# Franck-Hertz Experiment
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Abstract: This experiment observed that the electrons of Mercury reach excited states at intervals close to expected value of 4.9eV. The experiment was done at two temperature ranges at T between 187.2 - 200.0 degrees, averaged to 193.6 degrees, and T between 218.5-230.3 degrees which was averaged to 224.4 degrees. The separation distance between voltage minimums we're respectively calculated to be 4.833V with an error of +/- 0.118V and +/- 4.833V with an error 0.312V. The respective chi-square values for both data sets were evaluated at approximately 3 which agrees with the number of degrees of freedom of the N-1 where N is the number of troughs/minimums. There were 4 maximums and minimums found in this experiment.

**Usage:** Informational Purpose

## I. INTRODUCTION

James Franck and Gustav Hertz developed an experiment that would set out to prove that the excited states in Mercury atoms were discretely quantized which would accurately reflect Bohr's proposed model of atoms[1]. Electrons occupy orbits of varying energy levels and requires that for the molecule to move to a higher orbital it will need to acquire enough energy to become excited to move to the next state. The calculated energy that needed to be added to each electron to occupy higher energy levels was in multiples of 4.9eV.

The Franck-Hertz experiment uses an oven and a filament to emit and vaporize Mercury atoms that frees electrons by surpassing the work function. Then the electrons are accelerated by the positively charged grid. The negatively charged collecting plate will collect electrons that exceed the needed energy threshold to reach it.

## II. MEASUREMENTS AND PROCEDURES

The oven in this experiment frequently cycled when set to a temperature indicator on the apparatus and varied by about 13 degrees Celsius. Taking this into consideration the oven was set to two temperature ranges of 187.2C-200.0C and 218.5C-230.3C. The experiment was then conducted treating the the range of temperatures an average of the two respective of temperatures at 193.6C and 224.4C. The filament was provided with a 6.0V, the grid was made to be positively charged with 1.5V and the collector was negatively charged. A voltmeter was connected with this setup in order to measure the drops in voltage across the collector as the voltage was increased by a separate power supply that was taken in intervals of 0.5V from 0.0V to 35.5V. The collected data was originally measured in milliVolts so that the current could be calculated due to the voltmeter's internal resistor that has a resistance of 10 mega ohms.

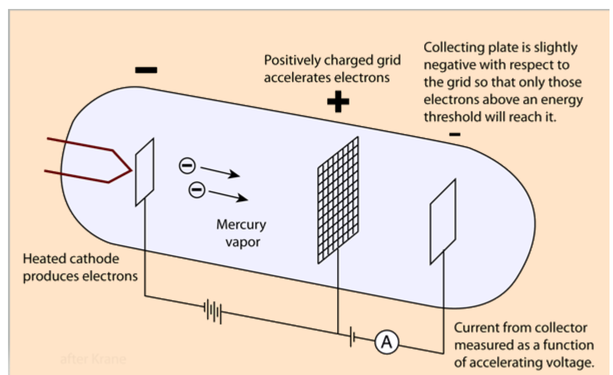



Fig 1: Circuit set up of Apparatus[1]

After data collection was complete, the data was then plotted and then ranges fitted to a quadratic which would allow for a smoother fit to measure the separation distance between all minimum values of each quadratic polynomial. Then a linear regression could be done to find the slope of the data which resulted in representing the accelerating voltage for each data set and providing a determinant value for each set.

$$V(voltage) = IR(1)$$

$$I(current) = \frac{V}{R}(2)$$

$$V_{diff} = V_{min_b} - V_{min_a}(3)$$

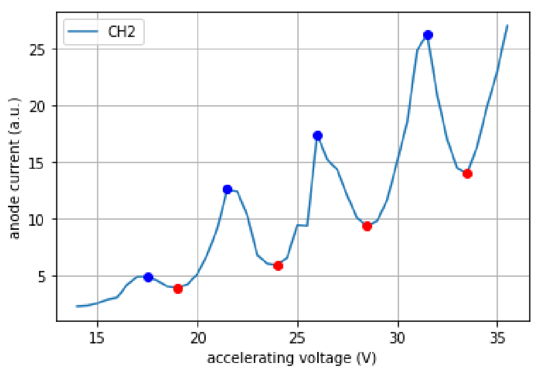
$$V_{Avg} = \Sigma\frac{V_{diff}}{N_{V diff}}(4)$$

* Franck-Hertz Experiment

Using equation 1 to rearrange to solve for the current in equation 2 we are able to take the data we collected from the voltmeter that measured the voltage output on the collector and the impedance of the voltmeter of 10 mega ohms and calculate the current.

