ASSESSMENT ONE

This assessment presents a task undertaken over a number of weeks. As a Scientific Investigation, the task sheets are involved and supportive of student work.

With thanks to Kaylyn Hennig for the cover artwork.

ASSESSMENT ONE TASK SHEET: PRACTICAL TASK AND REFLECTION	
Course:	Physics T
Unit:	Revolutions in Modern Physics
Year Group:	12
Assessment Conditions:	- Practical Group Task and Individual Written Reflection - Group and Individual task - 30% - Experiment conducted in class and a take home reflection task.
Prior learning:	The class has been studying the quantum mechanics component of the Physics course and developing science inquiry skills over the course of very unit.

TASK SUMMARY:

Task Requirements/Conditions Relevant:
Two experiments to be completed during class time. Manipulation of equipment to be completed in small groups. All writing to be completed individually.

Task Description:
This task consists of two practical tasks and a critical reflection:
Two experiments will be completed in class. Before the practical lesson you will be given a simple method that you will need to improve. Each experiment will be completed in class time using the improved method. A critical reflection analysing the practical results will be submitted to school academic integrity software platform on the due date.

You may work in small groups to manipulate equipment and to collect data. All analysis must be individual work.

Task Submission Requirements:

- Practical reflection must be completed and submitted to the school software platform by the due date.
- Declaration of Original Work is acknowledged when students assign their name or student number to a submitted task.

Outcomes Assessed:

2: Contexts
3A: Inquiry Skills - Investigative skills
3B: Inquiry Skills - Communication skills

- **Work strategies**

LATE PENALTIES:
The penalty for late submission is 5% of possible marks per calendar day late, including weekends and public holidays, until a notional zero is reached. If an item is more than 7 days late, it receives the notional zero. Submission on weekends or public holidays is not acceptable. Calculation of a notional zero is based on items submitted on time or with an approved extension. Please refer to the ACT BSSS Policy and Procedures Manual for further details, available at http://www.bsss.act.edu.au/

PLAGIARISM:
Plagiarism is the copying, paraphrasing or summarising of work, in any form, without acknowledgement of sources, and presenting this as your own work. Any work that is found to be plagiarised will incur a penalty.
All written work must be submitted through "[plagiarism checker name redacted]".
Using the Harvard referencing system is required of all students, and will assist in meeting obligations for academic honesty. Refer to guides on "Bibliographies" for additional information.
Refer to the ACT BSSS Policy and Procedures Manual for further details, available at http://www.bsss.act.edu.au/

Photoelectric Effect Practicals

The following pages contain the simple methods needed to investigate the aims given about the photoelectric effect.

Before you conduct the experiment, you need to read the methods, complete a risk assessment, and write down improvements to the method given that will increase the reliability of the results obtained.

After you complete the practicals, you will need to use a spreadsheet to create appropriate tables and graphs to represent the results clearly, and complete a critical reflection.

You will need to submit your spreadsheets and the critical reflection to the class webpage. The critical reflection will be submitted through plagiarism software.

Experiment 1

Aim:

1. To determine the effect of light frequency on the photoelectron energy produced by the photoelectric effect.
2. To determine the threshold frequency and work function of a Cesium metal cathode.

Apparatus:

Photoelectric effect kit, containing lamp and colour filters.

Method:

1. Record the wavelength of each colour filter in the table, and determine the frequency of each filter.
2. Attach the lamp to the photoelectric effect kit, and place the first filter in the available slot.
3. Switch on the lamp. 12V must be used.

   You are now required to determine the stopping voltage for each filter. (The voltage at which the photoelectrons emitted at the Caesium cathode only just fail to reach the anode. This voltage is a measure of the kinetic energy of the photoelectrons.)

4. Set the meter reading to TUBE CURRENT (0-20μA).

5. Increase the backing voltage so that the current registered decreases.
6. When the current reduces below 0.1 μA, switch the meter reading to the more sensitive 0 -200 nA range.
7. Continue to increase the backing voltage until the point where the current reach 0.0 nA.
8. Switch the meter reading to BACKING VOLTS, and measure the backing voltage applied at 0.0 nA.
9. Repeat steps 4-8 using the other colour filters.
10. Record your data in a table.
11. For each filter, determine the energy of the photoelectrons, in units of electron Volts.

Results

Record all results for this experiment in an appropriate table *in a spreadsheet*.

The table below gives a scaffold for the number of columns needed to collect and analyse the results for the given method.

Graph

Construct a graph *in your spreadsheet* showing the photoelectron energy as a function of frequency of incident light.

Improvements

Use this space to outline (using dot points), changes to the method you will make to improve the reliability of the results gained. These need to be signed off by your teacher before beginning the experiment. You need to follow your improved method when collecting the results.

Experiment 2

Aim:

To determine the effect of the quantity of incident radiant energy on the current produced by the photoelectric effect.

Apparatus:

Photoelectric effect kit, containing lamp, colour filters, and different sized apertures.

Method:

1. Record the diameter of each of the 4 apertures (in units of mm).

2. Calculate the area of each aperture (in units of mm^2).
3. Set up the photoelectric effect kit with the 428 nm filter and the smallest aperture, and the backing voltage set to zero.
4. Measure the current registered (in units of microamps).
5. Repeat steps 3-4 for the remaining apertures.
6. Record your data in a table.

Finally, as a separate measurement:

7. While the smallest aperture and 428 nm filter is inserted, determine the backing voltage as in experiment 1. Record the backing voltage and energy of the photoelectrons separately from your table.

Results

Record all results for this experiment in an appropriate table *in your spreadsheet*.

The table below gives a scaffold for the number of columns needed to collect and analyse the results for the method given.

Graph

Construct a graph *in your spreadsheet* showing the current registered as a function of aperture area.

Improvements

Use this space to outline (using dot points), changes to the method you will make to improve the reliability of the results gained. These need to be signed off by your teacher before beginning the experiment. You need to follow your improved method when collecting the results.

Risk Assessment

A hand-written copy of your risk assessment must be checked and signed off by your teacher before you begin the experiments

Risks in this experiment	Likelihood of risk	Level of risk	Control measure to manage risk
Consider what each risk is, and why it is a risk.	*Consider with reasoning the likelihood of the risk.*	*Consider with reasoning the level of the risk.*	*Should be appropriate to the level of risk.*

Results and Critical Reflection

All questions must be answered on a digital document and submitted via turnitin. Additionally, your spreadsheet used to create tables and graphs is to be submitted to Canvas.

1. **Present** your experimental results and uncertainty values in appropriately formatted and titled tables. *This will involve copying the tables from your spreadsheet and ensuring that all required formatting and features are present.*
2. **Present** appropriate titled graphs of your experimental results that will help answer the aims of the experiments. *These will also be copied from your spreadsheet.*

    a. First, you must include the graphs specified on the instruction sheet.
    b. Then, present other graphs you have chosen to plot to answer the aims of the experiment in more depth. Include titles, and a caption explaining why you have chosen to present this graph.
3. **Calculate** any values needed from the graphs to answer the aims given.
4. **Analyse** the reliability and validity of the results collected.
5. **Outline** the improvements you made to the given method.
6. **Evaluat**e how effectively your improvements to the method increased the validity and reliability of the experimental results.
7. **Critically analyse** the size of the uncertainty in your direct measurements.
8. Use your graphs to **analyse** the *experimental error* in your results for at least two of the aims given for the experiment.

*Hint: you need to give the size **and** direction of the experimental error, decide if the experimental error fits within the error bounds of the experiment, and give physics based reasons why your measured value may be above or below the expected value.*

9. **Discuss** two further improvements that could reduce the size of uncertainties or experimental error in this experiment. In your answer you may consider technology or measurement devices beyond what was available during the experiment.
10. **Evaluate** the meaning of your experimental results to provide at least <u>three</u> concluding statements. Each statement must do both of the following:
    a. Address one of the given aims of the experiment, i.e. outlining what this experiment has shown about the photoelectric effect.
    b. Include a sentence identifying how the results of experiment can be applied to solar power.

