Franck-Hertz Experiment

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***Abstract*—In this experiment, we excite atomic electrons of mercury gas by sending it energetic electrons. By applying voltage difference, we detect the current as a result of that excitation so that we can measure the sudden decrease in current which is due to the quantized energy level of the atom. We performed an experiment for 10 sets of data and got their weighted averages and found that the first excitation energy is 5.03838±0.0875944 eV.**

I. Theory

Before Franck-Hertz experiment, Bohr model was already a thing which is a precursor to quantum mechanics because of the quantized energy levels mentioned in the model. Hydrogen atom of Bohr's can have electron which occupies only some certain levels. Therefore, this experiment comes as a something to prove what is already claimed by other physicist: quantum mechanics. In 1914, the paper is presented to German Physical Society by James Franck and Gustavo Hertz, which gave their name to the experiment and got a noble prize for it in 1925. They designed a vacuum tube for studying energetic electrons that will collide with vapory of mercury atoms and excite them. Their observation was that only some certain amount of energy is absorbed so the quantum mechanical nature of the atoms is shown and transformed the understanding of the world completely. [1]

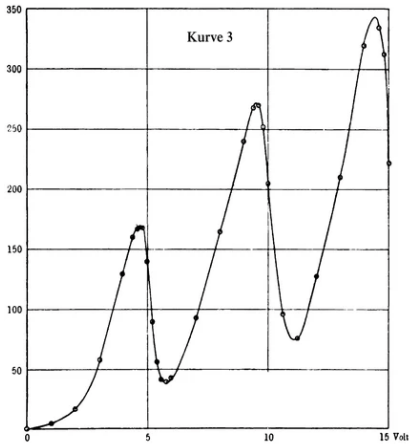


Fig. 1. Franck and Hertz's 1914 graph of current vs. accelerating voltage for slow electrons in mercury vapor [2]

Energy levels of an orbit can only be well-defined by certain discrete energies called E_n.

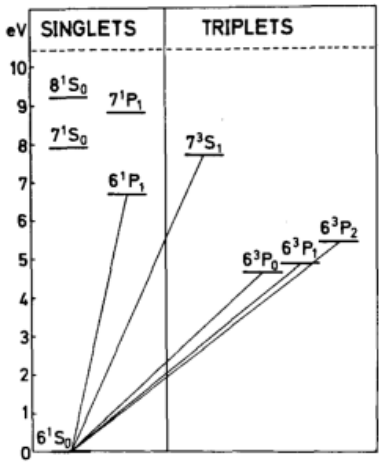


Fig. 2. the first excited states of the mercury atom [3]

$$E_n - E_m = hv = \frac{hc}{\lambda} \tag{1}$$

Electrons emit radiation not in the ground state but when they got excited and moves to a state which has higher binding energy. If we put the numerical values then:

$$E = \frac{6.6310^{-34}(Js).2.99810^{8}(\frac{m}{s})}{253710^{-10}(m).1.60210^{-10}(C)} = 4.89eV \tag{2}$$

Franck and Hertz observed a line in the spectrum of the target gas at 2537 A. This line corresponds to the first maximum in the current vs accelerating voltage of Franck-Hertz's and to the state 6^3P_1[3]

II. Method

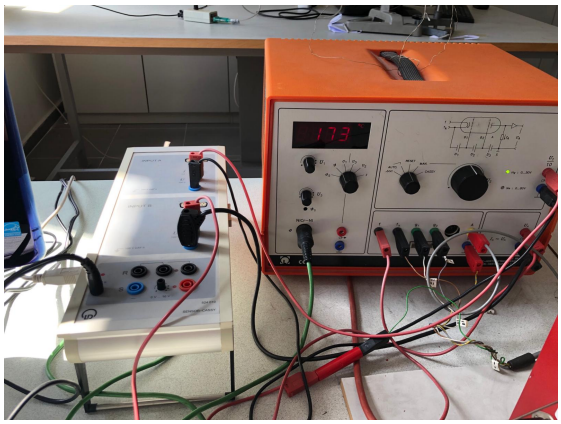
Energetic electrons have electromagnetic interaction with atomic electrons and results in excited atomic electrons. Although the deexcitation of those can also be seen by their emmited light in an environment which is carefully designed, rather we detected the number of electrons passing through the region by measuring the current as a function of accelerating field.[4]

1) Turn on the temperature tube so it heats
2) Turn on the filament power supply
3) Turn on the current amplifier
4) Take the data of the current versus U2İ accelerating voltage, by using the application in our computer

III. The Experimental Setup

Here's our setup:

Fig. 3. Franck-Hertz tube



- Franck-Hertz tube
- Electric owen with the special copper tube and the power supply
- Temperature probe with display
- Two multimeters
- Current amplifier
- Moving coil DC voltmeter(0-30V and 0-60V at least)
- AC filament power supply
- 1.5 V battery with a battery holder

IV. The Data

Since there is a huge number of dataset for each U1,U3 and T values, it is impossible to give all the exact values in tables, so I give them in U2 vs I graphs.

