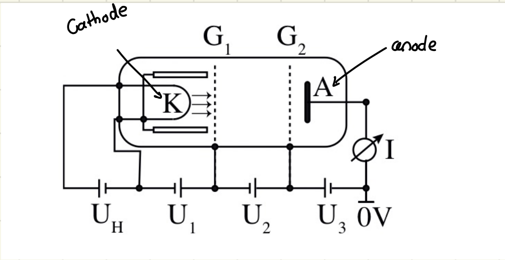
Day 1:

$d = 1cm$ for mercury.



Mercury.

- opened Franck Hertz Data logger.
- Target temperature of the Mercury sample - 145°C

Set U_1, U_3 = 1.50V

ran software → straight line.

±0.01V U_3 = 1.48 ± 0.01V

increased U_1 = 3 V, right shape but not many peaks before > Current=1   => U_2 Varying from 0-30V

decreased U_1 = 2.11V ← time step 30mV → data 1

Data 2: U_3 = 1.47 ± 0.01V

U_1 = 2.09 ± 0.01V

Data 3: U_3 = 1.53 ± 0.01V

U_1 = 1.94 ± 0.01V

4:

5:

Plotted varying U_2 0→30 against Current for each run (shown in figure 1)

Tried to find an average of data point and plot average values but voltage measurements didn't line up.

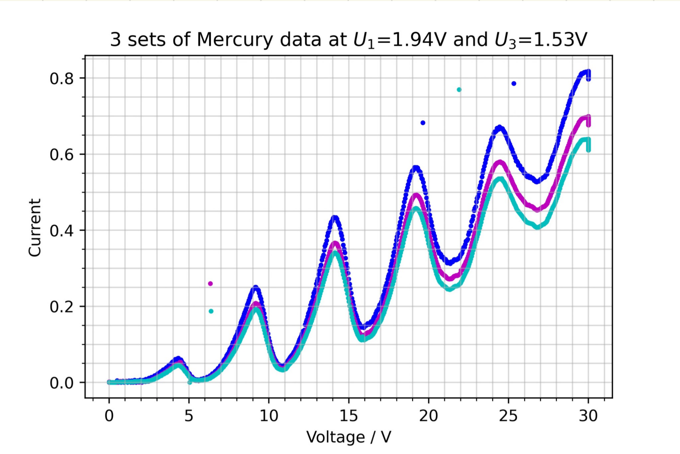
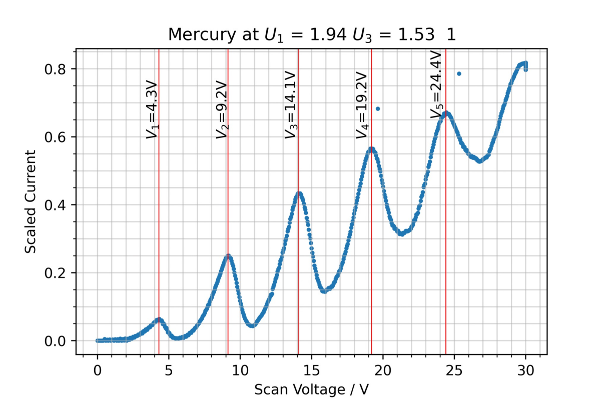


figure 1

Therefore, measured energy gap for each data set and averaged. figures (2, 3, 4)



Error on each reading was taken to be 1/10 of smallest increment on graph (0.1 V)

$\Delta V_{21} = V_2 - V_1 = 9.2 - 4.3 = \underline{4.9 \pm 0.1\,V}$

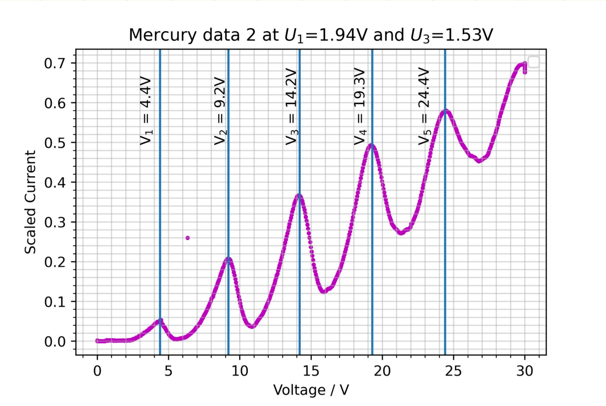
$\sigma_{V_{21}} = \sqrt{2} \times 0.1 = 0.14\,V$