These concluding facts will be the information from the experiments that you will need to use in your writing task. Be specific and concise with the facts that the experiment shows.

LINKS TO BSSS PHYSICS COURSE

Unit: Revolutions in Modern Physics

SCIENCE INQUIRY SKILLS

- identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes
- design investigations, including the procedure to be followed, the materials required, and the type and amount of primary and/or secondary data to be collected; conduct risk assessments; and consider research ethics
- conduct investigations, including use of simulations and manipulation of spectral devices, safely, competently and methodically for the collection of valid and reliable data
- represent data in meaningful and useful ways, including using appropriate si units, symbols and significant figures; organise and analyse data to identify trends, patterns and relationships; identify sources of uncertainty and techniques to minimise these uncertainties; utilise uncertainty and percentage uncertainty to determine the cumulative uncertainty resulting from calculations, and evaluate the impact of measurement uncertainty on experimental results; and select, synthesise and use evidence to make and justify conclusions
- interpret a range of scientific and media texts, and evaluate processes, claims and conclusions by considering the quality of available evidence; and use reasoning to construct scientific arguments
- select, construct and use appropriate representations, including text and graphic representations of empirical and theoretical relationships, simulations, simple reaction diagrams and atomic energy level diagrams, to communicate conceptual understanding, solve problems and make predictions
- select, use and interpret appropriate mathematical representations, including linear and non-linear graphs and algebraic relationships representing physical systems, to solve problems and make predictions
- communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes, including scientific reports

SCIENCE AS A HUMAN ENDEAVOUR

- ICT and other technologies have dramatically increased the size, accuracy and geographic and temporal scope of datasets with which scientists work
- models and theories are contested and refined or replaced when new evidence challenges them, or when a new model or theory has greater explanatory power
- the acceptance of science understanding can be influenced by the social, economic and cultural context in which it is considered
- people can use scientific knowledge to inform the monitoring, assessment and evaluation of risk
- science can be limited in its ability to provide definitive answers to public debate; there may be insufficient reliable data available, or interpretation of the data may be open to question

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- international collaboration is often required when investing in large-scale science projects or addressing issues for the Asia-Pacific region
- scientific knowledge can be used to develop and evaluate projected economic, social and environmental impacts and to design action for sustainability

SCIENCE UNDERSTANDING

SPECIAL RELATIVITY

- observations of objects travelling at very high speeds cannot be explained by Newtonian physics (for example, the dilated half-life of high-speed muons created in the upper atmosphere, and the momentum of high speed particles in particle accelerators)
- Einstein's special theory of relativity predicts significantly different results to those of Newtonian physics for velocities approaching the speed of light
- the special theory of relativity is based on two postulates: that the speed of light in a vacuum is an absolute constant, and that all inertial reference frames are equivalent
- motion can only be measured relative to an observer; length and time are relative quantities that depend on the observer's frame of reference
- relativistic momentum increases at high relative speed and prevents an object from reaching the speed of light
- the concept of mass-energy equivalence emerged from the special theory of relativity and explains the source of the energy produced in nuclear reactions

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<tr><td>Key concepts:</td><td>

Photoelectric Effects

- understand the consequences for space and time of the equivalence principle for inertial frames of reference
- understand how the quantum theory of light and matter explains blackbody radiation, the photoelectric effect, and atomic emission and absorption spectra
- understand how the Standard Model explains the nature of and interaction between the fundamental particles that form the building blocks of matter
- understand how models and theories have developed over time, and the ways in which physical science knowledge and associated technologies interact with social, economic, cultural and ethical considerations
- use science inquiry skills to design, conduct, analyse and evaluate investigations into frames of reference, diffraction, black body and atomic emission spectra, the photoelectric effect, and photonic devices, and to communicate methods and findings
- use algebraic and graphical models to solve problems and make predictions related to the theory and applications of special relativity, quantum theory and the Standard Model
- evaluate the experimental evidence that supports the theory of relativity, wave-particle duality, the Bohr model of the atom, the Standard Model, and the Big Bang theory
- communicate physics understanding using qualitative and quantitative representations in appropriate modes and genres.

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Key ideas:	Experimental methods Photoelectric effect To determine the effect of light frequency on the photoelectron energy produced by the photoelectric effect. To determine the threshold frequency and work function of a Cesium metal cathode
Cross-curriculum priorities:	Sustainability
General Capabilities:	Literacy Critical and Creative Thinking Numeracy Social and Personal Capability

Unit Title:	*Revolutions in Modern Physics*		**Unit Value:**	*1.0 Standard Units*
Due Date:	*Practicals:* *Practical Reflection:* *Research due and Writing Task:*	**Task Weight:** *30 %*	**Task Type:**	*Practical Task*

Student Name / ID: ______________________ **Teacher:** ____________________ **Submission Date:** ______________ **Penalties:** ____________________

Indicator	A	B	C	D	E	Mark
			Outcome 2: Contexts			
Evaluation of Improvements	Critically analyses the effectiveness of improvements in ensuring valid and reliable knowledge was gained from the experiment. **9-10**	Analyses the effectiveness of improvements in ensuring valid and reliable knowledge was gained from the experiment. **7-8**	Explains how improvements increased validity and/or reliability of the experiment. **5-6**	Describes how improvements increased validity and/or reliability of the experiment. **3-4**	Identifies that improvements had an impact on validity or reliability. **0-2**	**/10**
			Outcome 3A: Inquiry Skills - Investigative Skills			
Improvements to method and risk assessment	Improvements given are specific, insightful, and allow collection of detailed, valid and reliable results. Evaluation of risks demonstrates detailed analysis of level, likelihood and control of relevant risks. **9-10**	Improvements given are specific, relevant, and allow collection of valid and reliable results. Analysis of risks demonstrates specific consideration of level, likelihood and control of relevant risks. **7-8**	Improvements given are specific and allow collection of valid and/or reliable results. Explanation of risks demonstrates consideration of level, likelihood and/or control of mostly relevant risks. **5-6**	Improvements given allow collection of some valid or reliable results. Describes risks and identifies level, likelihood or control. **3-4**	Improvements have limited connection to aim or validity of results. Identifies risks. **0-2**	**/10**
Practical Conclusions, Reliability, Validity, Uncertainty Analysis	Conclusions use graphs to evaluate results and analyse the most relevant patterns and trends in the data. Makes insightful links between results and solar power. Critically analyses validity and reliability of results with detailed reference to research and experimental uncertainties. Uncertainty estimates are quantitative and correct, and effect on the results clearly evaluated. **17-20**	Conclusions use graph to analyse results and explain the relevant patterns and trends in the data. Makes clear and relevant links between results and solar power. Analyses validity and reliability of results with reference to research and experimental uncertainties. Uncertainty estimates are quantitative and correct, and effect on the results analysed. **14-16**	Conclusions use graph to explain accurate patterns and trends in the data. Makes relevant links between results and solar power. Describes validity and reliability of results with reference to research and/or experimental uncertainties. Uncertainty estimates are quantitative and mostly correct. **10-13**	Conclusions identify some correct patterns in data or make relevant links to solar power. Identifies features related to validity or reliability of results. Uncertainty estimates are quantitative but incomplete. **6-9**	Conclusions attempted with major errors. Validity, reliability of results, or uncertainties considered with major errors. **0-5**	**/20**
			Outcome 3B: Inquiry Skills Communication			