## III. DATA ANALYSIS

Fig 2: 193.6C



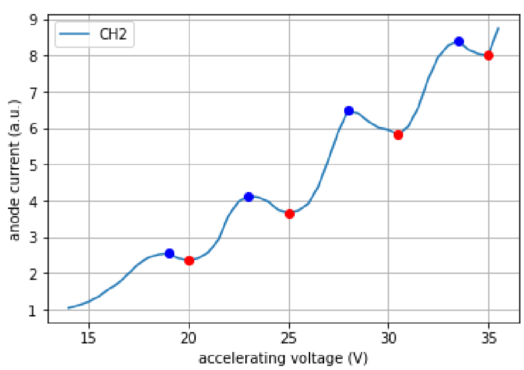




Fig 3: 224C

In Fig(2), [Vmin=(19V, 24V, 28.5V, 33.5V); Vmax=(17.5V, 21.5V, 26V, 31.5V)] . In Fig(3), [Vmin= (20V, 25V, 30.5V, 35V). Vmax=(19V, 23V, 28V, 33.5V)]. Using scipy's signal find function allows for the minimums and maximums to be found. This data is the raw data set plotted before it is fit to a quadratic. By quadratically fitting the data set it is easier to get less erratic lines and makes it easier to smooth out the plot in order to do a quadratic analysis between the regions that resemble a parabolic shape. This can be seen between the peaks of 24V and 28.5V.

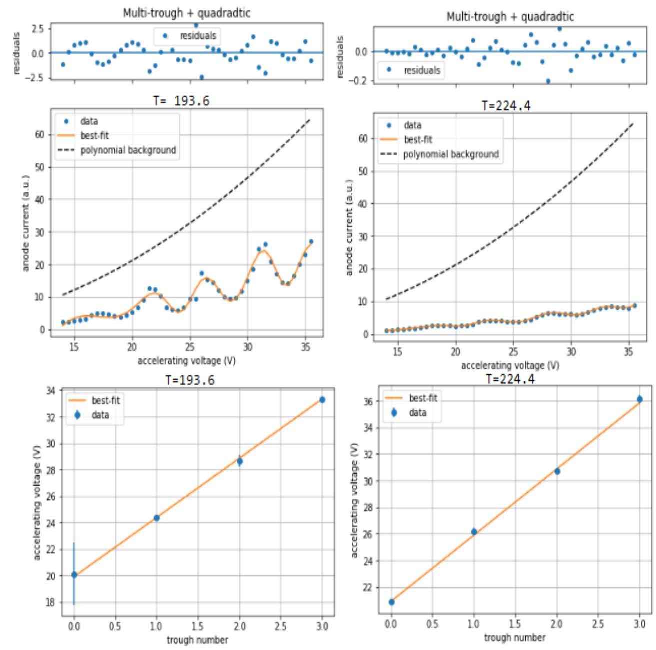



Fig 4: Quadratic Fit

By using lmfit the data is able to be fitted quadratically, create a linear regression, and create a residual plot. By fitting the data quadratically both Fig(2) and Fig(3) become less erratic and plotted smoothly which will allow us to see if the distance of separation between minimums is the same. The residual plot here shows by how much the minimums stray from the fit line. The data fits quite reasonably on the line of best fit and shows that there is a strong relationship between the minimums. The slope of the residual plot is fitted at 4.8V +/- 0.07V for T=193.6C and 4.966V +/- 0.09V. The slope here is the indicator that is being looked for as it describes the the relationship between all of the minimums and how the distance of separation between them is roughly the same.

| T1 Range | T=187-200 | | T2 Range | 218.5-230.3 | |
|---|---|---|---|---|---|
| Tavg | 193.6 | | Tavg | 224.4 | |
| Data(N) | 72 | | Data(N) | 72 | |
| Peak Avg | 4.667V | +/-0.312V | Peak Avg | 4.833 | +/-0.312V |
| Trough Av | 4.833V | +/-0.118V | Trough Av | 5 | +/-0.204 |
| Trough χ2 | 3.00232 | | Trough χ2 | 3.009 | |
| Reduce χ2 | 1.501 | | Reduce χ2 | 1.504 | |
| Slope Fit | 4.8 | +/-0.07 | Slope Fit | 4.966 | +/-0.09 |

Table 1: Statistical Measures

Overall, there were 72 Data points taken for each individual temperature range. In Table 1 the trough average is calculated using eq(4) which averages all of the differences of minimums using eq(2). At T = 193.6 the minimums averaged to 4.833V with an error of +/- 0.118V. At T = 224.4 the minimums averaged to 5.0 with an error of +/- 0.204V. After doing the quadratic fit a chi-square test was done for all of the minimums and was found to be calculated at roughly 3.0 which confirms that our data fits within our quadratic curve fit. The slope fit taken from the linear regression after doing the quadratic fit roughly agrees with the data analysis done before the quadratic fit. These values are within reason of the expected value of 4.9V found in the original Franck-Hertz experiment.

## IV. CONCLUSION

After concluding the data analysis, the statistical measures confirm with rough estimation that the excitation levels of Mercury differ by about 4.9eV. This experiment is extremely sensitive to fluctuations in temperature and strongly recommended to attempt to fit the data to quadratically in order to properly calculate the minimums of each valley of the measurements. Overall, this shows that the atomic levels of Mercury are quantized and the electrons occupy discrete energy levels at multiples of 4.9eV.

[1] R. Nave *:hyperphysics.phy-astr.gsu.edu/hbase/FrHz.html. Date Accessed: 10/28/2021*