Franck-Hertz Spectra

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1 Introduction

1.1 Purpose

Calculate the resonance potential of Neon in a neon filled Franck-Hertz tube from a plot of current vs accelerating potential created using the electron impact method. Observe quantized energy states. Calculate Planck's constant and determine the threshold frequency of two metals, sodium and zinc, using PhET online simulation.

1.2 References

Kash. M.M.; Shields. G.C. Using the Franck-Hertz Experiment To Illustrate Quantization: Energy States of the Neon Atom by Electron Impact *Journal of Chemical Education* **1994** *71*(6) pp 466-468

McQuarrie, D. A.; Simon, J. D. *Physical Chemistry: A Molecular Approach*; University Science Books: Sausalito, CA, 1997.

Ashika; Threshold Frequency. *SaveMyExams* 25 December 2024. https://www.savemyexams.com/a-level/physics/cie/25/revision-notes/22-quantum-physics/22-2-photoelectric-effect/threshold-frequency/

Wiser, D.; *Atomic Line Spectra*; Lake Forest College: Lake Forest, IL, 2020; pp 1-2.

Photoelectric Effect Ver. 1.10.00 PhET Interactice Simulations: University of Colorado 2013. https://phet.colorado.edu/sims/cheerpj/photoelectric/latest/ photoelectric.html

1.3 Safety Information

There are no safety risks associated with this experiment.

2 Methods

Materials for the Franck-Hertz experiment included a 3B Franck-Hertz Operating Unit (Model 1012818), a Fluke 75 multimeter used to measure the current, a Fluke 75 multimeter used to measure the voltage, and a 3B Franck-Hertz-Tube with Neon gas (Model 1000912) (Fig. 1). The operating unit used the ramp modus with $U_{a_{\min}}$ set to 0 V, U_F set to 6.1 V, U_E set to 8.3 V, $U_{a_{\max}}$ set to 63.5 V, and U_G set to 8.9 V.

The operating unit was used to slowly increase the voltage supplied to the tube and the values of voltage (X) and current (Y) were read from the multimeters.

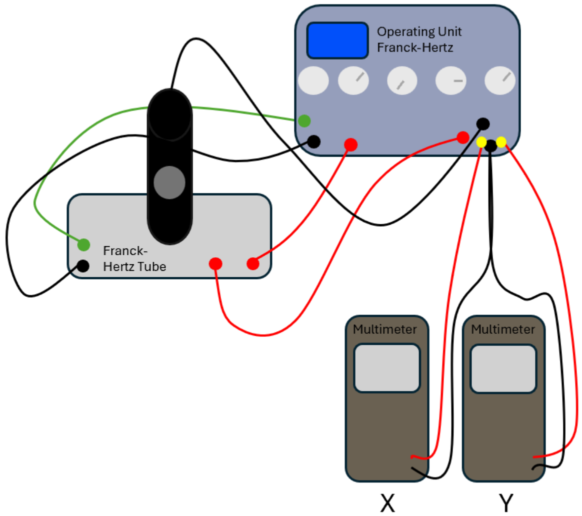

Figure 1: Cartoon depiction of setup for Franck-Hertz experiment with operating unit, multimeters, Franck-Hertz tube, and the wires that connected the devices.

The photoelectric effect was simulated using the PhET Interactive Simulations photoelectric effect simulator version 1.10. Sodium and Zinc acted as targets. The simulation graphed electron energy vs light frequency for a light with wavelengths ranging from 100 nm to 850 nm at 100% intensity (Fig. 2). Values along various points of the graph where selected and Planck's constant (h) was calculated from the slope of the line past the threshold frequency ($\tilde{v}_o$).

