Imperial College London

Photoelectric Effect

Cycle 1, Third Year Laboratory Course

Blackett Laboratory

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Theory

The **cut-off potential** is given by**:**

$$V_{ec}^{*} = \frac{h\nu}{e} - \varphi_c \quad [1]$$

This is the maximum voltage applied across the emitter and collector when the current is zero, i.e. no electron has enough energy to reach the detector.

More electrons are able to cross the potential gap in the cathode as the applied voltage increases.

Photoelectrons can have a range of kinetic energy which is dependent on:

- Energy (frequency) of incident photons.
- Different initial states of electrons with different binding energies in the emitter. [2]

$$E_k = h\nu - W - E_B$$

At the extremities, we expect:

- Low applied potential – zero current.
- High applied potential – saturation current.

[1] J. Mcginty, “The Photoelectric Effect.” Imperial College London, 2022.
[2] S. Hüfner, *Photoelectron spectroscopy: principles and applications*, 3rd ed. Berlin, Heidelberg: Springer, 2003, p. 4.

Preliminary

Stray light measurement:

The current produced by stray light is small (~10^{-12}A)

Lights and Filters:

Filter #	2	3	4	5	6
Peak λ (nm)	406.08	366.75	578.81*	437.20	546.80
Centroid λ (nm)	405.83	366.70	578.75	437.02	547.14
FWHM (nm)	2.19	2.62	1.86**	2.17	1.09

Quantum efficiency of photocell:

Positive correlation with frequency, ranging from 0.005% to 0.04%

Effect of intensity in measurements:

There is no effect on the intensity on the cut-off voltage.

* For filter 4, the actual spectrum is a doublet with wavelength of 577.79nm & 579.82nm. For the purpose of this experiment, the average of the doublet is used for data analysis.
** Since the widths are halved for the two peaks, we have decided to add together the FWHM of the individual spikes.

Methodology

Test measurements:

	Voltage Range	Step Size	# of Samples
1	-10 to 10V	0.5V	1
2	-2.5 to 2.5V	0.1V	5

Main Objective: To obtain a value for Planck's constant from the plot of

$$V_{ec}^{*} \quad vs \quad frequency$$

From the results of the prelims, we choose to focus our data collection near the cut-off potentials:

Range:	2.5V/2.0V to 0V
Step Size:	0.01V
Sample count:	5/step
Wait time:	5 seconds

Data Analysis

Method 1: Zero Crossings

Cut-off potential is obtained by determining the zero crossing.

Procedure:

Using data near the zero crossing, we fit a curve through it and find the x-intercept, which is our cut-off potential.

Fitting functions used:

- Linear (first 5 points above 0)
- Quadratic (first 5 points above 0)
- Quadratic (first 10 points above 0)

Method 2: Derivatives

Photoelectrons reaches the cathode when current is seen to be consistently increasing.

Procedure:

1. Calculate the gradients of the lines which connect any two neighboring data points.
2. Plot the gradients against frequencies.
3. If 10 successive gradients are positive, the cut-off potential is taken to be the first point. The step size would be our uncertainty.

Diagram 1: Zero-Crossing Method (Linear fit)

