

PHY 153 Final Project

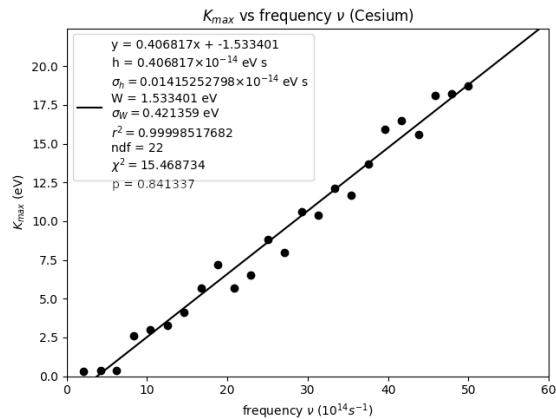
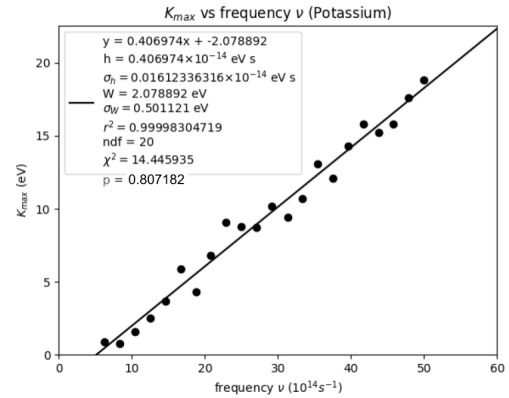
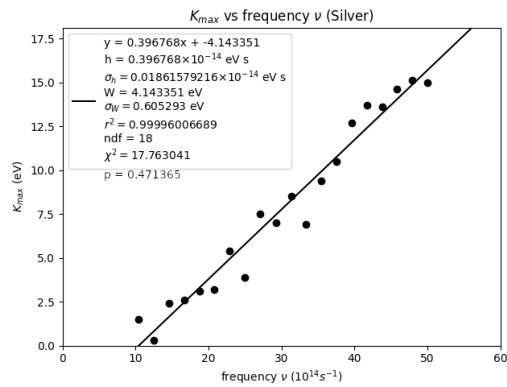
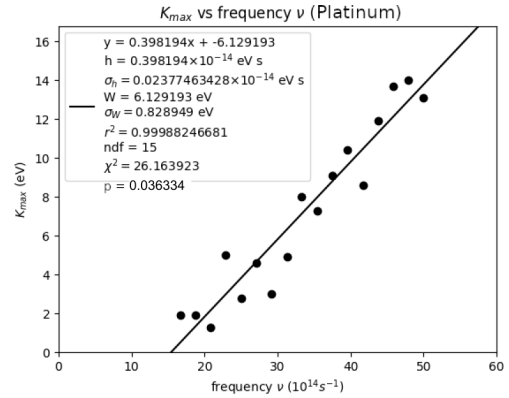
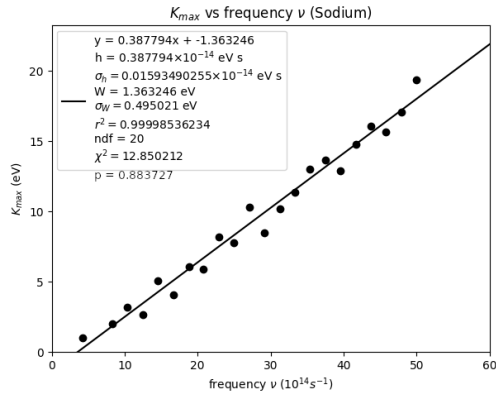
Henry Shi

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1 Part 1: Linear fit and evaluating W

- K_{max} vs frequency ν plots

(p-values are calculated from <https://www.socscistatistics.com/pvalues/chidistribution.aspx>)



Metal	W (eV)	σ_W (eV)	W_{true} (eV)	h (eV s)	σ_h (eV s)	χ^2
Sodium (Na)	1.363246	0.495021	2.3	0.387794×10^{-14}	0.015935×10^{-14}	12.850212
Platinum (Pt)	6.129193	0.828949	6.4	0.398194×10^{-14}	0.023775×10^{-14}	26.163923
Silver (Ag)	4.143351	0.605293	4.7	0.396768×10^{-14}	0.018616×10^{-14}	17.763041
Potassium (K)	2.078892	0.501121	2.2	0.406974×10^{-14}	0.016123×10^{-14}	14.445935
Cesium (Cs)	1.533401	0.421359	1.9	0.406817×10^{-14}	0.014153×10^{-14}	15.468734

Table 1: For the work functions W and their uncertainties σ_W , and for the Planck's constant h and its uncertainty σ_h , I used the linear regression models in the program “kmax-vs-nu-linreg.py” and its forks. For the p-value, I calculated it from the online calculator <https://www.socscistatistics.com/pvalues/normaldistribution.aspx>, with the f-value input as the “z-score” and the two-tailed hypothesis option. Significance level is $\alpha = 0.5$.

