

NOTES FOR USE



The LED Array™

Notes for Use 721

UNILAB L75279

v. 06/03

FifeX and UNILAB would like to acknowledge the support of Jim Jamieson (SSERC) and the Fife schools, in developing this exciting new product.



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Description

The LED Array™ is a robust and attractive device comprising 1 white LED and a set of 10 coloured LEDs from red to violet, wavelengths from 641 to 411 nanometres.

Purpose

It can be used to explore the interaction between colour filters and specific colours of light, to illustrate and explain the behaviour of different wavelengths of light, and to prove and work out a value for Planck's constant.

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

Kit Contents

- LED Array™
- Plugtop 5V 1A d.c. power supply

For the suggested experiments, you will also need:

Colour filters, at least two each of: red, green, blue, cyan, magenta, yellow

A diffraction grating (300 lines/mm)

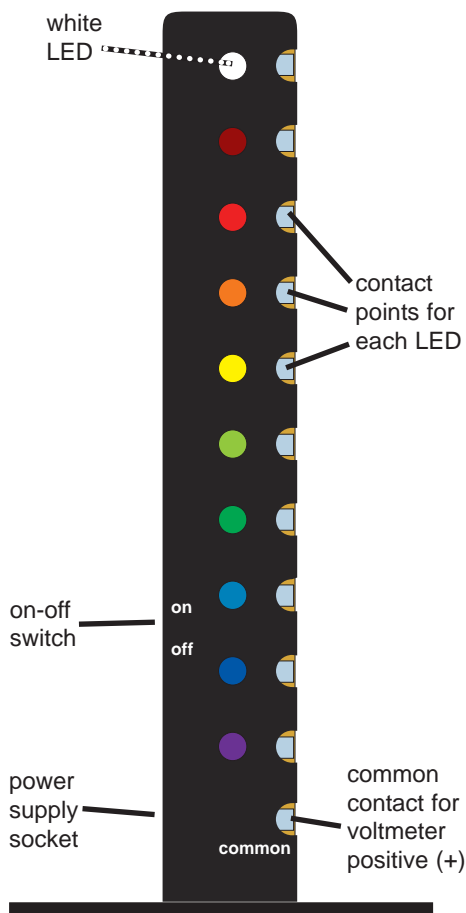
Diffraction gratings with different spacings, e.g. 200 and 600 lines/mm

A metre rule

A sheet of A3 white card and marker pen

A voltmeter to read 0 to 6V d.c.

The LED Array™



LED data

LED colour	wavelength nm	frequency 10 ¹⁴ Hz
deep red	641	4.68
red	627	4.78
orange	609	4.93
yellow	600	5.00
green	574	5.23
bright green	539	5.57
turquoise	494	6.07
blue	468	6.41
deep blue	451	6.65
violet	411	7.30

Voltages measured between the common connection point and the individual LED contacts, are in the range 1.8 to 4V.

Safety

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

The LEDs in this product are "ultra bright". Do not look directly at them from close range. Do not stare at any bright LED source.

When working in low ambient light levels, extra caution must be taken. Advise pupils not stare, and to look at the LEDs for the minimum time during experimental procedures.

FifeX and UNILAB accept no responsibility for injury or damage caused by misuse of the LED Array™.

Suggested experiments

1. Colour, and the effects of colour filters
2. Effect of a diffraction grating, and the link to colour and wavelength.
3. Prediction from initial observations, of the effect of using a different grating.
4. Calculation of wavelength for any colour
5. How LEDs generate light
6. Determination of Planck's constant, h
- 6b. Alternative method - measuring the striking voltages for the LED Array
7. Assumptions underlying the measurement of Planck's constant

Power supply

It is recommended that you use the 5V d.c. plugtop power supply provided.

Connect the plug top power supply lead to the socket on the left side of the LED Array™.

Plug the power supply into a mains socket.

Locate the on-off switch above the power supply socket. Switch on.

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1. Colour, and the effects of colour filters

Observe the colours of the LEDs, the sequence corresponds to a rainbow or spectrum produced by a prism.