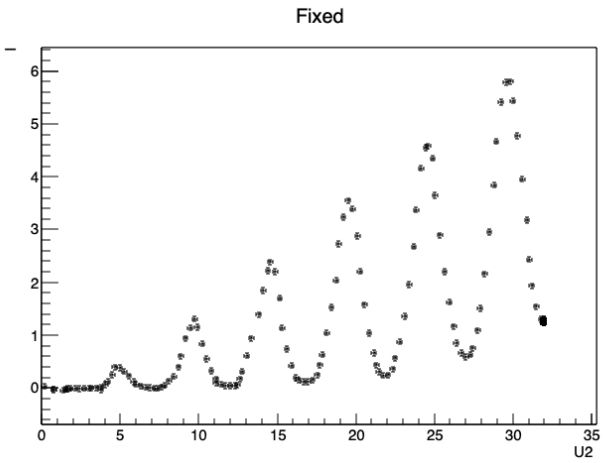


Fig. 4. U1 = 1.67V, U3= 2.34 V, T=180C

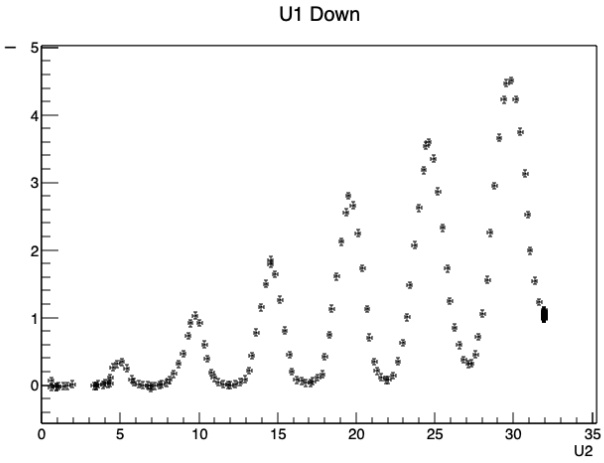


Fig. 5. U1 = 1.59V, U3= 2.34 V, T=180C

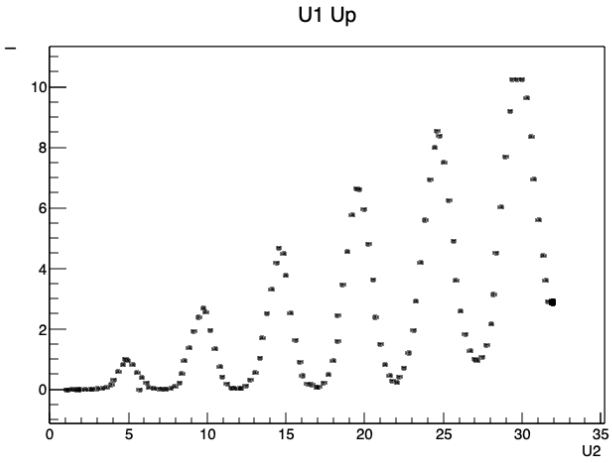


Fig. 6. U1 = 1.74V, U3= 2.34 V, T=180C

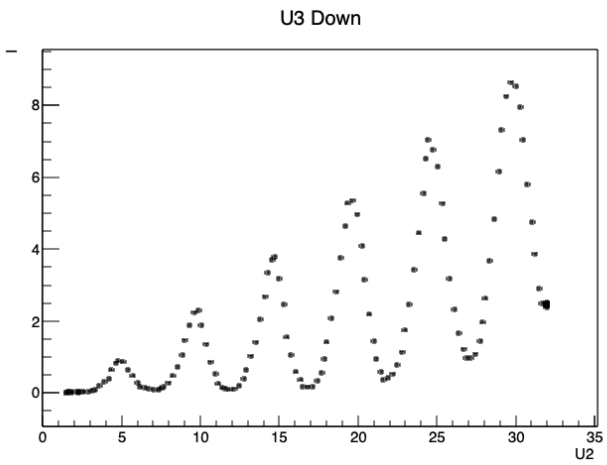


Fig. 7. U1 = 1.67V, U3= 2.17 V, T=180C

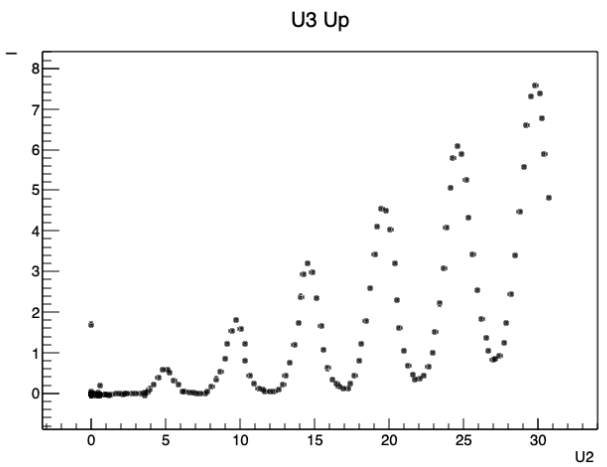


Fig. 8. U1 = 1.67V, U3= 2.39 V, T=180C

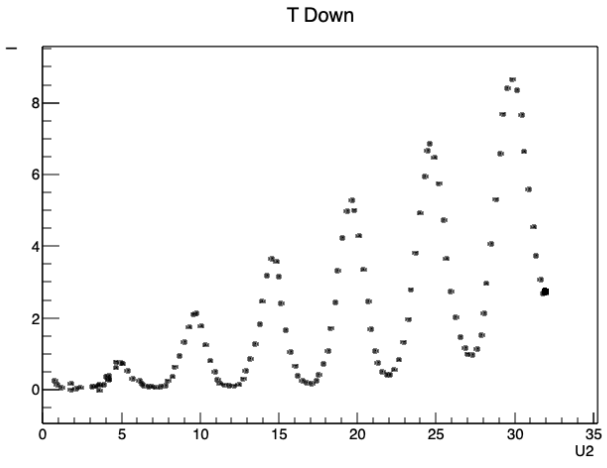


