Lab 3: Franck Hertz Experiment

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I. INTRODUCTION

With the original experiment being performed in 1914 by J. Franck and G. Hertz, the quantized absorption of energy by atoms is experimentally verified. Multiple methods are used, and comparisons of results are discussed in terms of both accuracy and precision.

II. EXPERIMENTAL METHODS

A similar method is applied to both mercury and neon vacuum tubes. An accelerating potential difference is applied to these tubes, going from 0 to -70 Volts for neon and 0 to -40 Volts for mercury. In addition to this potential that varies with time, a static retarding potential is applied between the anode and grid, preventing slower electrons from reaching the anode, enhancing minima and maxima contrast as measured by the electron current through the vacuum tubes. This small static retarding potential is 1.5 Volts for both neon and mercury tubes.

The current through the vacuum tubes is recorded onto paper, which was then digitized through the digitize2() function in MATLAB. A lock-in amp is used to also record the derivative of the current signal, allowing for easier analysis of minor inflections in the current signal, and was also digitized for further analysis. The digitized data for mercury can be seen in figure 1.

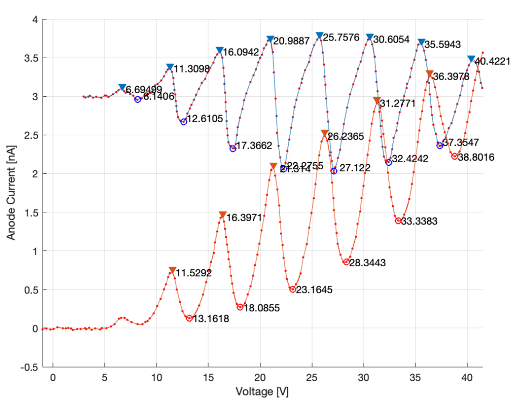

FIG. 1. Digitized Raw Hg Data

Peaks were found in MATLAB, however the peak and trough points were ensured to be manually sampled from the scanned raw data graph, allowing for an estimated close to no increase in uncertainty compared to if digitization had not occurred, and instead points were manually read from the raw graphs.

The locations of these peaks and troughs were then plotted by their peak/trough number, and both straight and 2nd order polynomials fitted through to give a value for average peak spacing. This can be seen in figure 2 for a linear fit which will have its parameters utilized for the average trough spacing method, and in figure 3 for a 2nd order polynomial fit.

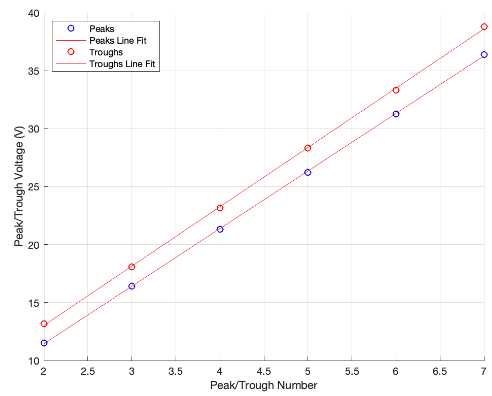

FIG. 2. Peak/Trough Location Linear Fit

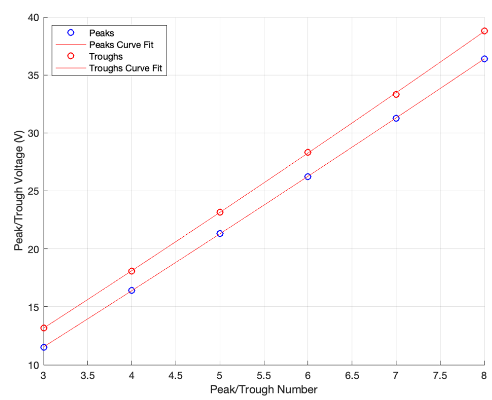

FIG. 3. Peak/Trough Location Polynomial Fit

The peak/trough differences were also plotted, and a linear line fit through them in an alternate method of analysis. This can be seen in figure **??**, which has its paramteres utilized for the Rapoir-Sengstock-Baev (RSB) method.

Finally, for cursory analysis, the small peaks in the lock-in amplifier traces were used to investigate neon state differences.

