Instruction Manual

For

Planck's Constant Apparatus

Model P67401

1-800-530-1500

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1. Applications

Planck's Constant Apparatus (Model P67401) is designed to measure Planck's constant by use of photoelectric effect. The instrument features open construction, simple operation, reliable performance, and high precision. The experiments can be conducted in a regular laboratory instead of a darkroom.

This instrument is used in experiments of modern physics and general physics at colleges and universities. The Picoampere amplifier and control unit can also be used to measure feeble current within 10^{-9}A~10^{-13}A.

2. Identification and Setup

The instrument has three component parts: a mercury light source, a photocell unit with lens and filter, and a Picoampere amplifier and control unit. The distance between the mercury light source and the photocell unit can be adjusted to meet the requirement of each experiment.

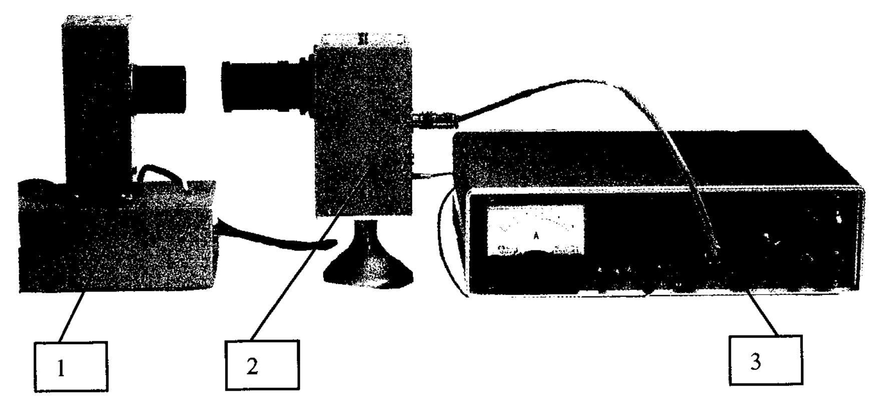


Fig.1-1 Setup

1 Mercury Light Source 2 Phototube with Filter 3 Picoampere Amplifier

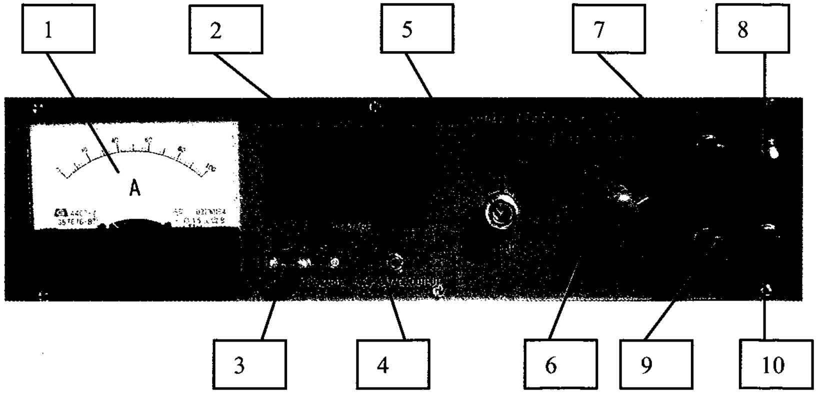


Fig. 1-2 Picoampere Amplifier

1	Ammeter	2	Voltmeter	3	Current Switch
4	Acc.Voltage Output	5	Input Jack	6	Range Selector
7	Zeroing Dial	8	Power Switch	9	Full Scale Dial
10	Acc.Voltage Control				

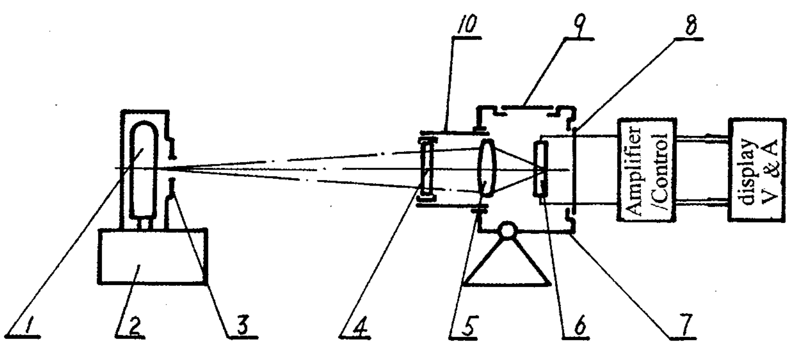


Fig 1-3 Optical Path

1. High voltage mercury lamp	2. Ballast	3. Diaphragm
4. Interference filter	5. Object glass	6. Phototube
7. Photocell unit with lens and filter	8. Dark-box's back cover	
9. Cover of observing window	10. Objective tube	

Mercury light source

A 50W high-voltage mercury lamp is used in the instrument. Its cover has a window on the side, with a fixed diaphragm. The ballast for the mercury la mp is mounted in the base.

