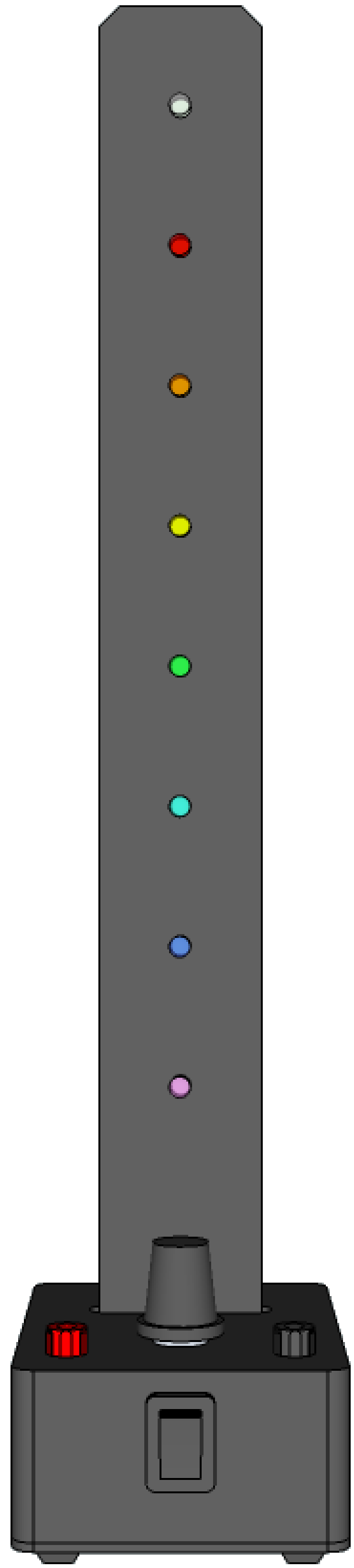
UNILAB® LED.line

NFU 731T

LED.line

The LED.line is a robust and attractive device consisting of 1 white LED and 7 colour LEDs.

Two 4mm sockets on the base are provided for connection to a voltmeter. The voltage across each LED can be measured, with LED selection via the rotary switch.



	LED Colour	**Wavelength (λ)** nm	**Frequency (f)** $\times 10^{14}$ Hz
1	White	n/a	n/a
2	Red	640	4.68
3	Orange	636	4.71
4	Yellow	598	5.01
5	Green	570	5.26
6	Turquoise	503	5.95
7	Blue	466	6.44
8	Violet	430	6.96

Purpose

The apparatus can be used as a tool for discussion of colour filters, to observe the behaviour of different wavelengths of light, and obtain a value for Planck's constant experimentally.

The experimental method for Planck's constant involves simple measurements (voltage and distance), and requires appreciation of errors and an awareness of underlying assumptions.

The kit consists of the LED.line and a power supply. A spare power supply is available using UNILAB catalogue code F4R03084. To carry out all the experiments described, you will also need:

Colour Filters **F4A46012**
Diffraction Gratings **F4L85261**
Easy Read meter **F4H79933**
and 20V d.c. attachment **F4H30919**
Metre ruler

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Safety

The LED.line should be used under the supervision of a qualified teacher, and with the plugtop power supply provided. A risk assessment is recommended before use.

The LEDs in the product are "ultra bright". Do not look directly at the LED at close range when it is turned on. Do not stare at any bright light source.

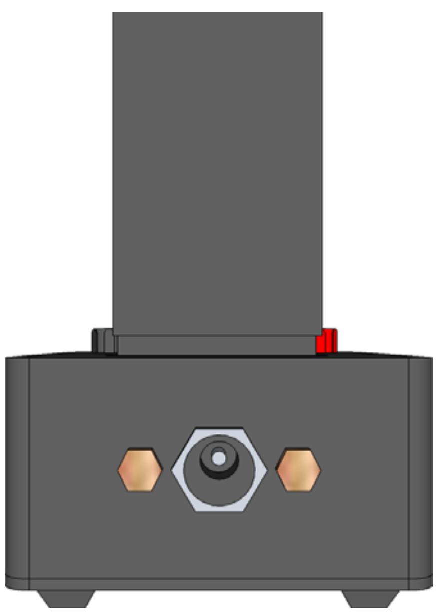
When working in low ambient light levels, extra caution should be taken. Advise pupils not to stare at the LEDs. Try to keep experiment times to a minimum. An audience to an experiment should be at least a metre away from the source.

