# Franck-Hertz Prelab

1) In 3-5 Sentences, explain the Franck Hertz experiment

The experiment is named for James Franck and Gustav Hertz who first performed it in 1914. They accelerated electrons through mercury toward a positively charged grid with a slightly negative plate beyond it. They measured drops in current and recorded the associated voltages; these are the voltages associated with excitations of electrons in the mercury. The experiment demonstrated discrete excited states in atoms, helping confirm the quantum theory that electrons occupy quantized energy states. Franck and Hertz were given the Nobel prize for their experiments in 1925.

2) In the process of accelerating electrons through vaporized mercury atoms, the electrons and atoms undergo collisions. What type(s) of collisions do they experience? If energy is transferred, explain the transfer, or explain why it isn't transferred between the electrons and atoms.

When electrons collide with atoms, ~~they do so in an if the atom~~ they do so in an inelastic collision. The electron does not "stick to" the atom in this experiment, as the mercury gas doesn't become ionized. Energy is transferred from the electron, in the form of voltage ($E=qV$), to the atom in the form of an excited state.

3) In the Hg tube, the light emitted by the vaporized atoms has a wavelength of 254 [nm]. Calculate the amount of absorbed energy (in [eV]) necessary for this

~~$E=h\nu \rightarrow E=h\,254\,[nm]$~~ $E=hf$, $f\nu=c \rightarrow E=h\frac{c}{\nu}=h\frac{c}{254[nm]}$

$\boxed{4.88\ [eV]}$

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Major Ideas: Kitt: 2 (Not energy energy to overcome $\Delta V$)
Glass: 1 ~~(Not en~~ (Inelastic collisions)

Equipment: Kitt: 1 (Quartz tube)
Glass: Keithley

Data Analysis: Kitt: Spacing & Energy Levels
Glass: Spacing & Temperature

# Franck-Hertz
## Notes

Eq. 3 is pulled from the reference article (New Features of the Franck-Hertz Experiment)

However, I don't understand where the floor function comes from. Is it a quirk of quantization?

So far, we need:

> L

> Convert ~~[illegible]~~ I/V data to E data

> A way to relate $\lambda$ to T numerically.

↳ Cross section valid for collisions. The article touches on this as being part of the curve fit in part III. So we'll have to solve for $\sigma$ in our data. $\lambda$ changes with T so we could find it in temperature-specific data.

→ $P = VI = \frac{E}{t}$, what is t? electrons & volts → [eV] —

Also, how do I solve for $\lambda$ without already having found E? I need it to find E, from what I'm understanding. But I need it to find $\sigma$ as well.

↳ How do I determine voltage accurately? I have swept voltage but not absolute voltage.

Screen is essentially selecting for high-energy electrons; this is why current increases with energy.

$\sigma$ relates to probability of scattering

Franck - [illegible]

# Procedure

15 - 20 [°C] difference in temperatures

Adjust 0.45 knob if anything

Error comes from the temperature primarily

Only have 1 grid

| $T_{base}$ | $\pm T$ |
| --- | --- |
| 160 | 5 |
| 180 | 5 |
| 200 | 5 |
| 210 | 4 |

← all ~~[illegible]~~ °C

$$\lambda = \frac{kT}{p\sigma}$$ ← cross section for inelastic collisions

pressure $= 8.7 \cdot 10^{\left(9 - \frac{3110}{T}\right)}$ [Pa]

(approximation valid for 300-500 [K])

$$\sigma = \frac{k_B T}{\left(8.7 \cdot 10^{(9 - 3110[K]/T)}\right)[Pa]\, \lambda}$$

For analysis:

- Spacing between minima/maxima → spacing between quantized states
- Mean free path of electrons decreases with $\vartheta$ and therefore with T by ideal gas law.

lowest excitation energy

(1) $E_n = n(E_a + \delta_n)$ ← additional energy gained over distance in electric field

energy from n collisions

corresponds to $\Delta V$.

mean free path

(2) $\delta_n = n\frac{\lambda}{L}E_a$

distance between grids or cathode & grid

So spacing between minima or maxima is

(3) $\Delta E_{(n)} = E_n - E_{n-1} = \left[1 + \frac{\lambda}{L}(2n-1)\right]E_a$ slope $= \frac{2\lambda}{L}$

And our lowest excitation energy is

(4) $E_a = \cancel{\frac{\Delta E}{n/2}}\ \Delta E_{(n=1/2)}$ ← find slope from the others then plug in 0.5

We can also derive the mean free path:

(5) $\lambda = \frac{L}{2E_a}\frac{d\Delta E_{(n)}}{dn}$ ~~[illegible]~~

# Franck-Hertz

## Week 2 Questions

1) The I vs V curve for this experiment is generally monotonically increasing because the electrons' energies are increasing. Since the grid is effectively selecting ~~for~~ electrons of a certain or above energy, as ~~they~~ electrons' energies increase, ~~their~~ the current should increase as well because more electrons are able to pass through.