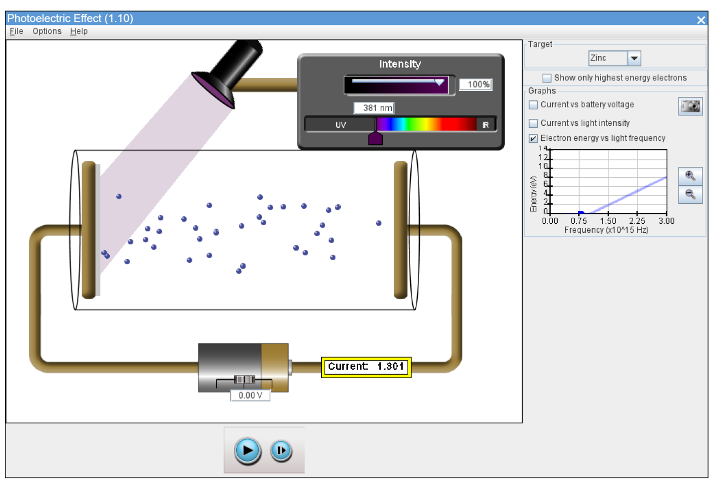

Figure 2: Snapshot of PhET simulation of the photoelectric effect with Zinc as the target of a light emitting a wavelength of 381 nm with 100% intensity.

3 Results/Data

3.1 Franck Hertz Experiment

The Franck Hertz experiment was conducted two times. For both trials, three current peaks were observed (Fig. 3). The first peak was observed around 18.5 A, the second around 37 A, and the third around 57.5 A. A pale orange light was observed in the tube after the first peak. After the second peak, an additional orange band of light was observed.

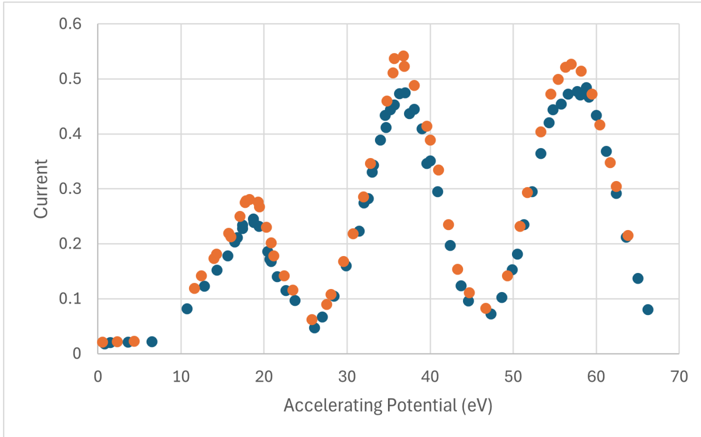

Figure 3: Graph of current vs accelerating potential of Franck Hertz Experiment. THe first trail is plotted in blue and the second trail is plotted in orange.

The calculated wavelength produced by the neon was in agreement for both trials (Table 1), with a percent difference of 0.7%. The calculated wavelength, of around 64 nm, was in the UV light region and did not account for the visible orange light that was observed.

Table 1: Observed maxes and calculated resoanace potential and wavelength from two trials of the Franck Hertz experiment.

Measurement	**Trial 1**	**Trial 2**
Max 1 (eV)	18.7	18.27
Max 2 (eV)	37.0	36.8
Max 3 (eV)	57.7	57
Resonance Potential 1 (eV)	18.3	18.5
Resonance Potential 2 (eV)	20.7	20.2
Mean Resonance Potential (eV)	19.5	19.4
Wavelength (nm)	63.6	64.1

Kash and Shields 1994 suggested three allowed energy transitions in neon that would produce visible orange light (Fig. 4). They suggest that the relaxation from $2p_1$ to ground state happens in a stepwise fashion. This suggestion explained the calculated UV wavelength and the observed orange light however it was not possible for us to determine which exact transition is responsible for the orange light. This would require further investigation.