UNILAB can not accept responsibility for injury or damage caused by misuse of the LED.line.

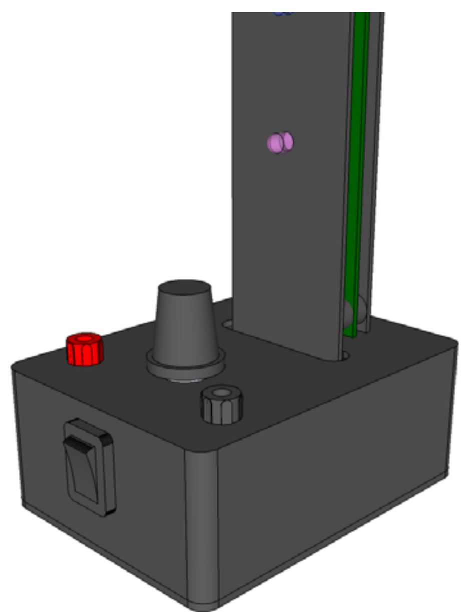
Basic Operation

The LED.line is supplied with a 5V 1A regulated plug-top power supply. Only this power supply should be used with the device.

Plug the power supply into a mains socket, and insert the plug into the socket on the back of the LED.line. Switch on.



Power socket (back)



ON/OFF switch (front)

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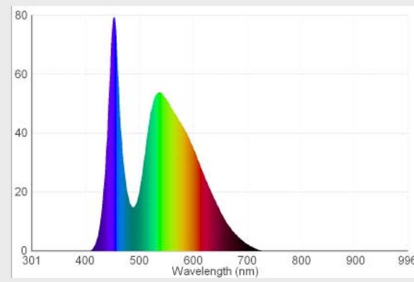
Colour Filters

This experiment is best conducted in low ambient light, and requires a set of colour filters.

Observe the colours of the LEDs. The sequence is similar to the visual spectrum as seen in a rainbow or from a glass prism.

Hold the **red** filter close to your eye, and look at the LED.line. Notice how the redder LEDs at the top appear far brighter than the green and blue ones towards the bottom. Notice also that the white LED appears red.

A **red** filter allows red light through, and absorbs most of light of other colours. Therefore, the light from the redder LEDs will be allowed through, and appear bright. Light from the green and blue LEDs will be absorbed, so they appear dim. The white LED emits light of many colours (which is what makes it white), but only the red light will be allowed through, making the white LED appear red.



The white LED spectrum shows it emits light across the visible spectrum, with a sharp peak in the blue, and another broader peak near green.

This time, try looking at the LED.line with a **green** filter. The greener LEDs will now appear brighter, and the white LED will appear green, because this filter only allows green light to pass and absorbs light of other colours.

Try to predict which LEDs will be brighter and which will be dimmer looking through the **blue** filter. What colour will the white LED appear to be?

You may notice that, although the red filter makes the blue LEDs appear dim, it doesn't extinguish them completely. There are two reasons for this.

The colour filter is not perfect – it will always allow some other colours through. Look around a well lit room through the filter. Although most things look red, the filter does not completely exclude every other colour.

The LEDs are not perfect. Although they might appear to be a single colour, in a later experiment it will be shown that the LEDs actually emit a range of colours.

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Diffraction Grating

A diffraction grating is a set of fine lines, very close together, typically from 80 lines mm^{-1} to 600 lines mm^{-1}. This has the effect of splitting incident light into many sources, and these sources interfere to form a diffraction pattern.

This pattern is dependent on wavelength, so different colours will be diffracted by different amounts, according to the formula:

$$n\lambda = d \sin\theta_n$$

n: order
d: slit separation
θ: angle of diffraction

This is sometimes known as the **grating equation**. The order, *n*, is the number of the image that appears off centre from either side. So for the first image, the order is 1. For the second image, the order is 2, and so on.

2nd order 1st order 0th order 1st order 2nd order

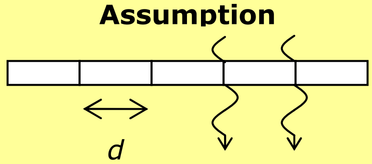
The slit separation, *d*, is the distance between the slits. It is simply the reciprocal of the lines per mm of the diffraction grating.

