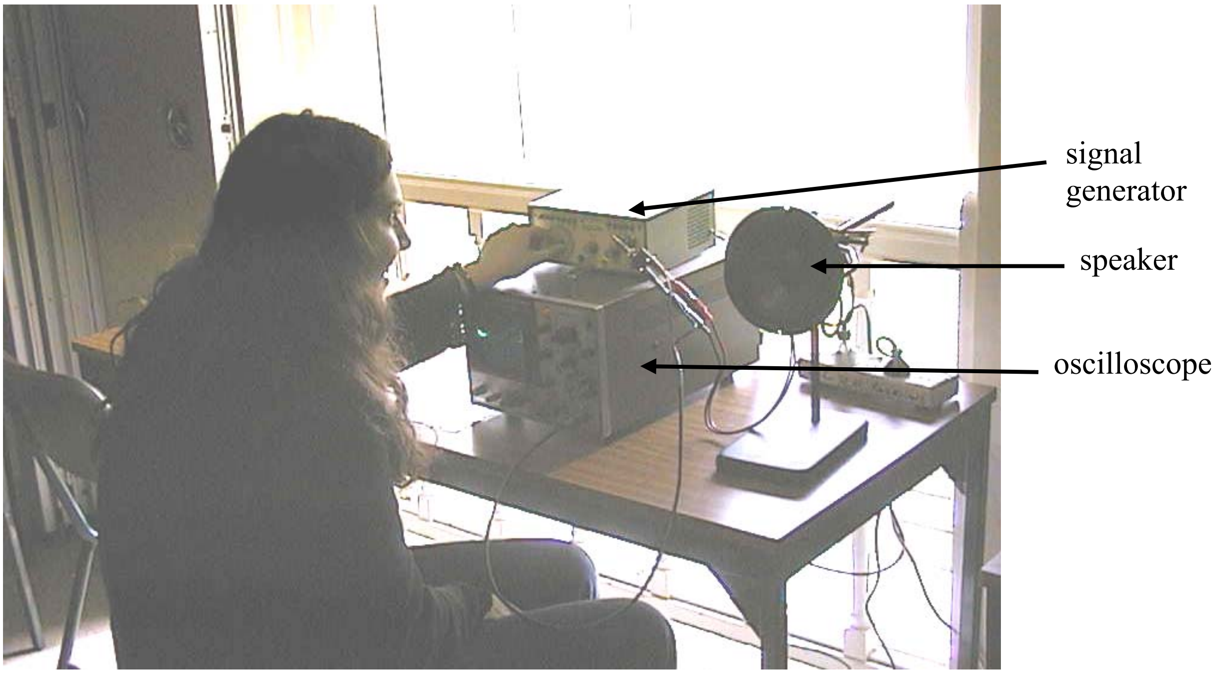
signal generator connected to an oscilloscope and a speaker

Action.

The students watch the display on the oscilloscope screen while adjusting the frequency and amplitude of the output from the signal generator. At the same time they listen to the changes in the sound produced via the speaker.

The Physics

Increasing the frequency shortens the period of the waveform, so the display shows more oscillations on the screen. The students also hear a higher pitch. Increasing the amplitude gives a "taller" waveform, and a louder sound, but does not affect the frequency (or pitch).



A University of Sydney student looking at and listening to waves.

Accompanying sheet

Look and Listen

A signal generator is connected to a loudspeaker and a CRO.

The CRO draws a graph showing variations in amplitude with time.

Describe what happens when you increase and decrease the frequency?
What do you see and hear?

What happens when you adjust the amplitude control?
(Remember that we only hear frequencies of ~ 20 Hz to 20 kHz.)

Losing Your Marbles

Apparatus

clear glass marbles, clear liquid with same refractive index as the glass marbles, for example sugar or salt solution or alcohol solutions, two glass beakers

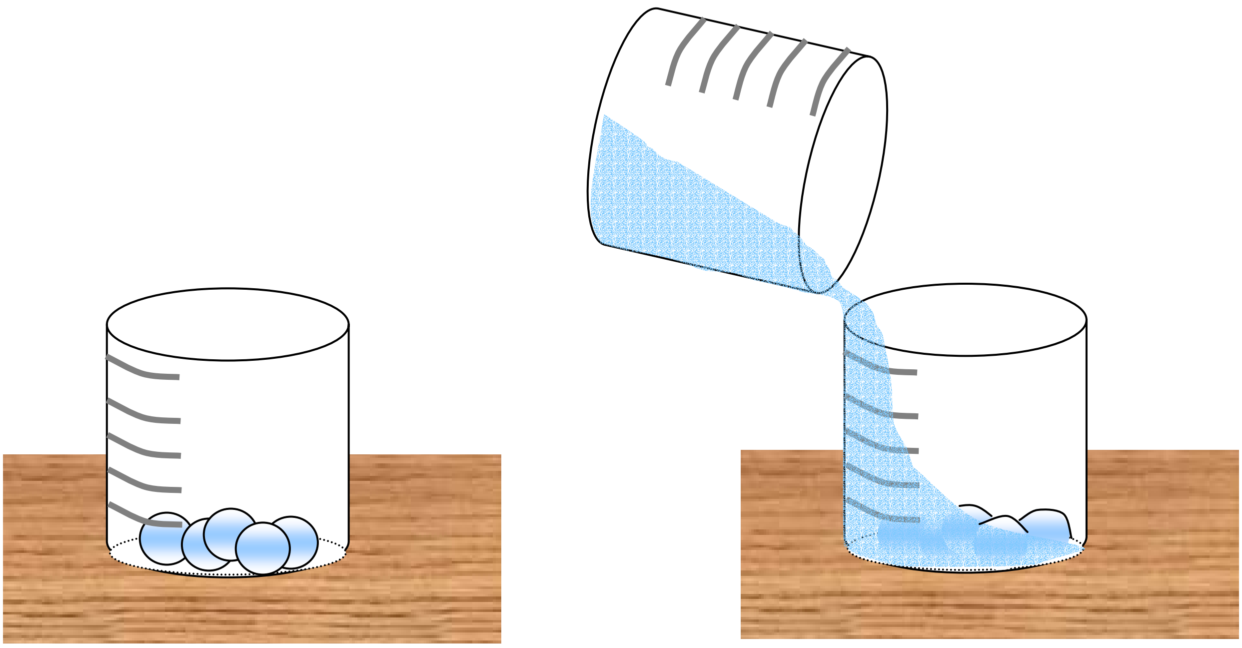
Action

The students observe the marbles in an otherwise empty beaker. They then pour the liquid into the beaker and explain why the marbles disappear.

The Physics

As long as the refractive index of the marbles and the liquid is the same, then light passing through the beaker will not be bent as it moves from water to marble to water again. If the marbles are transparent, they will be invisible in the liquid.

Note: There are many variations of this trick, for example hiding a whole test tube in a small tank of liquid, then dropping a broken one in and magically pulling it out good as new. These tricks make excellent lecture demonstrations, but broken glass should be avoided in tutorials.



Accompanying sheet

Losing Your Marbles

Pour the liquid into the container with the marbles in it.

Why do they appear to disappear?

What can you conclude about the refractive index of the marbles and the liquid?

