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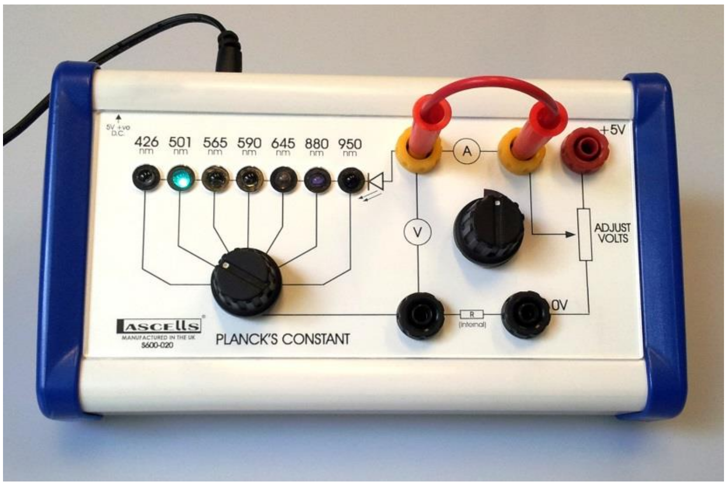
PLANCK'S CONSTANT

S600-020E

INSTRUCTIONS FOR USE

PLANCK'S CONSTANT APPARATUS
S600-020E

INTRODUCTION



This apparatus provides an array of clear envelope LEDs with peak emission wavelengths in the range 464 to 940nm. The controls allow each LED to be selected in turn and the applied voltage varied so that its electrical characteristics may be investigated. With some simple calculations, an estimate of Planck's constant may be made, the accepted value being:

$$h = 6.626 \times 10^{-34} \mathrm{Js}$$

PROCEDURE

Connect analogue or digital meters to the sockets indicated. The current range required is 0 - 20mA and the voltage range is 0 - 5V. If threshold voltages only are to be measured then the ammeter may be omitted and a wire link placed between the sockets.

<u>**Note**</u> **– For extra protection a 1Kohm resistor has been added to the circuit between the ammeter sockets and the LEDs (not shown on panel).**
The error caused shifts the graph slightly on the voltage axis but the gradient is the same, hence the value of h is not affected.
At the recommended current of 1µA – 10µA the error caused is between 1mV – 10mV.

Ensure that the on-board potential divider is rotated fully clockwise before starting.

Connect a 5V d.c. power supply to the right-hand terminals using 4mm connecting leads and observing the correct polarity. A smoothed d.c. supply is adequate. If a 5V supply is not available three 1.5V batteries in series may be used. A battery eliminator can be connected to the external d.c. socket on the rear of the unit as an alternative. If this type of supply is used the central pin is the positive terminal. Higher voltages can be used (e.g. a 9V PP3 battery) but the on-board potential divider would then be able to apply voltages higher than 5V to the LEDs and there is a risk of damage due to excessive current flowing. If higher supply voltages are used be aware that the LEDs could be damaged if the control is turned to its maximum.

EXPERIMENTS

Threshold voltage.

At low voltages no light is emitted from an LED. As the voltage is increased electrons in the semiconductor gain sufficient energy from the electric field to make the transition from the conduction band to the valence band. During the transition the electron loses energy equal to the gap energy between these bands and the energy is released as a photon of light. From the equation $E = hf$ we can see that for small energy values (E) the photon frequency (f) will be low (larger wavelengths) and for large energy values we will get lower wavelengths. h is Planck's Constant.

Select the 645nm LED and view it through the black tube provided. Increase the voltage by turning the potential divider anticlockwise and note the voltage when light is just detected from the LED. This is the minimum, or threshold voltage for emission of a photon. Repeat for the other LEDs down to 426nm and note that the threshold voltage (and hence the photon energy) increases as the wavelength of the light decreases.
(Remember that $v = f\lambda$ so we have $f = v/\lambda$ and $E = hv/\lambda$)

To make the different colour LEDs the semiconductor is doped with varying amounts of nitrogen and other impurities to adjust the energy gap so that different photon energies, and hence wavelengths, are produced. No *visible* light comes from the infra-red LEDs. Take the threshold voltage value when current just begins to flow, say 0.01mA.

THRESHOLD VOLTAGE AND PLANK'S CONSTANT

In the above experiment, since the wavelength of each LED is known we could calculate the value of Planck's constant from each LED if we know the link between threshold voltage and the photon energy. A good estimate of the photon energy comes from the equation $E = eV$ where E is the energy in J, e is the charge on the electron in coulombs (1.6×10^{-19}) and V is the threshold voltage in volts.

i.e $eV = hv/\lambda$ so that $h = eV\lambda /v$ (where v = velocity of light, $3 \times 10^{8}\ ms^{-1}$)

V/I CHARACTERISTICS AND PHONONS

For most purposes the previous theory is adequate but inevitably there are complications in reality. Electron transitions across the gap usually result in the production of phonons (lattice vibrations) as well as photons and some of the energy goes to the phonons so that the photons are of lower energy than that calculated from $E = eV$. Indirect transitions are also possible resulting in a spread of energies and a spread of wavelengths. The LEDs have peak wavelengths quoted by the manufacturer and the best results for the calculations are obtained by plotting the voltage / current characteristic for each LED.

Measure the conduction current for various voltages up to 15mA max. Plot the graph for each LED and extrapolate the linear region of the graph back to the voltage axis to estimate the voltage for peak wavelength emission.

Use this value in the $h = eV\lambda / v$ equation.

An alternative approach to the separate calculations for h is to rearrange the equation to $1/\lambda = (e/hv).V$ A graph of $1/\lambda$ on the y-axis against V on the x-axis should give a straight line of gradient e/hv from which h can be calculated.

LED WAVELENGTHS

The LED manufacturer's quoted emission wavelengths have been used. Advanced students could examine the spectrum produced by each LED with a spectrometer to get a more accurate value for the wavelength.

Results from this type of LED-based investigation often show a discontinuity or transition in the data at green wavelengths. This is due to differences in the way that blue LEDs are manufactured compared to red. The investigation should be regarded as an illustration of the $E = hf$ equation rather than a method of accurately determining the value of h.

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