Grating	Slit separation
80 lines mm^{-1}	1/80 mm
300 lines mm^{-1}	1/300 mm
600 lines mm^{-1}	1/600 mm

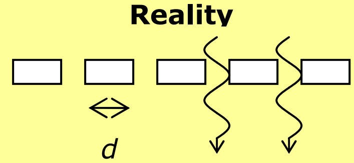
Assumption!

We assume that the gaps in the diffraction grating are infinitely narrow, so that all the space is taken by the separators between the slits. In reality, the slits have width of their own, so the slit separation will be less than the reciprocal.

Assumption



Reality



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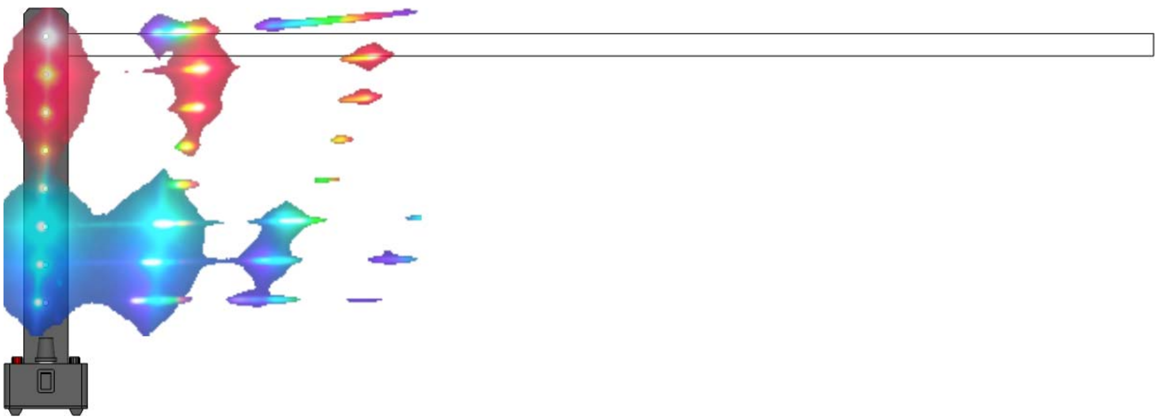
Measuring Wavelength

Having seen a diffraction pattern, and knowing the grating equation, it is possible to measure the wavelength of the light using a simple metre ruler.

One student should stand directly in front of the LED.line, holding a diffraction grating to one eye. They should stand at a distance away sufficient to see the first order image, and this distance should be recorded.

Another student should hold a metre ruler horizontally, at the level of one of the LEDs on the line. The LED should be at 0cm on the ruler.