Magnifying Glass

Apparatus

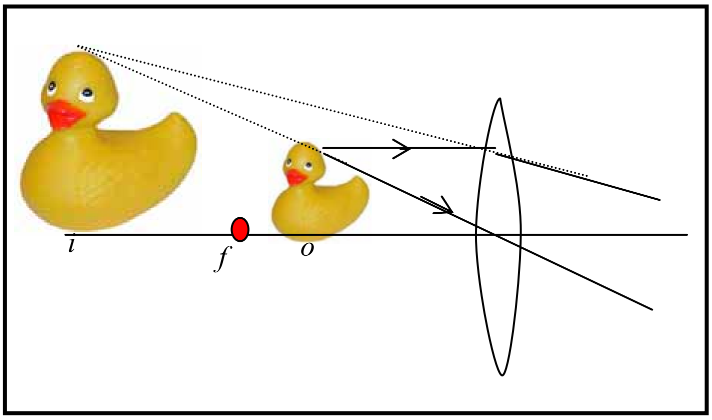
magnifying glass

Action

The students experiment with the forming images with the magnifying glass. They should draw a ray diagram showing the path of rays from an object seen through the magnifying glass to their eye. They should also determine what sort of image is formed by the magnifying glass, and whether is it a converging or diverging lens.

The Physics

A magnifying glass uses a convex lens, which is a converging lens to produce an image.
The image produced is upright, magnified and virtual as long as the object is at or within the focal length of the lens.



Accompanying sheet

Magnifying Glass

Look at a small object or fine print through the magnifying glass.
What sort of image is produced?

What sort of lens does a magnifying glass use?

Draw a ray diagram showing the path of a light ray from the object to your eye.

Microscope

Apparatus

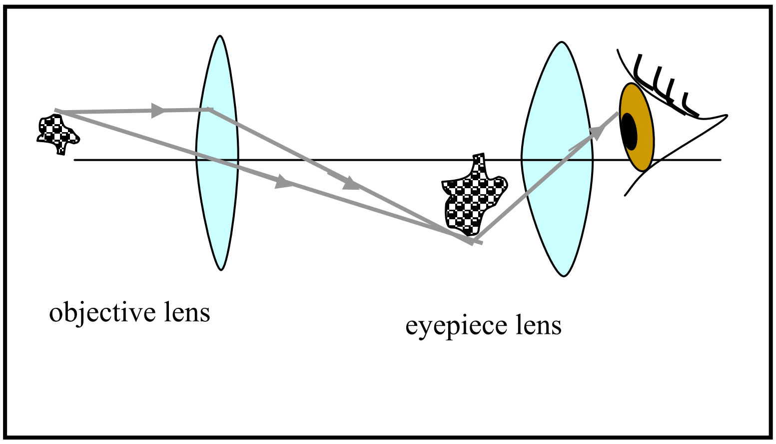
compound microscope and slides or small objects suitable for viewing through the microscope

Action

The students examine the slides or objects through the microscope. They should examine the lens system of the microscope, and draw a diagram showing how it works.

The Physics

A microscope is used to look at small objects close up. A simple microscope uses only one convex lens, and is really just a magnifying glass (described above). A compound microscope which is the most commonly used type, has a pair of convex lenses, as shown. The objective lens has a small focal length compared to the eyepiece lens. The image formed by the objective is viewed by the eyepiece which acts as a magnifier.



Accompanying sheet

Microscope

Use the microscope to look at a small object.

Examine the lenses in the microscope.

Describe how the microscope works.

What is the difference between a simple and a compound microscope?
What sort do you have here?

Oscillations of a Spring-Mass System

Apparatus

a stand with a variety of different springs, and at least two identical springs, a selection of masses which can be hung from the springs, stopwatch

Action

The students hang the masses on the springs and use the stop watch to investigate the effects of mass on period of oscillation. They can also investigate the effect of spring constant and amplitude of oscillations.

Caution: students should be warned to not stretch the springs too far as masses can fly off.

The Physics

If two identical objects are attached to identical springs, they both have mass *m* attached to a spring with spring constant *k*, so the periods of oscillation of the two springs are the same and are equal to $T_1 = T_2 = 2\pi\sqrt{\frac{m}{k}}$ .If one of the springs has a bigger mass attached to it, the period will be longer; if $m_2 > m_1$ then $T_2 > T_1$. Changing the spring constant also changes the period, if $k_2 > k_1$ then $T_2 < T_1$

For simple harmonic motion the period is independent of amplitude, i.e. extension does *not* affect the period of oscillation, hence stretching the spring more to start with makes no difference to period.

Accompanying sheet

Oscillations of a Spring-Mass System

Two identical objects are attached to identical springs.
How do their periods compare?

If the mass of one of the objects is increased
will there be any difference in the periods of the two systems?

If one of the springs is replaced with one with a larger spring constant,
how will this affect the period of oscillation?

Does the extension (small or large amplitude) affect the period of oscillation?

Polaroid Glasses

Apparatus

several pairs of Polaroid sunglasses and some non-polaroid glasses

Action

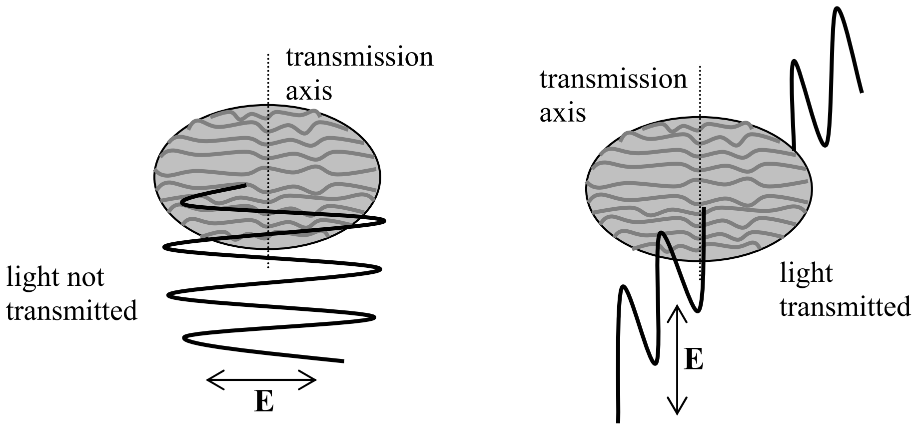
The students look through the various pairs of glasses, and determine which ones are Polaroid and which are not. By observing a reflection of sunlight off a desk top they can determine the axis of polarization of the glasses. The students look at a patch of glare through the glasses, and observe the effect of turning the lenses through 90^o.

The Physics

A pair of polaroid glasses can be found by holding two pairs of glasses at right angles and looking at a light source. When a pair is found such that light does not pass through them when the lenses are at right angles, both are polaroids. Once one pair is identified, one of the sets of polaroid glasses can be used to test the others.

Polaroid sunglasses use long chain molecules in a coating on the lenses. These molecules are aligned and have delocalised electrons, which are free to move along the chains. When light is incident on the lenses, electric fields parallel to the direction of the chains cause the electrons to oscillate, and lose energy to the electrons. Hence electric fields parallel to the molecular chains do not pass through the lenses. The transmission axis is perpendicular to the direction of the molecular chains. Electric fields in this direction pass through the lenses. Hence the lenses transmit light which has its electric field oscillating in one direction but not the other.

Sunglasses are useful for cutting out glare. The glare is due to light reflected from the horizontal surface, which is mostly horizontally polarised. Glare from water or shiny horizontal surfaces is effectively reduced by good sunglasses. Hence the transmission axis for the glasses must be vertical.



Accompanying sheet

Polaroid Glasses

Experiment with looking through the glasses.

Which ones are Polaroid, and which are not?
How can you tell?