Fig. 9. U1 = 1.67V, U3= 2.34 V, T=172C

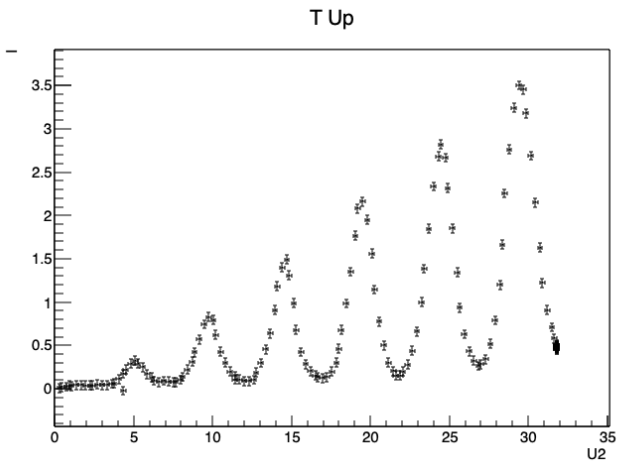


Fig. 10. U1 = 1.67V, U3= 2.34 V, T=191C

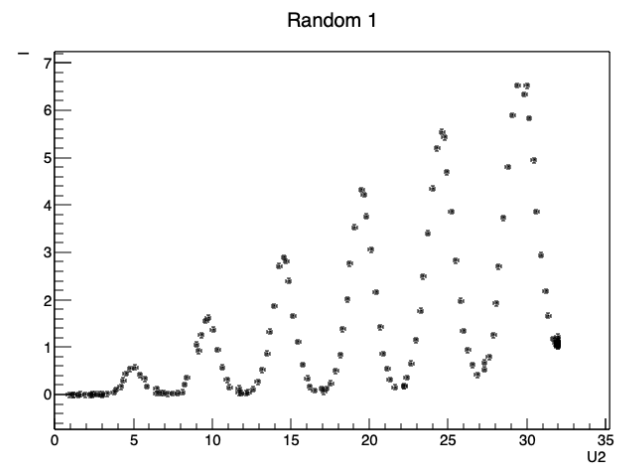


Fig. 11. U1 = 1.74V, U3= 2.34 V, T=187C

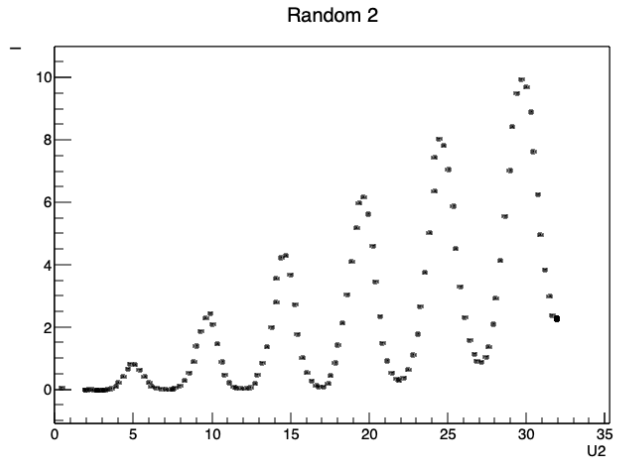


Fig. 12. U1 = 1.74V, U3= 2.30 V, T=182C

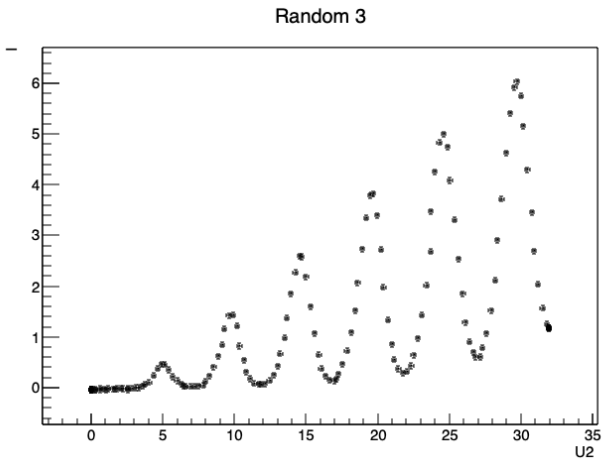


Fig. 13. U1 = 1.65V, U3= 2.13 V, T=179C

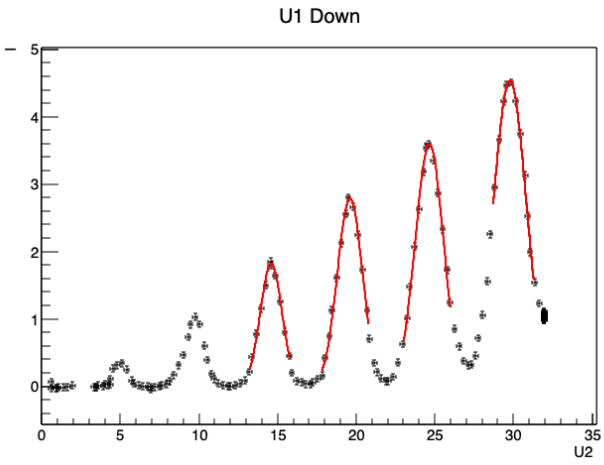


Fig. 15. Gaussian fit for U1 = 1.59V, U3= 2.34 V, T=180C

V. The Analysis

In the U2 vs I graphs, I applied a gaussian fit for the peaks via root in a small range around each peak. If one wants to be exact, it should be a polynomial fit actually. On the other hand, due to the fact that gaussian fit is easy to be applied by using root and it really converges to a polynomial fit provided that the range is small. Here are the gaussian fits for each data set:

