BIRZEIT UNIVERSITY

Faculty of Science

Physics Department

Physics 212

Planck's Constant

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– Abstract:

The aim of this experiment is to verify the inverse square law of radiation using a photoelectric cell and to determine Planck's constant and work function of a material by photoelectric effect. The first part of this experiment, the light source was placed at different distances. Then, the graph Current vs 1/(Distance)^2 was plotted. The result of this part was acceptable. The second part of this experiment, the stopping voltage was read for a different wavelength from different filters. Then by plotting Stopping Voltage vs Frequency of incident light, Planck's constant and work function of the material were found using Einstein's photoelectric effect equation. Planck's constant in this experiment was $h \pm \Delta h = (6.2 \pm 0.3) \times 10^{-34} J \cdot s$ and this result was acceptable. The work function of the material which used was $\Phi \pm \Delta\Phi = (1.46 \pm 0.10) eV$.

– Theory:

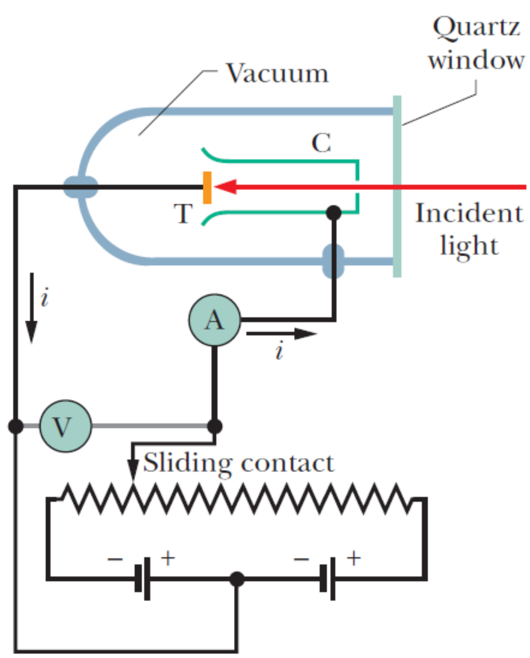
The quantum of a light wave of frequency f has the energy

$$E = hf$$

$h: Planck's\ Constant = 6.63 \times 10^{-34} J \cdot s = 4.14 \times 10^{15} eV \cdot s$

$f: frequency\ of\ photon$

If you direct a beam of light of short enough wavelength onto a clean metal surface, the light will cause electrons to leave that surface (the light will eject the electrons from the surface). This photoelectric effect is used in many devices, including TV cameras, camcorders, and night vision viewers. Einstein supported his photon concept by using it to explain this effect, which simply cannot be understood without quantum physics.



Einstein summed up the results of such photoelectric experiments in the equation:

$$hf = K_{max} + \Phi$$

$K_{max}: Kinetic\ Energy\ of\ the\ electron$

$\Phi: Work\ Function$

The maximum kinetic energy of the electron is:

$$K_{max} = eV_s$$

$e: electron\ charge$

$V_s: Stopping\ Voltage$

Substitute it in the Einstein's photoelectric effect equation,

$$hf = eV_s + \Phi$$

We get the equation of the curve Stopping Voltage vs Frequency of incident light,

$$V_s = \frac{h}{e} f - \frac{\Phi}{e}$$

$$slope = \frac{h}{e} \Longrightarrow \begin{Bmatrix} h = e \cdot slope \\ \Delta h = e \cdot \Delta(slope) \end{Bmatrix}$$

$$y_{int} = -\frac{\Phi}{e} \Longrightarrow \begin{Bmatrix} \begin{Bmatrix} \Phi = -e \cdot y_{int} \\ \Delta\Phi = e \cdot \Delta y_{int} \end{Bmatrix} in\ Joule\ unit\ (J) \\ \begin{Bmatrix} \Phi = -y_{int} \\ \Delta\Phi = \Delta y_{int} \end{Bmatrix} in\ electron\ volt\ unit\ (eV) \end{Bmatrix}$$

The frequency of the light incident is:

$$f = \frac{c}{\lambda}$$

– Procedure:

Prepare the apparatus: Photo Sensitive Devise, Light Source, Color Filters {red (635nm), yellow I (585nm), yellow II (540nm), green (520nm), blue (475nm)}, Accelerating Voltage, Current Detectiong Uint, Power Requierment, Optical Bench.

