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Photoelectric Effect

Determining the Planck's Constant experimentally and verifying Inverse Square law of radiation

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***Abstract*—Late in the 19th Century, it was discovered that incident light on metal surfaces ejected photo-electrons; the energy of these electrons was not dependent on the intensity of the light but instead the frequency and the energy carried by the light particles. This phenomenon was known as the Photoelectric Effect. The ratio constant relating frequency and KE of electrons is Planck's constant. In this session, (i) We found out the value of Planck's constant experimentally and (ii) Verified the Inverse Square Law of Radiation. The above experiments were performed with the help of a vacuum phototube and halogen tungsten lamp.**
In this session, we are calculating the excitation state of the Argon atom using both auto and manual modes.

***Index Terms*—photoelectric effect, Planck's constant, inverse square law, radiation etc.**

I. Objective

The aim of this experiment is:

a. Determine the value of Planck's constant experimentally and graphically
b. To verify the inverse square law of radiation.

II. Materials and Methods

The materials that were used are:- Halogen tungsten lamp, Optical bench, Drawtube, Cover chamber containing phototube, Display meter (Current and Voltage), Display mode switch, Current Multiplier, Light intensity knob, Voltage adjusting knob, Voltage direction switch, Power switch, Colour filters (x5)

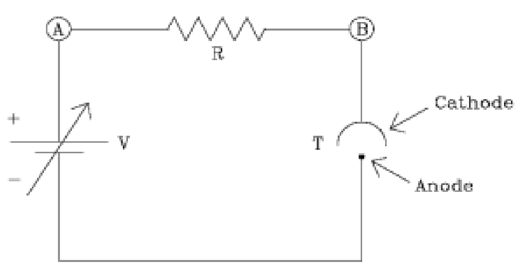


Fig. 1. Schematic diagram of the circuit used for demonstrating the photoelectric effect

The kinetic energy of emitted photoelectrons is measured by retarding potential technique, and the potential at which the photocurrent drops to zero is termed as stopping potential. So when the stopping potential Vs is plotted against the frequency, the slope yields the value of 'h', and the intercept on y axis gives the work function.

$$\frac{1}{2}mv^2 = eV_s \tag{1}$$

$$V_s = \frac{h}{e}v - \Phi \tag{2}$$

If L is the luminous intensity of an electric lamp and E is the luminescence at point 'r' from it, then according to the inverse square law

$$E \propto \frac{1}{r^2} \tag{3}$$

If light is allowed to fall on the photocathode from this distance(r), then the photocurrent(I) will be proportional to E. Thus, we get

$$E = KI = \frac{L}{r^2} \tag{4}$$

where K is constant.
Hence, When we plot a graph for I vs $\frac{1}{r^2}$ we should get a straight line, which will verify the inverse square law of radiation.

III. Procedure

A. Determination of Planck's constant

1) Begin by connecting the Planck's constant measuring instrument. Set the distance between the light source and the photocathode to 25 cm. Insert the red colour filter, and turn on the instrument. Adjust the light intensity to medium (it can be set at maximum intensity, but we are setting it at medium to avoid errors due to the heating up of the tungsten lamp), set the voltage direction to negative, and initialize the voltage at zero. Switch the display mode to current and record the readings.
2) Increase the de-accelerating (negative) voltage in fixed intervals, noting the displayed current readings. Continue until the photocurrent reduces to zero and take two to three more readings after the current drops to 0 A.
3) The voltage corresponding to zero current is the stopping voltage. Repeat these steps for other colour filters, collecting tabular data displaying frequency and stopping voltage.
4) After completing the experiment, ensure all knobs are turned to their minimum positions for the safety of the apparatus.

B. Inverse Square Law Experiment

1) Switch on the apparatus, Insert the red filter(635 nm), change the direction to positive and set the initial reading at +0.1 V.
2) Adjust the intensity to medium(We are not using the lamp at its maximum intensity to avoid errors due to its heating

effect) and establish a distance of 40 cm between the light source and photocathode.

3) Move the light source away from the photocathode at 2cm intervals until the distance between the source and the photocathode is 20 cm. Record the readings at each interval.