Practical Tables, Graphs, Calculations	Tables, graphs, and calculations present all results and uncertainties in a clear and insightful manner with correct formatting. **9-10**	Tables, graphs, and calculations present all required data and uncertainties using correct formatting. **7-8**	Tables and graphs present required data using correct formatting. **5-6**	Tables and graphs present data in way that can be understood, but has significant errors. **3-4**	Tables or graphs or diagrams attempted but are unclear or inaccurate. **0-2**	**/10**
Communication	Response written in clear and concise style, with correct terminology and logical sequencing that supports purpose of each question. **9-10**	Response written in clear style, with correct terminology and some logical sequencing that largely supports purpose of question. **7-8**	Response written in correct format with correct terminology without a consistent purpose. **5-6**	Response is written in correct format with some terminology. **3-4**	Response is written with major errors in terminology or no logical sequence. **0-2**	**/10**
					Grade and Mark Total:	**/60**

WRITTEN FEEDBACK:

Strengths: *What elements of the task were done well…*	**Feed-forward:** *What elements of the task needed more work…*

TASK ONE: ANALYSIS OF THE TASK USING THE BSSS QUALITY ASSESSMENT GUIDELINES

Outstanding	Coverage of BSSS Accredited Courses
Outstanding	Reliability
High	Bias Awareness
High	Levels of Thinking
High	Student Engagement
High	Academic Integrity

1. COVERAGE OF BSSS ACCREDITED COURSES

Outstanding Coverage of BSSS Accredited Course – Assessment tasks are strategically planned for alignment with Achievement Standards, unit goals and content descriptors. Assessments are not too big: assessing irrelevant content or criteria; nor too small: missing important content or criteria

COMMENTS

The task identifies elements of the achievement standards being assessed – Concepts Models and Applications ([CMA2], [CMA3]), Contexts ([C1]) and Inquiry Skills ([IS1], [IS2], [IS3], [IS5]). This is a suitable coverage for a single practical task and engages with key concepts related to inquiry in science.

2. RELIABILITY

Outstanding Reliability - Assessment tasks and marking are strategically designed to remove all sources of non-relevant variation in measurements.

COMMENTS

Instructions and conditions are clear and unambiguous. The marking rubric provides clear distinctions between levels of achievement and uses achievement standard verbs to good effect. There is some ambiguity in the connection of the rubric to specific requirements of the task. These are effectively removed by the Marking Guide provided. There is some tension between the (achievement standard oriented) rubric and the highly practical and reliability enhancing marking guide for the task.

3. BIAS AWARENESS

High Bias Awareness - The suite of assessment tasks is designed that promote the diverse needs of gender, socio-economic status, disabilities and/or cultures, and that do not marginalise or favour a student or group of students, or advantage or disadvantage certain background knowledge or ways of thinking.

COMMENTS

There are no identifiable sources of bias in the task. The task is accessible to students from a wide range of backgrounds and has no special requirements that would favour one group of students over another. The task is clearly focussed on the key ideas of the unit, in particular the inquiry skills from the achievement standards in the context of the content of this unit.

4. LEVELS OF THINKING

High Levels of Thinking – Clear assessment tasks are designed that allow students to engage at progressively higher cognitive demands. The suite of assessments demonstrates that there are expectations for all learners at all levels of learning and opportunities for extending all learners are planned for. Assessment tasks are flexible and varied, covering a range of assessment modes.

COMMENTS

Opportunities exist for students to demonstrate a range of thinking levels in the task. There is sufficient scaffolding to allow students at the D/E level to demonstrate what they are capable of, while presenting opportunities for A level students to extend themselves. Some elements of the rubric are more clearly connected to practical concerns in marking than to describing the levels of thinking required to achieve a particular outcome.

5. STUDENT ENGAGEMENT

High Student Engagement – Assessment tasks are thoughtfully planned to engage students. Assessment tasks are explicitly connected to contemporary issues or student lived experiences, interests, or prior knowledge. The suite of assessment tasks supports student ownership.

COMMENTS

Task and expectations are clear and unambiguous, not requiring any unexpected background knowledge or presenting any entry barriers to students. Task facilitates students thinking like an expert in some elements of the task, but does not provide a high degree of autonomy. There is an option for some limited autonomy in allowing the students to make improvements to their method. Connections are made to relevant applications of the scientific principals being investigated.

6. ACADEMIC INTEGRITY

High Academic Integrity - Academic integrity is discussed with students with expectations with respect to academic integrity and the consequences of cheating or plagiarising made clear. Assessment is designed to encourage original thinking from students and require individualised responses that will be different.

COMMENTS

Academic integrity and plagiarism are mentioned on the task sheet and student reflections are required to submit their reflection through a plagiarism checker. BSSS policies on penalties are referred to and it can be assumed that academic integrity and plagiarism have been discussed with students prior to assessment. The in-class nature of the practical task allows the teacher to have oversight of the collection and first parts of the analysis of results.

ANNOTATED STUDENT WORK : A GRADE

A Script

[IS2], [IS5] The information has been displayed logically and with consistent units, decimal places and significant figures, showing correct scientific conventions. Uncertainties have been reported correctly and are reasonable, supported by analysis that follows.

1. Present your experimental results and uncertainty values in appropriately formatted and titled tables.

Experiment 1 – The Effect of Light Frequency on Photoelectron Energy Produced by the Photoelectric Effect - Summary (Collated Averages)

Wavelength (nm)	Frequency (10^{14} Hz)	Frequency Uncertainty (%)	Stopping Voltage (V)	Current (nA)	Kinetic Energy (eV)	KE Uncertainty (%)
432±10	6.94±0.16	2.3	1.07±0.05	0.00±0.01	1.07±0.05	4.7
477±10	6.29±0.13	2.1	0.78±0.04	0.00±0.01	0.78±0.04	5.4
501±10	5.99±0.12	2.0	0.74±0.04	0.00±0.01	0.74±0.04	5.5
522±10	5.74±0.11	1.9	0.55±0.03	-0.01±0.01	0.55±0.03	5.5
582±10	5.15±0.09	1.7	0.30±0.02	0.00±0.01	0.30±0.02	6.7

Experiment 2 – The Effect of Light Intensity on Current Produced by the Photoelectric Effect – Summary (Collated Averages)

Aperture Diameter (mm)	Aperture Area (mm^2)	Relative Uncertainty (%)	Current (µA)
7.0±0.5	38±5	13	0.05±0.01
10.0±0.5	79±7	8.9	0.10±0.01
14.0±0.5	154±11	7.1	0.20±0.01
20.0±0.5	314±15	4.8	0.26±0.01

Separate Measurement as a part of Experiment 2 – Photoelectron Energy Produced by the Photoelectric Effect with Aperture of Documented 7mm Diameter Using Frequency of Light of Documented 432 nm (Graph Broken Up)