↳ $\sigma_f^2 = \sigma_x^2 + \sigma_y^2$ for $f = x \pm y$

$\Delta V_{32} = V_3 - V_2 = \underline{4.9 \pm 0.1\,V}$

$\Delta V_{43} = \underline{5.1 \pm 0.1\,V}$

$\Delta V_{54} = \underline{5.2 \pm 0.1\,V}$

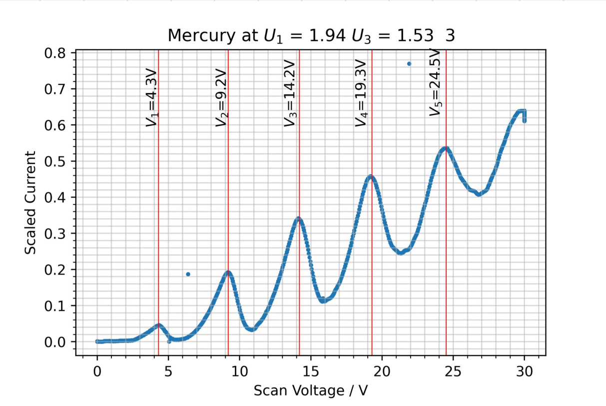


$\Delta V_{21} = 4.8 \pm 0.1\,V$

$\Delta V_{32} = 5.0 \pm 0.1\,V$

$\Delta V_{43} = 5.1 \pm 0.1\,V$

$\Delta V_{54} = 5.1 \pm 0.1\,V$



$\Delta V_{21} = 4.9 \pm 0.1\,V$

$\Delta V_{32} = 5.0 \pm 0.1\,V$

$\Delta V_{43} = 5.1 \pm 0.1\,V$

$\Delta V_{54} = 5.2 \pm 0.1\,V$

$\boxed{\text{Explain Graph in Theory}}$ ✓

Average:

$\bar{\Delta V} = 5.0$

$\sigma_{\Delta \bar{V}} = \Delta \bar{V} \sqrt{\sum_i \left(\frac{\sigma_{V_i}}{V_i}\right)^2} / \sqrt{N} = 0.1 \Rightarrow \left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2$ for $f = xy$

$\Delta \bar{V} = (5.0 \pm 0.1)\,V$

We then wrote code to fit parabolas to the data:

The data was split into seperate bins for data close to each maxima.
A second order polynomial was the fit to each of the 5 maxima.

$$y = ax^2 + bx + c$$

Each coefficient of this polynomial had its own error from the fit function. This was represented as a covariance matrix.

$$\begin{pmatrix} \sigma_{aa}^2 & \sigma_{ba}^2 & \sigma_{bc}^2 \\ \sigma_{ab}^2 & \sigma_{bb}^2 & \sigma_{bc}^2 \\ \sigma_{ac}^2 & \sigma_{bc}^2 & \sigma_{cc}^2 \end{pmatrix}$$

Therefore the squareroot of the diagonal gave the errors

The derivative of this equation would give the maxima when equated to 0.

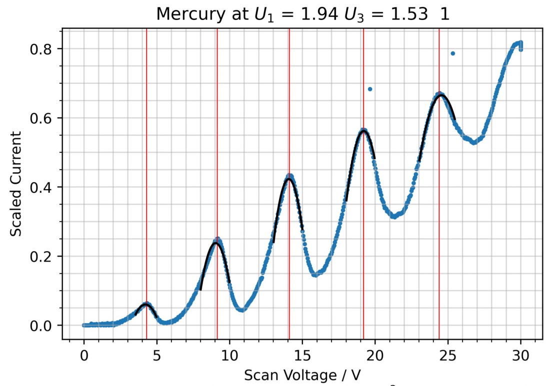
$$\frac{dy}{dx} = 0 = 2ax + b$$

$$x_{max} = \frac{-b}{2a}$$

With an error given by:

$$\sigma_{x_{max}} = x_{max}\sqrt{\left(\frac{\sigma_b}{b}\right)^2 + \left(\frac{\sigma_a}{a}\right)^2}$$