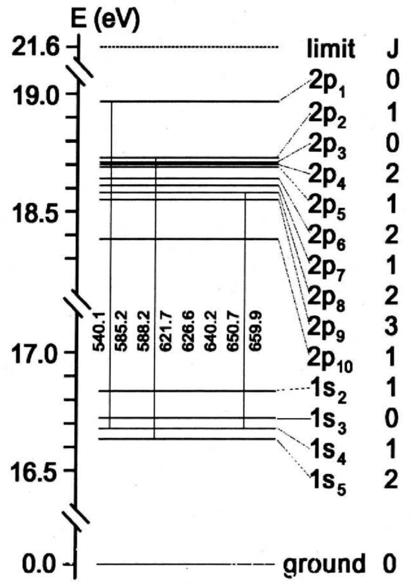

Figure 4: Energy transitions in neon that result in visible orange light taken from Kash and Shields 1994.

3.2 Photoelectric Effect

Under the threshold frequency no particles were animated as emitting from the target. Sodium produced a max current around 1.728 A while it was hit with a wavelength of 196 nm and zinc produced a max of 1.315 A at 149 nm. The most particles were visible at these wavelengths. The energy continued increasing even as the current decreased. The energy increased linearly after the threshold frequency. Below the threshold frequency there was no energy. Six data points were recorded from the PhET graph and the slope and x-intercept was calculated (Fig. 5).

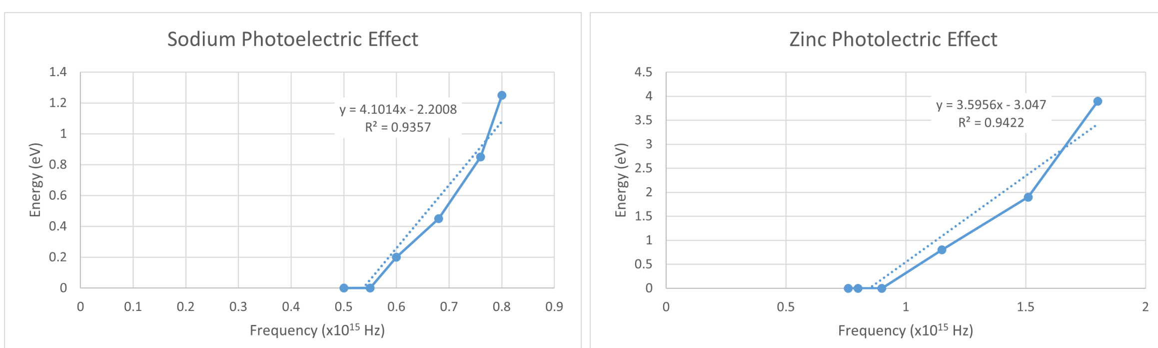

Figure 5: Graphs of energy vs frequency from data collected from PhET photoelectric effect simulation.

The slope of the line was adjusted to be in units of $J \cdot s$ and was compared the accepted value for Planck's constant, $6.626 \times 10^{-34} J \cdot s$. The x-intercept was calculated and compared to literature values from Ashika 2024 (Table 2). The error in the experimental values was partially due to difficulty reading the PhET simulation graph.

Table 2: Comparison between experimental values of Planck's constant and the threshold frequencies and their literature values from Ashika 2024.

	Calc. Planck's Constant	**% Error**	**Measured $\tilde{v}_o$**	$\tilde{v}_o$	% Error
Sodium	$6.57 \times 10^{-34} J \cdot s$	0.8	0.537×10^{15}	0.440×10^{15}	22
Zinc	$5.76 \times 10^{-34} J \cdot s$	13.1	0.847×10^{15}	1.02×10^{15}	17

4 Conclusion

We can only report on what we have evidence of and we have nothing to determine which of the energy transitions led to the visible orange light. The combination of UV and visible results suggests that relaxation is happening in a stepwise fashion however we are unable to determine which exact step is responsible for the visible orange light as there are multiple transitions that provide that result. The Franck Hertz tube contains multiple neon atoms so it is possible that more than one transition was happening.

Planck's constant was able to be calculated based on the slope of the line from the photoelectric effect after the threshold frequency. This measurement came with some degree of error. Part of that error may have been from difficulty reading the graph on the PhET simulator website.