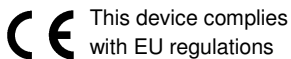


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## Operating instructions



This device complies with EU regulations



Fig. 1: Photocell for determination of Planck's constant  $h$  with housing 06779-00

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### 1 SAFETY PRECAUTIONS

- Carefully read these operating instructions completely before operating this instrument. This is necessary to avoid damage to it as well as for user safety.
- Use this instrument only for the purpose for which it was designed.

### 2 PURPOSE AND PROPERTIES

The photocell with housing serves the examination of the outer photoelectric effect.

The properties of the outer photoelectric effect show in the dependence of the current over voltage characteristic line of a photocell in dependence on intensity and wavelength of the light entering the photocell.

The interaction of photons with electrons, where an electron completely absorbs a photon is called photo effect. In the reaction the electron gains energy and momentum of the photon.

If the electron resides inside a substance near the surface, the electron may leave the substance if the gained energy is sufficient.

This electron emission of an illuminated surface is quoted outer photoelectric effect. When leaving the substance, the electron loses its binding energy. This binding energy is quoted electrochemical potential or work function. It depends on the state of binding the interacting electron.

Metals contain a high density of electron energy states in the vicinity of the Fermi level  $E_{\text{Fermi}}$ , to which the conduction band of the metal is filled. Electrons in these states have all a similar work function and have also high mobility and can interact with the photons. So metals start to emit many electrons when irradiated with photons of sufficient energy to lift the electrons from Fermi level to the potential of the space outside the substance, that is to overcome the work function.

The quantum efficiency of this process is low though, since the momentum of the photon is mostly towards the substance and there is a process needed to turn around the electron momentum or the photon is to react after or within the process of reflection.

So without a further electrode an illuminated body will electri-

cally charge until the then present positive charge on it restrains the electrons.

A photocell comprises inside a high vacuum tube a cathode with low work function and an anode with a for metals typical work function, which can gather the emitted electrons.

Since photo cells serve as light detectors, the cathode takes most of the available surface and is facing the light while the anode is positioned such that it least shadows the cathode but still is in best reach of the electrons.

When cathode and anode are electrically connected, a current starts to run. Since a fraction of the electrons is recaptured by the cathode – the energy of the electrons can eventually be lowered by entering the solid state – the photo current rises if the anode is biased positive with respect to the cathode. Then the field of the anode gathers the electrons before they can drop back into the cathode. The photo current saturates at the voltage that is sufficient to catch all the emitted electrons. This photo current is strictly proportional to illumination intensity.

If the anode is biased negatively with respect to the cathode, with increasing voltage less and less electrons reach the anode until finally the energy of the electrons emitted by the cathode is no longer sufficient to overcome the electrical field and reach the anode.

Thus the current characteristics of the photo cell at negative bias – anode negative with respect to cathode – contains information about the energy spectrum of the electrons.

A maximum electron energy appears to exist which does not depend on illumination intensity but on light frequency alone.

This behaviour confirms the quantum properties of light. Determining of the dependence of the maximum kinetic energy of the electrons on light frequency yields a linear correlation between light frequency and photon energy.

The linear constant between both is the Planck's constant and can so be determined with these measurements of current characteristics.

Due to electrons being also liberated from the anode by photo effect, a negative current can be measured, if a negative bias of sufficient strength is applied. This current is always present with illumination of sufficient energetic photons and has its own wavelength and intensity dependent characteristics. It is by far lower in strength than the cathode current. Additionally, thermal excitation and radioactivity can generate a dark current which is again lower by orders of magnitude.

To achieve the strongest possible photo current per light intensity and the widest possible light frequency range response, the cathode is coated with a material of especially low work function and a high density of electrons near the surface. Furthermore the material should have a large surface and is thus rough at microscopic scale. Such materials behave not necessarily like classical metals and in particular the electron density over energy near the surface within reach of the photons is no simple function.

The photocell response with respect to light intensity may strongly depend on light wavelengths and may also be no simple function of wavelength.

In many applications semiconductor photovoltaic cells have replaced the photocell, because vacuum tubes are far more expensive to produce and harder to miniaturize than semiconductor devices. The quantum efficiency of semiconductor photo detector cells is by far greater.