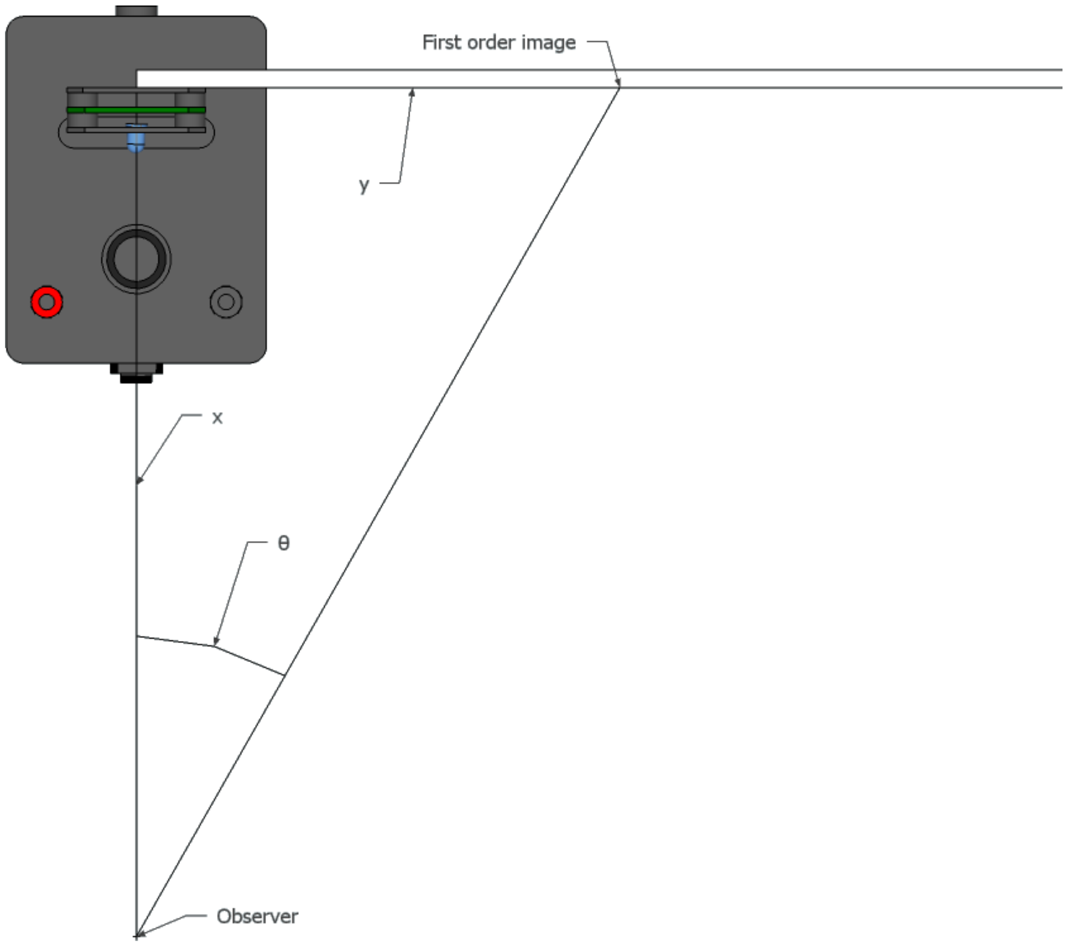
The first order image of each LED will appear a different distance away from the centre image. The student looking through the diffraction grating should guide the student holding the metre ruler to the point where the first order image appears over the ruler. This distance should be recorded for each LED.

	LED	Distance from LED.line m	First order image m
2	Red	2	
3	Orange		
4	Yellow		
5	Green		
6	Turquoise		
7	Blue		
8	Violet		

Error!

How accurately and precisely can you take readings from a metre ruler?
Because each LED has a spectrum, it is not easy to define exactly where the first order image occurs.

Consider the setup from above.



The angle θ can be determined from distances x and y which have already been measured.

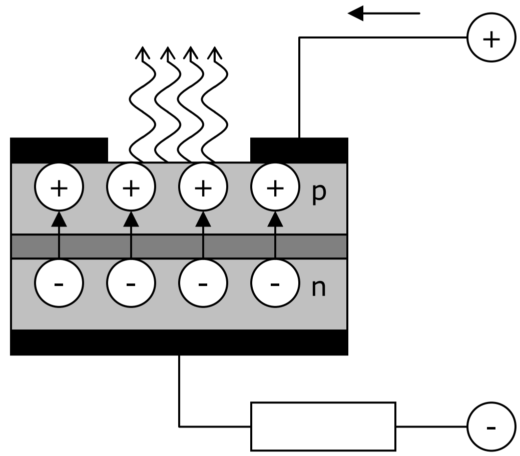
$$\sin\theta = \sin\left(\tan^{-1}\left(y/x\right)\right)$$

Using the grating formula, it is now possible to calculate the wavelength. The order n=1, and the slit separation *d* is the reciprocal of the lines per mm of the grating used. $\sin\theta \times d$ gives the wavelength in metres.

	LED	$\tan\theta$	$\sin\theta$	**λ (nm)**
2	Red			640
3	Orange			
4	Yellow			
5	Green			
6	Turquoise			
7	Blue			
8	Violet			

Compare your values with those given on the first page.

Measuring Energy



An LED consists of p and n type material. The n-type material has free electrons, and the p-type material has free moving positive charges called "holes".

When sufficient voltage is applied, the electrons have enough energy to flow to the p-type. When they encounter a hole, they "decelerate", falling to a lower energy level.

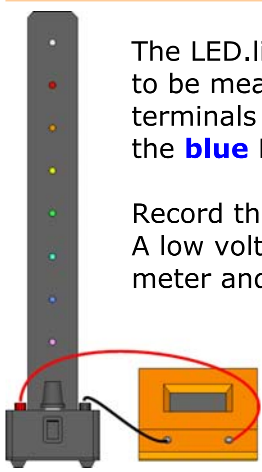
The voltage drop across the diode is caused by the deceleration of the electron. The energy lost in this deceleration is released as a photon.