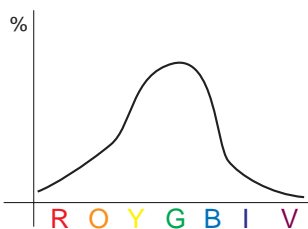
Work in a dark corner, look at the LED array through a variety of colour filters.

When a red filter is used, the red LEDs appear brighter than the rest. The red filter allows red light to pass and blocks other colours.

When a green filter is used, the green LEDs appear brighter than the rest. Green light passes through, and other colours are blocked.

You can see more than one colour of LED, through any particular filter.

Filter materials allow a small range of colours to pass, so the green filter might allow green, plus some blue and yellow light to pass.



If you have two filters of the same colour, use them to make a “double filter” and look at the LED array again. You should find that the blocking of other colours is more effective.

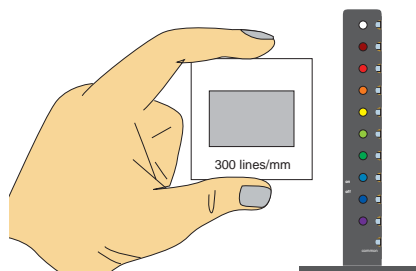
No matter which filter you use, the white LED looks the colour of the filter. This is because the white LED (like any source of white light) contains all colours.

2. Effect of a diffraction grating, and the link to colour and wavelength

A diffraction grating is a set of very fine, parallel lines ruled very close together on a transparent film. There may be 50, 300 or even 600 lines per millimetre. You can check using a microscope.

Switch on the LED array.

Hold the grating only by its card frame, to avoid touching the film.



With the grating close to one eye, look at the LED array. Sketch what you see.

What happens to the light from the white (top) LED? If you are not sure, ask someone to cover and uncover the white LED as you look through the grating.

How does the grating affect red light, compared with violet light?

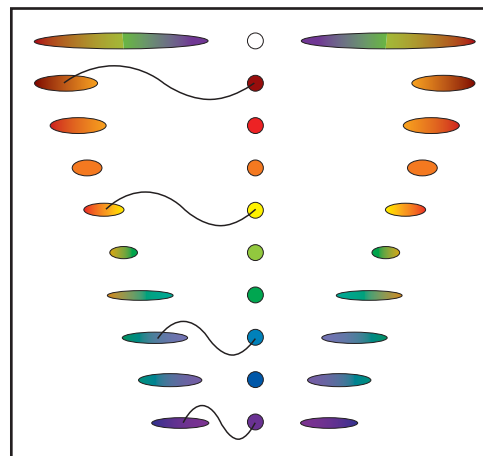
You should see the original LEDs, in a vertical line, with images of the LEDs to the left and right of the central line.

The white LED gives a spectrum from red to violet on the left, and violet to red on the right. Clearly, different colours behave slightly differently at a diffraction grating. Colours are separated into a spectrum.

Each LED gives a slightly stretched image, and not in a single colour! This tells us that each LED emits a range of colours, rather than a single colour.

Each LED's image is also a different distance from the central line.

Look at the sketch and imagine a number of single waves, stretching from the vertical centre line to the image of each LED. The wave for the red LED is longer than for the yellow or blue or violet LED.



The lengths of these imaginary waves are proportional to the actual wavelengths of the light. What is the approximate difference between the wavelengths of red light and violet light?

3. Prediction from initial observations, of the effect of using a different grating.

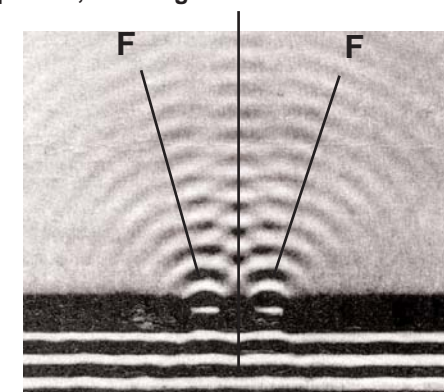
You have seen the effect of a diffraction grating on light of different colours, i.e. light of different wavelengths.

Diffraction is caused by interaction between light waves and the small gaps between the lines on the grating.

If we use a grating with more or less lines per millimetre, how will the image change? Predict what you expect to see, then test your prediction using a different grating.

