Sample F

Criteria	Teachers' mark
Personal Engagement	0
Exploration	3
Analysis	5
Evaluation	4
Communication	3
Total	15

Finding Planck's constant

Introduction

This document concerns itself with the Photon Energy Array. It is an investigation that involves calculating an estimate of Planck's constant through a series of tests where a variable amount of voltage is connected across a range of LEDs; in turn one has to estimate roughly when the first energetic Photon leaves the LED. The LED's that are involved range from 430 to 655 nm.

The main Formulas used where:

$$E = (1.6*10^{-19}) * V_{average}$$
$$F = (3*10^{8}\ ms^{-1}) / (\lambda*10^{-9} m)$$

Procedure

The method used in this investigation involved a series of LED's all connected to an electricity source, so that Voltage could be put across them. A black tube was placed over the fist LED that emitted a light at a wavelength of 655 nm. Whilst looking through the black tube, the voltage had to be increased, and the amount of voltage noted just as soon as the first signs of light where seen. These would be some of the first Photons produced when there is enough energy to let the LED light up.

Wavelength (nm)	$Voltage_1$ (±0.01) (V)	$Voltage_2$ (±0.01) (V)	$Voltage_3$ (±0.01) (V)
430	2.22	2.23	2.20
505	2.01	1.96	1.98
560	1.60	1.61	1.57
615	1.40	1.41	1.38
655	1.31	1.29	1.30

The uncertainties stated for the voltage in the heading is the uncertainty of the voltmeter reading when the results where obtained.

Uncertainties for wavelength (λ)

The uncertainties for the wavelength I obtained from a website (http://www.gizmology.net/LEDs.htm), where a spread of the LED spectra for different colors are posted. Due to the fact that LED's do not emit visible light for every spectrum it was hard to acknowledge at which wavelength the LED emitted the first photons of light. In order to account for this I calculated the uncertainties for the different wavelength using the data published on the website concerning the wavelength spectrum for each color of LED.
In order to calculate the uncertainty for the wavelength of the LED's, I used half the range of the data given on the website, divided the wavelength by this and multiplied it by 100 to get a percentage uncertainty. An example of this is as follows:

λ of 655 nm, is in the spectral region where a red light will be emitted. This region spreads from 640 nm to 700 nm. This means that the range of the region is 60 nm. Following the calculations above:

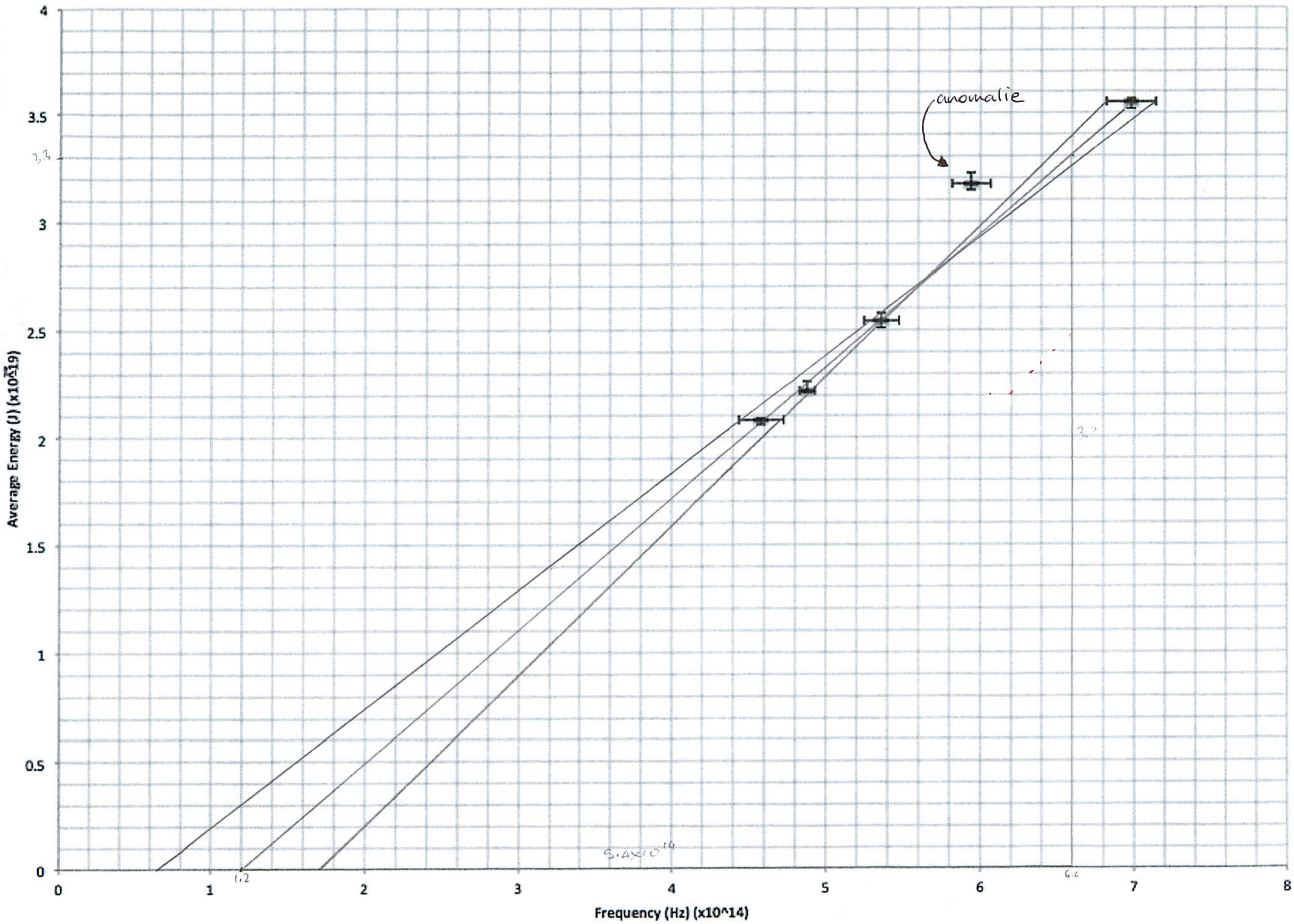
60 / 2 = 30 nm. Therefore: 30 / 655 = 0.4580 x 100 = 4.58 % = 5 % uncertainty.