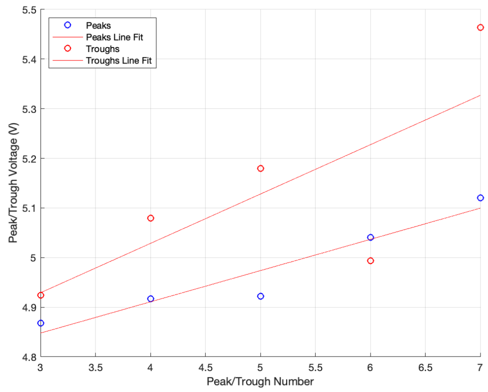

FIG. 4. Peak/Trough Location Linear Fit

III. RESULTS

For the first excited state of mercury, the RSB method experimentally provides a value of $4.7 \pm 0.8eV$, and the average trough spacing method provides a value of $5.1 \pm 0.1eV$. Accepted literature values for mercury are $4.64eV$ and $4.65 \pm 0.03eV$ from the RSB paper, which are included within calculated uncertainties of the experimentally confirmed value from the RSB method, but not the average trough spacing method.

For the first excited state of Neon, the RSB method provides a value of $17.1eV$ and the average trough spacing method provides a value of $18.3 \pm 0.2eV$. Accepted literature values for neon are $16.7eV$ and $16.5 \pm 0.2eV$ from the RSB paper, which are somewhat close to experimentally confirmed values.

IV. DISCUSSION OF METHODS

A. Experimental Uncertainties

It was determined that the statistical uncertainty provided by the fit parameters dwarfs any uncertainty that may arise from the digitization or initial reading of the paper plot processes. This, in combination with only having one trial of data, has led to the determination of propagating only the most significant source of uncertainty (statistical fit uncertainty) forwards. However, this leads to certain cases where an insufficient number of data points are had to give an uncertainty in fit parameters. This was considered, however due to not having a reasonable method of estimating random experimental uncertainties, the lack of uncertainty in certain final values experimentally obtained is noted but kept.

B. Statistical Uncertainties

1. Insufficient Data Case

Due to the RSB method requiring data from a plot of peak/trough differences rather than purely peak/trough positions, this means that the data set would be reduced from having n data points to $n-1$ for the RSB method. In the case of Neon, for example, this would reduce the number of points from three to two, leading to a zero statistical uncertainty, due to a linear line being able to fit two points with zero statistical uncertainty.

Further experimentation, perhaps with multiple trials for example, providing for more data points would alleviate and prevent this outlier, 'insufficient data' case from occurring.

2. Comparison of RSB and average trough spacing methods

It can be seen that the RSB method provides a larger uncertainty in results, due to the spread of the data points being larger in percentage from the fit line, as well as errors being propagated in the RSB method's math.

However, this method appears to give more accurate results for both mercury and neon, likely due to it accounting for the "extra" distance travelled by the electrons.

For mercury, the RSB method is off by +1.293% while the average trough spacing method is off by +9.914%. For neon, the RSB method is off by +2.395% and the average trough spacing method is off by +9.581%

V. OBSERVATION OF LIGHT

As one goes from very low Voltage to increasingly high Voltages, one observes the formation of bands of light between the grids. This is as expected with electron-atom interactions in this experiment. As one starts from low Voltages, where electrons and atoms act elastically with each other, a point is reached where the Voltage is high enough (exact values as previously discussed) to allow for inelastic collisions. This creates a point of light which originally starts right in front of the grid, and as one increases the Voltage one will observe an increasing number of these points of light due to these inelastic collisions, with the whole group of bands of light moving uniformly away from the grid and towards the cathode.

These inelastic collisions create this light as the electron is absorbed, and its energy later released in the form of light with a particular wavelength.

VI. LOCK-IN AMPLIFIERS

lock-in amplifier essentially allows for one to measure a single-frequency signal that would normally be hard to measure due to noise. It does this by exploiting the orthogonality of sinusoidal functions. In particular if a function of frequency f_s is multiplied by some other frequency that's not equal to f_s, which may be called fr, these can be integrated over some time that's much longer than the period of the two individual frequencies, the result is zero. This "time that's much longer than the period of the two" is generally from a few milliseconds to a few seconds. For most applications using lock in amps, the signal and reference frequency would be the same, so $f_s - f_r = 0$, or a DC signal. Once this process is finished, the two remaining peaks can be separated with a low pass filter, leaving us with the signal frequency which we originally wanted to measure.

For this experiment in particular, the lock-in amp is used to produce a graph of the derivative of the anode current. The amp gives an output of

$$V_{out} \approx \frac{A}{\sqrt{2}} \frac{dV}{ds}|_{\bar{s}}$$

where s is some input which experimenters have control over, and $\bar{s}$ is an average value at the reference frequency which the input is varying sinusoidally around.

Thus, one can use the lock-in amp to give information about the derivative of the input. The output is proportional to the modulation amplitude A, as well as the derivative of the system's response to our input evaluated at $\bar{s}$. The output generated has been utilized in this experiment in particular for more accurate measurement in inflection points which may otherwise have gone unseen, or have had larger uncertainties in position. These inflection points were then noted as corresponding to certain state transitions of electrons, and would not have been able be measured as effectively without such a lock-in amplifier.