If a ripple tank is available, study the interaction between plane waves and a barrier with two gaps in it.

Waves passing through the gaps produce a diffraction pattern. Here is a typical pattern, showing first order diffraction (F).



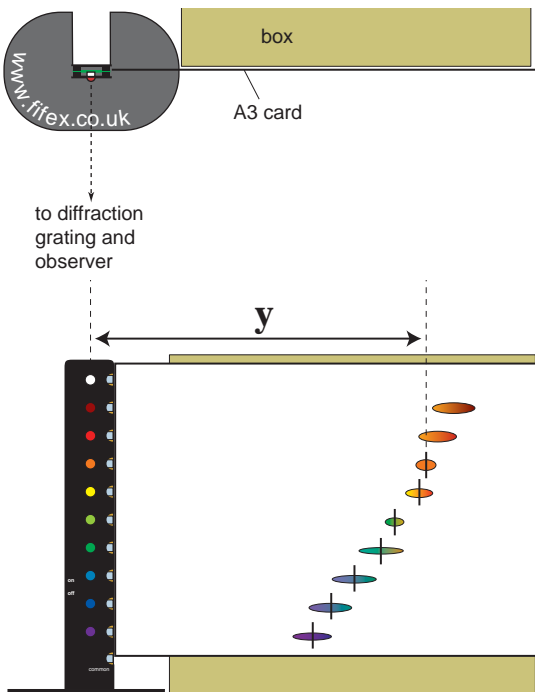
Change the wavelength or the size and separation of the gaps in the barrier. Observe changes in the diffraction pattern.

4. Calculation of wavelength for any colour

The images to left and right of the central vertical line of LEDs are called first order fringes. If you look again and hold the grating close to your eye, you should see a second set of images, fainter and further out from the vertical centre line. These are second order fringes.

By making simple measurements, you can calculate the wavelength of the light emitted by each LED.

Support a sheet of A3 card or paper, vertically, to one side of the LED array, this can be done using blu tac and a box.



Now face the LED array, with the diffraction grating 1 metre from the array, and close to your eye. Arranging the grating in a clamp stand might help you fix the distance accurately.

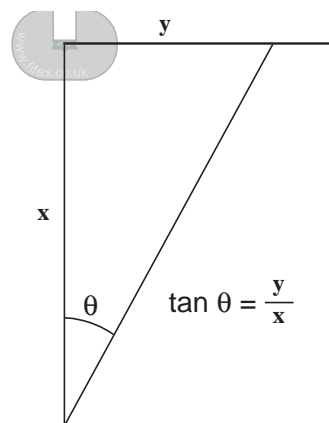
The A3 card should be at right angles to the line from your eye to the array.

As you look through the grating, guide another student to mark the centre of each first order image, using a marker pen.

Without disturbing the card, measure the distance, y , from the centre line of the LED array to each mark in turn, in metres.

Note the LED colour and the distance, y .

For each LED, calculate $\tan \theta$ in this case $x = 1$ metre



Use a scientific calculator (or the Windows Calculator accessory) to find the angle θ using the \tan^{-1} or "Inv tan" function.

Then find $\sin \theta$ and enter it in the table.

In the formula $m \lambda = d \sin \theta$

$m = 1$ for a first order fringe

λ = the wavelength of light from the LED
 d = the spacing of the lines in the grating, in metres.

For a 300 line/mm grating this is

$$\frac{1}{\frac{300}{1\text{mm}}} = \frac{1\text{mm}}{300} = \frac{10^{-3}\text{metre}}{300}$$

$$= 0.00333 \times 10^{-3}$$

$$d = 3.33 \times 10^{-6}\text{m}$$

So, for each LED $\lambda = 3.33 \times 10^{-6} \times \sin \theta$

A typical result has been entered for the deep red LED.

Measure y for the rest of the LEDs, calculate and enter the wavelength in the table.

Units

Your wavelength values in the table were calculated as 0.574×10^{-6} metre, for example.

Wavelengths of light are usually quoted in nanometres (nm), and that value would become 574 nm.