ZG-II medium film interference filters

An important feature of interference filters is allowing one spectrum line to pass while the others are blocked. When an interference filter of specified wavelength is inserted in front of the objective tube of the photocell unit, the monochromatic light of the specified wavelength will be obtained.

Object glass

The object glass is installed in the objective tube, which is located in front of the photocell unit. The user can rotate the objective tube to adjust the distance between the object glass and the phototube, in order to make the image of the mercury lamp clearer and bring it to the center of the phototube's cathode plate.

GD-2 phototube

The GD-2 phototube is mounted in the photocell unit. The height of the phototube can be adjusted after loosening the big screw on the ceramic holder. When necessary, the position of the photocell unit should be adjusted to bring the image of the filament to the center of the phototube's cathode plate.

In order to check the image of the mercury lamp on the phototube's cathode plate in experiments, the user should remove the cover at the top of the photocell unit.

Picoampere amplifier and control unit

This device measures micro-currents in the range of 10^{-9}~10^{-12}A. The zero shift is no more that +/- 2% for eight hours after the apparatus is warmed up. The voltage range is –2V~+2V. The unit has a digital voltmeter and a analog ammeter. The power supply provides the phototube with a voltage adjustable between –2V and +2V, with an error less than 2%.

V-I graphs of the phototube can be plotted with an x-y function recorder (not included) connected through the outlets on the back.

3. Specifications

1. Source light
(1) Lamp: GGQ-50W high-voltage mercury vapor lamp
(2) Spectral range: 320.3nm-872.0nm
(3) Spectrum lines: 365.0nm, 404.7nm, 435.8nm, 491.6nm, 546.1nm, 577.0nm.

2. GD-27 Phototube
(1) Anode: 25mm diameter nickel ring
(2) Cathode: Ag-O-K
(3) Window: boron-silicon glass

(4) Spectral response range:30nm~700nm
(5) Peak wave-length: 350nm +/- 20nm
(6) Minimum cathode sensitivity: 1 μ A/1m
(7) Dark-current: 10^{-12}A
(8) Ratio of Reverse to Positive saturation currents: <0.5%

6. ZD-II Medium film interference filters
(1) Wave-lengths: 365.0nm, 404.7nm, 435.8,nm, 546.1nm, 577.0nm
(2) Type: narrow-band, multi-layer film
(3) Diameter: 30mm

4. PC-II Picoampere amplifier and control unit (power supply of phototube is included)
(1) Voltmeter: 3 ½ digital LED display
(2) Current measurement range: 10^{-9}A~10^{-12}A in 5 steps
(3) Zero shift: < +/- 2% at 10^{-3}A for eight hours (60 minutes after instrument is turned on)
(4) Power supply of phototube: -2V~+2V, precisely adjustable with error ≤ 0.1%

5. Accuracy
< 5% with respect to the universally accepted value (h=6.62619 × 10^{34}J.S)

6. Power Supply: 110V, 50Hz

7. Weight: 13Kg

4.Theory

Planck's Constant

When light hits an object, only a part of its energy is absorbed by the object and turned into heat; the rest becomes the energy of electrons inside the object, enabling the electrons to escape to the surface. This phenomenon is called photoelectric effect. In this process, light shows its nature as particles. When he was looking for the energy distribution of blackbody's radiation in 1900, Planck introduced a universal constant in his particle hypothesis which is known as Planck's constant. It is used to determine whether a physical system should be handled by quantum mechanics.

In 1905, Einstein put forward the "light quantum" hypothesis in an effort to explain the photoelectric effect phenomenon: a photon with the frequency of ν possesses the energy of hν. When an electron absorbs the photon's energy hν, a part of the energy becomes the electron's escaping power w, and the rest is transferred into the electron's kinetic energy $1/2mv^2$:

$$1/2mv^2 = h\nu - w$$

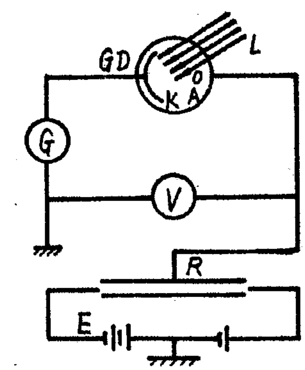
The relation is known as Einstein's photoelectric equation.