PART I:

1. Set the spurce of light at a distance 35cm.
2. Open the source of light and display the current.
3. Record the reading of current at that moment.
4. Repeat the previous steps by changing the position of the light source.
5. Current vs $1/(\text{Distance})^2$ (I vs $1/d^2$).

PART II:

1. Open the source of light and insert the red color filter.
2. Switch voltage at "-" and display the current, wait it until reaching zero.
3. Record the reading of voltage at that moment.
4. Repeat the previous steps by replacing the red color filter by the other filters.
5. Plot Stopping Voltage vs Frequency of incident light

– Data:

PART I:

Distance d(cm)	Current I(μA)
35.0	0.008
33.0	0.010
31.0	0.013
29.0	0.018
27.0	0.029
25.0	0.049
23.0	0.074
21.0	0.106
19.0	0.164
17.0	0.266
15.0	0.394

PART II:

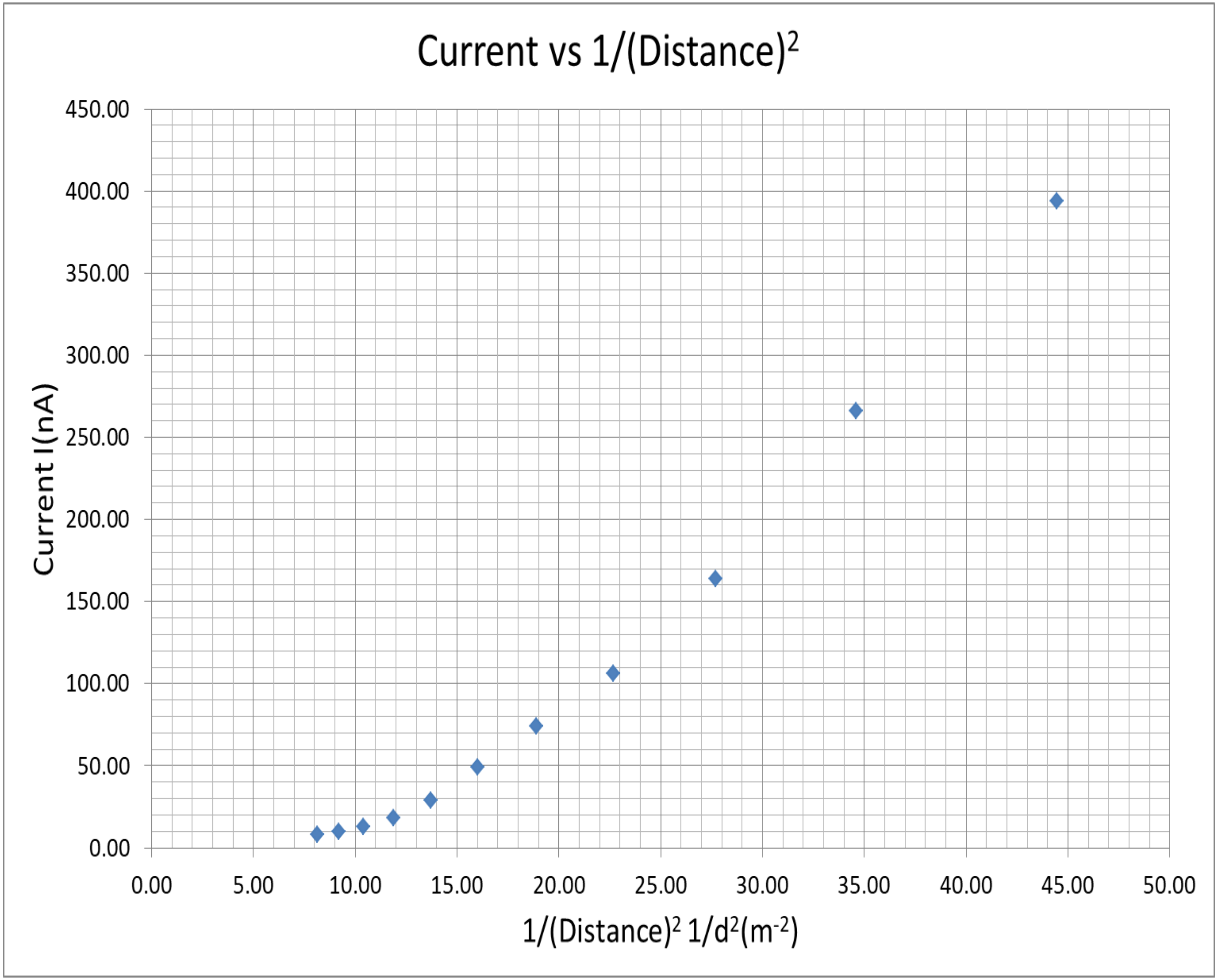
Color	Wavelength(nm)	V_s(Volt)
red	635	0.34
yellow I	585	0.54
yellow II	540	0.67
green	520	0.78
blue	475	0.96