1 nanometre is 10^{-9} or 1 thousand millionth of a metre. Visible light has wavelengths in the range 400 to 700nm, for a typical human eye.

Errors

The quoted wavelength for the deep red LED is 641 nanometres.

The value 639nm is quite close, within 0.5% in fact.

What are the likely sources of error in wavelength values measured in this way?

How can you change the method to give even more accurate values?

LED colour	y (m)	$\tan \theta$	$\sin \theta$	wavelength $\lambda = d \sin \theta$ (metres)	λ (nm)
deep red	0.196	0.196	0.192	$3.33 \times 10^{-6} \times 0.192 = 0.639 \times 10^{-6}\text{m}$	639
red					
orange					
yellow					
green					
bright green					
turquoise					
blue					
deep blue					
violet					

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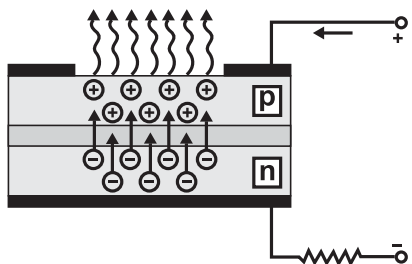


5. How LEDs generate light

In the p-region of an LED, there are many more positive than negative charges. In the n-region electrons are more numerous than positive electric charges.

When sufficient voltage is applied across the LED, electrons gain enough energy to move across the junction between p and n regions, into the p-region.

Once in the p-region, the electrons are immediately attracted to the positive charge due to Coulomb forces between the opposite charges and they re-combine.



For each re-combination the electric potential energy of the electron is released as a quantum of electromagnetic energy. This release takes the form of a photon of light in a very narrow frequency range, that is a characteristic of the doped semiconductor material.

If the applied excitation voltage exceeds the level at which photons are just emitted, then the excess energy appears mainly as phonons (quanta of lattice vibrational energy).

Calculating photon energy

The energy of the light emitted is related to the electric charge (e) of an electron and the voltage (V) required to just light the LED.

In a simplified form,
 energy = eV joules
 $e = 1.6 \times 10^{-19}$ coulomb

energy is also = hf
 h is Planck's constant
 f is photon frequency

so $eV = hf$
 and $V = hf/e$

A graph of V against f has a gradient of h/e subject to the assumptions in section 7.

6. Determination of Planck's constant, h

Use a diffraction grating to view the first order fringes, as in Experiment 4, and calculate the wavelength for each LED.

Enter the values in a table, see example.

Calculate the frequency for each wavelength, using the formula,
 $f = c/\lambda$
 λ is photon wavelength
 $c = 3 \times 10^8$ ms⁻¹

e.g. for the deep red LED, the wavelength is 641nm or 641×10^{-9} metres, so

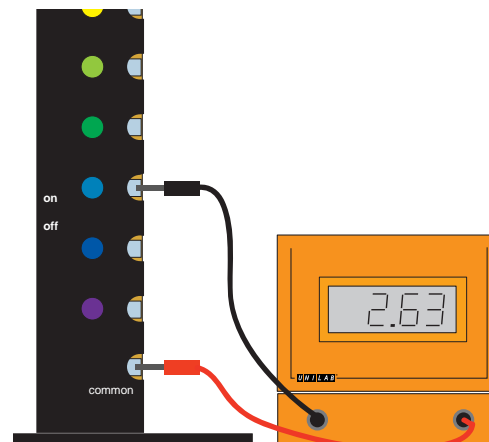
$$f = \frac{3 \times 10^8 \text{ ms}^{-1}}{641 \times 10^{-9} \text{ m}}$$

$$f = 0.00468 \times 10^{17} \text{ s}^{-1}$$

$$= 4.68 \times 10^{14} \text{ Hz}$$

Use a voltmeter(e.g. Unilab Easy Read with 20V d.c. attachment) to measure the forward voltage for each of the LEDs.