The dips in current occur in regions associated with the excitation energies for electrons in mercury. ~~These~~ electrons at these energies are giving most of their energies to Hg, so they no longer have enough energy to pass through.

2) The peaks are rounded rather than sharp because we are dealing with distributions of energies rather than the energy of a singular electron. Any individual electron may have more or less than the average energy, so any functions of energy are rounded, rather than jumping up at exact values

3) The 0-40[V] input is applied ~~at~~ across the grid/anode and the cathode
The 1.5[V] input is applied across the grid and collecting plate

4) The cathode produces electrons ~~by direct~~ because it is a filament designed to release electrons when heated. As temperature rises electrons have ~~enough~~ [are more likely to] enough energy to escape the metal by exceeding filament's work function.

5) In one data run, we should expect to see 8 minimas. Instead,

~~ground state:~~ Expected gap size: 4.67[eV]

$\frac{40}{4.6} = 8.7$

we only see six. This is because the difference in energy isn't constant ~~at all~~ between all states ~~/ the number of electrons~~; that is, the distance between states differs more than expected.

6) The first minimum is caused by electrons in inelastic collisions giving energy to Hg atoms to cause the Hg's electrons to become excited.

7) The second is caused by ~~electrons causing~~ the already-excited atoms to ~~enter more excited states~~/ by the collision of already-collided electrons losing even more electrons

Franck-Hertz
Procedure

Week 2 Data

$L = 8$ [mm]

| $T_{set}$ (°C) | $\pm T$ (°C) | |
|---|---|---|
| 160 | 4 | |
| ~~178~~ 178 | 5 | — Didn't save/error |
| 174 | 4 | |
| 189 | 4 | |
| ~~203~~ | | — error - didn't start collecting data |
| 203 | 4 | |

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(Week 2 Questions)

8) Changing the set temperature increases the base energy of the electrons, but also changes the base energy of the mercury.

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We have data flipped to show that it's increasing. Now to curve fit - ~~Matlab~~? Glass did this part in python. Thx!

Need to look up $\sigma$ - says it

$$E_n = nE_a + n\sigma_n = nE_a + n^2 \frac{\lambda}{L} E_a$$

$$E_n = nE_a \left(1 + n\frac{\lambda}{L}\right)$$

lowest energy state is ½

$$\lambda = \frac{L}{2E_a} \frac{d\Delta E(n)}{dn} = \frac{L}{2E_a} \text{ slope}$$

As T increases, Hg vapor has more atoms and moves more, taking up more space, increasing T.

$T_1 = \cancel{338}\ 433\ [K]$

| $n$ | [eV] |
|---|---|
| 3 | 14.10 |
| 4 | 19.14 |
| 5 | 24.19 |
| 6 | 29.31 |
| 7* | 34.37* |

probably trash
has a derailing

$T_2 = \cancel{453}\ 447\ [K]$

| $n$ | [eV] |
|---|---|
| 3 | 14.01 |
| 4 | 19.03 |
| 5 | 24.08 |
| 6 | 29.08 |
| 7 | 34.13 |
| 8 | 39.13 |

$T_3 = \cancel{473}\ 462\ [K]$

| $n$ | [eV] |
|---|---|
| 3 | 14.11 |
| 4 | 19.13 |
| 5 | 24.03 |
| 6 | 28.94 |
| 7 | 33.92 |
| 8 | 38.87 |

$T_4 = \cancel{488}\ 476\ [K]$

| $n$ | [eV] |
|---|---|
| ~~3~~ | * |
| 4 | |
| 5 | 24.26 |
| 6 | 29.33 |
| 7 | 34.19 |
| 8 | 39.01 |

probably [illegible]