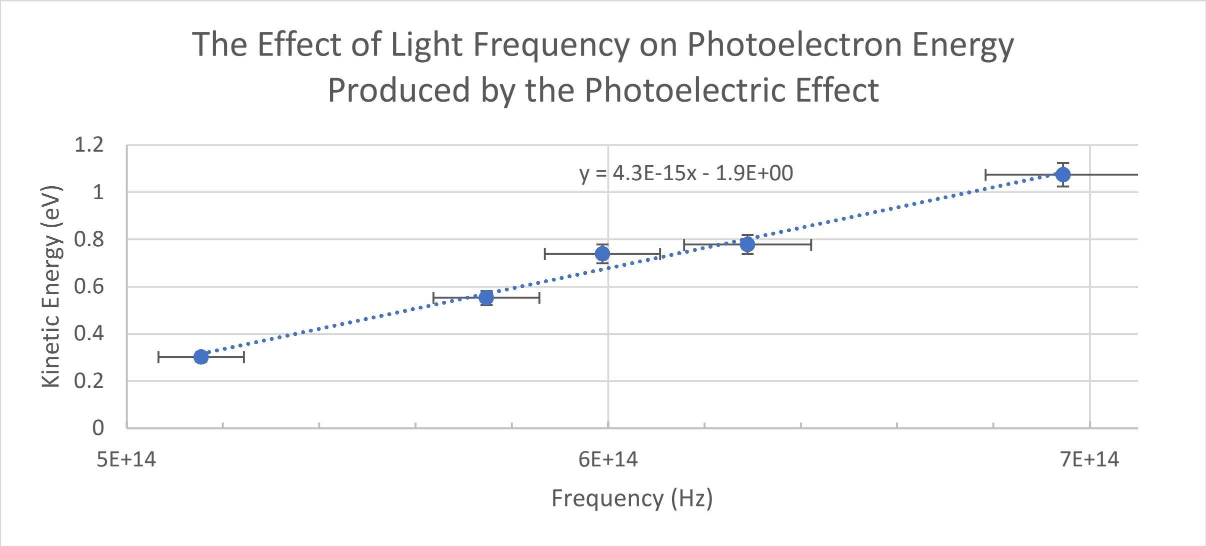
Aperture Diameter (mm)	Aperture Area (mm^2)	Aperture Uncertainty (%)	Wavelength (nm)	Frequency (10^{14} Hz)	Frequency Uncertainty (%)
7.0± 0.5	38± 5	13	432± 5	6.94±0.08	1.2

Stopping Voltage (V) (±0.001)	Current (nA)	Kinetic Energy (eV)	KE Uncertainty (%)
1.02±0.05	0.00±0.01	1.02±0.05	4.9

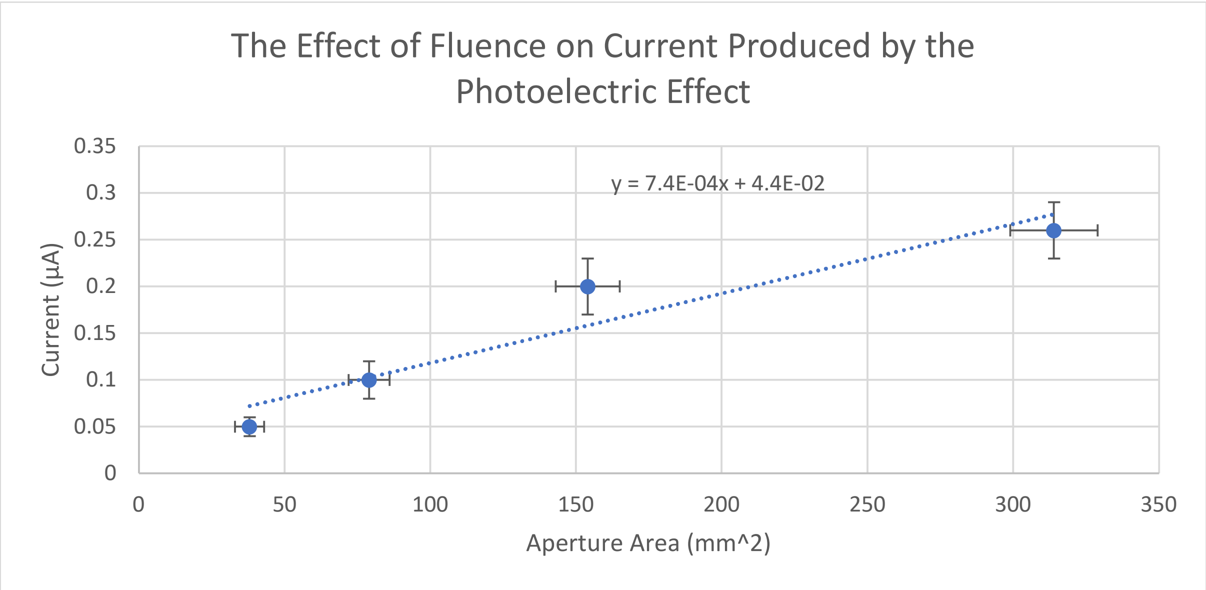
2. Present appropriate titled graphs of your experimental results that will help answer the aims of the experiments.

[IS2], [IS5] The graphs concisely and effectively and accurately represent the data collected and uncertainties reported.

Experiment 1



Experiment 2



3. Calculate any values needed from the graphs to answer the aims given.

Experiment 1

Linest Uncertainty:

Gradient:	4.284E-15	Y-Intercept:	-1.89
Gradient Uncertainty:	±3.23E-16	Y-Intercept Uncertainty:	±0.20

Work Function (Φ) - Y-Intercept:

∴ Φ = (1.89 ± 0.20) eV

Threshold Frequency (f0) - X-Intercept:

(0) = 4.284E-15x - 1.89 x = 1.89/3.610E-15 ∴ f0 = $(4.42 \pm 0.5) \times 10^{14}$ Hz

Planck's Constant (h) - Gradient*Joules of 1eV:

h = 4.284E-15 eV *1.602E-19 J/eV ∴ h = $(6.9 \pm 0.5) \times 10^{-34}$ Js

[CMA3], [IS2] The student has identified the relevant data and determined uncertainty correctly using an efficient method. Calculated values are communicated clearly and efficiently using appropriate conventions.

[IS2] Directly links reliability to the precision of measurements made.

4. Analyse the reliability and validity of the results collected.

The uncertainty in measured values in the stopping voltages varied by 4.7 – 6.7% depending on the filter used and hence wavelength of the light. The reliability could have been improved by increasing the number of trials further. This would allow for an improved statistical description of uncertainty and would reduce the effect of random errors introduced by individual measurements.

[IS2] Demonstrates a clear understanding of the role of repetition in reducing uncertainty.

The relationship between kinetic energy and frequency is linear, with the line of best fit falling within the range of uncertainties.

[IS2] Student has correctly analysed the data and identified the pattern. Student has demonstrated understanding of the relationship between uncertainties and trends.

[CMA3], [IS2] Clear analysis of the validity against one of the aims – student has compared the range of calculated values with the accepted value and reached a valid conclusion.

The accepted value of Planck's constant is within the range given by the uncertainty in the gradient, indicating a valid measurement. The work function of Caesium is just outside the indicated range from this experiment, as is the accepted value of threshold frequency. This is indicative of a systematic error in the results which has impacted the validity.

[IS2] Correct analysis has identified that an anomaly exists. Demonstrated understanding of systematic errors.

For Experiment 2, the relative uncertainty in the measurements of aperture was fairly high – 13% for the smallest aperture. This uncertainty was primarily due to the limit of reading in the instruments used to measure the diameter of the aperture. Current measurements were similarly variable.

[IS2] Clear identification of source of uncertainty.

The relationship between current and aperture (and hence fluence) was linear, though some degree of curvature in this relationship is evident. This is likely due to the light shade over the anode.

[IS2] Student has again identified a possible source of anomaly in the trend.

5. Outline the improvements you made to the given method.

<u>Experiment 1:</u>

Was changed to:

- Repeat steps 4-8 at least 3 times (5 was achieved)

- Use the same size aperture for the entirety of the experiment

- After all wires are connected, zero the voltage on the photoelectric kit to display zero voltage/stopping voltage

- Ensure light is directed to the centre of the filter slit

- Attach lamp the same distance away from filter

[IS1] Demonstrates an understanding of the role of repetition in decreasing uncertainty.

Demonstrates an understanding of controlled variables.

<u>Experiment 2:</u>

Was changed to:

- Repeat the experiment with the same aperture at least 5 times

6. Evaluate how effectively your improvements to the method increased the validity and reliability of the experimental results.

The addition of repeating the experiment helped the reliability immeasurably, as the very definition of reliability is showing how the results can be reproduced. Without repeating there would be no way to tell if the results are reliable. Repeating the results also minimises the impact of outliers, random uncertainty and errors, increasing validity.