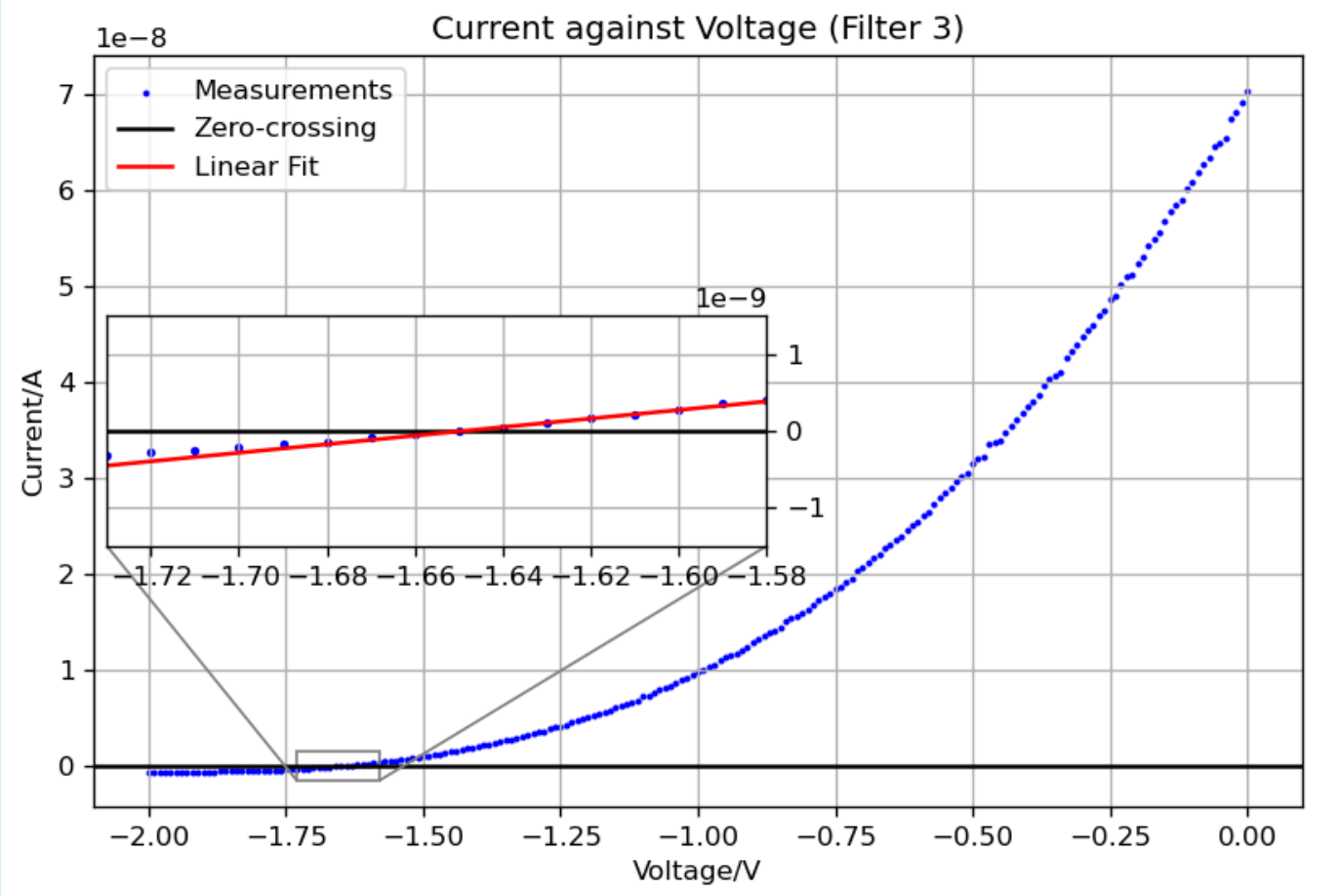


Diagram 2: Derivatives Method