Therefore once repeated for each parabola, the differences between maxima were calculated with error



$V_1 = 4.21 \pm 0.03$ V
$V_2 = 9.04 \pm 0.11$ V
$V_3 = 14.06 \pm 0.15$ V
$V_4 = 19.21 \pm 0.52$ V
$V_5 = 24.55 \pm 0.39$ V

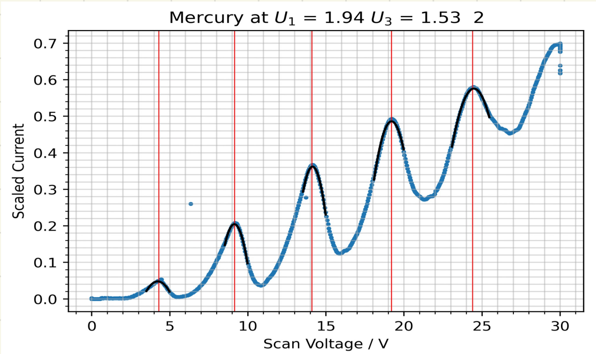
$y_1 = -0.06\,x^2 + 0.52\,x + -1.0445$
$y_2 = -0.13\,x^2 + 2.28\,x + -10.0675$
$y_3 = -0.17\,x^2 + 4.69\,x + -32.5845$
$y_4 = -0.14\,x^2 + 5.44\,x + -51.6891$
$y_5 = -0.08\,x^2 + 4.03\,x + -48.8238$

using $\sigma_f = \sqrt{\sigma_x^2 + \sigma_y^2}$

$\Delta V_{21} = 4.83 \pm 0.11$ V
$\Delta V_{32} = 5.02 \pm 0.19$ V
$\Delta V_{43} = 5.15 \pm 0.54$ V
$\Delta V_{54} = 5.34 \pm 0.65$ V

using $\sigma_m = \frac{1}{\sqrt{N}} \Delta V$

$\Delta V_{avg_1} = 5.09 \pm 0.44$ V



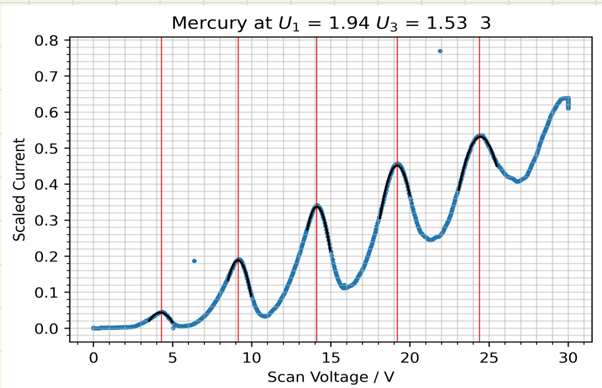
$V_1 = 4.23 \pm 0.03$ V
$V_2 = 9.14 \pm 0.07$ V
$V_3 = 14.14 \pm \cancel{0.33}$ V 0.09
$V_4 = 19.20 \pm \cancel{0.14}$ V 0.10
$V_5 = 24.48 \pm 0.06$ V

$y_1 = -0.05\,x^2 + 0.42\,x + -0.8468$
$y_2 = -0.15\,x^2 + 2.77\,x + -12.4380$
$y_3 = -0.19\,x^2 + 5.27\,x + -36.8983$
$y_4 = -0.13\,x^2 + 4.90\,x + -46.5173$
$y_5 = -0.08\,x^2 + 3.93\,x + -47.5330$

$\Delta V_{21} = 4.91 \pm 0.08$ V
$\Delta V_{32} = 5.00 \pm \cancel{0.34}$ V 0.11
$\Delta V_{43} = 5.06 \pm \cancel{0.36}$ V 0.13
$\Delta V_{54} = 5.28 \pm \cancel{0.15}$ V 0.12

$\Delta V_{avg2} = 5.06 \pm \cancel{0.26}$ V 0.11

$\Delta V = 5.07 \pm 0.30$ V



$V_1 = 4.23 \pm 0.02$ V
$V_2 = 9.13 \pm 0.07$ V
$V_3 = 14.12 \pm 0.09$ V
$V_4 = 19.18 \pm 0.13$ V
$V_5 = 24.46 \pm 0.06$ V

