

# Determination of Planck's Constant

## Objectives of the experiment

To demonstrate the photoelectric effect. To measure the kinetic energy of electrons as a function of the frequency of light. To determine Planck's constant,  $h$ . To show that the kinetic energy of electrons is independent of the intensity of light.

## Introduction

Electrons can be liberated from the surface of certain metals by irradiating them with light of a sufficiently short wavelength, this is known as the photoelectric effect. Their energy depends on the frequency,  $\nu$ , of the incident light, but not on the intensity; the intensity only determines the number of liberated electrons. This fact contradicted the principles of classical physics, and was first interpreted in 1905 by Albert Einstein, and was one of the founding principles which gave rise to the subject of quantum mechanics. Einstein postulated that light consists of a flux of particles, called photons, whose energy  $E$  is proportional to the frequency:

$$E = h\nu \quad (1)$$

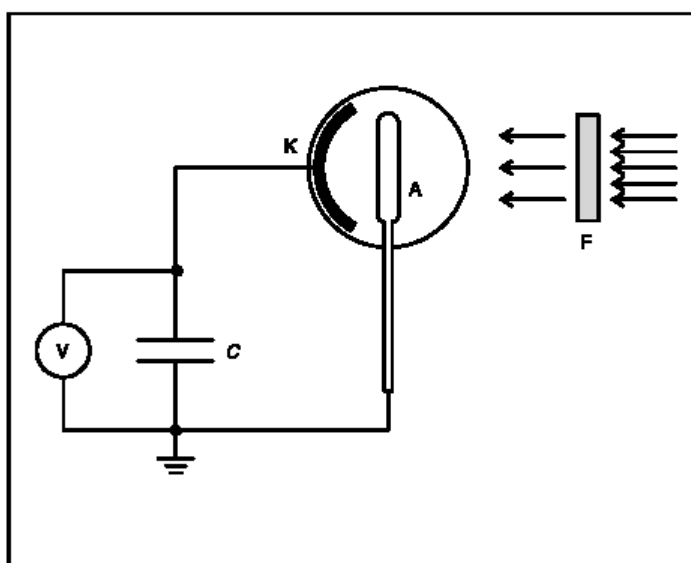
The proportionality factor  $h$  is known as Planck's constant, and is regarded as a fundamental constant of nature. In this conception of light as being particle in nature, each photoelectron (ejected electron) exits the material with the kinetic energy

$$E_{KE} = h\nu - W_K \quad (2)$$

where  $W_K$  is the work function of the electrons, and is equal to the amount of energy required to release the electrons from the particular material. We can determine Planck's constant  $h$  by exposing a

photocell to monochromatic light, i.e. light of a specific wavelength, and measuring the kinetic energy  $E_{KE}$  of the ejected electrons. Fig. 1 shows a schematic representation of such an experiment. The light falls through an annular anode, which in the present case a platinum wire, onto a potassium surface. Owing to its low work function – the valence electrons of alkali metals are weakly bound – thus potassium is a very suitable cathode material. Some of the ejected photoelectrons travel to the anode, where they are registered in the form of a photoelectric current  $I$ . If the photoelectrons are ejected against a negative

Fig. 1 Schematic representation of an experiment for measuring Planck's constant  $h$  with the aid of the photoelectric effect. Monochromatic light (produced by wavelength filter F) falls on cathode K of a photocell. The photoelectrons stimulated here travel to anode A and charge capacitor C up to the limit voltage  $U_0$ .



potential which is gradually increased, the photoelectric current continually decreases. The voltage at which the photoelectric current reaches precisely zero is called the limit voltage  $U_0$ . At this level, even the electrons with the weakest bonds, i.e. those with the lowest work function  $W_K$  and thus the greatest kinetic energy, can no longer overcome the anode voltage. In this experiment, the anode voltage is generated using a capacitor which is charged by the incident electrons up to a limit voltage  $U_0$  (see Fig. 1). We can use this limit voltage  $U_0$  to calculate the kinetic energy of these weakly bound electrons:

$$eU_0 = h\nu - W \quad (3)$$

where  $e$  is the elementary electron charge.

Note, here,  $W$  is no longer the work function  $W_K$  of the cathode, as the contact potential between the cathode and the anode is included in the energy balance.