For special applications at extreme or extreme broad frequency ranges e.g. for UV light or spectrometers or at harsh surroundings those tubes will still find their use.

### 3 FUNCTIONAL AND OPERATING ELEMENTS

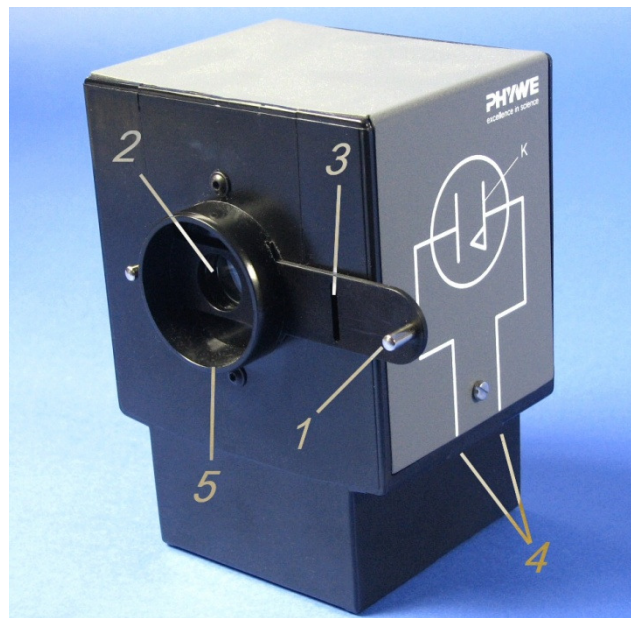


Fig. 2: Functional and operating elements of the photocell with housing

- 1 *Slider for photocell aperture*  
slider with three positions, in middle position the photocell is closed
- 2 *Round aperture*  
for maximum light admittance
- 3 *Slit aperture*  
for use with a grating spectrometer
- 4 *Electrical connectors for the photocell*  
with two 4 mm-sockets for connecting cathode and anode, cathode right
- 5 *Mount for lens- or diaphragm holder*  
to fit standard 44 mm lens holders on

### 4 NOTES ON OPERATION

For precise control of the bias voltage it is recommended to use a potentiometer circuit as bias supply to record the current-voltage ( $I/U$ ) characteristic.

Since the photo current is in the  $\mu\text{A}$  range, a measuring amplifier or a sensitive ampere meter is recommended for current measurement, e.g. 07042-00 multi range meter with amplifier, 13620-93 DC measuring amplifier or 13262-93 universal measuring amplifier.

The measuring circuit has to be connected such that the current through the voltmeter is not recognised by the ammeter (voltage error circuit) because the current through the voltmeter with typical 1 M $\Omega$  input resistance at 1 Volt is with 1  $\mu\text{A}$  of the same range as the photo current.

The illumination of the cell should be such, that a wavelength range of visible to UV light can be selected to enter the cell.

This can be done with help of a spectral lamp emitting a line spectrum of several narrow lines which can be selected using colour or interference filters.

Or else a wide-band emitting lamp like an incandescent lamp is used and the desired wavelengths are selected with help of interference filters or a grating spectrometer.

Fig 3 depicts an example for the connections for the recording of a  $I/U$  characteristic with help of the universal measuring amplifier 13626-93.

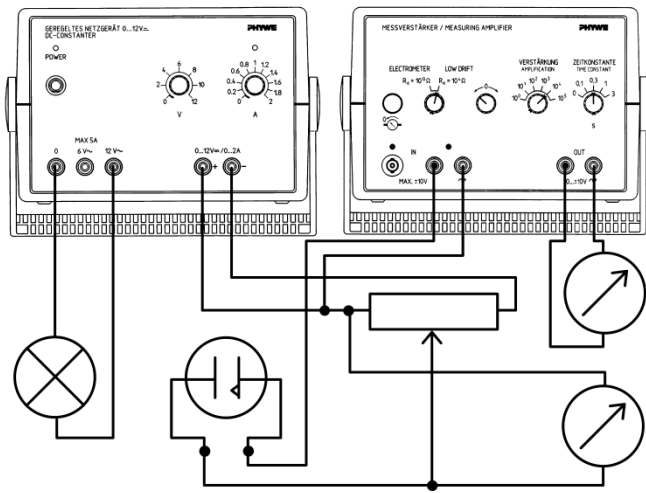


Fig. 3: Circuit for recording  $I/U$  characteristic

## 5 HANDLING

The photocell housing can be mounted into a slide mount with help of the rod with thread enclosed in the delivery for example for insertion in a grating spectrometer for wavelength selection assembled on an optical bench. Else it can be placed directly on the table.