$y_1 = -0.05\,x^2 + 0.38\,x + -0.7697$
$y_2 = -0.14\,x^2 + 2.58\,x + -11.6022$
$y_3 = -0.17\,x^2 + 4.84\,x + -33.8538$
$y_4 = -0.12\,x^2 + 4.79\,x + -45.5008$
$y_5 = -0.08\,x^2 + 3.79\,x + -45.8139$

$\Delta V_{21} = 4.90 \pm 0.07$ V
$\Delta V_{32} = 4.99 \pm 0.11$ V
$\Delta V_{43} = 5.06 \pm 0.16$ V
$\Delta V_{54} = 5.28 \pm 0.14$ V

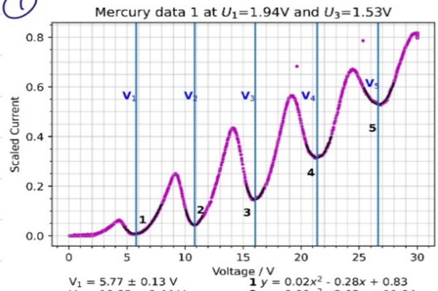
$\Delta V_{avg3} = 5.06 \pm 0.13$ V

This was repeated for the minima to gauge which method gave a value close to the true energy gap

This was decided to be the maxima

Graphs for minima

①



V_1 = 5.77 ± 0.13 V
V_2 = 10.85 ± 0.44 V
V_3 = 16.05 ± 1.04 V
V_4 = 21.38 ± 0.61 V
V_5 = 26.62 ± 1.02 V

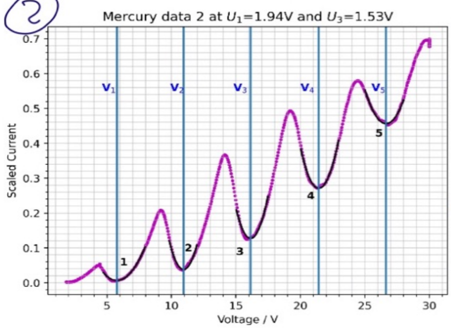
1 $y = 0.02x^2 - 0.28x + 0.83$
2 $y = 0.09x^2 - 2.03x + 11.04$
3 $y = 0.09x^2 - 2.94x + 23.72$
4 $y = 0.06x^2 - 2.49x + 26.93$
5 $y = 0.05x^2 - 2.43x + 32.87$

$\Delta V_{12} = 5.08 \pm 0.46$
$\Delta V_{23} = 5.2 \pm 1.13$
$\Delta V_{34} = 5.33 \pm 1.21$
$\Delta V_{45} = 5.24 \pm 1.19$

$V_{graph1} = 5.21 \pm 1.04$

$$(\sigma_f)^2 = (\sigma_{V_1})^2 + (\sigma_{V_2})^2$$
$$\sigma_f = \sqrt{(\sigma_{V_1})^2 + (\sigma_{V_2})^2}$$

②



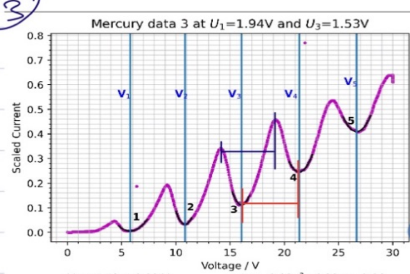
V_1 = 5.78 ± 0.12 V
V_2 = 10.94 ± 0.53 V
V_3 = 16.14 ± 0.72 V
V_4 = 21.42 ± 0.39 V
V_5 = 26.64 ± 0.77 V

1 $y = 0.02x^2 - 0.23x + 0.68$
2 $y = 0.07x^2 - 1.44x + 7.91$
3 $y = 0.07x^2 - 2.16x + 17.55$
4 $y = 0.06x^2 - 2.49x + 26.91$
5 $y = 0.04x^2 - 1.94x + 26.35$

$\Delta V_{12} = 5.16 \pm 0.54$
$\Delta V_{23} = 5.2 \pm 0.89$
$\Delta V_{34} = 5.28 \pm 0.82$
$\Delta V_{45} = 5.22 \pm 0.86$