Observe a patch of "glare" from a desk near the window.
Rotate the glasses while looking through them at the glare?
Determine which way the transmission axis of the glasses goes.

Prism

Apparatus

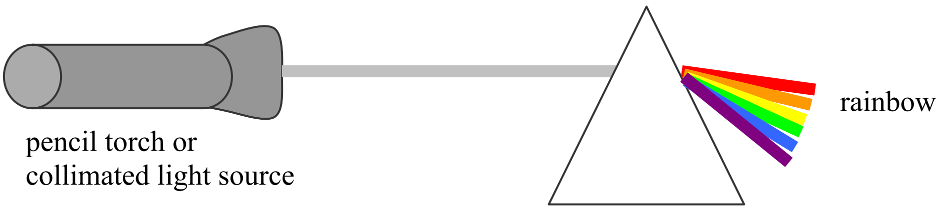
light box with collimated beam or pencil torch, prism

Action

The students shine the light through the prism and experiment by varying the angle between the beam and the side of the prism. They should observe a rainbow coming out of the prism at angles less than the critical angle.

The Physics

When light moves from air into the prism the light is refracted or bent, and it is bent again as it leaves the prism. The prism has a refractive index which varies for different wavelengths. The refractive is greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component. If a laser was shone through the prism, only a single colour would emerge as laser light is (approximately) monochromatic.



Accompanying sheet

Prism

Shine the light through the prism.

What do you see going into the prism?
What do you see coming out?

Which is refracted (bends) more – light of long or short wavelength?

Real and Virtual Images

Apparatus

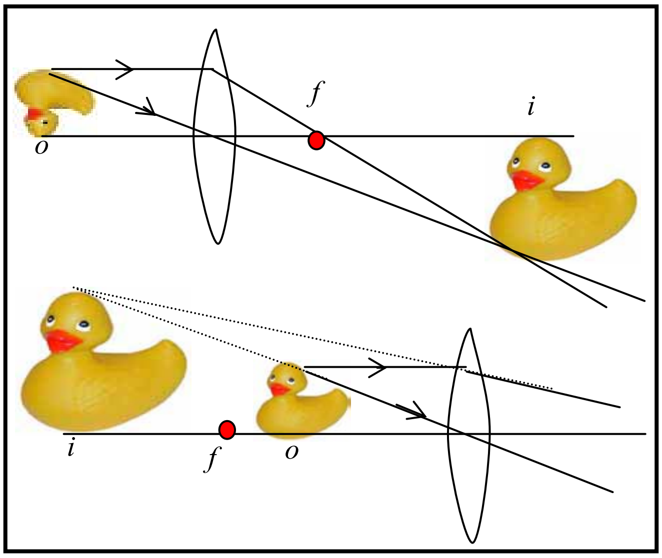
slide projector and magnifying glass

Action

The students examine both the slide projector and magnifying glass. They form an image using each, and draw a ray diagram showing how the images are formed. They then determine whether the images are real or virtual.

The Physics

A slide projector produces a real, inverted and magnified image. The image must be real, because otherwise you wouldn't be able to project it onto a screen. The image is inverted, so the slides have to be put in upside down. A projector uses a convex lens.
A magnifying glass also uses a convex lens. The image is upright, magnified and virtual. The object must be at or within the focal length of the lens.



Accompanying sheet

Real and Virtual Images

Examine the slide projector, and use it to produce an image.
Draw a ray diagram showing how the projector produces an image.
What sort of an image is this? How can you tell?

Now use the magnifying glass to produce an image.
Draw a ray diagram to show how this image is formed.
What sort of image is this one?

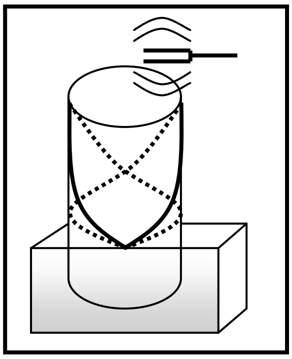
Resonance in a Tube

Apparatus

long plastic or glass tube, container of water, tuning forks

Action

The students strike the tuning fork and hold it at the top of the tube. They then raise and lower the tube and listen to the sound get louder and quieter. They should try to find the resonance length, and from this they can find the frequency which the tuning fork produces.



The Physics

The air in the tube will resonate when the length of the air column = ¼ nλ and λ is the wavelength of the sound produced. The upper end is a displacement antinode and the lower end is a node. Using $v = f / \lambda$, and the speed of sound in air, 340 $m.s^{-1}$, the students can calculate the frequency emitted by the fork.

Students at the University of Sydney experimenting with the resonance in a tube activity. The student on the left is raising and lowering the tube, which is partly immersed in a cylinder of water. The student on the right strikes and holds the tuning fork.

Accompanying sheets:

Resonance in a Tube

Strike a tuning fork and hold it above the tube.
Vary the height of the tube with the fork above.
What do you observe?
Why?

Now try it again with the other tuning forks.
What relationship is there between the sound you hear and the length of the pipe?

Right Angled Mirrors

Apparatus

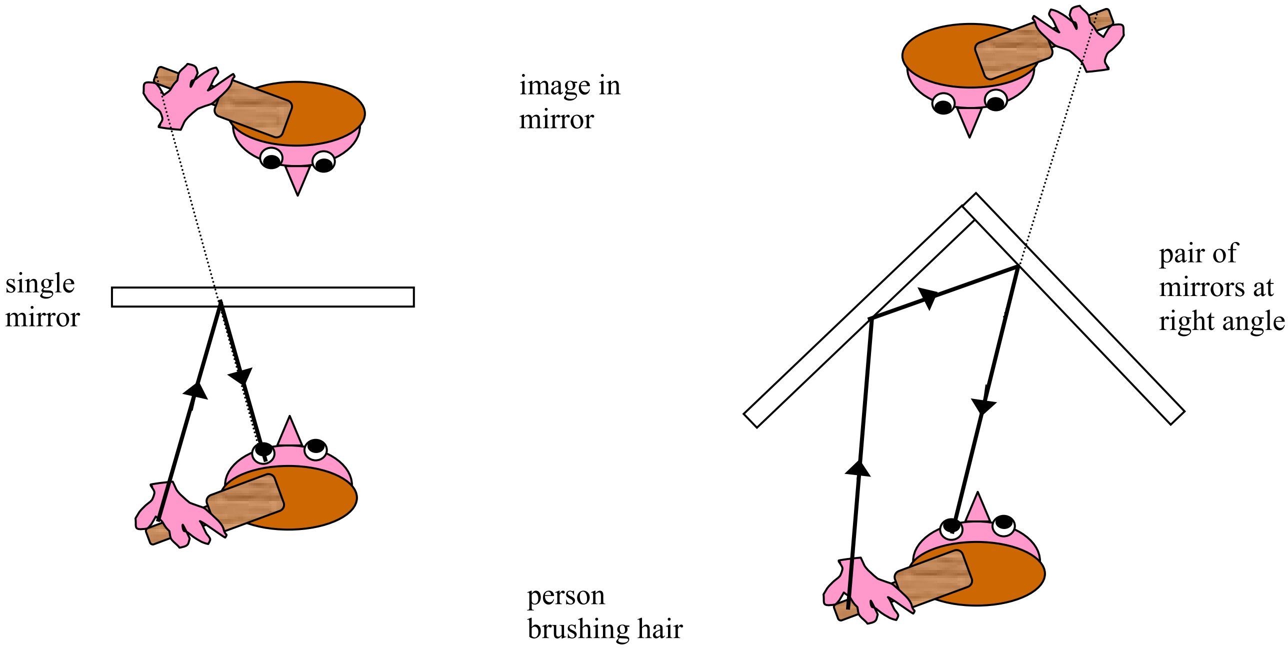
two flat rectangular mirrors, stuck together at the edge to form a right angle, see below

Action

The students look at their reflection in the mirror. They move their hand and see which way they move in the reflection. It may be interesting to ask them to pretend to brush their hair, or some other task done in front of a mirror.