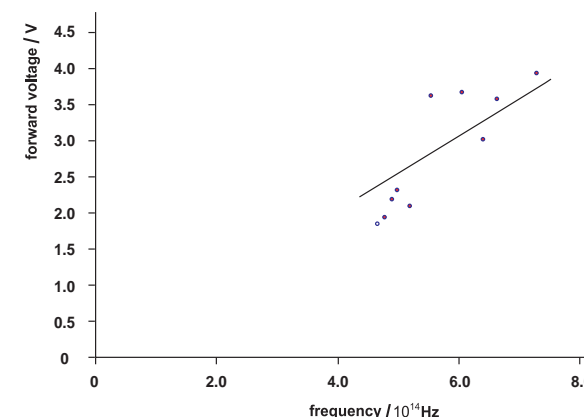
Connect the positive lead to the metal contact marked 'common' and touch the negative lead on the contact next each LED in turn.



Complete the table with frequency and forward voltage values for each LED.

Plot a graph of V against frequency, and draw a line of best fit.

The gradient of this graph is close to 0.5×10^{-14}



LED colour	Wavelength nm	frequency 10 ¹⁴ Hz	forward voltage V
deep red	641	4.68	1.85
red	627		
orange	609		
yellow	600		
green	574		
bright green	539		
turquoise	494		
blue	468		
deep blue	451		
violet	411		

So $h/e = 0.5 \times 10^{-14}$
 and $e = 1.6 \times 10^{-19}$

Finally, $h = 8.0 \times 10^{-34}$

This value is slightly high, the accepted value being 6.626×10^{-34} joule second.

The alternative method of measuring the voltage (below) may provide a more accurate value.

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6. Alternative method - measuring the striking voltages for the LED array

Instead of the plugtop power supply, connect a 0 to 5V d.c. variable, regulated power supply to the LED array.

Note: It is the responsibility of the user to check that the power supply gives:

- a maximum of 5 volts
- the correct polarity
- regulated d.c.

The correct connector is a miniature power jack with 5.5mm external and 2.5mm internal diameter.

The centre contact must be positive.

First, increase the voltage slowly from 0 to 5 volts. Observe that each LED “strikes” in sequence, from red to violet.

Next, with the voltmeter connected to each contact in turn, check the reading when each LED just lights. This is the striking voltage.

Add a column to the table, and record the striking voltage for each LED. The values are slightly different from the previous set of forward voltages, and in sequence.

Plot a graph of striking voltage against frequency.

Find the gradient and calculate the value of Planck’s constant, h , as before.

A complete set of results is given below.

LED colour	Wavelength nm	frequency 10^{14} Hz	forward voltage V	striking voltage V
deep red	641	4.68	1.85	1.437
red	627	4.78	1.96	1.466
orange	609	4.93	2.2	1.529
yellow	600	5.00	2.35	1.562
green	574	5.23	2.12	1.620
bright green	539	5.57	3.63	2.085
turquoise	494	6.07	3.68	2.115
blue	468	6.41	3.04	2.230
deep blue	451	6.65	3.58	2.300
violet	411	7.30	3.94	2.885

7. Assumptions underlying the measurement of Planck’s constant

Apart from errors introduced by the observers, these methods for determining Planck’s constant:

- ignore any potential drop across the semiconductor materials of the LED
- assume that the threshold of photon release is accurately determined (when using the variable d.c. supply)
- assume that, at recombination, 100% of the energy input, eV , is released as photon energy, hf .

When the fixed power supply is used, you will notice that there is a large gap in the forward voltage between the green and the bright green LEDs. This is due to different properties of the semiconductor materials used to make the LEDs above and below this point.

The plotted values appear to lie in two groups.

Two best fit lines may be drawn, one using the top 5 LEDs, the other using the bottom 5 LEDs. These gradients should provide a better value of Planck’s constant.

Online Support

Further information on experiments can be found at www.fifex.co.uk/flaonline.htm and you are invited to submit suggestions for new experiments, to the same site.

Troubleshooting

If one or more LEDs fail:

1. Switch off the LED array immediately.
2. Disconnect the power lead from the socket in the side of the LED array.
3. Check the output voltage of the d.c. supply. It should be 5V d.c.
4. Reconnect the power lead to the LED array and switch it on.

If the LEDs do not all light disconnect the supply and contact your supplier for advice.

If the plugtop power supply is lost or suspected damaged in any way, contact your supplier immediately.