IV. Results

A. Determining Planck's Constant by plotting Stopping Voltage

- Observation Tables and Graphs

images of the actual readings are shown in section VII

635nm

Voltage (in V)	Photocurrent (in A)
0.00	0.134
0.02	0.102
0.04	0.079
0.06	0.057
0.08	0.040
0.10	0.026
0.12	0.020
0.14	0.012
0.16	0.005
0.18	0,003
0.20	0.000
0.22	-0.002
0.24	-0.002
0.26	-0.005
0.28	-0.005
0.30	-0.005

TABLE I
PHOTOCURRENT FOR WAVELENGTH 635NM FOR VARYING VOLTAGES

570nm

Voltage (in V)	Photocurrent(in A)
0.00	0.390
0.02	0.322
0.04	0.286
0.06	0.238
0.08	0.196
0.10	0.167
0.12	0.135
0.14	0.113
0.16	0.082
0.18	0.068
0.20	0.049
0.22	0.035
0.24	0.026
0.26	0.018
0.28	0.011
0.30	0.007
0.32	0.004
0.33	0.000
0.36	-0.001
0.38	-0.002
0.40	-0.002

TABLE II
PHOTOCURRENT FOR THE WAVELENGTH 570NM FILTER FOR VARYING VOLTAGES

540nm

Voltage (in V)	Photocurrent (in A)
0.00	0.634
0.02	0.564
0.04	0.505
0.06	0.449
0.08	0.406
0.10	0.400
0.12	0.339
0.14	0.299
0.16	0.255
0.18	0.224
0.20	0.194
0.22	0.160
0.24	0.131
0.26	0.109
0.28	0.090
0.30	0.070
0.32	0.056
0.34	0.041
0.36	0.033
0.38	0.024
0.40	0.017
0.42	0.011
0.44	0.007
0.46	0.000
0.48	-0.001
0.50	-0.001
0.52	-0.003
0.54	-0.005

TABLE III
PHOTOCURRENT FOR WAVELENGTH 540NM FOR VARYING VOLTAGES

500nm

Voltage (in V)	Photocurrent(in A)
0.04	0.553
0.08	0.448
0.12	0.361
0.16	0.280
0.20	0.212
0.24	0.155
0.28	0.108
0.32	0.074
0.36	0.048
0.40	0.030
0.44	0.018
0.48	0.010
0.52	0.004
0.53	0.000
0.56	-0.003
0.60	-0.005

TABLE IV
PHOTOCURRENT FOR WAVELENGTH 500NM FOR VARYING VOLTAGES

460nm

Voltage (in V)	Photocurrent (in A)
0.00	0.814
0.04	0.702
0.08	0.590
0.12	0.508
0.16	0.420
0.20	0.344
0.24	0.276
0.28	0.212
0.32	0.164
0.36	0.129
0.40	0.101
0.44	0.075
0.48	0.055
0.52	0.040
0.56	0.029
0.60	0.019
0.64	0.012
0.68	0.005
0.71	0.000
0.76	-0.002
0.80	-0.005

TABLE V
PHOTOCURRENT FOR WAVELENGTH 460NM FOR VARYING VOLTAGES

Based on the experiment conducted in the lab, using different light filters with wavelengths of 635nm, 570nm, 540nm, 500nm, and 460nm, the value of stopping voltage is obtained as given in Table IV

Wavelength (in nm)	Stopping Voltage (in V)	Frequency (in Hz)
635	0.2	4.72114×10^{14}
570	0.33	5.25952×10^{14}
540	0.46	5.55171×10^{14}
500	0.53	5.99585×10^{14}
470	0.71	6.51723×10^{14}

TABLE VI
DATA POINTS USED TO PLOT FIG. 2.

The following figure shows the plot of Stopping voltage vs frequency

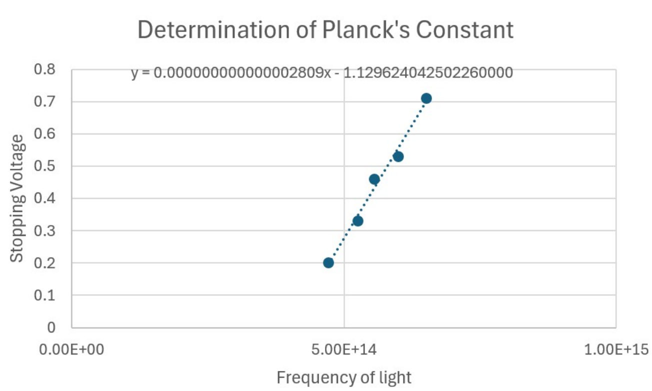


Fig. 2. Graph demonstrating the inverse square law

The above blue Plot is obtained by using the Least Square Fitting Method

The Equation of the line is

$$y = 2.809 \times 10^{15} x - 1.12 \tag{5}$$

which is of the form $y = mx + c$ where m is the slope and c is the y-intercept Therefore, $Slope = \frac{h}{e} = 2.809 \times 10^{-15}$