The Physics

See diagram below. In the right angled mirrors the reflection is *not* left-right reversed, as in a single mirror. This can be somewhat disorienting, as we are used to seeing a reversed reflection. The ray diagram can be constructed as shown below



Accompanying sheet

Right Angled Mirrors

Look at your image in the mirror.

What do you notice when you move your hands?

How is this different to a single mirror?

Draw a ray diagram showing the path of a light ray from your hand to your eye.

Ripple Tank I – Making Waves

Apparatus

Ripple tank with various attachments for oscillator, e.g. point source, long bar source for plane waves, etc, stroboscope, ruler

Action

The students experiment with making different waves of different shape and frequency. Using the stroboscope to "freeze" the waves, they measure the wavelength of the waves. They should look at the effect on wave speed and wave length of varying the frequency.

The Physics

The point oscillator will produce circular wave fronts. The long rod oscillator produces plane waves. Changing the frequency changes the wavelength, λ, of the waves produced, but does not affect the speed. The speed depends only on the medium, which is not changing.

Accompanying sheet

Ripple Tank I – Making Waves

Experiment with the different oscillators.
What sort of shaped waves can you produce?

Using the stroboscope, try to measure the wavelength of the waves.
How does the wavelength change when you change the frequency?

Do you think the wave speed changes when you change the frequency?

Ripple Tank II – Interference and Diffraction

Apparatus

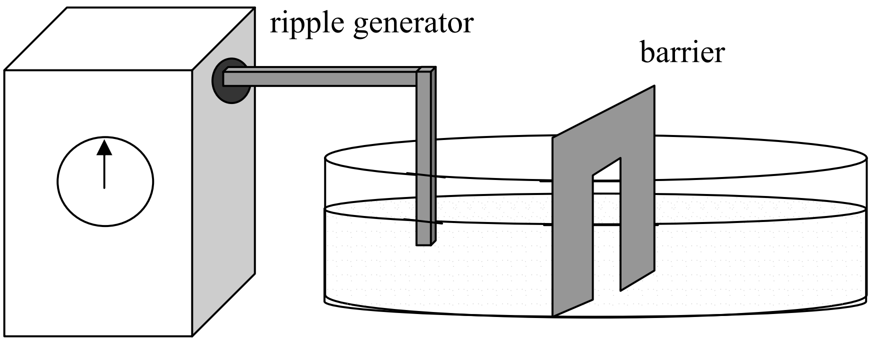
A ripple tank with long source to produce parallel plane waves, several barriers of different sizes and various slits

Action

The students investigate the patterns formed when the waves diffract around objects of various sizes, and through slits of various widths. They also observe interference patterns using multiple slits or sources.

The Physics

Waves passing around objects will show diffraction, as the waves bend around the objects. Waves will pass around small objects with very little bending, but show large diffraction effects with objects of similar size to the wavelength. Waves passing through the two slits interfere to give a pattern of fringes, with spacing depending on wavelength and slit separation. This can also be observed using two in phase sources.



Accompanying sheet

Ripple Tank II – Interference and Diffraction

Use the long wave source to produce parallel wave fronts.

What happens when you put a small object in front of the wave?
What about a larger object?

What happens when these waves pass through a small gap in a barrier?
Explain your observations.

Shaving Mirror

Apparatus

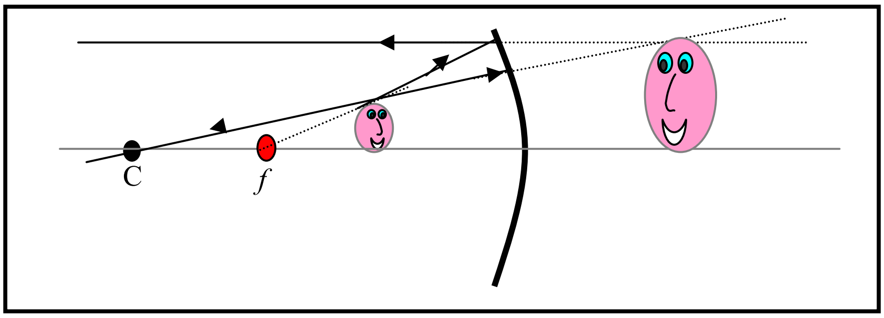
shaving mirror

Action

The students observe their reflection in the mirror, and determine what sort of image is formed and whether the mirror is concave or convex.

The Physics

A shaving mirror gives an enlarged image. The mirror is concave. You must have your face within the focal length of the mirror, to get an upright and enlarged image. If you move far enough away from the mirror your reflection will invert and become smaller when you move outside the focal length (but this is a long way).



Accompanying sheet

Shaving Mirror

Look at your reflection in the shaving mirror.

What do you notice about the reflection?

Examine the mirror closely.
What can you say about the shape of the mirror?

Single Slit Diffraction

Apparatus

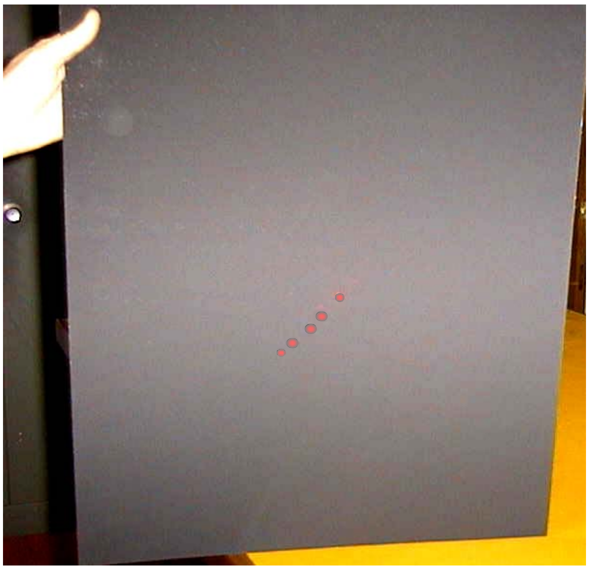
laser with single slits of various sizes

Action

The students observe the diffraction pattern formed by passing the laser light through the single slit. They can experiment with the different slits, and arrive at a relationship between the fringe spacing and the slit width.

The Physics

Diffraction patterns occur when light passes through a single slit. A diffraction pattern is an interference pattern due to the path difference between light arriving at a point from the left hand side of the slit and light arriving from the right hand side of the slit. A slit of width a will give a path difference of $a \sin\theta$ for the two rays. The diffraction minima occur when the path difference is equal to a multiple of $\frac{1}{2}\lambda$, i.e. where $a \sin\theta = \frac{1}{2} m\lambda$, so $\sin\theta = \frac{1}{2} m\lambda/a$. The wider the slit, the smaller the spacing between fringes will be.



Accompanying sheet

Single Slit Diffraction

What sort of pattern do you expect when waves (such as light) pass through a single slit?

Shine the laser light through the single slit.
What sort of pattern do you observe? Why?
How does this match your prediction?