$\Delta V_{graph2} = 5.22 \pm 0.79$

③



V_1 = 5.78 ± 0.18 V
V_2 = 10.85 ± 0.40 V
V_3 = 16.05 ± 1.03 V
V_4 = 21.37 ± 0.49 V
V_5 = 26.66 ± 0.96 V

1 $y = 0.02x^2 - 0.22x + 0.64$
2 $y = 0.07x^2 - 1.61x + 8.78$
3 $y = 0.07x^2 - 2.40x + 19.41$
4 $y = 0.05x^2 - 2.06x + 22.24$
5 $y = 0.04x^2 - 2.05x + 27.74$

$\Delta V_{12} = 5.07 \pm 0.44$
$\Delta V_{23} = 5.20 \pm 1.10$
$\Delta V_{34} = 5.32 \pm 1.14$
$\Delta V_{45} = 5.29 \pm 1.07$

$\Delta V_{graph3} = 5.22 \pm 0.98$

$\Delta V_{avg\,total} = 5.22 \pm 0.94$

Therefore, the average energy gap found by fitting functions to the data set is:

$$\Delta V = 5.07 \pm 0.30 V$$

Then using $E = qV$

$$\Delta E = (5.07 \pm 0.30)\ eV$$

This Corresponds to a wavelength of:

$$E = \frac{hc}{\lambda}, \quad \lambda = \frac{hc}{E} \qquad \sigma_\lambda = \lambda \times \frac{\sigma_E}{E}$$

$$\lambda = (245 \pm 15)\ nm$$

Ground state Configuration:
$(Xe)(4f)^{14}(5d)^{10}(6s)^2$

f full
$L=0$
$M_L=0$

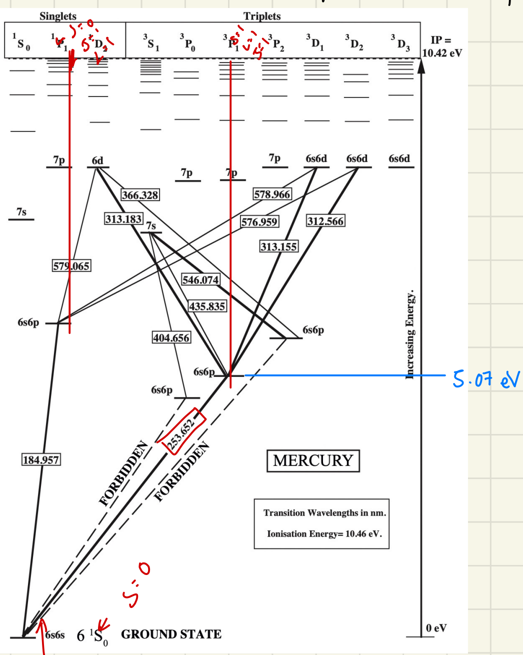
This transition is the $6s6s \rightarrow 6s6p$

$6\,{}^1S_0 \qquad 6\,{}^3P_1$

This transition is expected to emit a photon with wavelength of $\lambda = 253.652$ nm

ground state: $6\,{}^1S_0$

$L=0, S=0, J=0$



from grotrian diagrams on lab Script

New features of Franck Hertz, Gerald Rapior Klaus Sengstock and Valery Baev.
Quotes the excitation energy from $6\,{}^1S_0 \rightarrow 6\,{}^3P_1$ to be

$$E = 4.89\ eV$$

which is in the range of our calculation

The ${}^3P_1$ State is excited as this is the allowed transition with the lowest energy. It is important to note that electrons gain energy slowly across the grid and due to the high density of Hg atoms they collide as soon as they have the required energy so the electrons never have enough energy to perform the ${}^1P_1$ transition.