- Comparing W values

- For sodium, I obtained a work function of $W_{exp} = 1.373246 \pm 0.495021$ eV, and its actual work function is $W_{true} = 2.3$ eV. Its f-value is therefore

$$\begin{aligned}
 f &= \frac{W_{exp} - W_{true}}{\sigma_{W_{exp}}^2 + \sigma_{W_{true}}^2} \\
 &= \frac{1.363246 - 2.3}{0.495021^2 + 0^2} \\
 &= -3.822771,
 \end{aligned}$$

which corresponds to a p-value of 0.000132. With a significance level of $\alpha = 0.05$, we have $p < \alpha$, so my work function for sodium is **not** in agreement with the actual work function.

- For platinum, I obtained a work function of $W_{exp} = 6.129193 \pm 0.828949$ eV, and its actual work function is $W_{true} = 6.4$ eV. Its f-value is therefore

$$\begin{aligned}
 f &= \frac{W_{exp} - W_{true}}{\sigma_{W_{exp}}^2 + \sigma_{W_{true}}^2} \\
 &= \frac{6.129193 - 6.4}{0.828949^2 + 0^2} \\
 &= -0.394098,
 \end{aligned}$$

which corresponds to a p-value of 0.693581. With a significance level of $\alpha = 0.05$, we have $p > \alpha$, so my work function for platinum is in agreement with the actual work function.

- For silver, I obtained a work function of $W_{exp} = 4.143351 \pm 0.605293$ eV, and its actual work function is $W_{true} = 4.7$ eV. Its f-value is therefore

$$\begin{aligned}
 f &= \frac{W_{exp} - W_{true}}{\sigma_{W_{exp}}^2 + \sigma_{W_{true}}^2} \\
 &= \frac{4.143351 - 4.7}{0.605293^2 + 0^2} \\
 &= -1.519323,
 \end{aligned}$$

which corresponds to a p-value of 0.128762. With a significance level of $\alpha = 0.05$, we have $p > \alpha$, so my work function for silver is in agreement with the actual work function.

- For potassium, I obtained a work function of $W_{exp} = 2.078892 \pm 0.501121$ eV, and its actual work function is $W_{true} = 2.2$ eV. Its f-value is therefore

$$\begin{aligned}
 f &= \frac{W_{exp} - W_{true}}{\sigma_{W_{exp}}^2 + \sigma_{W_{true}}^2} \\
 &= \frac{2.078892 - 2.2}{0.501121^2 + 0^2} \\
 &= -0.482267,
 \end{aligned}$$

which corresponds to a p-value of 0.629806. With a significance level of $\alpha = 0.05$, we have $p > \alpha$, so my work function for potassium is in agreement with the actual work function.

- For cesium, I obtained a work function of $W_{exp} = 1.533401 \pm 0.421359$ eV, and its actual work function is $W_{true} = 1.9$ eV. Its f-value is therefore

$$\begin{aligned} f &= \frac{W_{exp} - W_{true}}{\sigma_{W_{exp}}^2 + \sigma_{W_{true}}^2} \\ &= \frac{1.533401 - 1.9}{0.421359^2 + 0^2} \\ &= -2.064842, \end{aligned}$$

which corresponds to a p-value of .038923. With a significance level of $\alpha = 0.05$, we have $p < \alpha$, so my work function for cesium is **not** in agreement with the actual work function.

Metal	W (eV)	σ_W (eV)	W_{true}	f-statistic	p-value	In agreement?
Sodium (Na)	1.363246	0.495021	2.3	-3.822771	0.000132	No
Platinum (Pt)	6.129193	0.828949	6.4	-0.394098	0.693581	Yes
Silver (Ag)	4.143351	0.605293	4.7	-1.519323	0.128762	Yes
Potassium (K)	2.078892	0.501121	2.2	-0.482267	0.629806	Yes
Cesium (Cs)	1.533401	0.421359	1.9	-2.064842	0.038923	No

2 Calculating and evaluating Planck's constant h

Metal	h (eV)	σ_h (eV)
Sodium (Na)	0.387794×10^{-14}	0.015935×10^{-14}
Platinum (Pt)	0.398194×10^{-14}	0.023775×10^{-14}
Silver (Ag)	0.396768×10^{-14}	0.018616×10^{-14}
Potassium (K)	0.406974×10^{-14}	0.016123×10^{-14}
Cesium (Cs)	0.406817×10^{-14}	0.014153×10^{-14}