Try the other slits.
What effect does changing the slit width have on the pattern?

Speed of Light

Apparatus

microwave oven, tray or plate of marshmallows, ruler

Note – this also works with a layer of cheese on toast.

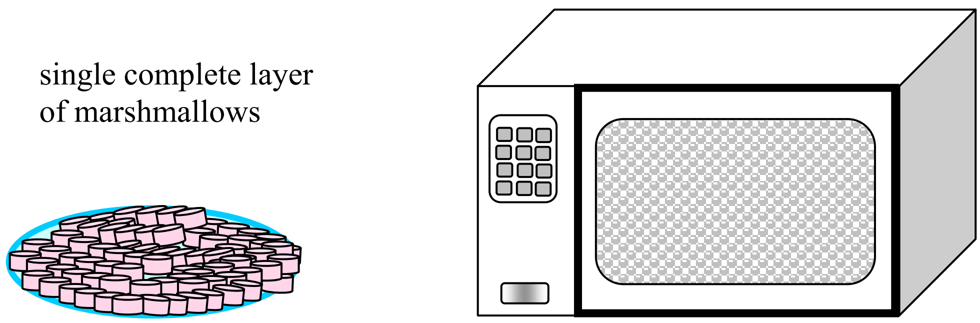
Action

The rotating plate should be removed from the microwave or the rollers beneath the plate, so that the tray can sit still in the microwave. The marshmallows should be placed in a single complete layer on the tray, and placed in the microwave. The microwave is then turned on. The students (**and tutor**) should watch carefully while the microwave runs, and when sections of marshmallow begin to melt. The microwave should be turned off immediately and the marshmallows allowed to cool for a minute. The students them measure from melted patch or line to the next melted patch or line and calculate the wavelength of the standing waves in the microwave from this.

The Physics

The melted patches occur at antinodes in the standing wave pattern inside the microwave. The distance between two antinodes is ½ λ,. The speed of light can then be found using $c = \lambda f$, where the frequency, f, is read off the compliance plate on the back of the microwave. The resulting speed should be within ~ 30% of the accepted value. Not that this is not a particularly accurate method, but does supply post-tute snacks.

Note: some caution needs to be exercised as the melted marshmallows are very hot. This activity is best done with small groups. (Molten marshmallow makes an excellent filling between two plain biscuits.)



Accompanying sheet

Speed of Light

Arrange the marshmallows carefully on the tray in a single layer.
Put the tray in the microwave.

While watching carefully, turn the microwave on.
Stop the microwave as soon as patches of marshmallow begin to melt or bubble.

Measure the distance between melted patches, and calculate the speed of light.

Standing Waves on a String

Apparatus

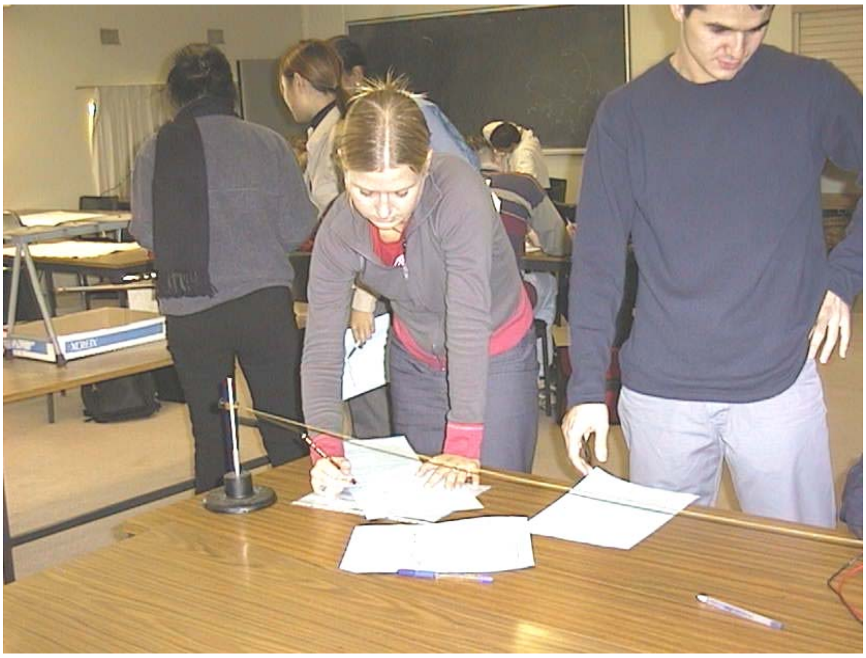
taut cord or wire attached to oscillating driver with frequency control, the driver with amplifier is attached to one end of the cord, the other end is fixed.

Action

The students vary the frequency of the oscillator to produce standing wave patterns. They can vary the tension in the string by stretching it and see the effect that this has on the frequencies required to produce standing waves.

The Physics

The standing wave is set up by the superposition of waves traveling from the oscillating end of the string and waves reflecting back from the fixed end. Only certain wavelengths are possible for the standing waves; $\lambda = 2l/\text{n}$, where l is the length of the cord and n = 1, 2, 3… The velocity of the wave is fixed by the properties of the string, so the frequencies at which standing waves occur are $f = v/\lambda = nv/2l$.



Students at the University of Sydney making waves on a string.

Accompanying sheet

Standing Waves on a String

Change the frequency to find harmonics and
sketch the patterns on the string.
How are standing waves formed?

How many harmonics can you see?

Change the tension and see what happens.
How does the pattern change?

Stress Lines

Apparatus

light source, such as overhead projector, sheets of Polaroid, piece of perspex with adjustable screws in it

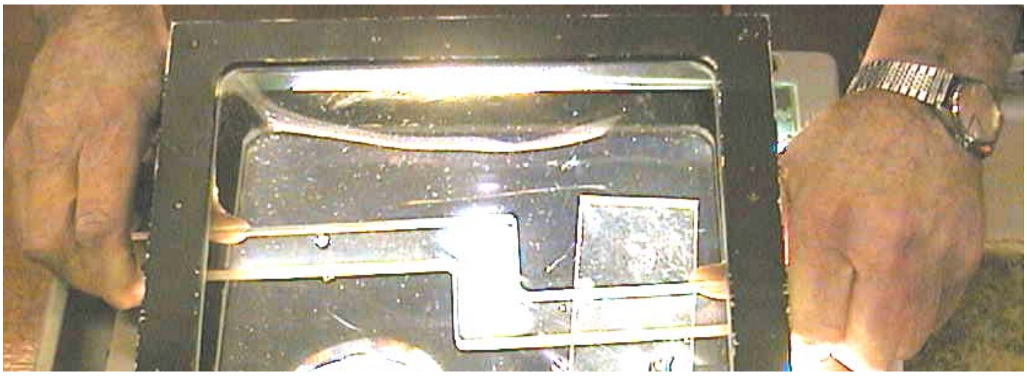
Action

The students place a sheet of Polaroid on the light source, the perspex block above that sheet, and a second sheet above the block. They observe the Perspex block through the upper sheet of Polaroid, while rotating the sheet. They then adjust the screw in the block to see how the patterns of stress lines change.

They may also want to look at a pair of spectacles between the polaroids, as they often show patterns of stress around the edges of the lenses, particularly on old pairs which have been damaged or twisted.

