

## Planck's Constant Apparatus (115 V, 50/60 Hz) Planck's Constant Apparatus (230 V, 50/60 Hz)

1000536 / U10700-115  
1000537 / U10700-230

### Instruction manual

10/15 ALF



- 1 LED with connecting lead
- 2 Nanoammeter
- 3 Voltmeter
- 4 Protective cover for photocell
- 5 Collector tube for photocell
- 6 Coaxial power socket for power supply
- 7 Power supply with connector socket for LED
- 8 Back EMF adjustment (coarse)
- 9 Back EMF adjustment (fine)
- 10 Intensity knob
- 11 Empty sleeve

### 1. Notes

The photocell in the Planck's constant apparatus is highly sensitive. Bright light can cause it to age quickly and can cause permanent damage. Following irradiation it ideally needs to be left for quite a long period before it regains its stability.

- The protective cover for the photocell should never be removed.
- When the experiment is completed, slide the empty sleeve over the collector tube of the photocell.
- Keep the apparatus secure so that it does not get shaken and do not expose it to extreme temperatures, high humidity, moisture or direct sunlight.

### 2. Scope of delivery

- 1 Basic apparatus with photocell, voltmeter, nanoammeter and LED power supply
- 1 Empty sleeve for covering the photocell collector tube
- 5 LEDs (472 nm, 505 nm, 525 nm, 588 nm, 611 nm) in case with connector leads
- 1 Plug-in power supply, 12 V AC
- 1 Instruction manual

### 3. Description

The Planck's constant apparatus is for determining the magnitude of Planck's constant  $h$  and the work  $W$  done in emitting electrons from a caesium cathode in a photocell using the back-EMF method.

It contains a vacuum photocell, a voltmeter for measuring back EMF, a nanoammeter for measuring the photocell current and a power supply for the LEDs. Five different light-emitting diodes (LEDs) are provided, which emit light at differing known average frequencies. The intensity of the emitted light can be varied between 0 and 100% in each case. The photocell itself consists of a cathode with caesium condensed onto its surface and a ring-shaped anode. When the apparatus is switched on, a voltage is applied between the two electrodes and this can be adjusted by two knobs for coarse and fine adjustment.

Power is supplied to the apparatus via the plug-in transformer provided. The Planck's constant apparatus with order number 1000536 / U10700-115 is designed for a mains voltage of 115 V ( $\pm 10\%$ ) while the version with order number 1000537 / U10700-230 is for 230 V ( $\pm 10\%$ ).

### 4. Technical data

Photocell:	Type 1P39, caesium (Cs)
Voltmeter:	3½-digit LCD
Precision:	0.5% (typically)
Nanoammeter:	3½-digit LCD
Precision:	1% (typically)
LEDs:	472 nm, 505 nm, 525 nm, 588 nm, 611 nm
Dimensions:	280x150x130 mm
Weight:	1.3 kg approx.

### 5. Theoretical principles

At the end of the 19th century and the beginning of the 20th, it almost seemed as though Physics had explained all there was to know, but the so-called photo-electric effect was one of the last riddles. Classical theories were unable to account for this effect. In 1905, though, Albert Einstein devised a brilliantly simple theoretical description of the phenomenon using the quantum theory which had been introduced by Max Planck. His assumption was that light consisted of particles, so-called photons (quanta of light), with an energy  $E$  which was directly proportional to their frequency  $f$  and a momentum  $p$  indirectly

proportional to the wavelength  $\lambda$ :

$$E = h \cdot f \cdot p = h / \lambda$$

The constant of proportionality here  $h$  was Planck's "quantum of action". What it meant was that energy in the form of electro-magnetic radiation could only be emitted in small, discrete packets called quanta. This minimum energy was dependent on the frequency. Planck's constant is one of the fundamental constants of nature and has a value to a high accuracy of  $h = 6.62606896 \cdot 10^{-34}$  Js.