[IS2], [IS3] Demonstrates an understanding of the need to isolate variables

Measuring the diameter of the apertures in experiment 2 however did not affect the validity at all because the documented value was accurate from the start to the precision that was available to be measured with the ruler. Even though this did not change the experimental results, it did allow for increased confidence in the validity of the experiment and provided an opportunity to estimate the uncertainty in the aperture size.

[IS2], [IS3] Accurate evaluation of the role of repetition in increasing reliability.

The other suggestions for attaching the light at a specific distance and making sure the light was directed properly would have had a large positive impact on the validity if the apparatus didn't force that to happen automatically. This was the same for zeroing.

[IS2], [IS3] Response correctly evaluates the impact of changes on the reliability and validity of results.

7. Critically analyse the size of the uncertainty in your direct measurements.

In experiment 1, the precision of the multimeter used did not contribute significantly to the uncertainty in the measurements of the stopping voltage. There was a significant

[CMA3], [IS2] Student has correctly compared an uncertainty source with observed variations and drawn accurate conclusions.

variation in readings, however. Possible sources of these differences include variations in the light source over time as well as the potential for light leakage in the apparatus.

[IS2] Student has analysed the experimental method and suggested possible sources of uncertainty.

The uncertainty in the wavelengths passed by the filters seems likely to have been underestimated. The wavelength uncertainty here was estimated to be ±10 nm, but it was impossible to verify this. Therefore the true uncertainty could be bigger.

The presence of a linear trend and an accurate (within the range given by uncertainties in the gradient) combined with the systematic error suggests the trend line should have an overall shift to higher frequencies. This is in agreement with the likely overestimation of the lowest wavelength/highest frequency that the filters passed through.

[IS2] Student is drawing on research to identify potential causes of systematic error in experimental results. Demonstrates critical analysis.

The aperture diameter uncertainty of 0.5mm was big as an effect of its analogue technology. This resulted in flow on effects to the uncertainty of the aperture. The size of these errors was relatively large, with a maximum value of 13%, but had relatively little impact on the validity of the experiment, as the aim was only to identify a trend rather than specific values like in the first experiment. The uncertainty which had the most impact was the current in the second experiment. ±0.01 is a equivalent to 20% in the smallest measured current values. The effect of this can be seen on the graph, with the ends of the error bars touching the correct position of the data point to meet the curve, indicating that this experiment was subject to random uncertainty. Some degree of curvature in the trend is evident, with the shape of the light shade over the anode being the likely cause.

[IS2] Evaluates the potential impact of the identified cause of systematic error

[IS2] Correct analysis of the size of the uncertainties and their impacts.

[IS2], [CMA3] Evaluation of the trend. Research has been used to identify a cause of the observed trend, indicating critical analysis.

8. Use your graphs to analyse the experimental error in your results for at least two of the aims given for the experiment.

Experimental Error:

	Work Function (Φ): (eV)	**Threshold Frequency (f0): (Hz)**	**Plancks Constant (h): (Js)**
Real Answer	2.14	5.16E+14	6.6E-34
Experimental Answer	1.89	4.42E+14	6.9E-34
% Error	12	14	5
E.A w/ Uncertainty in its Favour	2.09	4.92E+14	NA
% E w/ Uncertainty in its Favour	2	5	0, within range

As can be seen in the table, the experimental estimates of the work function and threshold frequency were low compared with accepted values, with the accepted value falling outside the estimated range. This means a systematic error or errors must be occurring for every result to receive an error same direction. The accepted value of Planck's constant lies within the range found experimentally, with an error of 5%. This suggests that the systematic error had the impact of shifting the line of best fit to the left (smaller frequencies).

[IS5] Successfully and efficiently communicates key findings of the experiment in table form

The most likely cause of the systematic error is due to the unknown range of wavelengths that the colour filters allow to pass through. The stopping voltage is a result of the highest frequency and therefore lowest wavelength photons that the filter allows through. This means that the documented wavelengths for the colour filters are likely higher than those that affected the measurement of stopping voltage. Assuming that the error was fairly consistent from one filter to the next, this would have resulted in an unchanged value of the gradient (Planck constant) and a low estimate of the work function and threshold frequency, fitting with the results obtained.

[IS2] Evaluation of possible sources of systematic error resulting in a possible suggestion.

[IS3] Evaluates the plausibility of the source of error resulting in the anomaly identified.

9. Discuss two further improvements that could reduce the size of uncertainties or experimental error in this experiment.

Experiment 1

Lasers have one specific wavelength that is much more precise and would be documented, bypassing the need for interpreting graphs for the measured spectrum, making the experiment more reliable and fixing the possible issue that affected this experiment.

[IS1] Evaluates experimental method and suggests a valid improvement that addresses the primary source of systematic error.

Increase the repetition of individual measurements to decrease the impact of outliers and increase the reliability. Use a larger range of wavelengths to better estimate the work function by decreasing sensitivity to variations in gradient.

Experiment 2

An issue with measuring the diameter of the aperture with the analogue ruler is that it was not precise enough to improve on the documented measurement. Using a digital calliper will allow for a more precise measurement reducing the uncertainty significantly.

[IS1] Demonstrates understanding of good experimental technique and the impact of the impact of the uncertainty in one measured value on another. A complex analysis of multiple factors.

The uncertainty in experiment two for the measured current was very high (20%) for small currents. To fix this work with an ammeter that reads smaller than microamps or work with more intense light/bigger apertures to make sure values are big enough to be more precisely measured.

[IS1] Valid suggestions to decrease uncertainty in individual results.

10. Evaluate the meaning of your experimental results to provide at least three concluding statements.

Experiment 1:

The experiment aimed to find the effect of light frequency on photoelectron energy produced by the photoelectric effect. This was successful in that it was found that the frequencies relationship to photoelectrons energy was proportional relative to a constant in the equation E=hf, where the constant h was given the gradient value called Planck's constant that was below the real value by 5% but within the range when including uncertainties. This was supported by the theory that the higher the frequency, the higher the energy given to the photoelectron as all energy after it takes to ionise to converted to kinetic energy.

[CMA3] Synthesises one of the primary findings of the experiment and clearly communicates using appropriate scientific terminology.

These findings can be applied to solar panels; areas with known high high-frequency light from the sun would be most efficient for solar farms as the amount of energy produced is proportional. This could be further improved in conjunction with a metal with a lower work function as it will produce more voltage (as less power is gone into ionisation) and therefore power with the same amount of sunlight.

[CMA2] Applies key findings of the experiment to an important application of this principal

The secondary aim of the experiment was to determine the threshold frequency and work function of a caesium cathode. This was limitedly successful in the determined value of threshold frequency was 1.89 eV ± 0.20 eV, 2% below the accepted value. This was similar to the work function which was determined to be $(4.42 \pm 0.5)\times10^{14}$ Hz , 5% under the accepted value.

[CMA3], [IS5] Accurate and succinct summary of the second primary finding of the experiment using scientific terminology and convention accurately

Experiment 2:

The experiment aimed to find the effect of light intensity on current produced by the photoelectric effect. This was successful in that it found the relationship was consistent with a linear trend, although the trend may also have been consistent with a curve. A proportional increase was expected by the theory that a great intensity of light means more photons will be able to ionise the metal to produce more electrons which is measured as increased current. The curve could suggest that this is the maximum amount of ionisation allowed by the surface area of the metal exposed to the light.

[CMA3] Identifies overall (qualitative trend) and suggests ambiguity together with an explanation for that ambiguity

These findings can be applied to solar panels, as solar panels can be located where the intensity of light is the greatest (i.e. sunny areas that receive a lot of light for long amounts of time with low cloud coverage) to produce the greatest amount of current and therefore energy. Also, the surface area exposed to light by the solar panels can be maximised to take full advantage of the sunlight.