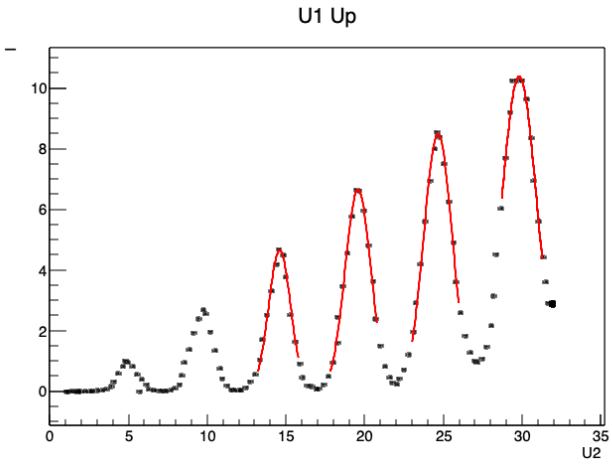


Fig. 16. Gaussian fit for U1 = 1.74V, U3= 2.34 V, T=180C

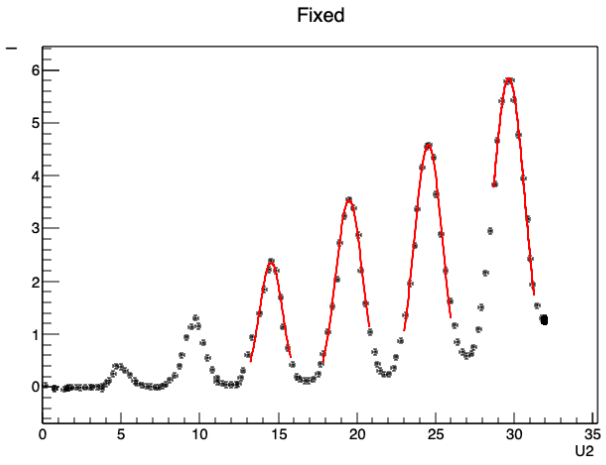


Fig. 14. Gaussian fit for U1 = 1.67V, U3= 2.34 V, T=180C

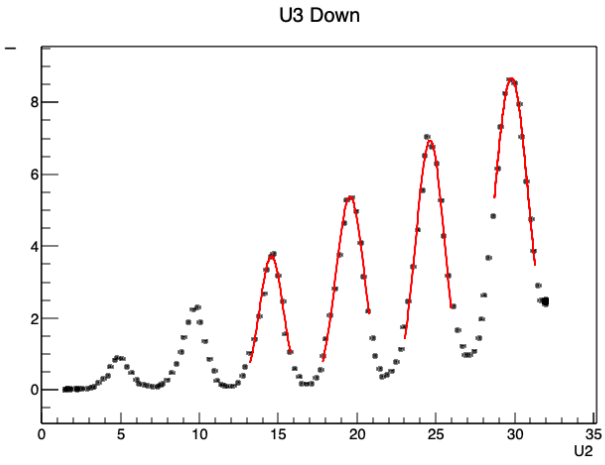


Fig. 17. Gaussian fit for U1 = 1.67V, U3= 2.17 V, T=180C

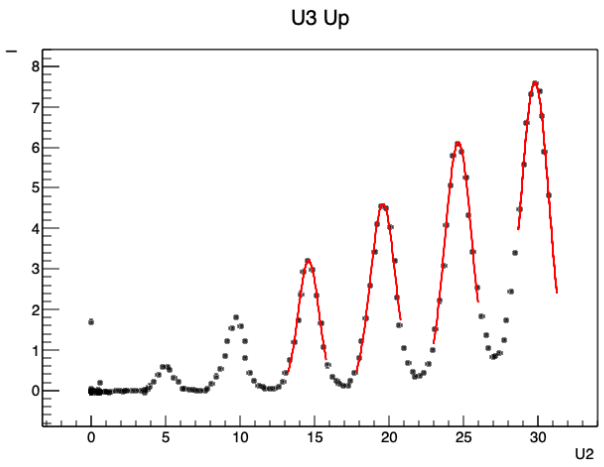


Fig. 18. Gaussian fit for U1 = 1.67V, U3= 2.39 V, T=180C

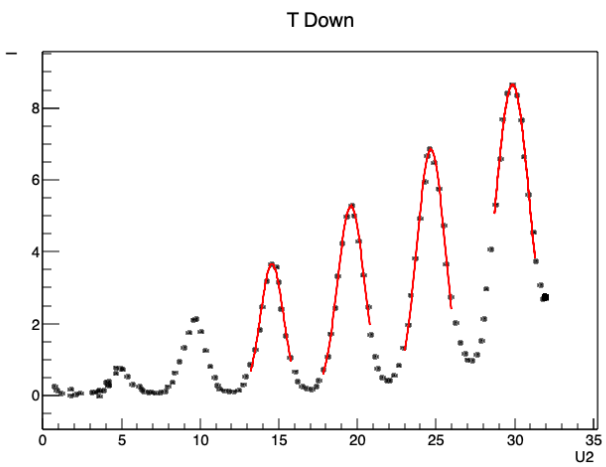


Fig. 19. Gaussian fit for U1 = 1.67V, U3= 2.34 V, T=172C

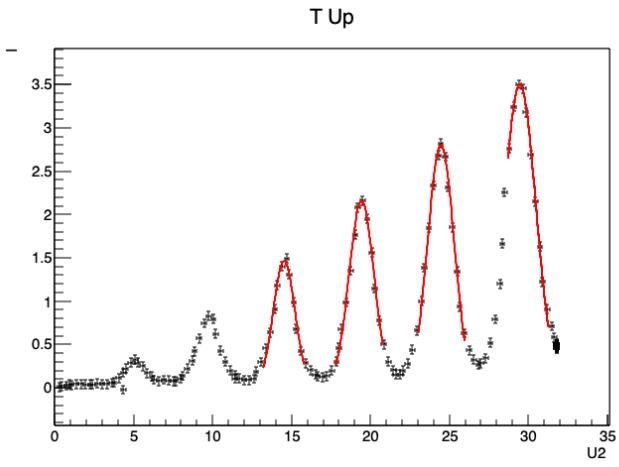


Fig. 20. Gaussian fit for U1 = 1.67V, U3= 2.34 V, T=191C

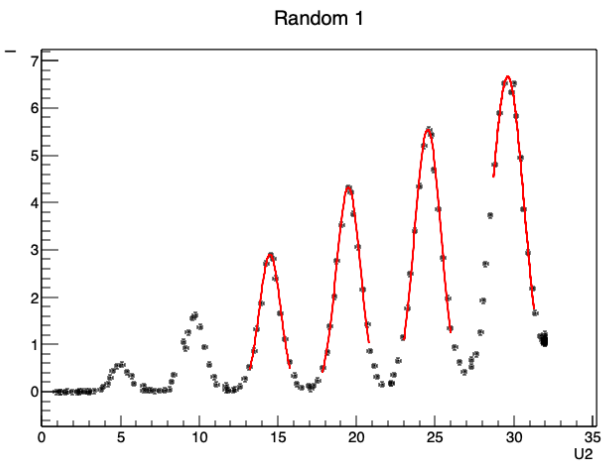


Fig. 21. Gaussian fit for U1 = 1.74V, U3= 2.34 V, T=187C

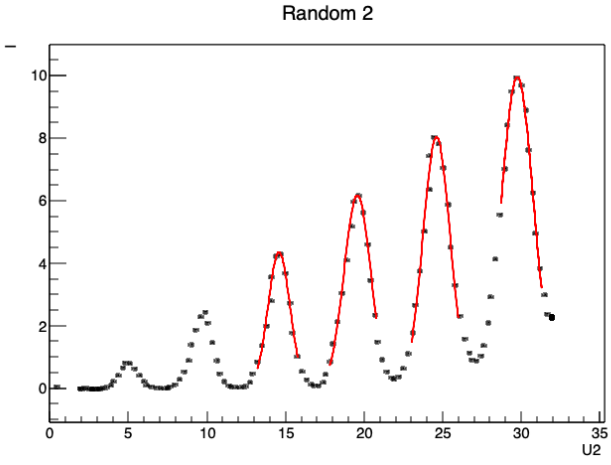