The measurements are conducted for various wavelengths  $\lambda$  and frequencies

$$\nu = \frac{c}{\lambda} \quad (4)$$

where  $c$  is the speed of light in a vacuum. When the frequency of the incident light increases by  $\Delta\nu$ , the electron energy increases by  $h\Delta\nu$ . The limit voltage must be increased by  $\Delta U_0$  to compensate for the rise in the photoelectric current. When we plot the limit voltage  $U_0(\nu)$  as a function of  $\nu$ , equation (3) gives a straight line with the slope:

$$\frac{\Delta U_0}{\Delta \nu} = \frac{h}{e} \quad (5)$$

For a known elementary charge  $e$ , this gives Planck's constant  $h$ . In this experiment, narrow-band interference filters are used to select the wavelengths; each filter selects precisely one spectral line from the light of a high-pressure mercury lamp. The wavelength specification on the filter refers to the wavelength of the transmitted mercury line.

## Experimental Details

The experiment involves the use of a high pressure mercury lamp. **Note that the lamp also emits light in the UV band and this can cause damage to the eyes. So never look directly at the lamp, nor at reflections.** The lamp itself does not reach full intensity until after 10 minutes. Switch on the lamp whilst you are setting up the experiment so that it reaches full intensity when you are ready to make measurements. Fig 2. shows the experimental set-up.

- Connect the mercury lamp power supply to the mains via the distribution box.
- Mount the high-pressure mercury lamp at the marked position using an optical rider (height,  $H = 90$  mm), connect it to the power supply and switch it on.
- Mount the photocell at the marked position using an optical rider ( $H = 90$  mm); remove the cover and align the photocell so that the coated black surface is facing the mercury lamp.
- Mount the iris diaphragm on the optical bench at the marked position using an optical rider ( $H = 120$  mm).

– Mount the lens at the marked position using an optical rider (H = 120 mm) and adjust

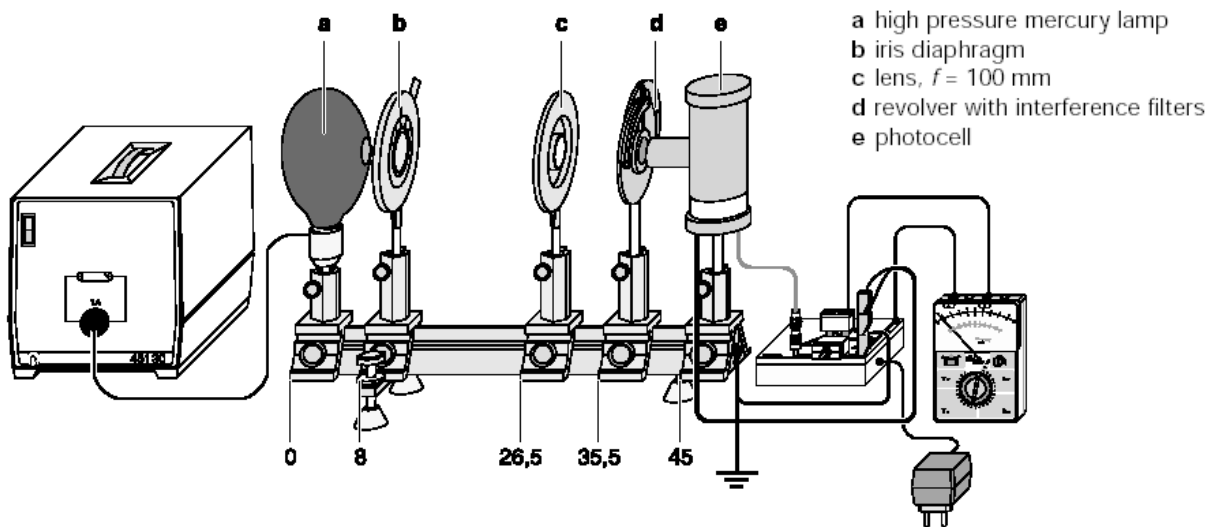


Fig. 2. The experimental arrangements of the various pieces of equipment. The distances between each element is given in cm in the lower part of the figure.

its height so that the center of the lens is at the same height as the center of the iris diaphragm. The light from the mercury lamp should now produce a sharp light spot on the black coating (the sensitive area) of the photocell. The light should not fall on the metal ring nor on the part of the black-coated area to which the contacts are attached.

The edge zones should not be illuminated either. To ensure that this is so, carry out the following procedure, repeating as often as necessary to produce the optimum image:

- Vary the height of the iris diaphragm and the lens so that the light spot falls on the black zone of the photocell; make sure that the center of the lens is always on the same level with that of the iris diaphragm. You may also need to adjust the height and inclination of the photocell (using the screws below the base).
- Using the iris diaphragm, adjust the size of the light spot so that it illuminates the largest possible area of the black zone of the photocell, without shining on the outer zones, the metal ring or the contacts on the black coating.
- Focus the light spot as necessary by moving the lens along the optical bench.
- Place the cover on the photocell.
- Place the filter revolver with iris diaphragm directly in front of the photocell using an optical rider (H = 120 mm) and connect the iris diaphragm of the filter revolver with the cover of the photocell to prevent scattered light from reaching the photocell.

