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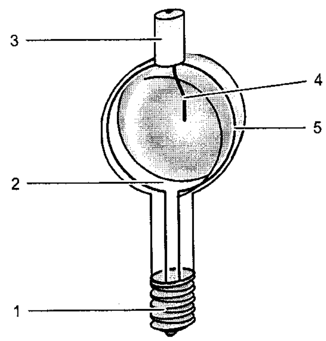


Instruction Sheet 558 77

Photo cell for determining Planck's constant (558 77)

1 E14 base, for contact connection of anode ring
2 Evacuated glass bulb
3 Brass cap, for contact connection of photocathode
4 Photocathode
5 Anode ring

1 Description

The photo cell is used to demonstrate the photoelectric effect. When the photocathode is irradiated with light, electrons are liberated from the photocathode and can be detected at the anode ring as a photoelectric current in a suitable circuit. This device can be used to show that the energy of the light is proportional to the frequency of the radiation and independent of the intensity of the radiation. When the photocathode is irradiated with monochromatic light, it is possible to determine Planck's constant.

In addition to confirming Planck's calculations for the radiation of a black body, Einstein's interpretation of these experiments confirmed the quantum nature of light.

Safety notes

The photo cell consists of an evacuated glass bulb - fragile!

- Do not subject the photo cell to mechanical stresses.

Intensive heating of the photocathode can irreparably destroy the photo cell.

- Protect the photo cell from overheating.
- Protect the photo cell against excessive incident light.
- Store the photo cell e.g. in the *basic device for photo cell* (558 791) or the *compact arrangement for determining Planck's constant* (558 79) and protect these from direct sunlight.
- Be sure to read the Instruction Sheet before baking out the anode.

2 Technical data

Photocathode:

Material:	Potassium with oxidized silver coating
Dimensions:	40 mm dia.
Contact type:	cylindrical brass cap, 10 mm dia.

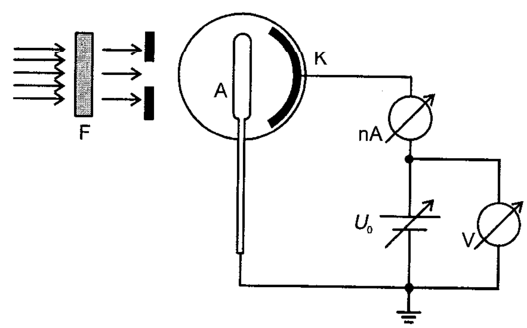
Anode ring:

Material:	platinum-rhodium alloy
Dimensions:	30 mm dia.
Contact type:	two-pin on E14 base, for baking out the ring
Resistance:	1-2 Ω

General data:

Typical photoelectric current:	0.1-1 µA (for illumination with unfiltered light from the Hg lamp)
Dimensions:	11 cm × 4 cm × 2.5 cm
Weight:	20 g

3 Operation



- Use a suitable monochromatic light source.
- Connect the photo cell in a suitable circuit (see also the Instruction Sheet of the *basic device for photo cell* (558 791) or the *compact arrangement for determining Planck's constant* (558 79)).
- Check to make sure that the light beam falls on neither the anode ring nor the connection wire of the photocathode.
- When changing the wavelength, make sure that the same spot on the photocathode is always illuminated.

Note: The coating of the photocathode can vary locally; thus the emission work for the photoelectrons can vary locally as well. This can falsify the measurement results when the light spot on the photocathode is altered when the wavelength is changed. This factor has been compensated in the *basic device for photo cell* (558 791) and the *compact arrangement for determining Planck's constant* (558 79) by means of suitable diaphragms.

4 Principle of determining Planck's constant

Principles:

When the photocathode of the photo cell is illuminated with light of a sufficiently short wavelength, this can cause the release of electrons. The energy of the photons is used to overcome the electronic work function *W*. The surplus energy is transformed into the kinetic energy of the electrons. We can thus say:

$$h \cdot \nu = \frac{m}{2} \cdot v^2 + W$$

It is important to note here that the electronic work function *W* is a material constant which incorporates the different emission potentials of the cathode and the anode. Particularly the emission potential of the cathode is a quantity that is difficult to estimate, as due to the manufacturing process the cathode surface is not homogeneous. It is composed of a mixture of potassium, potassium oxide and oxidized silver. For this reason, you need to take care that the same area is always illuminated when illuminating the cathode with light of various wavelengths.

If we now apply an opposing voltage *U* between the cathode and the anode, a current will flow as long as the following condition obtains:

$$\frac{m}{2} \cdot v^2 < e \cdot U$$

As soon as the opposing voltage is so great that the electrons can no longer overcome it, the current stops flowing. For the cutoff value

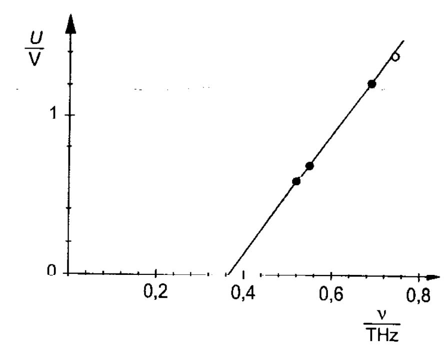
$$U_0 = \frac{1}{e} \cdot \frac{m}{2} \cdot v^2$$

we can say

$$U_0 = \frac{1}{e} \cdot (h \cdot \nu - W)$$

When we plot this value against the frequency ν, the slope of the line for a known electron charge *e* gives us Planck's constant *h*.