Fig. 22. Gaussian fit for U1 = 1.74V, U3= 2.30 V, T=182C

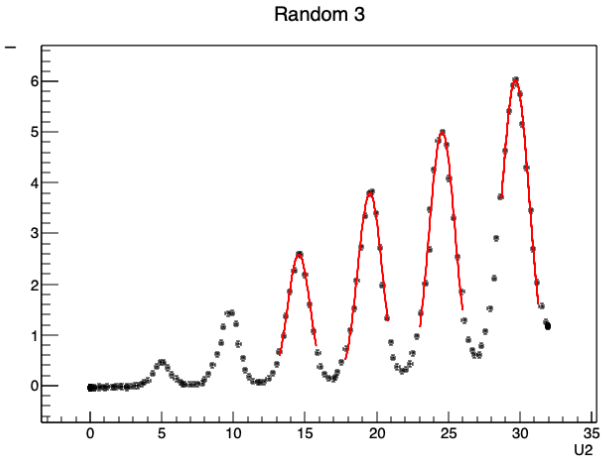


Fig. 23. Gaussian fit for U1 = 1.65V, U3= 2.13 V, T=179C

Here is the table of 10 first excitation level each one is obtained by calculating the weighted averages of 4 different peak values and their corresponding sigma values

TABLE I
TIME TABLE FOR 3.0 KV AND 2 SQUEEZES

Weighted average Δ E's
5.048133 ± 1.2410975
5.0622 ± 1.21960525
5.071667 ± 1.26795
5.075133 ± 1.2918825
5.069867 ± 1.217415
5.0978 ± 1.2745825
4.9797 ± 1.1823875
5.0354 ± 1.18132
5.055267 ± 1.232815
5.039867 ± 1.1803455

Finally, ı put all 30 peak differences to a histogram by using root and apply a gaussian fit them to get the final result of our experiment.