In this experiment light from the light emitting diode connected in the circuit passes through a ring-shaped anode before striking the cathode. If an electron is struck by a photon, the photon can give up all of its energy ( $E = h \cdot f$ ) to the electron. Part of that energy may then propel the electron out of the metal surface (the so-called work function  $W$ ). The rest of it is converted into kinetic energy for the electron:

$$E_{\text{kin}} = h \cdot f - W$$

The work done in emitting electrons from the cathode is dependent on the material as well as on the temperature. For caesium it is 2.14 eV at 0 K and about 2 eV at room temperature.

Depending on the adjustment of the back EMF between the cathode and anode, a current of electrons should flow from the former to the latter. This can be measured using the nanoammeter. If the back-EMF corresponds to the critical voltage  $U_0$ , where

$$e \cdot U_0 = E_{\text{kin}} = h \cdot f - W \text{ and } e = 1.6021 \cdot 10^{-19} \text{ C,}$$

then this current should have a magnitude of 0 nA.

Plot a graph of  $e \cdot U_0$  against  $f$  for the critical voltages  $U_0$ , measured for various frequencies of light  $f$ , to obtain a line of gradient  $h$  crossing the y axis at  $W$ . The point where the line crosses the y-axis is different for all cathode materials, so that the corresponding straight lines are all different too. The gradient of the line depends on the cathode material.

### 6. Operation

#### 6.1 Measurement of critical voltage at a light intensity of 75%.

- Plug in the transformer to supply power.
- Set the intensity of the light source to 75%.
- Insert the plug for the first light source into the LED connector socket.
- Push together the jaws of the clip for the sleeve over the collector tube of the photocell and remove the sleeve.

- Push the LED unit fully onto the collector tube of the photocell until the jaws of the clip snap into place.
- Set the fine adjustment knob for the back-EMF to a central position.

Note: it is worth waiting a few minutes to set the critical voltage before starting the first measurement.

- Slowly turn the coarse setting knob till the photoelectric current measured by the nanoammeter is approximately 0.
- Use the fine setting knob to optimise the calibration. Turn it round till the display oscillates between 0 and -0.
- Take note of the back-EMF as set in this fashion and record it as the critical voltage  $U_0$ .
- Repeat this measurement for the four other LEDs.
- After the experiment, close the plastic cover back over tube for attaching the LED.

### 6.2 Determining Planck's constant $h$ .

- Work out the frequencies of the light from the printed wavelengths  $\lambda$  using the formula  $f = \frac{c}{\lambda}$  where  $c = 3 \cdot 10^8 \frac{\text{m}}{\text{s}}$ .
- Use the critical voltages  $U_0$  to work out the energies  $e \cdot U_0$  where  $e = 1.6021 \cdot 10^{-19} \text{C}$ .
- Plot the values obtained on a graph of energy against frequency.
- Draw a straight line through the points and determine Planck's constant  $h$  from the gradient and the work  $W$  from where the line crosses the Y axis.

Note: It is easiest to evaluate the results, particularly those referring to the back-EMF, with the help of the supplied Excel spreadsheet. This merely involves entering the measured critical voltage into the relevant table. Afterwards the gradient  $h$  and the y-axis crossing point  $W$  can be read from a graph and any discrepancies from quoted values can be calculated by entering the quoted figures into the relevant cell in the second table.

### 6.3 Proof that the critical voltage does not depend on the light intensity.

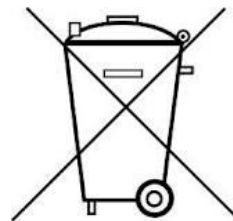
- Select an LED.
- Set the light to maximum intensity and determine the critical voltage  $U_0$ .
- Reduce the intensity to zero in a set of steps and determine the critical voltage  $U_0$  in each case.

## 7. Cleaning

- Only use conventional mild washing-up liquid and never aggressive detergents.
- Make very sure that no moisture gets inside the equipment.
- Unplug the power supply to turn off the equipment.
- Clean the equipment using a slightly damp and non-fluffy cloth.

## 8. Disposal

- The packaging should be disposed of at local recycling points.
- Should you need to dispose of the equipment itself, never throw it away in normal domestic waste. Local regulations for the disposal of electrical equipment will apply.