For example, if the voltage drop across the red LED is 1.95V, then the energy lost by the electron, and therefore the energy of the emitted photon, is 1.95eV (electron volts). 1eV is equivalent to 1.6×10^{-19} Joules.

The energy, and therefore the wavelength and colour of the emitted photon, is determined by the specific n-type and p-type materials are used.

Assumption!

We assume all the energy emitted by the photon is turned into light. In fact, some energy is lost as "lattice energy" (i.e. heat).



The LED.line has two 4mm sockets that allow the voltage across each LED to be measured. The rotary selection switch determines which LED the terminals are connected to. For example, to measure the voltage across the **blue** LED, set the switch to 7.

Record the voltage across each LED and the corresponding energy of each. A low voltage d.c. voltmeter should be used, such as the Easy Read digital meter and 20V d.c. attachment.

	LED	Voltage (V)	Energy (eV)	Energy ($\times10^{-19}$ J)
2	Red	1.96	1.96	3.14
3	Orange			
4	Yellow			
5	Green			
6	Turquoise			
7	Blue			
8	Violet			

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Determining Planck's Constant

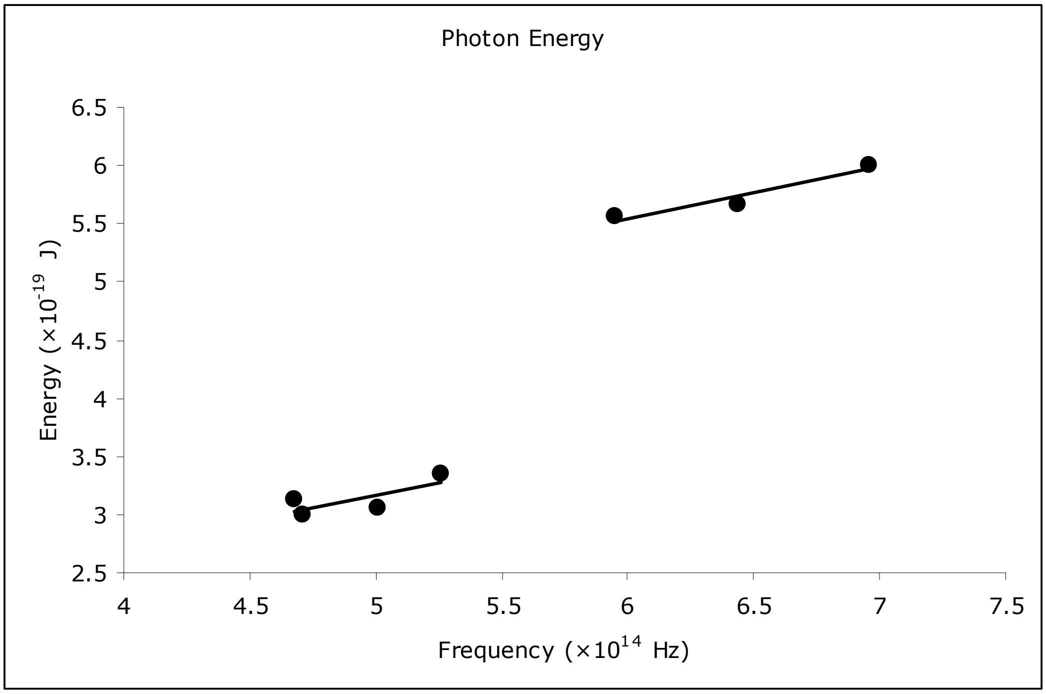
The energy and wavelength of the photon are related by the following formula:

$$E = hf = \frac{hc}{\lambda}$$

h: Planck's constant
f: frequency
c: speed of light
λ: wavelength

Planck's constant, as the name suggests, is a constant. This formula holds true for all photons.

From our previous experiments, we measured the frequency of the light, and the energy of the photons from each LED. Therefore, we should be able to obtain a value for Planck's constant by plotting the frequency against the energy.



You will notice that there is a large gap between the forward voltages of the first 4 LEDs and the last 3. This is because of the different types of material used to produce them.