[CMA2] Identifies impacts of the findings of this experiment on an application

ANNOTATED STUDENT WORK : C GRADE

Results and Critical Reflection

All questions must be answered on a digital document and submitted via “platform”. Additionally, your spreadsheet used to create tables and graphs is to be submitted to “platform”.

1. Present your experimental results and uncertainty values in appropriately formatted and titled tables. This will involve copying the tables from your spreadsheet and ensuring that all required formatting and features are present.

[IS5], (C) Communicates accurately demonstrating scientific literacy.

Student response could be strengthened by synthesising the data into a more concise form.

Experiment 1 tables:

	Wavelength 432 (blue)						
	Wavelength ± 0.1 nm	Wavelength Relative Uncertainty (%)	Frequency (e^14) ± 0.01 Hz	Frequency Relative Uncertainty (%)	Stopping Voltage ± 0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	432.0	0.023	6.94	0.14	0.878	0.878	0.11
	432.0	0.023	6.94	0.14	0.878	0.878	0.11
	432.0	0.023	6.94	0.14	0.878	0.878	0.11
	432.0	0.023	6.94	0.14	0.879	0.879	0.11
	432.0	0.023	6.94	0.14	0.878	0.878	0.11
	432.0	0.023	6.94	0.14	0.878	0.878	0.11
	432.0	0.023	6.94	0.14	0.879	0.879	0.11
	432.0	0.023	6.94	0.14	0.879	0.879	0.11
	432.0	0.023	6.94	0.14	0.879	0.879	0.11
	432.0	0.023	6.94	0.14	0.877	0.877	0.11
Average	432.00	0.023	6.94	0.14	0.878	0.8783	0.11

	Wavelength 471 (green)						
	Wavelength ± 0.1 nm	Wavelength Relative Uncertainty (%)	Frequency (e^14) ± 0.01 Hz	Frequency Relative Uncertainty (%)	Stopping Voltage ± 0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	471.0	0.021	6.37	0.16	0.737	0.737	0.14
	471.0	0.021	6.37	0.16	0.739	0.739	0.14
	471.0	0.021	6.37	0.16	0.738	0.738	0.14
	471.0	0.021	6.37	0.16	0.738	0.738	0.14
	471.0	0.021	6.37	0.16	0.737	0.737	0.14
	471.0	0.021	6.37	0.16	0.739	0.739	0.14
	471.0	0.021	6.37	0.16	0.739	0.739	0.14
	471.0	0.021	6.37	0.16	0.738	0.738	0.14
	471.0	0.021	6.37	0.16	0.739	0.739	0.14
	471.0	0.021	6.37	0.16	0.740	0.740	0.14
Average	471.0	0.021	6.37	0.16	0.738	0.738	0.14

	Wavelength 501 (yellow)						
	Wavelength ± 0.1 nm	Wavelength Relative Uncertainty (%)	Frequency (e^14) ± 0.01 Hz	Frequency Relative Uncertainty (%)	Stopping Voltage ± 0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.643	0.643	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.641	0.641	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.644	0.644	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
	501.0	0.020	5.98	0.17	0.642	0.642	0.16
Average	501.0	0.020	5.98	0.17	0.642	0.642	0.16

	Wavelength 522 (orange)						
	Wavelength ± 0.1 nm	Wavelength Relative Uncertainty (%)	Frequency (e^14) ± 0.01 Hz	Frequency Relative Uncertainty (%)	Stopping Voltage ± 0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	522.0	0.019	5.74	0.17	0.560	0.560	0.18
	522.0	0.019	5.74	0.17	0.561	0.561	0.18
	522.0	0.019	5.74	0.17	0.559	0.559	0.18
	522.0	0.019	5.74	0.17	0.560	0.560	0.18
	522.0	0.019	5.74	0.17	0.562	0.562	0.18
	522.0	0.019	5.74	0.17	0.561	0.561	0.18
	522.0	0.019	5.74	0.17	0.560	0.560	0.18
	522.0	0.019	5.74	0.17	0.560	0.560	0.18
	522.0	0.019	5.74	0.17	0.561	0.561	0.18
	522.0	0.019	5.74	0.17	0.559	0.559	0.18
Average	522.0	0.019	5.74	0.17	0.560	0.560	0.18

	Wavelength 582 (red)						
	Wavelength ± 0.1 nm	Wavelength Relative Uncertainty (%)	Frequency (e^14) ± 0.01 Hz	Frequency Relative Uncertainty (%)	Stopping Voltage ± 0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	582.0	0.017	5.15	0.19	0.377	0.377	0.27
	582.0	0.017	5.15	0.19	0.375	0.375	0.27
	582.0	0.017	5.15	0.19	0.376	0.376	0.27
	582.0	0.017	5.15	0.19	0.378	0.378	0.26
	582.0	0.017	5.15	0.19	0.380	0.380	0.26
	582.0	0.017	5.15	0.19	0.380	0.380	0.26
	582.0	0.017	5.15	0.19	0.379	0.379	0.26
	582.0	0.017	5.15	0.19	0.379	0.379	0.26
	582.0	0.017	5.15	0.19	0.379	0.379	0.26
	582.0	0.017	5.15	0.19	0.379	0.379	0.26
Average	582.0	0.017	5.15	0.19	0.378	0.378	0.26

Experiment 2 tables:

	Diameter 7.02 ±0.5 mm			
	Aperture Diameter ±0.5 mm	Area mm^2	Relative Uncertainty (%	Curent ±0.01 µA
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.22
	7.0	38.7	1.3	0.21
	7.0	38.7	1.3	0.21
Average	7.0	38.7	1.3	0.22

	Diameter 9.82 ±mm			
	Aperture Diameter ±0.5 mm	Area ±mm^2	Relative Uncertainty (%	Curent ± 0.01 µA
	9.8	75.7	0.66	0.31
	9.8	75.7	0.66	0.30
	9.8	75.7	0.66	0.30
	9.8	75.7	0.66	0.31
	9.8	75.7	0.66	0.30
	9.8	75.7	0.66	0.30
	9.8	75.7	0.66	0.31
	9.8	75.7	0.66	0.30
	9.8	75.7	0.66	0.31
	9.8	75.7	0.66	0.30
Average	9.8	75.7	0.66	0.30

	Diameter 13.9 ±mm			
	Aperture Diameter ±0.5 mm	Area ±mm^2	Relative Uncertainty (%	Curent ±0.01 µA
	13.9	151.7	0.33	0.39
	13.9	151.7	0.33	0.39
	13.9	151.7	0.33	0.39
	13.9	151.7	0.33	0.38
	13.9	151.7	0.33	0.38
	13.9	151.7	0.33	0.38
	13.9	151.7	0.33	0.39
	13.9	151.7	0.33	0.39
	13.9	151.7	0.33	0.38
	13.9	151.7	0.33	0.38
Average	13.9	151.7	0.33	0.39

	Diameter 20.08 ±mm			
	Aperture Diameter ±0.5 mm	Area ±mm^2	Relative Uncertainty (%	Curent ±0.01 µA
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.45
	20.1	316.7	0.16	0.44
	20.1	316.7	0.16	0.44
Average	20.1	316.7	0.16	0.44

	Diameter 7.02 ±0.5 mm & Wavelength 432 (blue)						
	Aperture Diameter ±0.5 mm	Area mm^2	Relative Uncertainty (%)	Wavelength ±0.1 nn	Stopping Voltage ±0.001 V	Electron Volts (eV)	Voltage Relative Uncertainty (%)
	7.0	38.7	1.3	432.0	0.878	0.878	0.11
	7.0	38.7	1.3	432.0	0.878	0.878	0.11
	7.0	38.7	1.3	432.0	0.878	0.878	0.11
	7.0	38.7	1.3	432.0	0.879	0.879	0.11
	7.0	38.7	1.3	432.0	0.878	0.878	0.11
	7.0	38.7	1.3	432.0	0.878	0.878	0.11
	7.0	38.7	1.3	432.0	0.879	0.879	0.11
	7.0	38.7	1.3	432.0	0.879	0.879	0.11
	7.0	38.7	1.3	432.0	0.879	0.879	0.11
	7.0	38.7	1.3	432.0	0.877	0.877	0.11
Average	7.0	38.7	1.3	432.0	0.878	0.878	0.11

2. Present appropriate titled graphs of your experimental results that will help answer the aims of the experiments. These will also be copied from your spreadsheet.