Millikan justified this equation with experiment for the first time in 1916, with the value of h measured as 6.57 × 10^{-34}J.S. Its percentage error was about 0.5%. In 1923, Millikan won the Nobel Prize for this work.

This experiment helps us learn the concept of quantization of light and provides a method of measuring h.

Theory of the Experiment

The working principle of the apparatus is shown as follows.



GD: phototube; K: cathode of phototube; A: anode of phototube
G: micro-current meter; V: voltage meter; E: battery; R: Rheostat

The accelerating voltage U_{AK} is obtained by adjusting the Rheostat. The monochromatic lights are selected from the mercury lamp's spectrum by filters, with wavelengths as 365.0nm, 405nm, 436nm, 546nm and 577nm.

When no light enters the cathode, the anode and cathode is open-circuited, and there is no current going through G.

When light reaches the cathode, electrons escaped from it as photocurrent. The higher the U_{AK} is, the stronger the photocurrent will be. When U_{AK} reaches a certain value, the cathode photocurrent no longer increases – this value is called its saturation value I_H (Fig. 2).

If a negative U_{AK} is applied, the cathode photocurrent will decrease. When U_{AK} reaches a certain negative value, the cathode photo current becomes 0. Its corresponding voltage is called stopping potential and is indicated as Ua. The absolute value of Ua is not dependent on light intensity; it increases with the frequency of light (Fig.3).

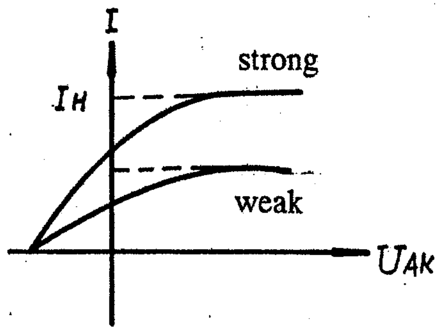


Fig. 2

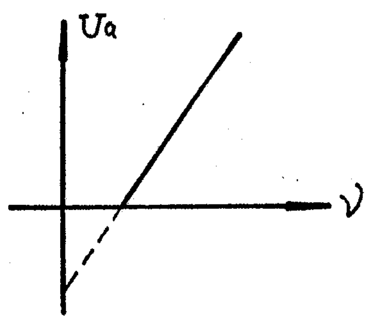


Fig. 3

The following conclusions can be made from the observations.

(1) The saturation current is related to the intensity of light.

(2) The escaping electrons from cathode possess initial kinetic energy. Its maximum value is equal to the work done against the force of electric field that is $\frac{1}{2}mv^2 = eUa$. Because $Ua \propto \nu$, the initial kinetic energy is independent of the intensity of light. It only increases with the light frequency. $Ua \propto \nu$ can also be expressed as $Ua = h/e\ \nu - w/e$, according to Einstein's equation. In experiments users can measure the corresponding stopping potential (Ua_1, Ua_2, ...) for monochromatic light of different frequency, plot the Ua-ν curve, and calculate h as the slope of the curve.

(3) If the photon's energy is less than w ($h\nu \leq w$), no matter how intense the light is, no photoelectron will escape. The corresponding frequency is called the red limit of the cathode, expressed as νo ($\nu o \leq w/h$). In the Ua-ν curve, the intercept is the red limit from which escaping work can be obtained.

The purpose of the experiments is to determine the stopping potential and plot the Ua-ν curve.

5. Operation

(1) Connect the input jack of the Picoampere amplifier and control unit to the output jack labeled"K" on the photocell unit with a high frequency accordant cable; connect the accelerating voltage input jack "A" of the photocell unit to the accelerating voltage output jack of the Picoampere amplifier and control unit with a shield cable; switch on the Picoampere amplifier and control unit; turn on the ballast of the mercury lamp, and let it fully warm up. (The warm-up usually takes about 20 minutes)

(2) Turn the range selector dial on the Picoampere amplifier and control unit to "SHORT". Remove the objective cover on the mercury light source; open the observing window. Adjust the position of the mercury light source, the photocell unit and the object glass to bring the mercury lamp's image to the center of the phototube's anode ring, focus it and then replace the objective cover.