If you attempt to draw a best fit line of all points at once, the result will be distorted. Instead, draw two separate best fit lines, measure the gradients and take an average. The result should be close to Planck's constant:

$$h = 6.63 \times 10^{-34}\, Js$$

Please note you are likely to obtain a value that appears to be quite different from this. A result of the correct order (i.e. $\times 10^{-34}$Js) should be considered excellent.

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Discussion of Results

Errors: When measuring the distance that the first order image occurs from the centre, it is difficult to define exactly where the image occurs, as it is a spread rather than a point. This error in measurement will affect the result of measuring the wavelength. This error can be reduced by viewing the LED.line from a greater distance, say 5 metres, giving larger values for y and x.

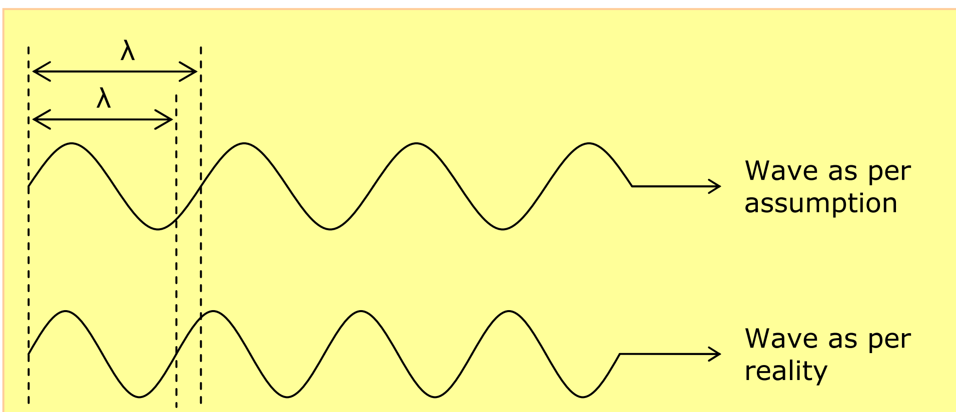
Assumption 1: The gaps in the diffraction grating are infinitely narrow, so the entire grating is made up of slit separation, so:

$$d = \frac{1}{\text{lines mm}^{-1}}$$

Reality: The gaps have width, so not all of the space is taken up by slit separation, so:

$$d < \frac{1}{\text{lines mm}^{-1}}$$

Consequence: To find the wavelength, we multiply $\sin\theta$ by *d*, so if the assumed value of *d* is larger than reality, then the wavelength will also be larger than reality.



Assumption 2: All of the energy lost by the electron encountering a hole in the p-type material is emitted as light, so:

$$eV = hf$$

Reality: Some of the energy is lost to the surrounding lattice in the p-type material, causing it to vibrate, so:

$$eV < hf$$

Consequence: The actual energy of the photons is lower than measurements suggest.

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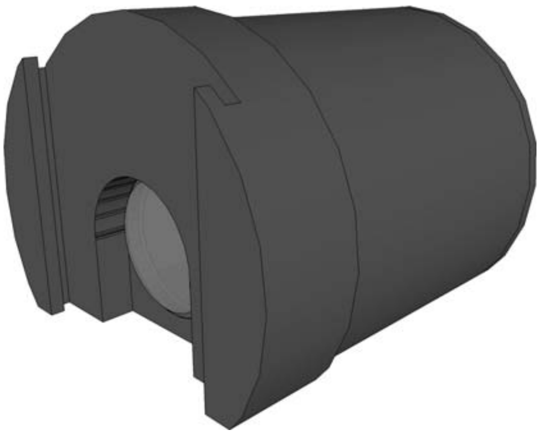
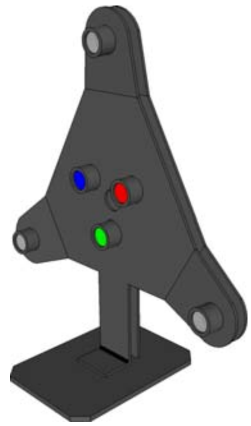
Other products in the UNILAB LED.range





LED.white F4L87348
An excellent replacement for the traditional ray box, with a better spectrum, longer life and safer operation. Now with integral slit plate holder.

LED.mixer F4L75267
Investigate colour perception by mixing primary colours to make any colour you like, and give ordinary objects an eerie appearance!