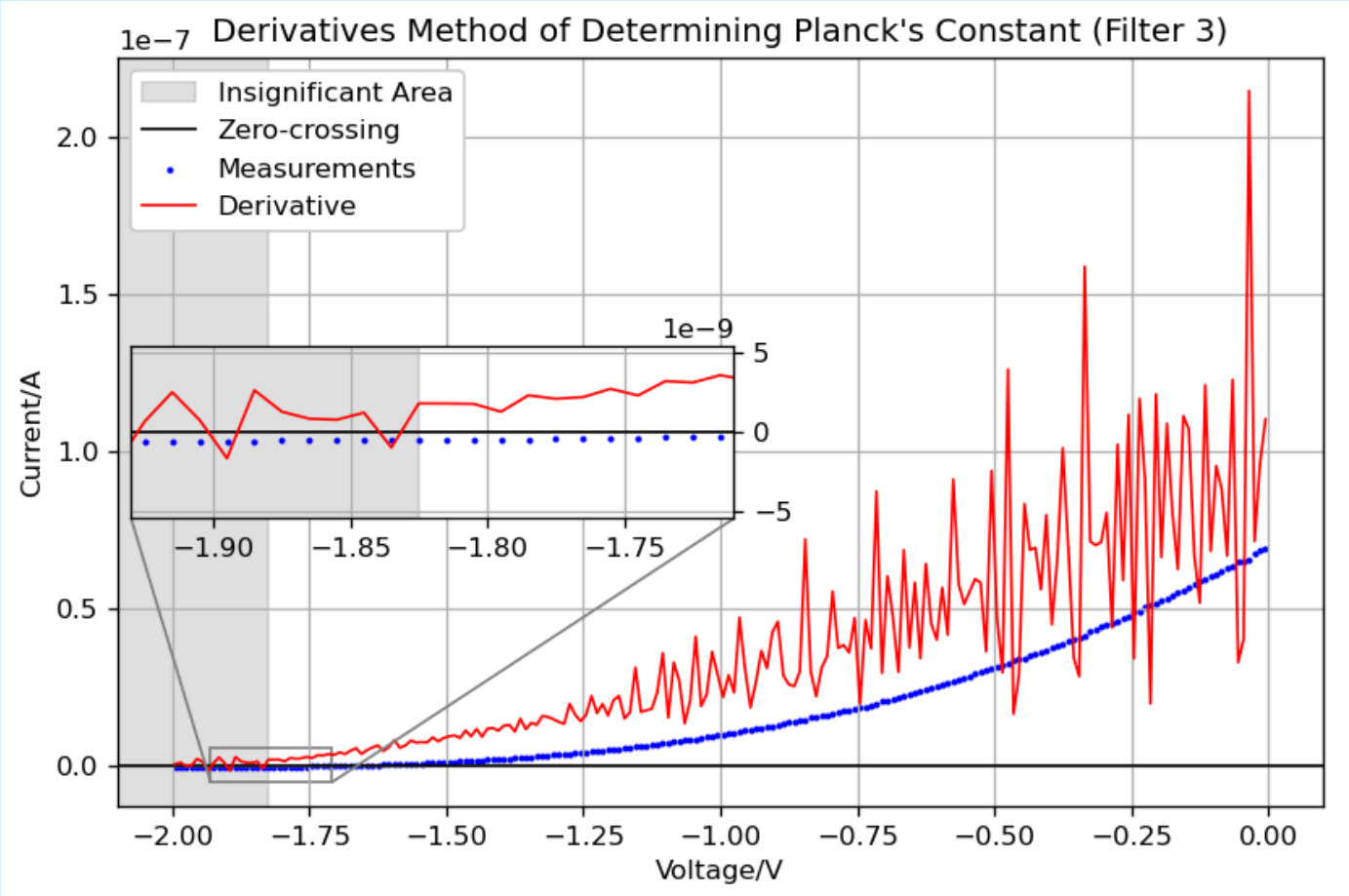
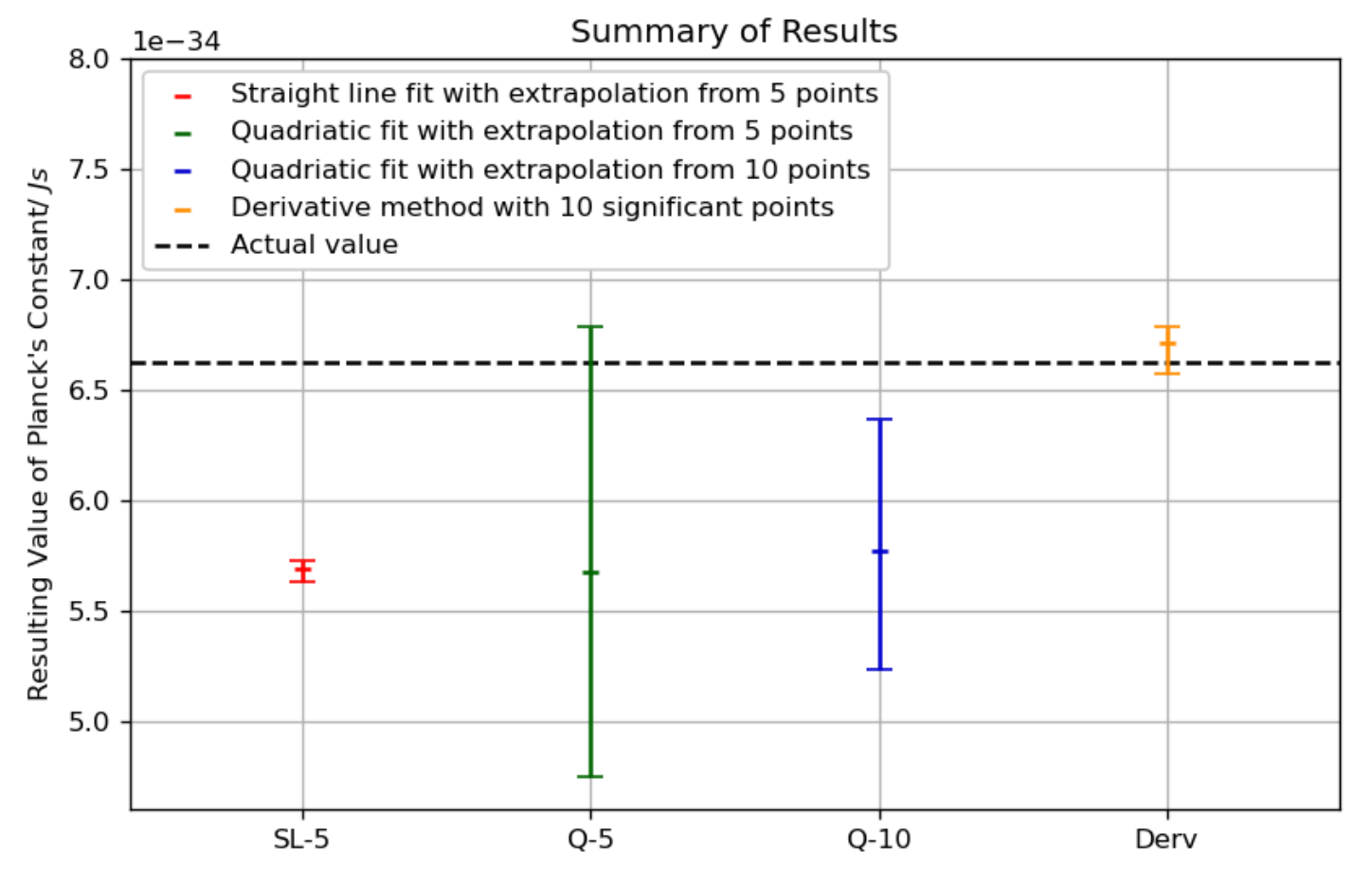