Fig. 4: Example of a experiment set-up with interference filters

Example for performing the experiment with the set-up of Fig. 4:

- Set amplifier to low drift mode, amplification  $10^4$ , time constant 0.3 s
- Check zero point of the amplifier: Set the multimeter reading to zero with the zeroing control when nothing is connected to amplifier input
- Set the power supply to 3 V and 1 A
- Attach one of the interference filters to the photocell opening
- Put the photocell housing directly in front of the lamp, select the round aperture with the slider
- Note down the amplifier output voltage in dependence on photocell bias voltage, bias 0...3 V
- The amplifier output voltage is proportional to photo current, at 10 kOhm input resistance of the amplifier with amplification factor  $10^4$ , 1 V at the output correspond to current strength 10 nA
- Especially note down the bias voltage value at which the photo current is zero and plot this over frequency of the

light in use (calculate this from the interference filter central wavelength)

- Continue with the next interference filter

## 6 EVALUATION

The incoming photons supply the energy  $hf$  each, which after the emission of the electron from the cathode is split into the cathode work function  $W_C$  and the kinetic energy of the electrons  $W_{kin}$  (if no other collisions slow the electrons down)

$$hf = W_C + W_{kin} \quad (1)$$

and the kinetic energy  $W_{kin}$  in case of the current zero point  $I = 0$  is used up completely to cross the bias voltage  $U_0$  and the unknown contact voltage  $U_{AC}$  between anode and cathode,

$$e(U_0 + U_{AC}) = W_{kin} \quad (2)$$

with electron (elementary) charge  $e = 1.602 \cdot 10^{-19}$  As.

For contact voltage it is:

$$e U_{AC} = e(U_A - U_C) = W_A - W_C \quad (3)$$

with the electrochemical potentials of anode and cathode  $U_A$  and  $U_C$  and the work function of the anode  $W_A$ .

This yields the linear function of frequency  $f$

$$e U_0 = hf - W_A \quad (4)$$

or else

$$U_0 = \frac{h}{e} \cdot f - U_A \quad (5)$$

with the constants  $h$  and  $W_A$ . By plotting the measured zero current voltage  $U_0$  over frequency of the light Planck's constant  $h$  can be read from the slope of the graph divided by elementary charge  $e$ .

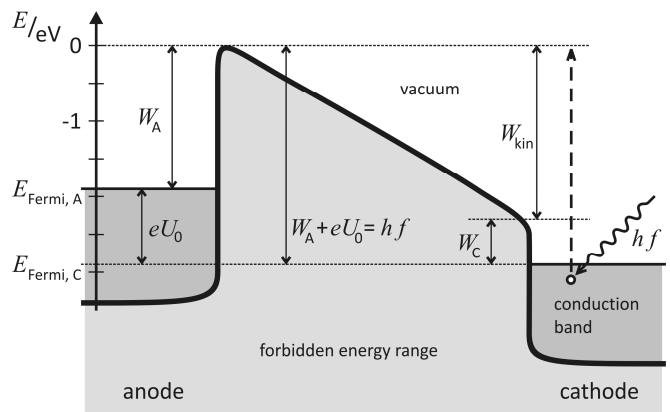


Fig. 5: Energy diagram for electrons, showing the conditions in the photocell at illumination with light of  $\lambda = 436$  nm. Here the bias voltage is just high enough that electrons cannot reach the anode and current strength is zero,  $U_0 = 1$  V. The Fermi levelsof cathode and anode differ by 1 eV correspondingly.