Thus,

$$h = 2.809 \times 10^{-15} \times e\, Js$$
$$h = 2.809 \times 10^{-15} \times 1.602 \times 10^{-19}\, Js$$
$$h = 4.500 \times 10^{-34}\, Js$$

and the y-intercept is,

$$\phi = |-1.12| V$$
$$\phi = 1.12V$$

B. *Inverse Square Law Experiment*

The following table represents the photoelectric current as a function of $\frac{1}{r^2}$

$1/r^2$ in cm^{-2}	Current in A
0.000625	0.128
0.000693	0.142
0.000772	0.154
0.000865	0.178
0.000977	0.201
0.001111	0.231
0.001276	0.272
0.001479	0.32
0.001736	0.388
0.002066	0.483
0.0025	0.59

TABLE VII
DATA POINTS USED TO PLOT FIG. 3.

The following figure represents the plot of Current (I) vs $\frac{1}{r^2}$

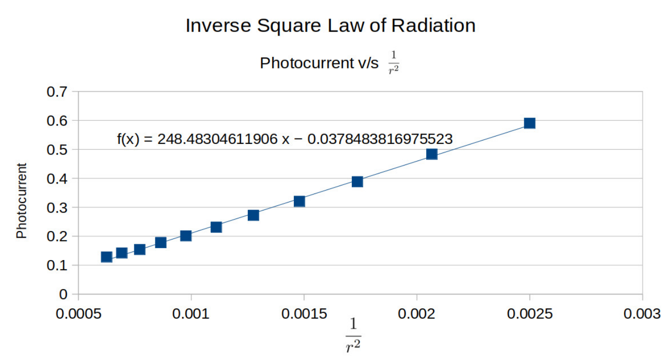


Fig. 3. Graph demonstrating the inverse square law

V. Discussion and Analysis

A. Discussion

I For Part 1 of the experiment, the current was obtained for different colour filters at varying voltages. Using this data, stopping voltage for different wavelengths of light was obtained. It was observed that for a constant voltage, the photocurrent increases as wavelength decreases and frequency increases. Thus, we can say that as frequency increases, more voltage is needed to oppose it and hence, the magnitude of stopping voltage increases. Therefore stopping voltage is directly proportional to the frequency of the emitted light and is independent of light.

II For Part 2, 11 readings for photocurrent were obtained at varying distances, and it was observed that as distance decreases, the photocurrent increases. It can be explained as follows:

a The number of electrons emitted by the source per unit area per unit time (intensity) is constant.

b However, as the distance decreases, the number of electrons received by the photocell per unit area per unit of time increases. Thus, the photocurrent increases.

c Hence, the graph of current vs $\frac{1}{r^2}$ is a straight line.

B. Error analysis

We can analyse the error in the obtained value of h and Φ by taking multiple values of h and Φ. Since we have performed the experiment only once, we have used the following procedure:

i There are 5 data points. So choose any two out of these data points.

ii Thus, we obtain 10 lines and corresponding 10 values of h and Φ

iii We now used these values to find out the mean value of h and Φ and the mean error in h and Φ as given in the following table.