– Calculations:

PART I:

d(cm)	d(m)	d^2	1/d^2
35.0	0.350	0.123	8.16
33.0	0.330	0.109	9.18
31.0	0.310	0.0961	10.4
29.0	0.290	0.0841	11.9
27.0	0.270	0.0729	13.7
25.0	0.250	0.0625	16.0
23.0	0.230	0.0529	18.9
21.0	0.210	0.0441	22.7
19.0	0.190	0.0361	27.7
17.0	0.170	0.0289	34.6
15.0	0.150	0.0225	44.4

I(μA)	I(nA)
0.008	8.00
0.010	10.0
0.013	13.0
0.018	18.0
0.029	29.0
0.049	49.0
0.074	74.0
0.106	106
0.164	164
0.266	266
0.394	394


Current vs 1/(Distance)²
Current I(nA)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
1/(Distance)² 1/d²(m⁻²)

PART II:

Color	Wavelength(nm)	$f(10^{14}Hz)$	V_s(Volt)
red	635	4.72	0.34
yellow I	585	5.13	0.54
yellow II	540	5.56	0.67
green	520	5.77	0.78
blue	475	6.32	0.96

	Slope	y_{int}
Value	3.85179E-15	-1.45995875
Error	1.88441E-16	0.104123287

$$h = e \cdot slope = 1.60 \times 10^{-19} \times 3.85 \times 10^{-15} = 6.17 \times 10^{-34} J \cdot s$$

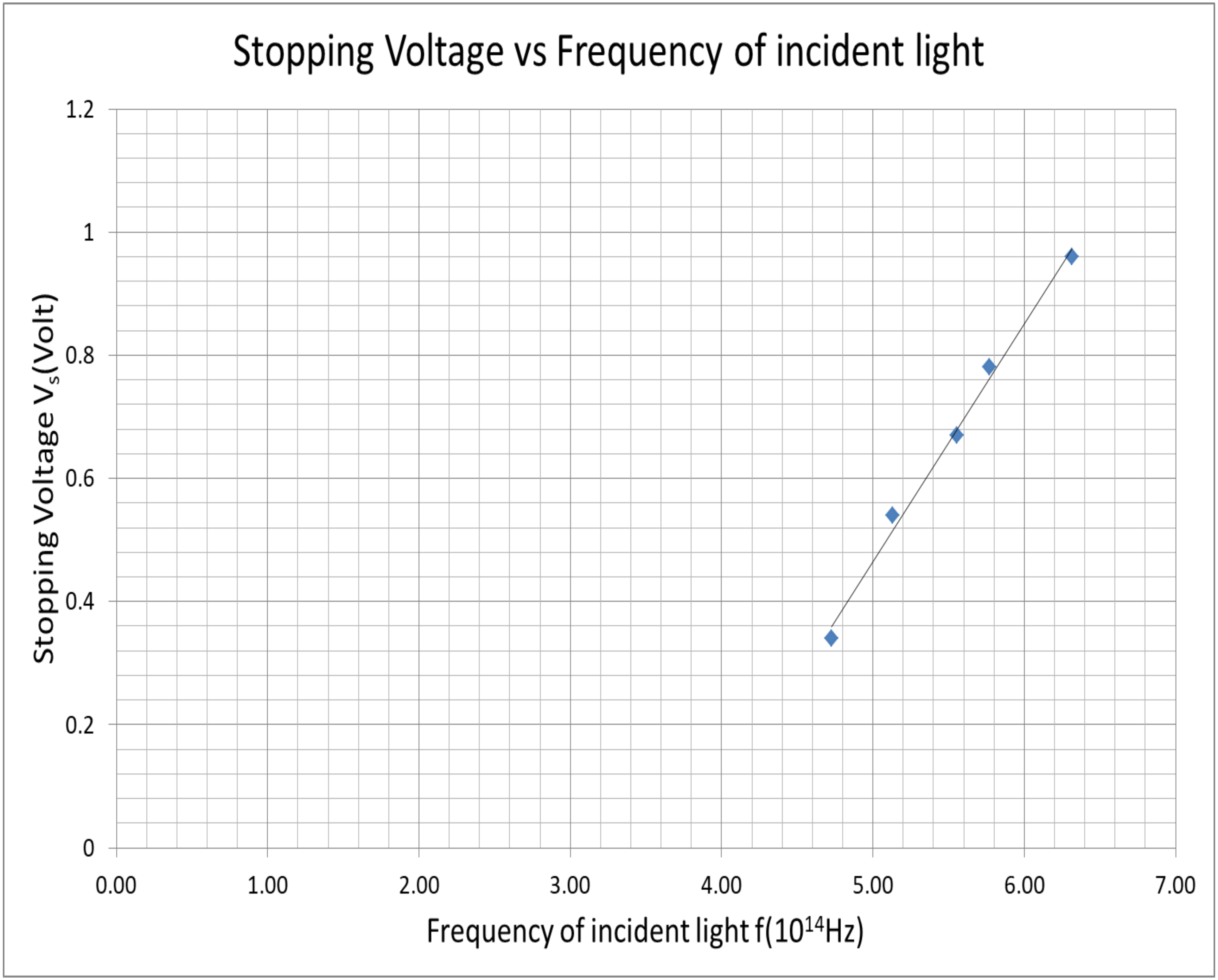
$$\Delta h = e \cdot \Delta(slope) = 1.60 \times 10^{-19} \times 1.88 \times 10^{-16} = 0.3 \times 10^{-34} J \cdot s$$