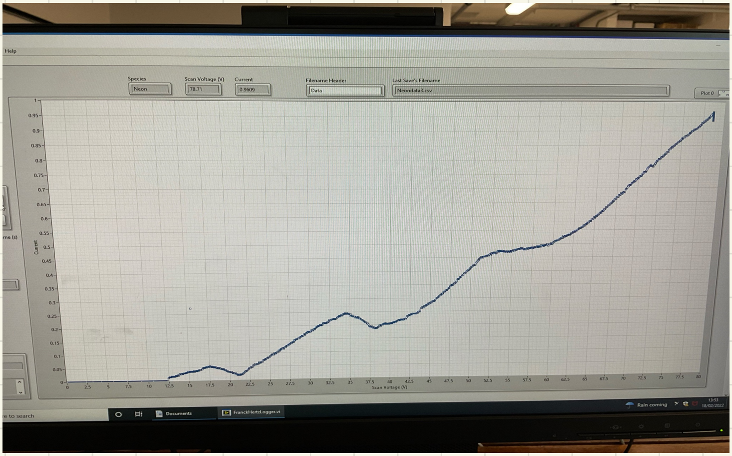
Neon

Room temp: 21.5C $\pm 0.25^\circ C$

$U_1 = 2.66 \pm 0.01V$ ← neondata2.csv
$U_3 = 2.83V \pm 0.01V$

$U_1 = 2.97 \pm 0.01V$ ← neondata3.csv
$U_3 = 2.59 \pm 0.01V$

It was fand that by applying Voltages U_1 and U_3 to get a 3^{rd} minimum, the amplitudes became too small to measure accurately. Therefore we settled for 2.

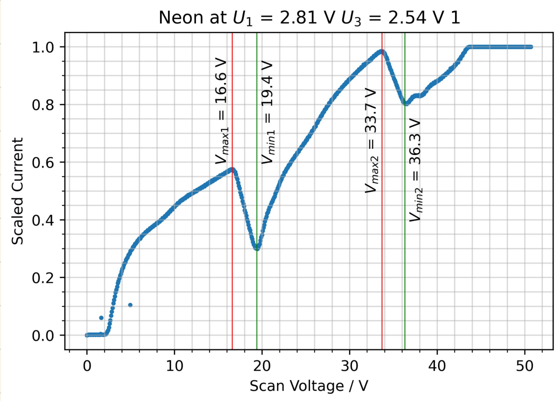


d = 0.55cm

$\left.\begin{array}{l} U_1 = 2.81 \pm 0.01V \\ U_3 = 2.54 \pm 0.01V \end{array}\right\}$ 3 repeats were taken for these values as these maximised the peaks. at 33 ms interval

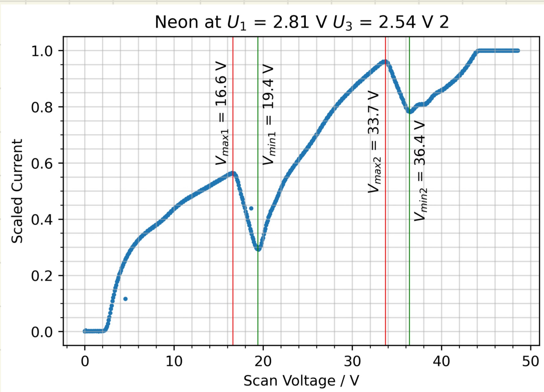
(4, 5, 6)

We then estimated the minima and maxima for each set of readings:



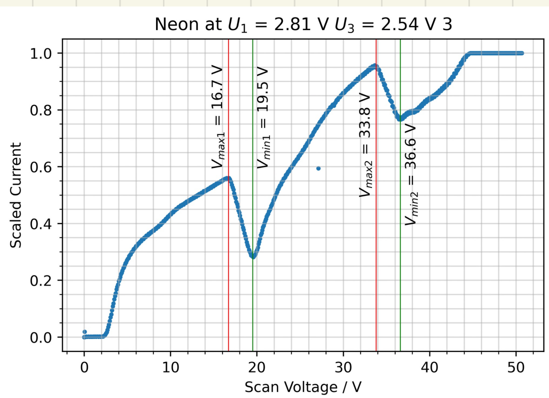
ΔV_{min} = 16.9 ± 0.1

ΔV_{max} = 17.1 ± 0.1



ΔV_{min} = 17.0 ± 0.1

ΔV_{max} = 17.1 ± 0.1



ΔV_{min} = 17.1 ± 0.1

ΔV_{max} = 17.1 ± 0.1

The errors for each voltage reading was estimated to be ±0.1 V as when plotting lines this was the smallest distinguishable difference.