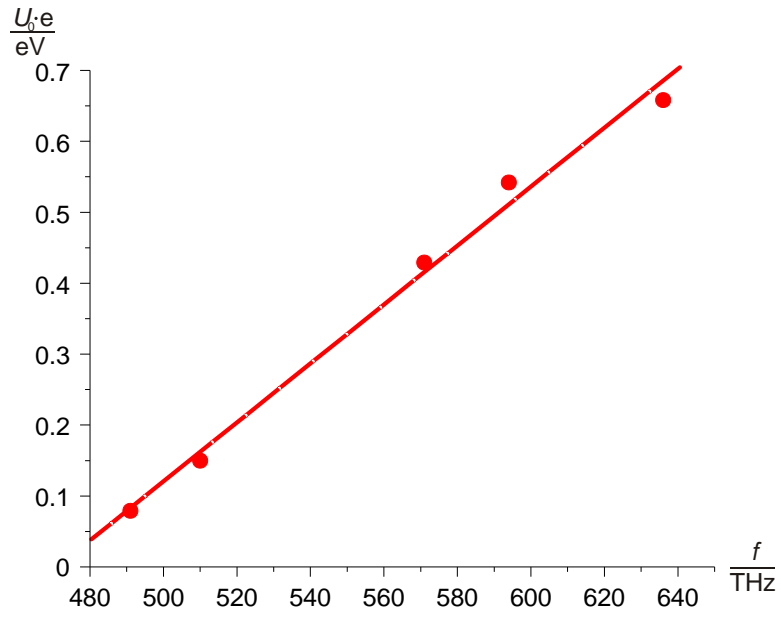


Fig.1 Critical energy  $U_0 \cdot e$  against frequency  $f$

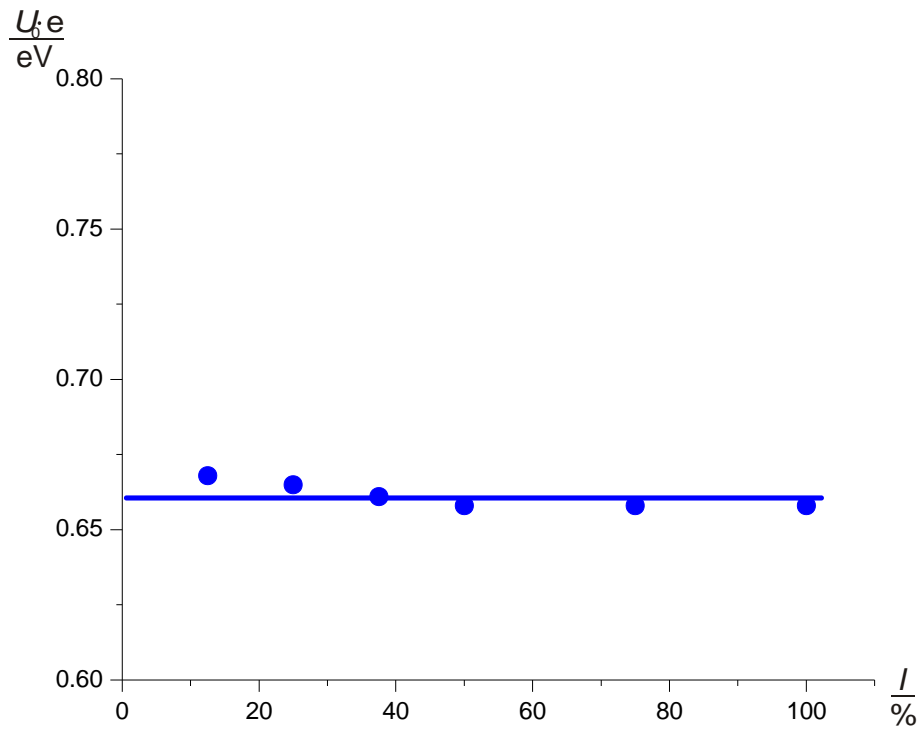


Fig. 2 Critical voltage  $U_0$  against light intensity  $I$  at a wavelength of 472 nm