$$h \pm \Delta h = (6.2 \pm 0.3) \times 10^{-34} J \cdot s$$

$$\Phi = -y_{int} = -1 \times -1.46 = 1.46 eV$$

$$\Delta\Phi = \Delta y_{int} = 0.10 eV$$

$$\Phi \pm \Delta\Phi = (1.46 \pm 0.10) eV$$


Stopping Voltage vs Frequency of incident light
Stopping Voltage V_s(Volt)
1.2
1
0.8
0.6
0.4
0.2
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Frequency of incident light f(10^14Hz)

– Results:

$h \pm \Delta h = (6.2 \pm 0.3) \times 10^{-34} J \cdot s$

$\Phi \pm \Delta\Phi = (1.46 \pm 0.10) eV$

– Discussion:

The curve of Current vs 1/(Distance)^2 has a semi-straight trendline. The current is inversely proportional with the square of the distance.

$$Current \propto \frac{1}{d^2}$$

The intensity of the light source on a certain point is inversely proportional with the square of the distance.

$$Intensity \propto \frac{1}{d^2}$$

By increasing the number of photons, the amount of electrons which releases form their atoms would increase. So, the current is directly proportional with the intensity of light.

$$Current \propto Intensity$$

The result of this part was acceptable.

The real value of Planck's constant is $6.6 \times 10^{-34} J \cdot s$. The experimental value of Planck's constant was $(6.2 \pm 0.3) \times 10^{-34} J \cdot s$. Both results are close to each other. So, this result is accepted.

The work function of the material which used was $(1.46 \pm 0.10) eV$. To convert it in Joules unit:

$$\Phi_J = e \cdot \Phi_{eV} = 1.60 \times 10^{-19} \times 1.46 = 2.34 \times 10^{-19} J$$
$$\Delta\Phi_J = e \cdot \Delta\Phi_{eV} = 1.60 \times 10^{-19} \times 0.10 = 0.2 \times 10^{-19} J$$

$\Phi_J \pm \Delta\Phi_J = (2.3 \pm 0.2) \times 10^{-19} J$

Photoelectric equation of Einstein is:

$$hf = K_{max} + \Phi$$

Threshold (Cutoff) frequency is defined as the minimum frequency of incident light which can cause photo electric emission. That's mean, the maximum kinetic energy of the electron equal zero ($K_{max} = 0$).