Franck-Hertz
Analysis

$\sigma_E^2 = \sigma_\lambda^2$

$\frac{dE}{d\lambda}$

$\sigma_E^2 =$

$\cancel{\sigma_\lambda^2 = \sigma_T^2}$

$\cancel{\lambda_{(T)}}$

$\cancel{\frac{d\lambda}{dT} = \frac{k}{\sigma}}$

$\cancel{\sigma_E^2 =}$

$\sigma_\sigma^2 =$

$\sigma$

Franck-Hertz
Analysis

Error Propagation

$$\sigma_E^2 = \sigma_\lambda^2 \left(\frac{dE}{d\lambda}\right)^2 + \sigma_V^2$$

$$\cancel{\frac{dE}{d\lambda} = \frac{2n}{L} - \frac{1}{L}}$$ use slope for E here

$$\sigma_E^2 = \sigma_\lambda^2 \frac{4}{L^2} + \sigma_v^2$$ ← resolution

$$\cancel{\sigma_\lambda^2 = \sigma_T^2 \left(\frac{d\lambda}{dT}\right)^2}$$

$$\cancel{\lambda_{(T)} = \frac{k_B T}{\sigma\, 8.7 \cdot 10^{(9-3110/T)} [Pa]}} \qquad \cancel{\frac{d\lambda}{dT} = \frac{k_B [Pa^{-1}]}{\sigma 8.7}\left(\frac{1}{10^{(9-3110[K]/T)}} + T\frac{d}{dT}10^{3110/T-9}\right)}$$

$$\cancel{\frac{d\lambda}{dT} = \frac{k_B [Pa^{-1}]}{\sigma 8.7}\left(\frac{1}{10^{(9-3110[K]/T)}} + T \ln 10 \frac{3110}{-T^2} 10^{(3110[K]/T-9)}\right)}$$

$$\cancel{\sigma_E^2 = \underbrace{\left(\frac{k_B [Pa^{-1}]}{\sigma 8.7 \cdot 10^{(9-3110[K]/T)}}\left(1 + \ln 10 \frac{3110}{T}\right)\right)^2 \sigma_T^2}_{\sigma_\lambda^2} + \sigma_v^2}$$

$1.149 \cdot 10^{-10} \cdot 10^{3110/T} \dfrac{k(T-7161.04)}{\lambda T}$

$$\sigma_\sigma^2 = \sigma_\lambda^2 \left(\frac{d\sigma}{d\lambda}\right)^2 + \sigma_T \left(\frac{d\sigma}{dT}\right)^2$$

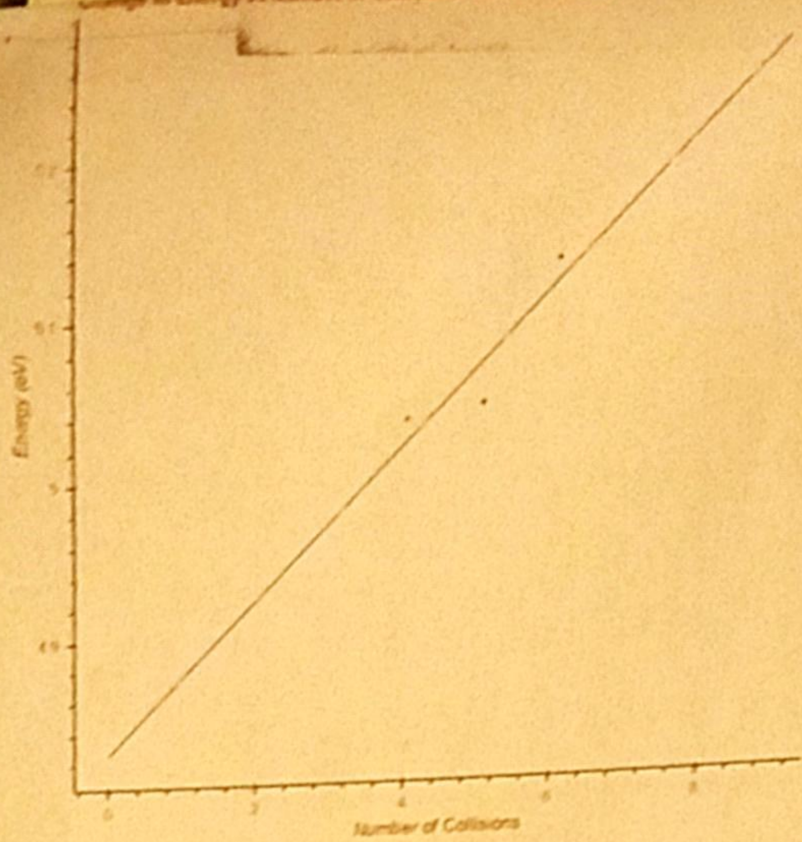
$$\frac{k_B T}{-\lambda^2 8.7 \cdot 10^{(9-3110[K]/T)}} \qquad \cancel{\frac{d\lambda}{dT}\frac{\sigma}{\lambda}}$$

$$\sigma_\lambda^2 = \sigma_L^2 \left(\frac{d\lambda}{dL}\right)^2 + \sigma_E^2 \left(\frac{d\lambda}{dE}\right)^2$$