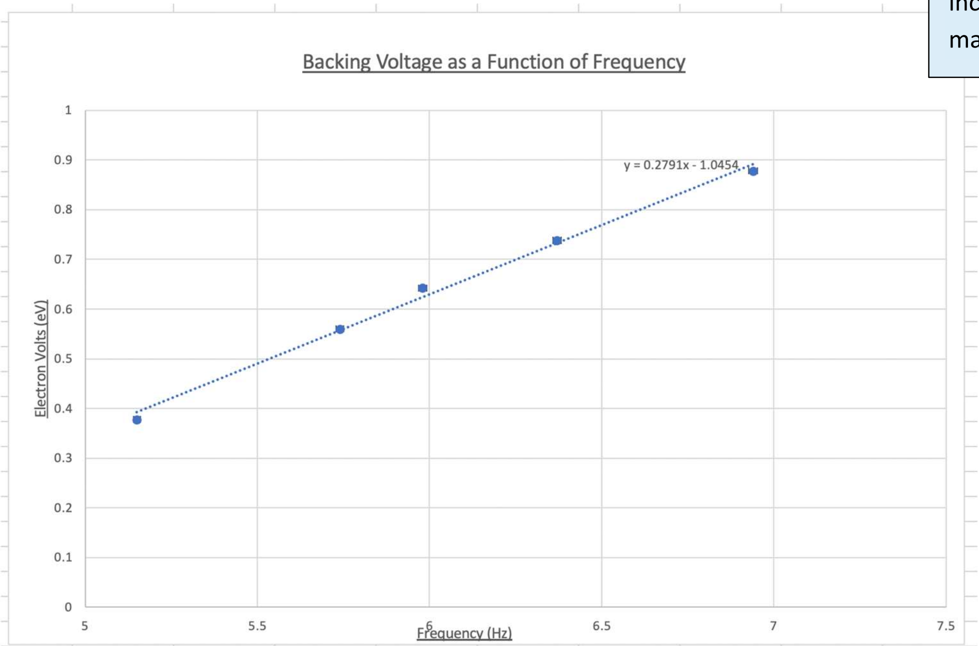
1. First, you must include the graphs specified on the instruction sheet.
2. Then, present other graphs you have chosen to plot to answer the aims of the experiment in more depth. Include titles, and a caption explaining why you have chosen to present this graph.

[IS2] (C) Uncertainties are reported using rules for the limitations of the device used but could be improved by identifying other sources.

Reports common errors.

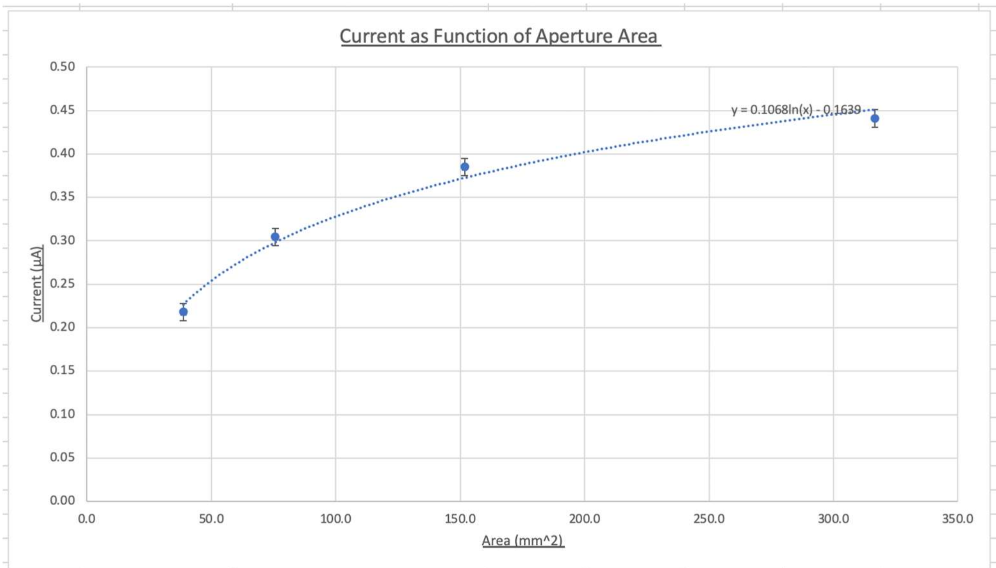
The student has used incorrect order of magnitude for units.

Experiment 1 Graph:



As the frequency increased the energy increased in a linear way.

Experiment 2 Graph:



Current increases with the area of the aperture, but flattens off as area increases.

3. Calculate any values needed from the graphs to answer the aims given.

Experiment 1: Threshold frequency is equal to the x intercept. From the equation on the graph, y = 0.2791x – 1.0454. Let y = 0, to solve for x. 0 = 0.2791x – 1.0454, 1.0454 = 0.2791x, x = 3.746. Therefore, threshold frequency = $3.74*10^{14}$ Hz.

Work function is equal to y intercept. From the equation on the graph, y = 0.2791x – 1.0454. Let x = 0, to solve for y. y = 1.0454. Therefore, work function = 1.0454 eV.

4. Analyse the reliability and validity of the results collected.

The results can be considered reliable across both experiments, as they were able to be reproduced. There was little spread for the backing voltage as a function of frequency for each of the 5 different wavelengths and the 10 tests conducted. This also holds true for current as function of aperture area, for each 4 different aperture areas and the 10 tests conducted.

The results for experiment 1, aim 1 can be considered valid as the experiment measured what it intended to. The effect of light frequency on the photoelectron energy was found to increase in a linear matter and this is what was expected. Unfortunately, the results for experiment 1, aim 2 cannot be considered as valid because there was a high level of experimental error. The experimental threshold frequency was 60.3% lower than the real value. And the experimental work function was 52.4% lower than the real value.

5. Outline the improvements you made to the given method.

Experiment 1: The first improvement made was recording the wavelength of each light filter using the Vernier Spectral Analysis software, as opposed to using the stated wavelength. The next improvement was repeating the experiment 10 times for each colour filter.

Experiment 2: The first improvement was recording the aperture diameter with a micrometre, as oppose to recording the supplied values for aperture diameters. The next improvement, similar to experiment 1 was recording the wavelength of the 428 nm filter using the Vernier Spectral Analysis software. The final improvement was repeating the experiment 10 times for each different size aperture.

6. Evaluate how effectively your improvements to the method increased the validity and reliability of the experimental results.

The first improvement, recording the different wavelengths with Vernier software, slightly improved the validity. This is because a closer to the real value of wavelength was used, as oppose to the given wavelength. The reliability was also effectively improved, as the results can now be more easily reproduced in the future, with more valid values for wavelength. The

[IS2], [IS5] (C) Describes a correlational relationship in the data. Graphs demonstrate scientific literacy mostly accurately.

[CMA3] (D) Develops evidence-based conclusions in calculating required values.
Response could be improved by identifying relevant uncertainties.

[IS2] (C) Explains reliability and validity of data and discusses common errors.