The Physics

The molecules in the perspex are stretched by the applied stress, and align like the molecules in the sheets of polaroid. When viewed between two crossed polaroids, the light areas show where the material between the polaroids is rotating the polarisation axis of the light coming through the first polaroid. This is a very useful technique, and is called optical stress analysis. Engineers use it to look for stress in models of structures. You will probably be able to see stress lines in the lenses of a pair of spectacles, showing the lenses have been stressed to fit them into the frames, or where the lenses are stressed due to damage to the frames, for example by dropping or sitting on the glasses.



The areas under stress are visible as bright areas, letting the polarized light pass.

Accompanying sheet

Stress Lines

Examine the stressed Perspex between the sheets of Polaroid.
What happens when you increase the stress?

If someone in your group wears glasses,
ask them to let you see them between the sheets of Polaroid.
Can you see stress lines in the glasses?

Can you think of a way this effect might be useful?

Sunset in a Jar

Apparatus

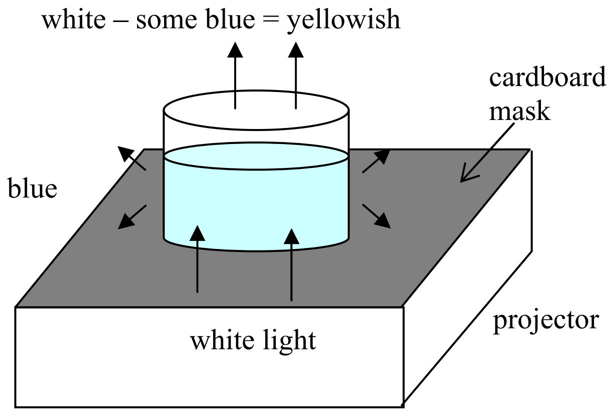
large glass beaker with water and a few drops of milk, overhead projector, cardboard mask
The cardboard mask is a piece of heavy, ideally black, card, with a circular hole cut in it of the same diameter as the beaker, or slightly smaller. The card sits on the overhead projector, with the beaker on top, lined up over the hole.

Action

The students observe the colour of the light coming out the sides of the beaker, scattered by the milk and water. The light coming out the top should be projected onto a white wall or screen, so that the colour of this transmitted light can be seen. They should be able to explain why the sky on Earth is blue.

The Physics

The milky water scatters the blue light more than other colours, so you should be able to see a faint blue tinge to the light coming from the sides of the beaker. This is like a very small but condensed version of the atmosphere scattering the light from the sun. The sky on Earth is blue because we are seeing light scattered by the atmosphere. If you looked directly at the sun (which you should never do!) it would look yellow, like the light coming out the top of the beaker. At sunset, the sky around the horizon where the sun is setting often looks reddish or orange. This is because the light is traveling through a greater thickness of atmosphere, so the amount of blue lost from the beam is greater and it appears more red, like the light from the top of the beaker



Accompanying sheet

Sunset in a Jar

Look at the light transmitted through the top of the beaker.
What do you notice about its colour?

What do you notice about the light coming out the sides of the beaker?
Explain the difference in these colours.

Explain why the sky on Earth is blue.
Why is it different at sunset?

Telescope

Apparatus

small astronomical (refracting) telescope, and/or cut open telescope showing the arrangement of lenses

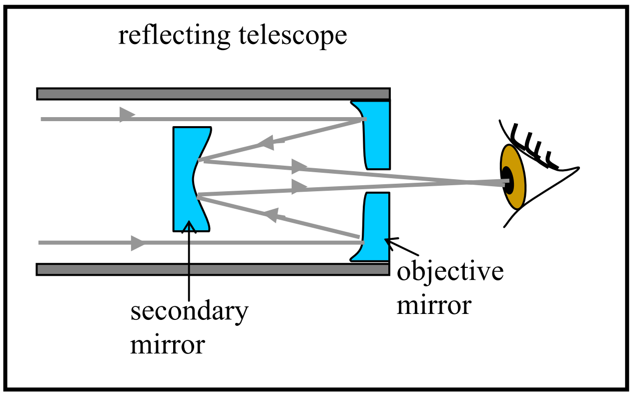
Action

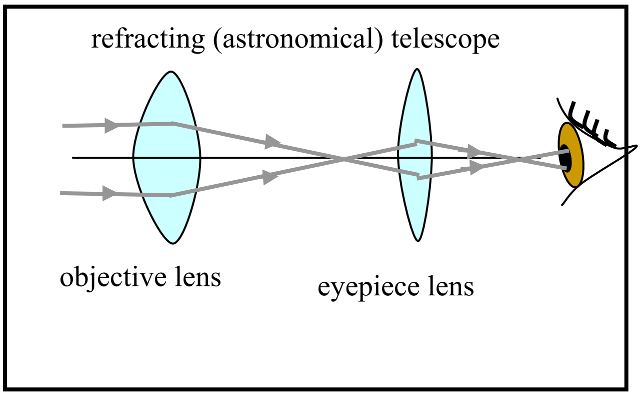
The students look through the telescope, and identify the type of image that they see. They should identify the type of telescope they have, and draw a schematic diagram showing the main optical elements.

The Physics

A telescope is used to look at (relatively) large objects a long way away. The telescope on the left is a reflecting telescope. It uses concave mirrors to produce a real, enlarged image at the eye. Rays from a distant object come in approximately parallel and are converged by the mirrors. The telescope on the right is a refracting telescope, also called an astronomical telescope. This telescope uses a pair of convex lenses to produce a real, enlarged, upright image. The focal length of the eyepiece should be much smaller than the focal length of the objective lens.

The telescope that you used was a refracting telescope. This is the common sort of simple astronomical telescope or spotting telescope.





Accompanying sheet

Telescope

Look at the diagrams shown.
What sort of telescopes are these? Explain how they work.

Now examine the telescope on display.
Use the telescope to view a distant object out the window.
What sort of telescope is this?

Thumb in Your Eye

Apparatus

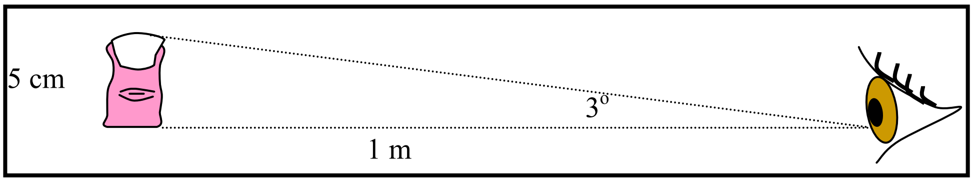
nothing – students use own thumbs, and ruler or tape measure if necessary

Action

The students hold their thumb at arms length and look at it. They then calculate the angle subtended at their eye by their thumb.

The Physics

When you hold your thumb at arms length it is approximately a metre away, and is about 5 cm tall. The angle subtended is only 3^o. The resolving power of the eye is very good, and it is easy to resolve small features on your thumb which have an angular separation much less than this.



Accompanying sheet

Thumb in Your Eye

Hold your eye at arms length and look at it.
How can you work out the angle subtended at your eye by your thumb?

What does this tell you about the resolving power of the eye?