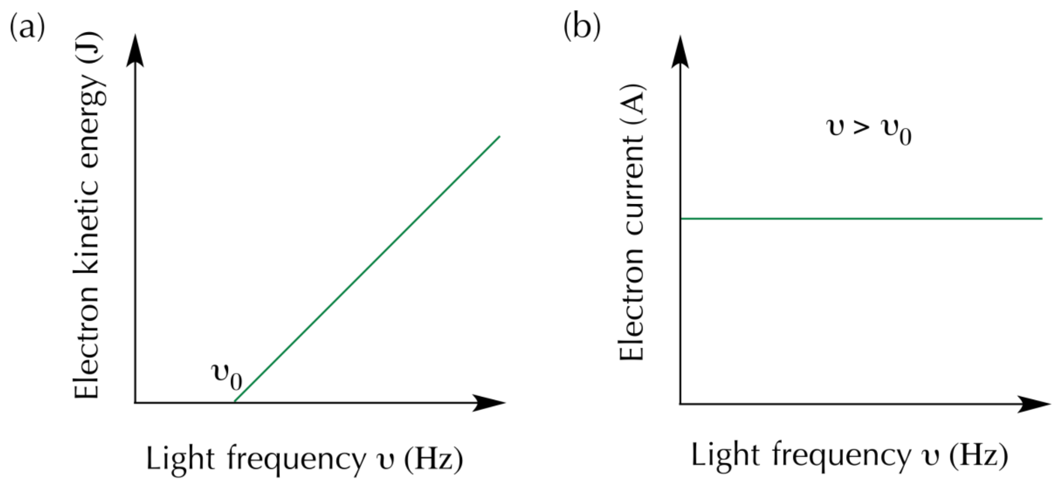
$$hf_0 = \Phi \Longrightarrow \left\{ \begin{array}{c} f_0 = \dfrac{\Phi}{h} \\ \Delta f_0 = \dfrac{\Delta\Phi}{h} \end{array} \right\}$$

$$f_0 = \frac{\Phi}{h} = \frac{2.3 \times 10^{-19}}{6.6 \times 10^{-34}} = 3.8 \times 10^{14} Hz$$

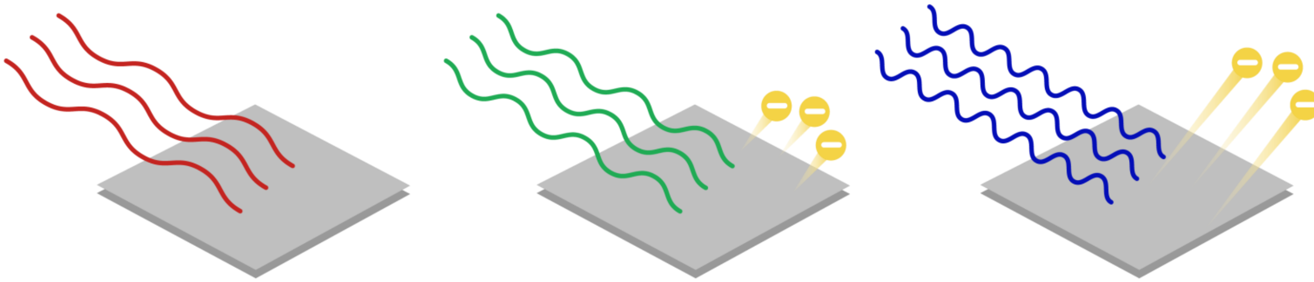
$$\Delta f_0 = \frac{\Delta\Phi}{h} = \frac{0.2 \times 10^{-19}}{6.6 \times 10^{-34}} = 0.3 \times 10^{14} Hz$$

$$f_0 \pm \Delta f_0 = (3.8 \pm 0.3) \times 10^{14} Hz$$

The photoelectric effect does not occur if the frequency is below a certain cut off frequency or, equivalently, if the wavelength is greater than the corresponding cut off wavelength. This is so no matter how intense the incident light is.



Increasing the light intensity increases the number of photons in the light, but the photon energy, given by equation $(E = hf)$, is unchanged because the frequency is unchanged. Thus, the energy transferred to the kinetic energy of an electron is also unchanged.