Wavelength (nm)	Spread (nm)	Percentage uncertainty (%)
430	± 20	5
505	± 20	4
560	± 20	4
615	± 10	2
655	± 30	5

The reason why the spread and the percentage uncertainty is only to 1 significant figure and no decimal places is in order to ensure that the uncertainty is larger enough to be able to ensure that it contains the actual value of the Planck's constant.

Method of calculations/values obtained

The way all the values where calculated on my processed data was by using the following formulas:
- For the frequency I used the formula Frequency = F = C / λ = **$(3x10^{8}\ ms^{-1})$ / (λ),** where the necessary values have to be plugged in which lets it end up like in this example where a wavelength of 430 nm was used:
$(3x10^{8}\ ms^{-1}) / (430x10^{-9}m) = 6.98x10^{14}Hz$
- The energy a photon was provided by one electron $E_{average}$ = **E = QV,** where **Q**= the elementary charge of $1.6x10^{-19}$ C, when the values are used accordingly turns into: $1.6x10^{-19}$ x $V_{average}$ (which is composed of the averages of each according voltage for each wavelength.) in the example shown a average voltage of 3.55 V was used:
$(1.6x10^{-19}) x 2.22 = 3.55x10^{-19}$ J
- E_{min} and E_{max} are calculated in the same way from the highest and lowest values of voltages from the three repeats made.



Average Energy (J) (x10^-19)
Frequency (Hz) (x10^14)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
7
8
anomalie
3.3
1.2
6.6
5.4x10^14

Frequency (Hz)	λ (nm)	AvV (V)	AvE ($x10^{-19}$) (J)	E_{min} ($x10^{-19}$) (J)	E_{max} ($x10^{-19}$) (J)
$6.98*10^{14}$	430	2.22	3.55	3.52	3.57
$5.94*10^{14}$	505	1.98	3.17	3.14	3.22
$5.36*10^{14}$	560	1.59	2.54	2.51	2.58
$4.88*10^{14}$	615	1.40	2.22	2.21	2.26
$4.58*10^{14}$	655	1.30	2.08	2.06	2.09

Analysis of Graph

The graph that is most applicable in this investigation is the graph involving the average energy on the Y-axis and the frequency on the x-axis. The gradient of the trend line of this graph is the estimate of my Planck's constant and through we can state the investigation as valid or not. Deducing from the formula used for this investigation:

E (J) = h x f

I was able to spot that the results themselves weren't the problem as a value that was very close to the accepted one was calculated. This means that the gradient of the graph a good estimate, however there is a systematic error due to the fact that there is a negative y-intercept, whereas instead in the line should be passing through the origin. It could also mean that the voltage was actually higher than the recorded voltage, if this would be the case, the line would be shifted to the left, causing it to get closer to going through the origin. The systematic error can be clearly spotted as the frequency at = energy is 1.5 *10^14, which doesn't make any sense.

I calculated three gradients, the maximum, minimum and the average. This would allow me to see whether the values including the uncertainties supported the hypothesis that the gradient of the graph will equal the Planck's constant.