Total Energy of a Spring-Mass System

Apparatus

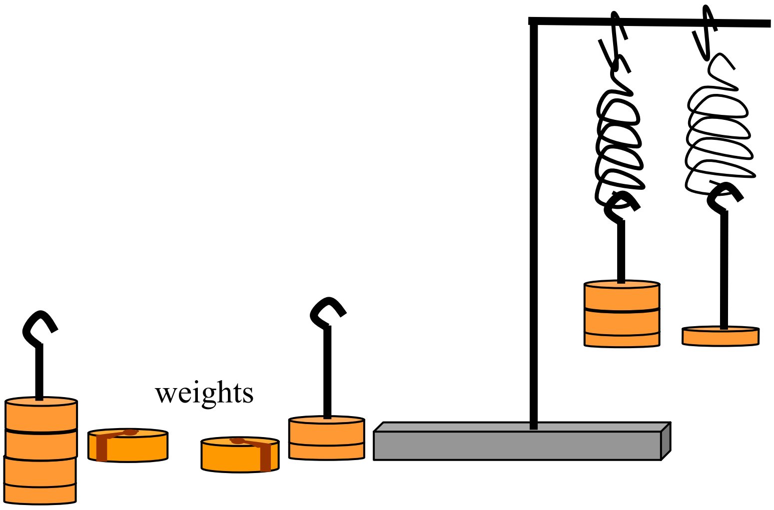
two springs with different spring constants and same lengths, suspended from a stand, with a selection of masses with mass holders

Action

The students hang weights on the two springs such that they have the same extension. They should discuss which system will have the greater energy when it is set oscillating, and which will have the greater period. They then test their prediction of which will have the greater period.

The Physics

When mass m_1 is hung from spring A and a smaller mass m_2 is hung from spring B, the springs are stretched by the same distance. Using $F = mg = k\Delta x$, if Δx is the same for both springs, but the mass on A is greater, then the spring constant of A, k_A, must be greater than that for B, k_B.
The elastic potential energy is $\frac{1}{2} kx^2$. As both systems are at the same extension, x, but A has a greater k, spring A has more elastic potential energy than B.
When the springs are stretched then released and allowed to oscillate, the initial elastic potential energy is converted to kinetic energy and gravitational potential energy, but the total energy is conserved.
The period is equal to $T = 2\pi\sqrt{\frac{m}{k}}$, but we know that $\Delta x = mg/k$ was the same for both springs, therefore T will be the same.



Accompanying sheet

Total Energy of a Spring-Mass System

The two springs have different spring constants.
Hang weights on the springs such that they have the same extension.

Which spring will have the greater energy for a given amplitude of oscillation?

Which will have the longer period?
Test your prediction.
Explain what happens.

Total Internal Reflection

Apparatus

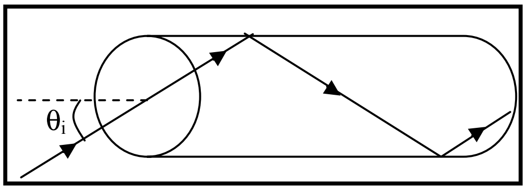
laser, length of fibre optic cable or large Perspex rods

Action

The students shine the light into the cable, and observe where it goes. They can experiment with bending the cable, and if it is a wide cable, with the angle of incidence of the beam onto the end of the cable.

The Physics

The light ray that enters the cable is totally internally reflected provided the incident angle, θ_i, is greater than the critical angle. Light is trapped inside the cable and almost none gets out the sides.



All the light from the laser exits the end of the Perspex rod.

Note: this can also be done using water rather than fibre optic cable or perspex

Accompanying sheet

Total Internal Reflection

Shine the light into the cable.

Can you see the light through the sides of the cable?
Where is the light going, and why?

What happens when you bend the cable?
(Be careful not to break it!)

Caution- do not look into the beam!!

Transverse Waves

Apparatus

torsional wave device – see picture below

These can be easily made using a length of string or two strips of sticky-tape and icy-pole sticks or drinking straws. The device can be hung from a stand or attached to the ceiling if very large.

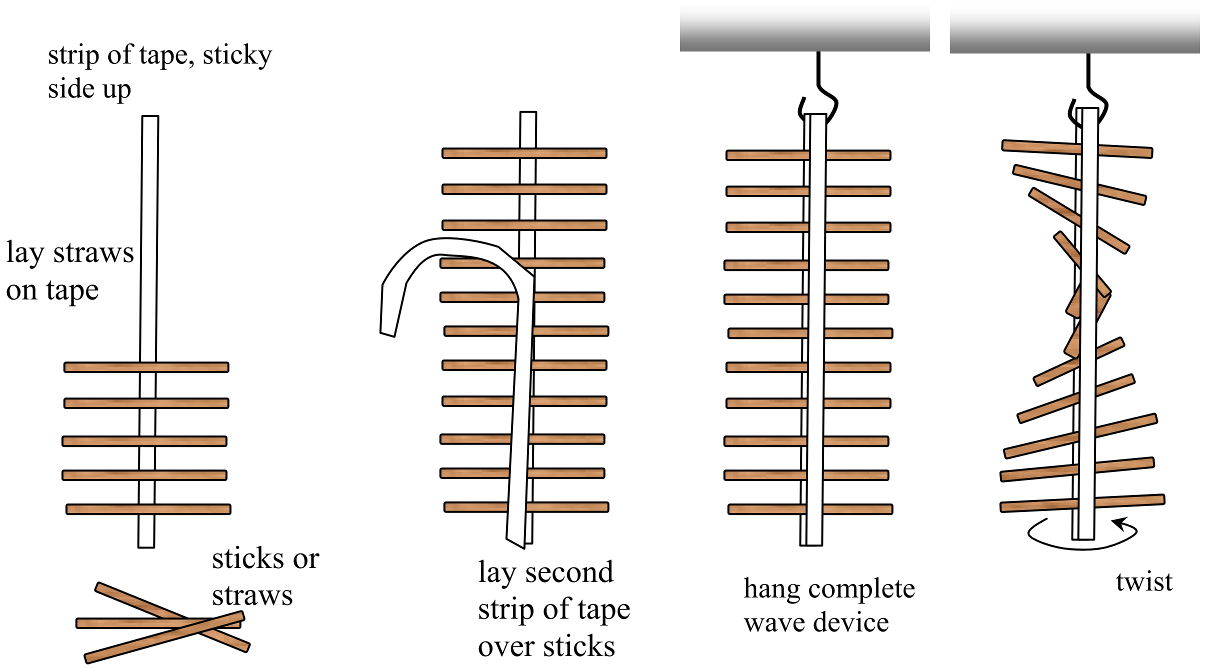
Action

The students twist the bottom straw or stick, and then release it. This causes a torsional wave to travel up the string, and reflect off the fixed top end.

The Physics

The wave produced is a transverse wave, the direction of displacement of the particles (the rods) is perpendicular to the direction of travel of the wave. It is different to more familiar transverse waves, such as waves on a vibrating string, in that the displacement is due to twisting, and the amplitude would be described by an angle rather than a linear displacement.

Note: if you have long tutorials, it is fun for students to build their own wave machine.



Accompanying sheet

> **Transverse Waves**
>
> Examine the wave machine.
> Send a wave from the bottom to the top.
> This is a torsional or “twisting wave”.
>
> Explain why this is called a transverse wave.
> How is it different to the transverse waves you are familiar with?