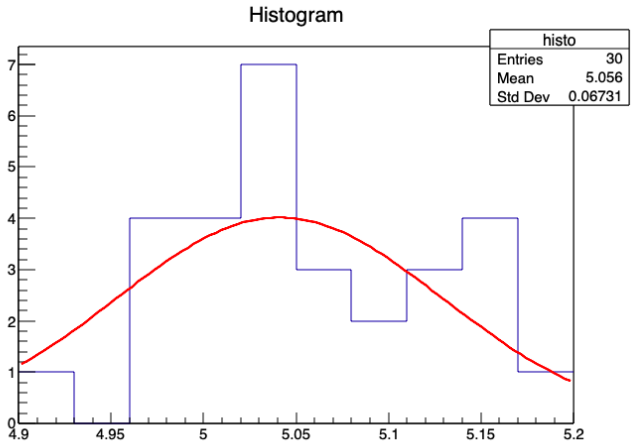


Fig. 24. Histogram for 30 peak values and gaussian fit

VI. THE RESULT

After using root's built-in function to plot an histogram and gaussian for 30 different peaks, the final result is 5.03838±0.0875944 eV.

VII. THE CONCLUSION

We first tried to find U1,U3, and T values such that gives a smooth graph of current versus accelerating voltage. After that, we made one of those variables a little bit higher and lower while taking other those two values fixed. By doing so we tried to check if there is a correlation between the excitation levels and those variables. Furthermorei we add three more measurements which is completely random so that we can ensure that if there is a correlation or not. At the end of the day our data suggested us that the peak differences are indifferent to the changes we made to the initial values. Although the final result is slightly higher than the theoretical difference, it seems like our experiment seems to be get a satisfactory result. Keeping in mind also that our apparatus is not free of errors, that is it is not perfect obviously, we got reasonably close first excitation level of the mercury.

VIII. ACKNOWLEDGEMENT

REFERENCES

[1] *FH wikipedi*. URL: https://en.wikipedia.org/wiki/Franck%E2%80%93Hertz_experiment#:~:text=The%20Franck%E2%80%93Hertz%20experiment%20was,James%20Franck%20and%20Gustav%20Hertz. (visited on 04/27/2024).

[2] *graph*. URL: https://link.springer.com/article/10.1007/s00016-014-0139-3/figures/9 (visited on 04/27/2024).

[3] *mercury*. URL: https://n.ethz.ch/~marnikm/files/franckHertz.pdf (visited on 04/27/2024).

[4] E. Gülmez. *Advanced Physics Experiments*. 1st. Boğaziçi University Publications, 1999.