Diagram 3


Summary of Results
1e−34
8.0
7.5
7.0
6.5
6.0
5.5
5.0
Resulting Value of Planck's Constant/ Js
Straight line fit with extrapolation from 5 points
Quadriatic fit with extrapolation from 5 points
Quadriatic fit with extrapolation from 10 points
Derivative method with 10 significant points
Actual value
SL-5
Q-5
Q-10
Derv

Conclusion

A value of Planck's constant is calculated by method of obtaining the cut-off voltage from the photoelectric effect.

The values obtained are:

- Line fit (5 points):

$$\mathbf{5.69^{+0.04}_{-0.06} \times 10^{-34}}$$

- Quadratic fit (5 points):

$$\mathbf{5.68^{+1.11}_{-0.93} \times 10^{-34}}$$

- Quadratic fit (10 points):

$$\mathbf{5.77^{+0.59}_{-0.93} \times 10^{-34}}$$

- Derivatives (10 points):

$$\mathbf{6.71^{+0.07}_{-0.14} \times 10^{-34}}$$

Suggestions for further improvement:

- **A time-series data for the current could be obtained for each applied voltage.** This is because the measured current was seen to be varying with time. Our experiment assumed that the changes are systematic and thus take data at fixed time-points.
- **Sources of error:**
  - Instability of mercury source
  - Past certain voltage, behavior of circuit changes
- Taking data over a larger range to investigate free electron behaviour.

Thank You