**Electrical assembly:**

The photoelectrons incident on the metal ring of the photocell charge a capacitor, generating the limit voltage  $U_0$  required for determining the kinetic energy. The electrometer amplifier is used to measure the voltage at the capacitor.

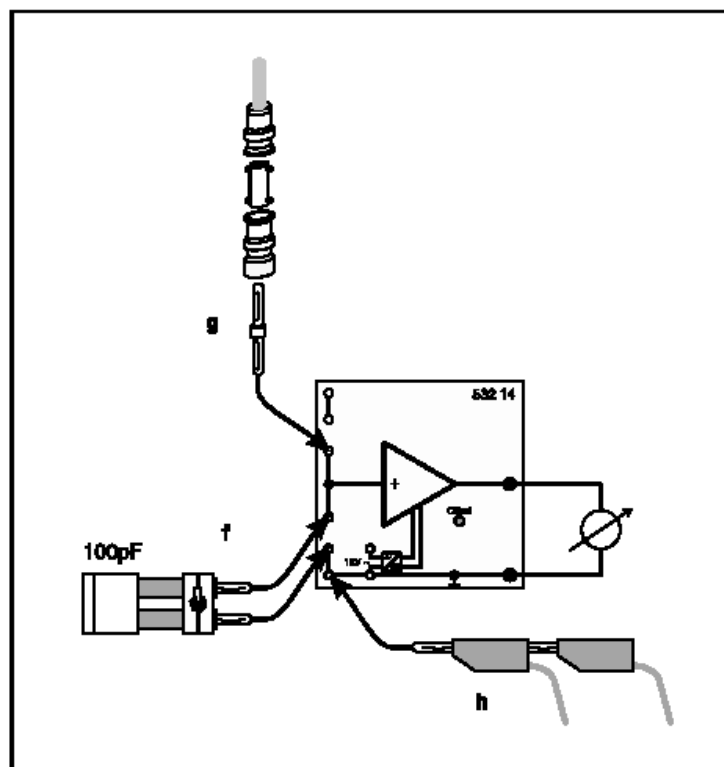
Set up the electrometer amplifier circuit as shown in Fig. 3.

- Attach terminal plug (f) and connect the 100 pF capacitor and the key switch.
- Attach coupling plug (g), the BNC/4 mm adapter and the straight BNC and connect these to the gray screened cable of the photocell.
- Connect both black cables (h) of the photocell to the ground connection on the electrometer amplifier.
- Connect the multimeter to the output of the electrometer amplifier.

Also:

- Connect the plug-in supply unit (12 V) to the electrometer amplifier and plug it in via the distribution box.
- Connect the optical bench (and possibly the rod of the basic device of the photocell) to the ground connection of the electrometer amplifier, and connect this terminal to the external ground of the distribution box or power supply.

Fig. 3 Electrometer amplifier circuit for measuring the limit voltage  $U_0$



## Carrying out the experiment

*Notes:*

*Dirt on the photocell can cause leakage currents between the anode and the cathode which can affect the measurement of the limit voltage  $U_0$ . Clean the photocell with alcohol. The voltage at the capacitor can be influenced by induction effects. Move this part as little as possible during the experiment. You do not need to darken the room; this has no effect on the measurement results.*

- Switch on the multimeter and set the range switch to V DC.
- Turn the interference filter for yellow light ( $\lambda_{\text{Hg}} = 578 \text{ nm}$ ) into the beam path.
- Discharge the capacitor by holding down the key switch until the multimeter reads zero V.
- Start the measurement by releasing the key switch; wait about 30 s to 1 minute, until the capacitor has charged to the limit voltage  $U_0$ . Write down the measured value for  $U_0$ .
- Turn the interference filter for green light ( $\lambda_{\text{Hg}} = 546 \text{ nm}$ ) into the beam path and repeat the measurement.
- Repeat the measurement with the blue ( $\lambda_{\text{Hg}} = 436 \text{ nm}$ ) and violet ( $\lambda_{\text{Hg}} = 405 \text{ nm}$ ) interference filters.
- Vary the intensity of the incident light at the photocell using the iris diaphragm of the filter revolver and measure the limit voltage  $U_0$  for each setting.

*Note: If the iris diaphragm is closed too far, this may affect the uniform illumination of the light spot on the cathode. Also, leakage currents will play an increasing role.*

Deduce a value of Planck's constant from your measurements.

## References

Adapted from Leybold instruction sheets P6.1.4.3