(3) Turn the range selector dial to "SHORT".Rotate the zeroing dial to make the short current of amplifier "00.0". Turn range selector to "FULL SCALE". Turn the full scale dial to make the current "100.0". Turn the range selector to the required range for measurement.

(4) Adjust the Acc.Voltage Control until the voltmeter shows"−2V. Turn the range selector to 10^{-11}A. The value displayed on the digital ammeter is the dark-current at this voltage. Repeat the above procedure for lower voltages and dark-currents, at an interval of 0.2V from −0V to −2V, and plot the dark-current's characteristic curve for each setting.

(5) Remove the objective cover from the photocell unit; install the 365.0nm interference filter. Turn the range selector to 10^{-11}A. Adjust the Acc.Voltage Control to set the voltage to 0V. Record the current value. Then, increase the voltage by 0.1V and record the current again. Use 0.1V as voltage increment and continue to record the voltage and current values until the current reaches a value determined by the user (for example 100). Then, plot the photocurrent's characteristic curves. At the turn-corner of the curve the voltage step can be set to 0.05V and additional data can be taken for higher accuracy. The intercept of the two characteristic curves (the photo-current graph from step 5 and the dark-current curve from step 4) is the stopping potential for 365.0nm.

(6) Repeat step 5 with wavelengths of 404.7nm, 435.8nm, 546.1nm, and 577.0nm to obtain the photocurrent's characteristic curve and corresponding Ua' for each wavelength.

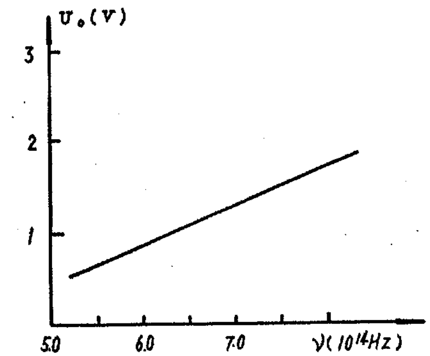
(7) Plot a Ua' $-\nu$ curve with the data by means of linear regression; determine the coefficient of correlation "Y" and Planck's constant "h".

(8) If a recorder is used, connect the x-y function recorder to the binding post on the back of the Picoampere amplifier. The black post is the ground; the "y" post should be connected to the "y" output and the "x" post should be connected to the "x" output. A V-I characteristic will be obtained on the recorder.

(9) Change the distance between mercury light source and phototube, and observe the relationship between photocurrent and light intensity to verify the law of photoelectric effect.

Sample Data

Wavelength (nm)	365	405	436	546	577
Frequency ν ($10^{14}S^{-1}$)	8.27	7.41	6.88	5.49	5.19
Stopping Potential U_0(V)	1.81	1.43	1.20	0.63	0.51
Coefficient of correlation γ			0.999642		
Slope $\Delta v/\Delta \nu$			$4.09x10^{-15}V_0S$		
Planck's constant h			$6.83x10^{-34}J_0S$		
Percentage error E_0			3.14%		



6. Maintenance

1 The mercury lamp may not turn on again immediately after it is turned off. Wait for a few minutes.

2 The proper distance between the mercury light source and the photocell unit is 30cm ~ 50cm. The light emitted from the mercury light source must be focused on the center of phototube's cathode. Be sure the light does not reach the anode filament, otherwise the result will be inaccurate.

3 During the experiment, the opening of the objective tube may not be exposed to other intense light source, such as sunlight. After each experiment, replace the objective cover.

4 Leave the phototube in the photocell unit. Before each experiment, blow the surface of phototube and the inside of the photocell unit with a hair-dryer.

5 The instrument should be protected from magnetic fields, electric fields, vibrations, and moisture.

6 If dust or oil is found on the surface of the mercury lamp, phototube, or object glass, clean them with absorbent cotton soaked in rubbing alcohol.

7 Keep the instrument in a dry, clean place with a dust cover.

7. Packing List

1. Mercury light source 1 each

2.	Photocell unit with lens and filter	1 each
3.	Picoampere amplifier and control unit	1 each
4.	ZD-II medium filmed interference filters	5 each
5.	High frequency accordant cable (50 Ω, 50cm)	1 each
6.	Objective Cover	1 each
7.	Power cord	1 each
8.	GD-27 phototube	1 each
9.	Instructional manual	1 each