IX. APPENDIX

I was not able to plot the histogram in the same file so I plotted histogram and the gauss fit which gave the final result of the experiment in a different file. That's why there is two pieces of code.

```
{

   std::vector<std::string> filenames = {
      "fixed.txt",
      "u1down.txt",
      "u1up.txt",
      "u3down.txt",
      "u3up.txt",
      "tdown.txt",
      "tup.txt",
      "random1.txt",
      "random2.txt",
      "random3.txt",


    };

    std::vector<std::string> titles = {
      "Fixed",
      "U1 Down",
      "U1 Up",
      "U3 Down",
      "U3 Up",
      "T Down",
      "T Up",
      "Random 1",
      "Random 2",
      "Random 3"
   };

   std::vector<std::vector<double>> peakRanges
       = {
      {13.2,15.8}, {17.8, 20.8},{23,
          26},{28.7, 31.3},
      {12.8,15.8}, {18, 21},{22.3,
          25.8},{28.3, 31.7},
      {12.8,15.8}, {17.9, 20.9},{22.5,
          25.5},{27.3, 30.6},
      {13.8,16.8}, {18.2, 21.2},{22.3,
          25.3},{28, 31.8},
      {12.9,15.9}, {18, 21},{23, 26},{28.8,
          31.4},
      {13.3,16.3}, {18.2, 21.2},{22.7,
          25.7},{28.5, 31.4},
```

```
    {13.4,16.4}, {17.8, 20.8},{22.9,
        25.9},{28.2, 31.5},
    {13.2,16.2}, {18.1, 21.1},{23.3,
        26.3},{228.7, 31.6},
    {13.1,16.1}, {18.2, 21.2},{22.7,
        25.7},{28.4, 31.5},
    {13.1,16.2}, {18.1, 21.2},{23,
        26},{28.5, 31.5},



};

std::vector<double> peakValues;
std::vector<double> sigmaValues;
std::vector<double> peakSigmas;



 for (int i = 0; i < filenames.size(); ++i)
     {
    TGraphErrors *gr = new
        TGraphErrors(filenames[i].c_str());
    TCanvas *c = new TCanvas();
    gr->Draw("AP");
    gr->SetTitle((titles[i] + "; U2 ;
        I").c_str());

    for (int j = 0; j < 4; ++j) {
      TF1 *gauss = new
          TF1(Form("gauss_%d_%d", i, j),
          "gaus", peakRanges[j][0],
          peakRanges[j][1]);
      gr->Fit(gauss, "R");
      gauss->Draw("same");
      double peak = gauss->GetParameter(1);
      double sigma = gauss->GetParameter(2);
      cout << "graph "<< i << "'s " << j <<
          " peak is ="<< peak <<"and its
          sigma is="<< sigma << "\n";
      peakValues.push_back(peak);
      sigmaValues.push_back(sigma);

    }

     c->Draw();

float peakDifferences[30] = {4.9776,
    5.0419, 5.1249, 5.0140, 5.0480, 5.1246,
    4.9793, 5.0770, 5.1597,
4.9942, 5.0686, 5.1626, 4.9995, 5.0672,
    5.1429, 5.0213, 5.0847, 5.1874,
4.9057, 5.0261, 5.0073, 4.9834, 5.0416,
    5.0812, 4.9873, 5.0358, 5.1427,
4.9623, 5.0404, 5.1169};

}
  for (int m = 0; m < 40; ++m) {
    cout << "number" << m << "peak value
        is"<< peakValues[m] << "\n";

}
  for (int k = 0; k < 40; ++k) {
    if (k != 39 || k % 4 != 0){
      float first =
          sigmaValues[k]*sigmaValues[k];
      float second =
          sigmaValues[k+1]*sigmaValues[k+1];
      float result = sqrt(first + second);
      peakSigmas.push_back(result);

    }
    cout << "number" << k << "peak sigma
        value is"<< peakSigmas[k] << "\n";


}
  float peakDifferencesWeighted ={5.048133,
  5.0622,
  5.071667,
  5.075133,
  5.069867,
  5.0978,
  4.9797,
  5.0354,
  5.055267,
  5.039867}

  float sigmasWeighted = { 1.2410975,
  1.21960525,
  1.26795,
  1.2918825,
  1.217415,
  1.2745825,
  1.1823875,
  1.18132,
  1.232815,
  1.1803455
  }



}

{
 TF1 *gaus = new
     TF1("gauss","TMath::Gaus(x,15,1)",0,30);
 gauss->Draw();

 TH1F *histo = new
     TH1F("histo","Histogram",10, 4.9, 5.2);

 float data[30] = {4.9776, 5.0419, 5.1249,
     5.0140, 5.0480, 5.1246, 4.9793, 5.0770,
     5.1597,
   4.9942, 5.0686, 5.1626, 4.9995, 5.0672,
      5.1429, 5.0213, 5.0847, 5.1874,
   4.9057, 5.0261, 5.0073, 4.9834, 5.0416,
      5.0812, 4.9873, 5.0358, 5.1427,
   4.9623, 5.0404, 5.1169};
 for (int i=0; i<30; i++)
     histo->Fill(data[i]);
 histo->Draw();

 TF1 *gaussian = new TF1("gaussian", "gaus",
     4.9, 5.2);

 histo->Fit("gaussian", "R");
 gaussian->SetLineColor(kRed);
 gaussian->Draw("same");


 cout << "Fit parameters:" << endl;
```

```
  cout << "Mean: " <<
      gaussian->GetParameter(1) << endl;
  cout << "Standard deviation: " <<
      gaussian->GetParameter(2) << endl;
}
```