h	Φ	$h - h_0$	$\Phi - \Phi_0$	$\lvert h - h_0 \rvert$	$\lvert \Phi - \Phi_0 \rvert$
4.549E-34	-1.14	-6.131E-36	0.03	6.131E-36	0.03
3.868E-34	-0.94	-7.419E-35	0.23	7.419E-35	0.23
5.015E-34	-1.28	4.047E-35	-0.11	4.047E-35	0.11
4.147E-34	-1.02	-4.629E-35	0.15	4.629E-35	0.15
4.840E-34	-1.26	2.300E-35	-0.09	2.300E-35	0.09
4.148E-34	-0.98	-4.622E-35	0.19	4.622E-35	0.19
5.531E-34	-1.54	9.205E-35	-0.37	9.205E-35	0.37
7.127E-34	-2.01	2.517E-34	-0.84	2.517E-34	0.84
4.351E-34	-1.10	-2.589E-35	0.07	2.589E-35	0.07
2.525E-34	-0.41	-2.085E-34	0.75	2.085E-34	0.75
Mean h		4.610×10^{-34}			
Mean Φ		-1.17			
Mean deviation in h		0.814×10^{-35}			
Mean deviation in Φ		0.280			

TABLE VIII
Error analysis

The value of h comes out to be,

$$h = (4.500 \pm 0.814) \times 10^{-34} Js \tag{6}$$

The percentage error in h is:

$$\frac{\Delta h}{h} \times 100 = \frac{0.814 \times 10^{-34} Js}{4.500 \times 10^{-34} Js} \times 100 \tag{7}$$

$$= 18.08\%$$

The value of Φ comes out to be,

$$\Phi = 1.178 \pm 0.280\, V \tag{8}$$

The percentage error in Φ is:

$$\frac{\Delta \Phi}{h} \times 100 = \frac{0.280V}{1.178V} \times 100 \tag{9}$$

$$= 23.76\%$$

- <u>Possible factors that caused errors in both the experiments</u>

  i There is a possibility that the colour filters that we are using are imperfect, due to which a band of frequencies will be transmitted instead of discrete values, which can affect the value of stopping potential.

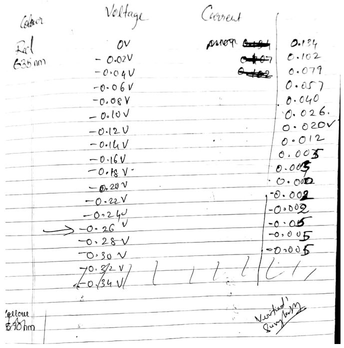
  ii There could have been other random and human errors in both experiments, One of them being the heating up and flickering of the lamp. There may have also been a parallax error. In order to avoid such errors, we should try to conduct the experiment in an ideal environment and should take the reading by looking from the top of the apparatus instead of the sides.

VI. Conclusion

1) Thus the value of the Planck's constant and the work function was obtained experimentally and graphically.
2) While doing the experiment, it was also concluded that as the frequency of the light increases, the photocurrent increases, and thus, the magnitude of stopping voltage also increases.
3) This experiment proves the particle nature of light as such a behaviour of immediate release of electrons as soon as the light strikes the metal surface cannot be explained by the wave nature of the light.
4) The value of Planck's constant came out to be 4.500×10^{-34} which has an error of around 32 percent reasons for which are mentioned in section V B
5) For Part 2, we verified that the photocurrent is inversely proportional to the square of the distance between the source and the photocell. That is, as the distance decreases, the photocurrent increases

VII. Reading images

The following are the images of the observations taken in the lab.

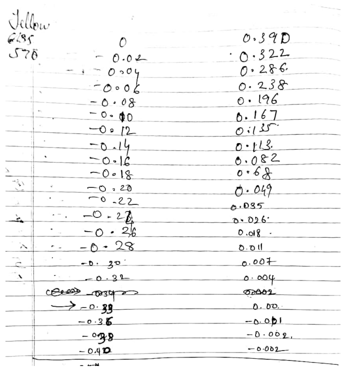


Colour: Red 635 nm

Voltage	Current
0V	0.134
-0.02V	0.102
-0.04V	0.079
-0.06V	0.057
-0.08V	0.040
-0.10V	0.026
-0.12V	0.020
-0.14V	0.012
-0.16V	0.005
-0.18V	0.005
-0.20V	0.000
-0.22V	-0.002
-0.24V	-0.002
-0.26V	-0.005
-0.28V	-0.005
-0.30V	-0.005
-0.32V	
-0.34V	