Table 1: Measurement example

$\lambda$ / nm	$U_0$ / V	$f/10^{12}$ Hz
366	-1,50	820
405	-1,20	741
436	-1,00	688
546	-0,50	550
578	-0,40	520

With the data of table 1 the slope is

$$\frac{e \cdot U_0}{h \cdot f} = 0,00366 \text{ V} / \text{THz}$$

and thus

$$h = 5,59 \cdot 10^{-34} \text{ Js}$$

to compare with literature value

$$h = 6,63 \cdot 10^{-34} \text{ Js}$$

## 7 TECHNICAL DATA

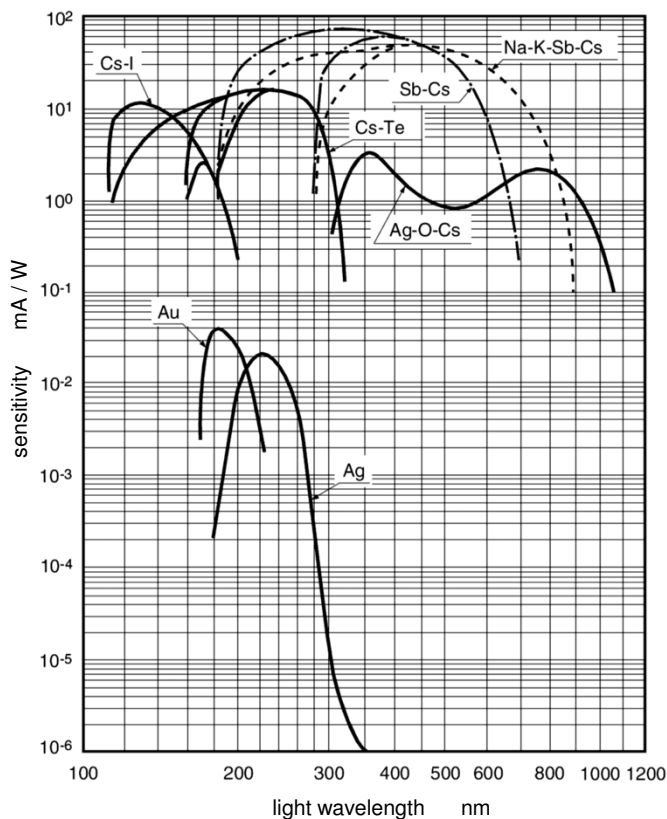


Fig. 6: Sensitivity of the Bb-Cs cathode in use in the photocell in comparison to other cathode materials

active diameter	15 mm
wavelength range	185...650 nm
best sensitivity at	340 nm
cathode material	Sb-Cs
sensitivity	110 $\mu\text{A}/\text{lm}$ 70 mA/Watt
maximum cathode current	6 $\mu\text{A}$
maximum allowed voltage	100 V
operating voltage	15 V
dark current at 15 V	2,0 pA
cell capacity	2 pF

## 8 SCOPE OF DELIVERY

Photocell with housing

Rod 100 mm x 10 mm with M6 thread for mounting

## 9 MATERIAL LIST

(as of Fig. 4)

1 x 06779-00	Photocell for $h$ -determination, with housing
1 x 08461-00	Interference filters, set of 3
1 x 08463-00	Interference filters, set of 2
1 x 11601-00	Experimental lamp 5
1 x 13505-93	Power supply, 0...12 V DC/ 6 V, 12 V AC
1 x 13626-93	Universal measuring amplifier
1 x 07122-00	Digital multimeter
1 x 06114-02	Rheostat 100 Ohm, 1.8 A
4 x 07361-01	Connecting cord, 32 A, 500 mm, red
3 x 07361-04	Connecting cord, 32 A, 500 mm, blue
1 x 07361-02	Connecting cord, 32 A, 500 mm, yellow
2 x 07361-05	Connecting cord, 32 A, 500 mm, black
1 x 07363-04	Connecting cord, 32 A, 1000 mm, blue

## 10 NOTES ON THE GUARANTEE

We grant a warranty of 24 month inside EU and 12 month outside EU for this device. Excluded from warranty are defects due to disregard of the operating instructions, misuse or usual wear.

The manufacturer can be held responsible for function and security of the device, only if servicing, repair and technical modifications have been executed by the manufacturer or institutions explicitly authorized by the manufacturer.

## 11 WASTE DISPOSAL

The packaging consists predominately of environmentally compatible materials that can be passed on for disposal by the local recycling service.



Should you no longer require this product, do not dispose of it with the household refuse.

Contact your local authorities for proper disposal or return it to the address below:

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