Then when finding the difference, this error was propagated using: $\sigma_f^2 = \sigma_x^2 + \sigma_y^2$

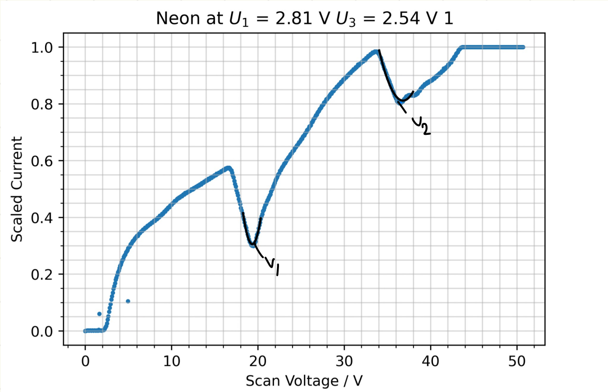
for $f = x+y$

and this was rounded down to 0.1 V to fit to 1dp.

$\Delta V_{min\ avg} = 17.0 \pm \cancel{0.1}\ 0.2$ V ← using $\sigma = \frac{\Delta x}{\sqrt{2}}$

$\Delta V_{max\ avg} = 17.1 \pm 0.1$ V

This process was then repeated using the same method as mercury to fit parabolas to the minima:

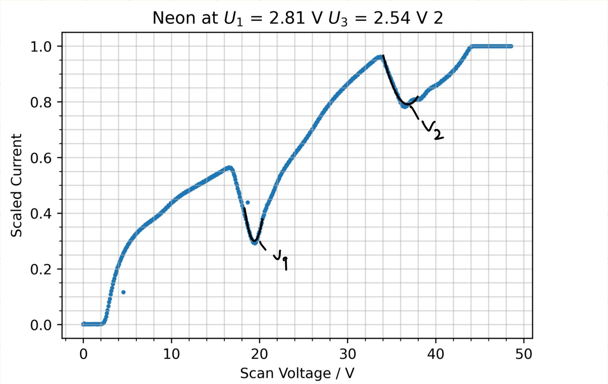


V_1 = 19.34 ± 0.13 $y_1 = 0.10\,x^2 - 3.68\,x + 35.88$

V_2 = 36.80 ± 0.07 $y_2 = 0.02\,x^2 - 1.70\,x + 32.10$

ΔV = 17.46 ± 0.15

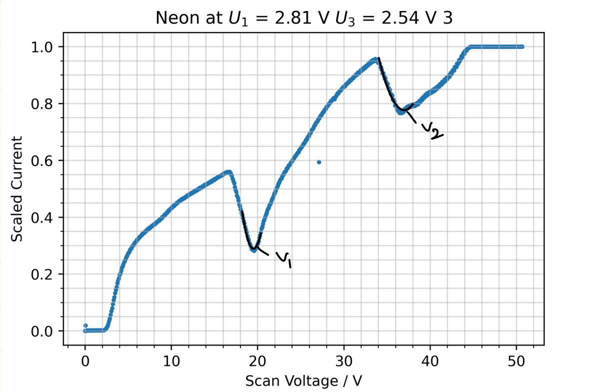
* all using propagation as before



V_1 = 19.41 ± 0.43 $y_1 = 0.09\,x^2 - 3.63\,x + 35.53$

V_2 = 36.84 ± 0.07 $y_2 = 0.02\,x^2 - 1.64\,x + 30.93$

ΔV = 17.43 ± 0.44



V_1 = 19.52 ± 0.12 $y_1 = 0.08\,x^2 - 2.95\,x + 29.13$

V_2 = 36.99 ± 0.08 $y_2 = 0.02\,x^2 - 1.56\,x + 29.68$

ΔV = 17.47 ± 0.14

$\boxed{\Delta V_{avg} = 17.45 \pm 0.28}$

The most probable excitations are the 10 from the ground state ($2\,^1S_0$) to the 3 P states
These are between (18.38 - 18.97) eV (errors negligable)

The ground state to 3s states are also possible but less probable. These energies are from 16.62 eV to 16.85 eV

The lowest energy most probable excitation is therefore $\Delta E = (18.38 \pm 0.0000012)$ eV
from NIST.