We calculate the best value of Planck's constant, h_{best} , using the program h-calc.py. The program uses the following formula:

$$\begin{aligned} h &= \frac{\sum_{i=1}^N \left(\frac{h_i}{\sigma_{h_i}^2} \right)}{\sum_{i=1}^N \left(\frac{1}{\sigma_{h_i}^2} \right)} \\ h &= 0.400016 \times 10^{-14} \text{ eV s} \end{aligned}$$

We calculate the variance of the best value using h-calc.py, using the following formula:

$$\begin{aligned} \sigma_h &= \frac{1}{\sum_{i=1}^N \left(\frac{1}{\sigma_{h_i}^2} \right)} \\ \sigma_h &= 0.007574 \times 10^{-14} \text{ eV s} \end{aligned}$$

Therefore, our best value of h is:

$$h_{best} = (0.4000155025 \pm 0.0075740073) \times 10^{-14} \text{ eV s}$$

With a true value Planck's constant of $h_{true} = 0.4135667696 \times 10^{-14}$ eV s, we calculate f:

$$f = \frac{h_{best} - h_{true}}{\sigma_{h_{best}}^2 + \sigma_{h_{true}}^2}$$

$$f = \frac{0.4000155025 - 0.4135667696}{0.0075740073^2 + 0^2}$$

$$f = -236.226$$

Using the calculator www.socscistatistics.com/pvalues/normaldistribution.aspx, we obtain a p-value of approximately 0. At an $\alpha = 0.05$ significance level, we have $p < \alpha$, so our value of Planck's constant h_{best} does not agree with the true value h_{true} .

h_{best} (eV s)	$\sigma_{h_{best}}$ (eV s)	h_{true} (eV s)	f-statistic	p-value
0.4000155025	0.0075740073	0.4135667696	-236.226	0

3 Conclusion

3.1 K_{max} vs ν linear regression

- Overall, every metal's K_{max} vs ν plot has a linear model that is a good fit. Sodium has $p=0.884$, platinum has $p=0.036$, silver has $p=0.471$, potassium has $p=0.807$, cesium has $p=0.841$. At a significance level of $\alpha = 0.05$, platinum has $p < \alpha$ and thus its linear model is not a good fit for data. The other metals all have $p > \alpha$ and hence their linear models are a good fit for their data.

3.2 W

- For the metals sodium and cesium, the calculated value of work function W does not agree with the true value of work function W_{true} . Sodium has an f-statistic of -3.822771 and cesium has an f-statistic of -2.064842, indicating that both metals' work functions are lower than their true values. Sodium has a p-value of 0.000132 and cesium has a p-value of 0.038923, both of which are less than the $\alpha = 0.05$ significance level. This lack of agreement in results may be due to physical properties of the metal making it difficult to measure the maximum kinetic energy K_{max} of the ejected electrons, as sodium and cesium are both Group I metals. The lone valence electron is ejected easily, leading to a large uncertainty in the maximum kinetic energy of the ejected electron. It is also possible that the measuring instrument was calibrated incorrectly for sodium and cesium, leading to measured K_{max} values that were systematically too low.
- For the metals platinum, silver, and potassium, W agrees with W_{true} . Platinum has an f-statistic of -0.394098 and a p-value of 0.693581, silver has an f-statistic of -1.519323 and a p-value of 0.128762, potassium has an f-statistic of -0.482267 and a p-value of 0.038923. All p-values are less than the significance level of $\alpha = 0.05$.
- All f-statistics were negative, indicating that our measured work functions W were systematically lower than the actual work functions. However, this experiment did not account for energy lost as the ejected electron hit the detector device. It is also possible that the detector was calibrated so that it made measurements lower than their actual values.
- In future experiments, I will collect more points for each metal to reduce random error in the calculation of W and h from the linear regression. I will also make sure the device is calibrated correctly, and I will try to use a device that does not lose as much energy when making measurements.

3.3 h

- Our calculated value of Planck's constant h_{best} does not agree with the true value of Planck's constant h_{true} . h_{best} has a very low f-statistic of -236.226 and a p-value very close to 0. In other words, our calculated value of Planck's constant is systematically too low. This may be due to systematic error in

our measured K_{max} values; the K_{max} tend to be lower than their actual values, and the error scales up as K_{max} increases. For each metal plot, this would result in a slope and hence h that is too low; averaged together, they would produce a h_{best} that is systematically lower than h_{true} .

In future experiments, I will collect more points for each metal to reduce random error in the calculation of W and h from the linear regression. I will also make sure the device is calibrated correctly, and I will try to use a device that does not lose as much energy when making measurements. That way, the K_{max} values are less likely to be systematically too low, and hence W and h calculations would be closer to their actual values.