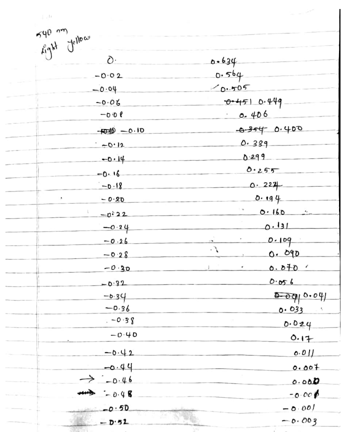
Yellow 570 nm

Verified



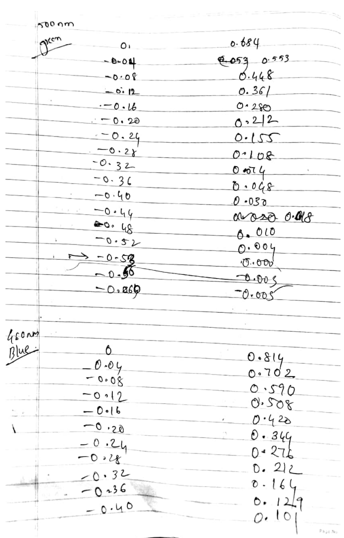
Yellow 578

0	0.390
-0.02	0.322
-0.04	0.286
-0.06	0.238
-0.08	0.196
-0.10	0.167
-0.12	0.135
-0.14	0.113
-0.16	0.082
-0.18	0.68
-0.20	0.049
-0.22	0.035
-0.24	0.026
-0.26	0.018
-0.28	0.011
-0.30	0.007
-0.32	0.004
-0.34	0.002
-0.33	0.00
-0.35	-0.001
-0.38	-0.002
-0.40	-0.002



540 nm light yellow

0	0.634
-0.02	0.564
-0.04	0.505
-0.06	0.449
-0.08	0.406
-0.10	0.400
-0.12	0.389
-0.14	0.299
-0.16	0.255
-0.18	0.227
-0.20	0.194
-0.22	0.160
-0.24	0.131
-0.26	0.109
-0.28	0.090
-0.30	0.070
-0.32	0.056
-0.34	0.041
-0.36	0.033
-0.38	0.024
-0.40	0.17
-0.42	0.011
-0.44	0.007
-0.46	0.000
-0.48	-0.001
-0.50	-0.001
-0.52	-0.003
-0.54	-0.005

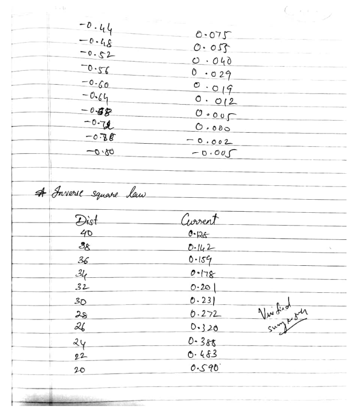


500 nm green

0	0.684
-0.04	0.553
-0.08	0.448
-0.12	0.361
-0.16	0.280
-0.20	0.212
-0.24	0.155
-0.28	0.108
-0.32	0.074
-0.36	0.048
-0.40	0.030
-0.44	0.018
-0.48	0.010
-0.52	0.004
-0.58	0.000
-0.60	-0.003
-0.62	-0.005

460 nm Blue

0	0.814
-0.04	0.702
-0.08	0.590
-0.12	0.508
-0.16	0.420
-0.20	0.344
-0.24	0.276
-0.28	0.212
-0.32	0.164
-0.36	0.129
-0.40	0.101



-0.44	0.075
-0.48	0.055
-0.52	0.040
-0.56	0.029
-0.60	0.019
-0.64	0.012
-0.68	0.005
-0.72	0.000
-0.76	-0.002
-0.80	-0.005

Inverse square law

Dist	Current
40	0.126
38	0.142
36	0.159
34	0.178
32	0.201
30	0.231
28	0.272
26	0.320
24	0.388
22	0.483
20	0.590

Verified

VIII. AUTHOR CONTRIBUTIONS

Name	Roll number	Contribution	Signature
Faayza Vora	23110109	Objective,Methods for part2,Observation tables,Conclusion, Discussion and error analysis	
Goraksh Bendale	23110118	Title, document structure, Abstract, Graph making	
Dishant Tanmay	23110100	Procedure, Taking readings in the lab, Document Structure, Index	
Haravath Saroja	23110127	Taking readings in the lab, Author Contribution, Cover page	

TABLE IX
AUTHOR'S CONTRIBUTION