Rise / run = gradient

Average gradient: (3.3 x 10^-19) / (5.4 x 10^14) = 6.1 x 10^-34
Maximum gradient: (3.2 x 10^-19) / (4.6 x 10^14) = 6.96 x 10^-34
Minimum gradient: (1.1 x 10^-19) / (2.0 x 10^14) = 5.5 x 10^-34

Half of the range between the maximum and minimum gradient is the spread. This can be used to obtain an uncertainty value for the average gradient in order to find out whether the actual value for Planck's constant is involved in the gradient of any gradient possible between the error bars.

Spread = Range / 2

Maximum gradient - minimum gradient = 6.96 x 10^-34 - 5.5 x 10^-34 = 1.46 x 10^-34

Spread = 1.46 x 10^-34 / 2 = 7.3 x 10^-35

Adding this onto the average gradient gives us the best approximation to the actual Plank's constant:

6.1 x 10^-34 + 7.3 x 10^-35 = 6.83 x 10^-34 J s

Conclusion and Evaluation:

Conclusion:

- The relationship between the two variables is as follow, the frequency increase directly proportional with the photon energy, however in the case of my graph it doesn't go through the origin, which is a systematic error, as with no frequency there would be no energy, and vice versa.
- The systematic uncertainty is displayed strongly. The line should be passing through the origin, so that the values are directly proportional to each other, but in the case of my graph it doesn't, cause the line has a negative y-intercept which leads to the conclusion that there is a systematic uncertainty, either in the frequency, or in the energy causing the line to be shifted to the left. The x-intercept, and also systematic error for the average line is 1.2 x 10^14 Hz whereas for the maximum gradient line it is 1.7 x 10^14 and 0.65 x 10^14. This shows that even when using the minimum gradient the systematic uncertainty is too high, causing the line not to go through the origin.
- There is an anomaly at (5.94,3.17). This anomaly defines itself due to the fact that it doesn't seem to be in line with the other recorded values. The most likely reason for this is that the voltage was read off after photons where emitted. Although this was also the case for the other wavelength the possibility that it was more extreme for this case present as the light emitted would be blue green, which is not as easily visible as other more contrasting colors. The reason why the systematic error is most likely to due the voltage reading is because the Energy of the wave is made up of; Q x V where, Q is the constant of elementary charge, and V the voltage.
- The accepted value of the Planck's constant is; $6.626\text{x}10^{-34}$ Joules. The closest approximation calculated in my experiment is; $6.83\text{x}10^{-34}$ joules. This leads to the conclusion that the voltage recorded for each wavelength was slightly too high, and in the case of the anomaly it was significantly too high.
- The LED needs different amounts of voltage and therefore energy to emit photons of different wavelengths. In the case of this investigation, the LED with the smallest wavelength, 430 nm, needed the most voltage across, and the LED with the largest wavelength, 655 nm, needed the smallest voltage across it. This leads to the

conclusion that wavelength and voltage needed to light the bulb up are inversely proportional.

Evaluation:

- The procedure used in the investigation was sufficient. The main problem that caused a systematic error was that one couldn't exactly see when the first photon of light at any particular wavelength was emitted. The error was dealt with as soon as the data was plotted on the graph.
- The voltage recorded was accurate to ±0.01 V, even considering that the main problem in the investigation was the voltage reading. The three repeats of the voltage all move within ± 0.04 V of each other, which let to believe that the readings taken had a systematic error in them, and the uncertainties weren't made up of random anomalies during result taking. The weakness, of not being able to see the LED's smallest unit of glow is a systematic error as it runs throughout the whole experiment and effects every result taken and calculated.
- The maximum and minimum gradient of the graph let to believe that the accepted result was within the uncertainties and consideration of the anomaly at (5.94,3.17).
- The fact that all the repeats taken where within ± 0.04 V of each other shows that the repeats where not the main reason as to why there was a systematic error. So there was no weakness of time, as I believe that no matter how many repeats one would have done the voltage recorded would have been in a very small spread. The reason for this is that the one wasn't able to see exactly when the first photon was emitted meaning that the voltage recorded would always be higher.
- The limiting factor caused by the equipment used was the most significant one. As stated above the main limiting factor to more accurate results was the lack of recognizing the first photons of light emitted. A light meter would improve the quality and accuracy of the experiment very significantly.

Improvements:

This type of investigation could have been slightly improved by increasing the number of repeats, as then the random anomalies of the raw data would get cancelled out in the average. However if the error is systematic the average of many repeats wouldn't cause it to move any closer to the origin cause the problem is represented in every measurement. Measuring the amount of light given off by the bulb at any given voltage, with an apparatus that is more precise than the human eye, would be rather helpful, as it would push the trend line more towards the origin, due to the increase in preciseness. Increasing the number of repeats would minimize the random uncertainties of the investigation, and using a more precise light detector would possibly even be able to fully cancel out the systematic error, which would lead to the Planck's constant calculated to be even closer to the accepted value.