There were some sources of systematic error. Firstly, the dust on filters and lenses. Secondly, the errors of approximations in distances and values in calculations. Another reason, the systematic errors in the Photo Sensitive Devise. Moreover, the perturbations of a lot of sources form the environment of the experiment.

– References:

1. Fundamentals of Physics Extended, 10th Edition, David Halliday, Robert Resnick, Jearl Walker.
2. CRC Handbook of Chemistry and Physics 97th Edition, William M. Haynes.
3. THE CONSTANTS OF NATURE: From Alpha to Omega--the Numbers that Encode the Deepest Secrets of the Universe, John D. Barrow.
4. User’s Manual, PLANK’S CONSTANT MEASURING SET-UP, Model : PC101.
5. http://hyperphysics.phy-astr.gsu.edu
6. https://www.citycollegiate.com
7. https://www.khanacademy.org

– Appendix:

Element	Plane	Φ/eV	Method
Ag	100	4.64	PE
	110	4.52	PE
	111	4.74	PE
Al	100	4.20	PE
	110	4.06	PE
	111	4.26	PE
As	polycr	(3.75)	PE
Au	100	5.47	PE
	110	5.37	PE
	111	5.31	PE
B	polycr	(4.45)	TH
Ba	polycr	2.52	TH
Be	polycr	4.98	PE
Bi	polycr	4.34	PE
C	polycr	(5.0)	CPD
Ca	polycr	2.87	PE
Cd	polycr	4.08	CPD
Ce	polycr	2.9	PE
Co	polycr	5.0	PE
Cr	polycr	4.5	PE
Cs	polycr	1.95	PE
Cu	100	5.10	FE
	110	4.48	PE
	111	4.94	PE
	112	4.53	PE
Eu	polycr	2.5	PE
Fe	100	4.67	PE
	111	4.81	PE
Ga	polycr	4.32	PE
Gd	polycr	2.90	CPD
Ge	polycr	5.0	CPD
Hf	polycr	3.9	PE
Hg	liquid	4.475	PE
In	polycr	4.09	PE
Ir	100	5.67	PE
	110	5.42	PE
	111	5.76	PE
	210	5.00	PE
K	polycr	2.29	PE
La	polycr	3.5	PE
Li	polycr	2.93	FE
Lu	polycr	(3.3)	CPD
Mg	polycr	3.66	PE
Mn	polycr	4.1	PE
Mo	100	4.53	PE
	110	4.95	PE
	111	4.55	PE
	112	4.36	PE
	114	4.50	PE
	332	4.55	PE
Na	polycr	2.36	PE
Nb	001	4.02	TH
	110	4.87	TH
	111	4.36	TH
	112	4.63	TH
	113	4.29	TH
	116	3.95	TH
	310	4.18	TH
Nd	polycr	3.2	PE
Ni	100	5.22	PE
	110	5.04	PE
	111	5.35	PE
Os	polycr	5.93	PE
Pb	polycr	4.25	PE
Pd	polycr	5.22	PE
	111	5.6	PE
Pt	polycr	5.64	PE
	110	5.84	FE
	111	5.93	FE
	320	5.22	FE
	331	5.12	FE
Rb	polycr	2.261	PE
Re	polycr	4.72	TE
Rh	polycr	4.98	PE
Ru	polycr	4.71	PE
Sb	amorp	4.55	
	100	4.7	
Sc	polycr	3.5	PE
Se	polycr	5.9	PE
Si	n	4.85	CPD
	p 100	(4.91)	CPD
	p 111	4.60	PE
Sm	polycr	2.7	PE
Sn	polycr	4.42	CPD
Sr	polycr	(2.59)	TH
Ta	polycr	4.25	TH
	100	4.15	TH
	110	4.80	TH
	111	4.00	TH
Tb	polycr	3.0	PE
Te	polycr	4.95	PE
Th	polycr	3.4	TH
Ti	polycr	4.33	PE
Tl	polycr	(3.84)	CPD
U	polycr	3.63	PE
	100	3.73	PE
	110	3.90	PE
	113	3.67	PE
V	polycr	4.3	PE
W	polycr	4.55	CPD
	100	4.63	FE
	110	5.22	FE
	111	4.45	FE
	113	4.46	FE
	116	4.32	TH
Y	polycr	3.1	PE
Zn	polycr	3.63	PE
	polycr	(4.9)	CPD
Zr	polycr	4.05	PE