Tuning Forks and Beats

Apparatus

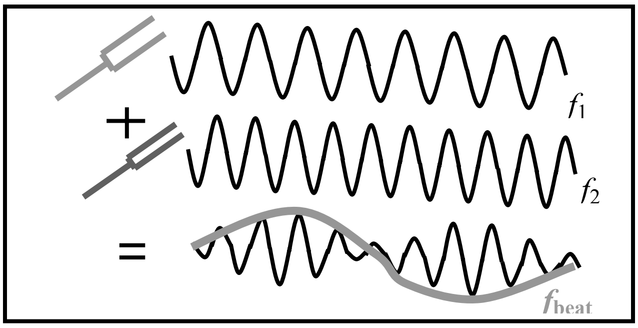
two tuning forks of similar frequency, or one tuning fork and one adjustable tuning fork

Action

The students strike one tuning fork and then the other. They listen for beats and describe what they hear and why they hear it. If you have an adjustable tuning fork they can adjust the frequency to see what effect this has on the beat frequency. They can also attempt to match the frequencies, at which point the beats disappear.

The Physics

The beat frequency you hear from two notes is the difference between the frequencies of the two notes, $f_{beat} = f_1 - f_2$. The closer together the frequencies (notes), the fewer the beats. The further apart the notes, the faster the beats.



Musicians tune their instruments by sounding a known note, for example with a tuning fork, then adjusting their tuning until the frequency from their instrument is the same and no beats can be heard. This is what happens when the adjustable tuning fork produces the same frequency as the other tuning fork.

When the two tuning forks have similar frequencies beats can be heard.

Accompanying sheet

Tuning Forks and Beats

Strike one tuning fork, then the other.

Listen to the beats when both are sounding.

What happens when you adjust the frequency of one of the forks?
How do musicians use tuning forks to tune their instruments?

Two Source Interference Pattern

Apparatus

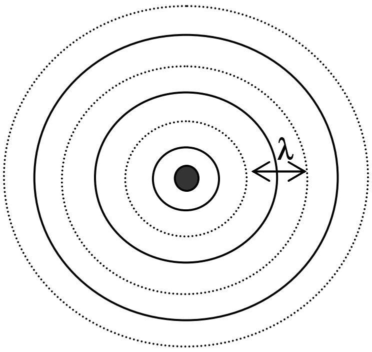
sheet of paper with concentric circles around central spot, alternating solid and dashed, overhead transparency sheet with identical set of concentric circles and spot, overhead (water soluble) markers

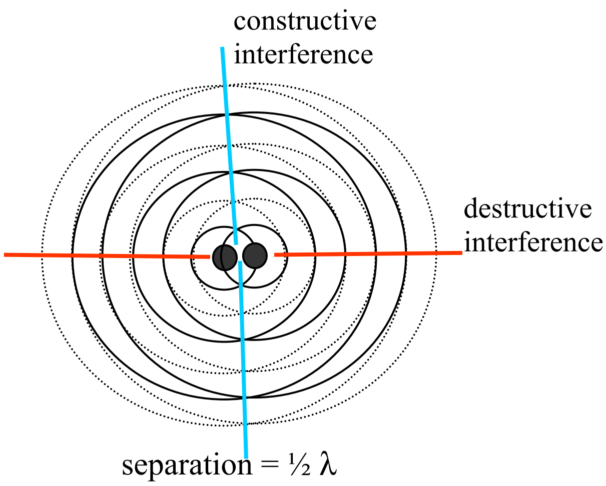
Action

The students sit the sheet of transparency over the paper. The dashed lines represent troughs and the solid lines represent peaks, around the source (dot) at a given moment in time. When the two sources are in the same position there is effectively only a single source. The students move the sources apart by sliding the transparency over the paper. They should be able to find points of maximum constructive interference and maximum destructive interference. The overhead markers can be used to mark in interference patterns for given source separations. They should find the source separation at which they first get nodal lines or lines of destructive interference, and when they first find antinodes, or constructive interference.

The Physics

For a trough from one source to meet a crest from the other requires a path difference of ½ λ between the two waves. Hence a nodal line first appears along the axis joining the two sources when the sources are ½ λ apart. At any separation smaller that this there are no lines along which troughs and crests meet to give destructive interference.





Accompanying sheet

Two Source Interference Pattern

Place the circular wave pattern on the transparency over the pattern on the paper so that the sources are at the same point.

Now move them apart until you first get nodal lines.

How far are the sources apart now (in multiples of λ)?
Why can't there be any nodal lines for smaller separations?

Visualising Speech

Apparatus

microphone connected to oscilloscope.

Action.

The students speak, shout, sing and whistle into the microphone and observe the wave patterns produced.

The Physics

The higher the pitch the greater the frequency (the shorter the period) of the waveform, and the louder they shout the greater the amplitude. This demonstration goes well with the "look and listen" demonstration. They will observe that the waveforms they produce are not simple sinusoidal patterns when they speak or sing, but are complicated waveforms made up of many frequencies. A clear whistle gives a good approximation to a sinusoid.

Students at the University of Sydney observing their "speech patterns".

Accompanying sheet:

Visualising Speech.

A microphone is connected to the CRO.

As you speak into the microphone the CRO shows your speech as sound waves. How do these signals compare with those from the signal generator?

How does the pattern change when you whistle, scream, whisper, sing or shout?

Tap the microphone gently. Why does a wave appear on the screen?

Waves in Rubber Tubes

Apparatus

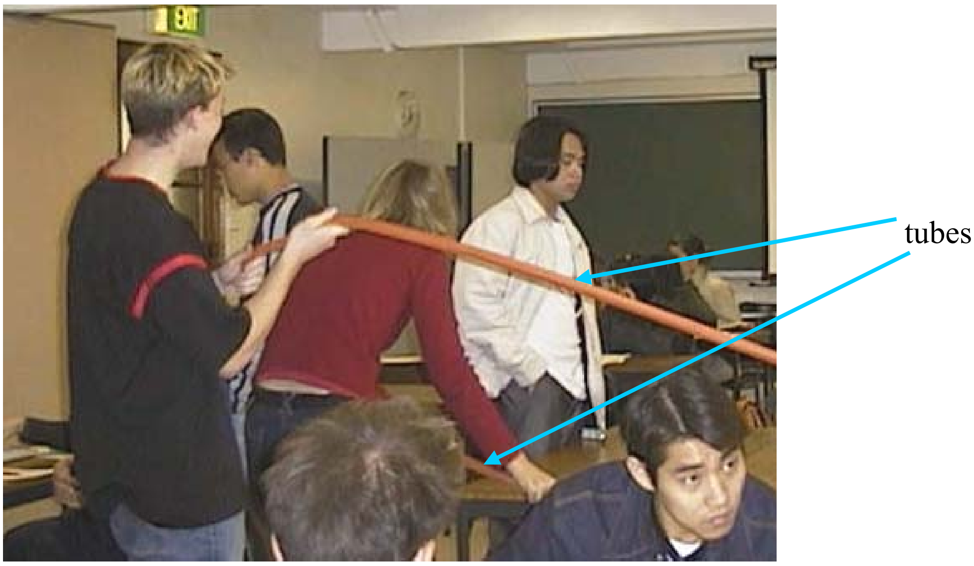
two very large rubber tubes, tied off at both ends, one filled with water and the other with air
It is easier to use if one end of each tube is tied to some fixed point, such as a post or wall.

Action

One student jerks the free end of each tube up and down to send a pulse along the tube. Other students observing the waves should be able to determine which tube is filled with water and which with air.

The Physics

Wave speed depends on tension and mass, and varies inversely with mass (linear density). The wave on the air filled tube travels much faster than that on the water filled tube.



Students at the University of Sydney
experimenting with the rubber tubes.

Accompanying sheet

Waves in Rubber Tubes

One group member sends a pulse down each tube while the others watch.
(Do not tell the others which tube is which!)

The rest of the group observe the waves
and determine which has air, and which has water in it.

Explain how you can tell.