Measuring example:



Color	$\frac{\lambda}{\text{nm}}$	$\frac{\nu}{\text{THz}}$	$\frac{U_0}{\text{V}}$
yellow	578	0.519	0.59
green	546	0.549	0.70
blue	436	0.688	1.23
violet	405	0.741	1.40

Slope of line: $\frac{\Delta U_0}{\Delta \nu} = 3{,}8 \cdot 10^{-15} \frac{\text{V}}{\text{Hz}}$

If $e = 1.602 \cdot 10^{-19}$ C we obtain $h = 6.1 \cdot 10^{-34}$ Js

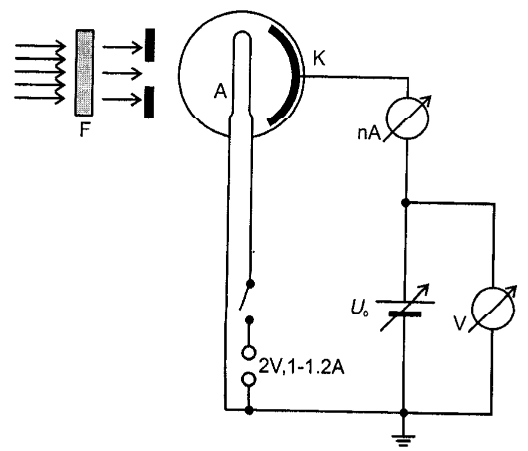
Literature value: $h = 6.626 \cdot 10^{-34}$ Js

Note: The measured values for the voltages U_0 given in the table can vary greatly from device to device, and even as a function of the illuminated area of the photo cell. The differences in the voltages, on the other hand, are reproducible within the limits of measurement accuracy.

5 Baking out the anode ring

Potassium can precipitate on the anode ring in very old photo cells, in the course of storage at higher ambient temperatures or under illumination of the photo cells at very high intensities, making it necessary to bake out the anode ring.

Attention: Bake out the anode ring only if the measurement results cannot be improved by any other means, as the potassium atoms baked out of the anode ring can precipitate over the entire photo cell. Particularly when the process is performed improperly, the potassium layer of the photocathode can be overheated, releasing more potassium which can precipitate over the entire photo cell and thus irreparably damage the device.



- Set up the electrical circuit as shown in the illustration.
- Apply an opposing voltage U_0 of 1 - 2 V between the anode and the cathode.
- Switch on the measuring amplifier for measuring the photoelectric current.
- Switch on the heating voltage for the anode ring (2 V, approx. 1.0-1.2 A) and observe the indicator for the photoelectric current.

As soon as the sign of the photoelectric current changes, after approx. 1-2 s. (The change in sign is the best indication for sufficient baking-out.):

- Switch off the heating voltage immediately.
- Never heat beyond this point or work for longer periods with lower heating currents.

6 Fault-finding

Problem: The measured values for the opposing voltage U_0 vary greatly and are not reproducible.

Cause	Solution
The photoelectric currents are very low so that interference factors have a great effect. The device has no been grounded carefully.	- Ground the setup in star configuration, eliminate loops which can function as antennas. - Ground housing of photo cell. - Ground screening of coaxial cable for current measurement. - Ground optical bench if necessary. - Use earth handle if necessary.

Problem: The measured values for the opposing voltage U_0 are stable, but the voltage differences are too slight.

Cause	Solution
The insulation of the photo cell is impaired.	- Clean the photo cell, particularly the glass bulb. - Clean the cell with alcohol if necessary.
Corroded contacts are causing contact resistances.	- Clean the contacts carefully, e.g. with alcohol; to remove stubborn contamination use an eraser and then alcohol.
The potassium coating of the cathode and thus the electronic work function is unevenly distributed. A different area is illuminated after chnging the wavelength.	- Use a diaphragm at the entrance to the photo cell (included in 558 79 and 558 791).
The anode ring is directly illuminated. Electrons are being emitted from the anode ring and increase the opposing voltage.	- Use a diaphragm at the entrance to the photo cell (included in 558 79 and 558 791).
Excessive light intensities causing reflections on the anode ring.	- Do not set the light intensity too high, possibly use an iris diaphragm as a space filter or crossed polarizers to attenuate the light.
Potassium has precipitated on the anode ring. The electronic work function is thus extremely low and the opposing currents are very high.	Only as a last resort when all else fails: - Bake out the anode ring to vaporize the potassium.

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