[CMA3] (C) Demonstrating understanding of reliability

[CMA3] (C) Demonstrating understanding of validity by linking to experimental error

[IS2] (C) Explains correlational relationship

[CMA3] (C) Identifies limitations in the results

[IS1] (B) Suggests improvements to safe, ethical inquiries

[IS1] (B) Improvements suggested are focused on improving reliability.

above increases of the validity and reliability also hold true for measuring the aperture diameter with a micrometre.

The final improvement of 10 repeats for each wavelength/diameter greatly increase both validity and reliability. By increasing the number of repeats, the spread of results (which were minimal) are clearer to see and therefore verify the experiment's validity/reliability.

[C1], [IS3] (C) Explains processes and claims and identifies alternatives with reference to reliable evidence. Explains how improvements mean the experiment will provide justifiable scientific knowledge

7. Critically analyse the size of the uncertainty in your direct measurements.

Experiment 1: The uncertainty used for wavelength was ± 0.1 nm. This proved to be far too small, as the graph's error bars did not intercept the trendline. A larger value for uncertainty should have been used, as the point where the graph dipped in the Vernier Spectral Analysis, was not clear. The next uncertainty value was for stopping voltage, ± 0.001 V. According to the handbook, uncertainty for digital apparatus is ± the smallest division scale, which was used above. However, the photoelectric effect kit may have its own uncertainty.

[IS2], [CMA3] (C) Explains reliability and discusses common errors. Identifies limitations in their data.

Experiment 2: The uncertainty used for diameter was ± 0.5 mm, and for current, ± 0.01 µA. The uncertainty for both variables followed the rules in the handbook. Diameter was ± half the smallest division scale, as the apparatus was analogue, and current was ± the smallest division scale, as the apparatus was digital. The current uncertainty was acceptable as the error bars on the graph intercepted the trendline. However, the error bars for area were barely visible – indicating too small of an uncertainty.

Example of discussion of error

[CMA3] (C) Identifies the existence of a limitation

8. Use your graphs to analyse the experimental error in your results for at least two of the aims given for the experiment.

[IS2], [CMA3] (C) Explains validity and identifies common errors. Develops evidence-based conclusions and identifies limitations.

Experiment 1, aim 1: determining a value for Planck's Constant from the graph. M = $0.2791*10^{-15}$. Charge of electron = 1 eV = $1.602*10^{-19}$. Planck's constant = $(0.2791*10^{-15}) * (1.602*10^{-19}) = 4.466*10^{-34}$ J s. Experiment error = $\frac{6.626*10^{-34} - 4.466*10^{-34}}{6.626*10^{-34}} \times 100 = 33\%$ The real Planck's constant is 33% higher than the experimental value found. From the equation above, this indicates that the gradient was too small (either eV was too small or frequency too large). In addition to this, a rather narrow spectral range was used by the five filters (432.0 nm – 582.0 nm). This would've contributed to the large experimental error when determining Planck's constant.

[CMA3] (C) Calculation of Planck's constant is an example of developing an evidence-based conclusion

[CMA3] (C) Uses experimental error to identify a limitation and explain validity and attempts to discuss a reason for this limitation.

Experiment 1, aim 2: threshold frequency and work function of a Cesium metal cathode. Experiment threshold frequency = $3.74*10^{14}$ Hz. Real threshold frequency = $9.42*10^{14}$ Hz. Experiment error = $\frac{9.42*10^{14} - 3.74*10^{14}}{9.42*10^{14}} \times 100 = 60.3\%$ The real threshold frequency is 60.3% higher than the experimental value found.

[CMA3] (C) Threshold frequency calculation is an example of developing an evidence-based conclusion

Experiment work function = 1.0454 eV. Real work function = 2.1 eV. Experiment error = $\frac{2.1-1.0}{2.1} \times 100 = 52.4\%$ The real work function is 52.4% higher than the experimental value found.

[CMA3] (C) Again, uses experimental error to identify a limitation and explain validity

Hint: you need to give the size and direction of the experimental error, decide if the experimental error fits within the error bounds of the experiment, and give physics based reasons why your measured value may be above or below the expected value.

9. Discuss two further improvements that could reduce the size of uncertainties or experimental error in this experiment. In your answer you may consider technology or measurement devices beyond what was available during the experiment.

[CMA3] (C) Again, uses experimental error to identify a limitation and explain validity

The first improvement for experiment 1, which would greatly decrease uncertainties and the overall experimental error is using lasers, such as, HeNe lasers, laser diodes, and laser pointers. Instead of using a lamp and filters to illuminate the cell, the beam of one of five lasers (blue, green, yellow, orange, and red) would. This improvement ensures a narrow spectral width of the beam, compared to the broad spectral width when using filters.

[IS1] (B) Suggests a plausible improvement (Experiment 1). Identifies a plausible alternative with reference to some evidence of the spectral width of the laser.

The second improvement for experiment 2, which would reduce the experimental error would be increasing the number of apertures used. Increasing the number of results, would increase the reliability as more apertures means more areas, and therefore more currents produced. This would in turn reduce the experimental error in the graph because the trendline would be based off more data.

[IS1] B Suggests an improvement that would increase validity, however, mislabels it as an improvement to reliability.

10. Evaluate the meaning of your experimental results to provide at least three concluding statements. Each statement must do both of the following:

1. Address one of the given aims of the experiment, i.e. outlining what this experiment has shown about the photoelectric effect.
2. Include a sentence identifying how the results of experiment can be applied to solar power.

[CMA3], [CMA2] (C) Explains evidence and develops straightforward evidence-based conclusions. Explains an application of the theory based on evidence.

Experiment 1, aim 1: The results showed that the energy produced increased proportionally to the frequency of the light. This in turn produced a linear graph and a linear relationship. In terms of the photoelectric effect, a light of higher frequency will produce more energy than that of a light of lower frequency. This knowledge can then be applied to solar panels. The sun produces the entire spectrum of radiation but only the light of high enough frequency will produce the photoelectric effect and in turn the photovoltaic effect. Coloured filters can then be used to determine the desired frequency and produce voltage.

[CMA2] (C) Explains the trend in reference to models

Experiment 1, aim 2: The work function and threshold frequency was calculated from the graph produced using the 1st experiment's results. The cesium metal threshold frequency = $3.74*10^{14}$ Hz and work function =

1.0454 eV. This relates to the photoelectric effect, as the threshold frequency is the minimum frequency to release a photoelectron, and the work function is the least amount of energy to ionise an electron. This relates to solar panels because selecting a material with the lowest work function, will ensure maximising the kinetic energy produced.

[CMA2] (D) Attempts to apply the model to solar panels with some accuracy, however the solution proposed is implausible

Experiment 2: The results showed that current produced by the photoelectrons increased in a logarithmic manner to the area of the aperture. The effect is therefore as area increases so does the current produced. This relates to solar panels because the greater the light intensity/area, the more current produced.

These concluding facts will be the information from the experiments that you will need to use in your writing task. Be specific and concise with the facts that the experiment shows.

Risk Assessment

Risks in this experiment	**Likelihood of risk**	**Level of risk**	**Control measure to manage risk**
Photoelectric effect apparatus. Possibility of electric shock.	Medium likelihood, because apparatus is frequently being turned off and on. Apparatus cords are also being handled and plug in and out of electrical socket.	Medium to high level risk, as electric shock can result in death, in extreme cases. Can be considered medium risk because an unpleasant zap may all that was felt. Level of risk depends on output voltage.	Inspect regularly for signs of damage to the cord. Check cord loose in outlet or cord loose at entry to power supply, or any signs of corrosion or other damage.
Lamp. Becomes hot during use. Danger of burns.	Medium likelihood, because will frequently be touching lamp in order to change colour filters, and apertures.	Medium to high level of risk, as levels of burn can vary between minor to 3rd degree burns.	Use apparatus, such as tweezers to remove and replace colour filters, and apertures, to avoid physical contact.