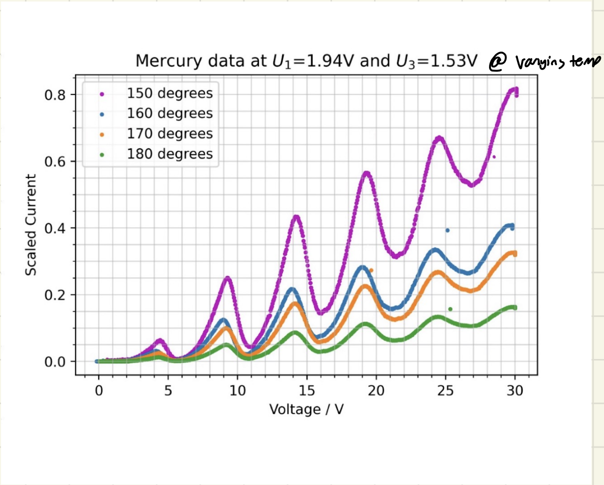
This does not overlap with our value.
This could be due to a bad fit function or (more likely) the wrong minima was measured. If the other minima was measured the energy gap would be shifted up by ~1 eV which would then fall in range.

Orange light was observed which is consistent with electrons falling from 3P→3s state.

Equipment resolution not able to detect fine structure of atoms.

3^2P_1

Mercury Temperature Dependence



We repeated the experiment at varying temperatures to investigate a possible temperature dependence.
It was observed that an increasing temperature decreased the current readings but the energy gap was uneffected

This is explained as an increasing temperature increases the random motion of the mercury atoms.
Therefore there are more collisions between electrons and atoms.
Thus the increase in elastic collisions results in scattered electrons travelling a longer path, thus the time taken to reach the detector is higher and as

$$I = \frac{dQ}{dt}$$

the current is lower.

Electric Field

$$\Theta_0 = \left(-\frac{b}{\underbrace{v_0}_{x}}\right)^{1/3} \qquad \sqrt{\left(\frac{\sigma_b}{b}\right)^2 + \left(\frac{\sigma_{v_0}}{v_0}\right)^2}$$

$$\sigma_{\Theta_0} = \frac{1}{3}\,\Theta_0 \times \left(\frac{\sigma_x}{x}\right)$$

The electric field can be calculated by:

$$E = \frac{V}{d}$$

And $F = Eq$ so, $F = \frac{Vq}{d}$

Therefore, $W = Fx = \frac{Vqx}{d}$ which is equal to kinetic energy

So $T(x) = \frac{Vqx}{d}$

d is width of grid
q is electron charge
x is distance travelled
and V is potential.

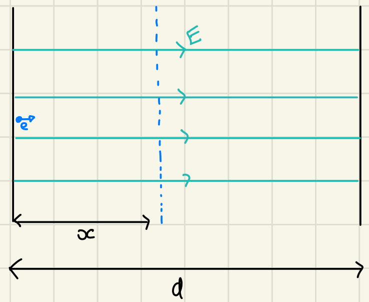
$d = 0.01$ m for mercury.

We expect from experiment that each electron collides twice before reaching the end of the accelerating voltage at 10V. (two peaks)
This is confirmed by:

$T = 5.07 \pm 0.30$ eV

$d = 0.010 \pm 0.005$ m

Set $V = 10$ V



high density of Hg makes this approximation valid

$$T = \frac{10 q x}{d}$$

$$x = \frac{dT}{10q} = 5.07 \times 10^{-3}$$

$$\sigma_x = x \sqrt{\left(\frac{\sigma_T}{T}\right)^2 + \left(\frac{\sigma_d}{d}\right)^2}$$

$$= 2.55 \times 10^{-3}$$

$x = (5.07 \pm 2.55)$ mm

Electron travels a distance x to gain the excitation energy before it inelastically collides (assume instant) At this point the electron has zero kinetic energy and is accelerated a further distance x.

Therefore the number of expected inelastic collisions is:

$$n = \frac{d}{x}$$

Therefore for 10v, $n = 1.97$

$\sigma_n = 1.40$ which includes the expected value of $n=2$.

$$\sigma_n = n\sqrt{\left(\frac{\sigma_d}{d}\right)^2 + \left(\frac{\sigma_x}{x}\right)^2}$$

dominant error from measuring d with ruler. more accurate measurement (Caliper?) would decrease error.

20v:

$x = 2.535$ mm

$\sigma_x = 1.28$ mm

$x = (2.54 \pm 1.28)$ mm

$$n = \frac{10}{2.54} = 3.94$$

$\sigma_n = 2.80$

$n = (3.94 \pm 2.80)$ which includes the expected $n=4$