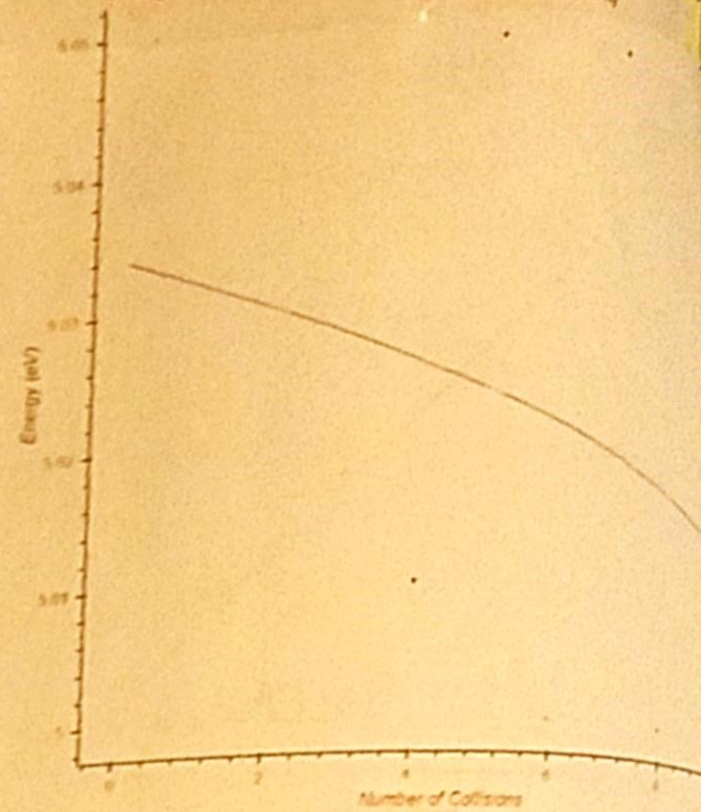
$$\frac{d\lambda}{dL} = \frac{1}{2E_a}\frac{d\Delta E_{(n)}}{dn} \qquad \left(\frac{d\lambda}{dE}\right)^2 = \left(\frac{+L}{2E_a^2}\frac{d\Delta E_{(n)}}{dn}\right)^2 = \left(\frac{L}{2E_a}\right)^2$$ for this purpose

# Franck-Hertz
## Data - Curve Fitting

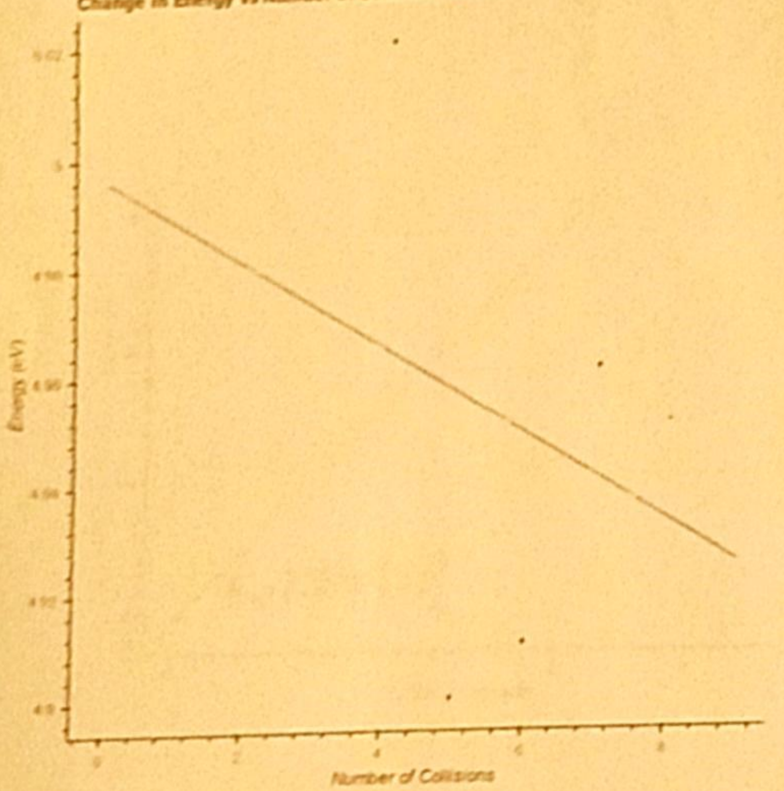
Change in Energy vs Number of Collisions: Curve Fit (433K)



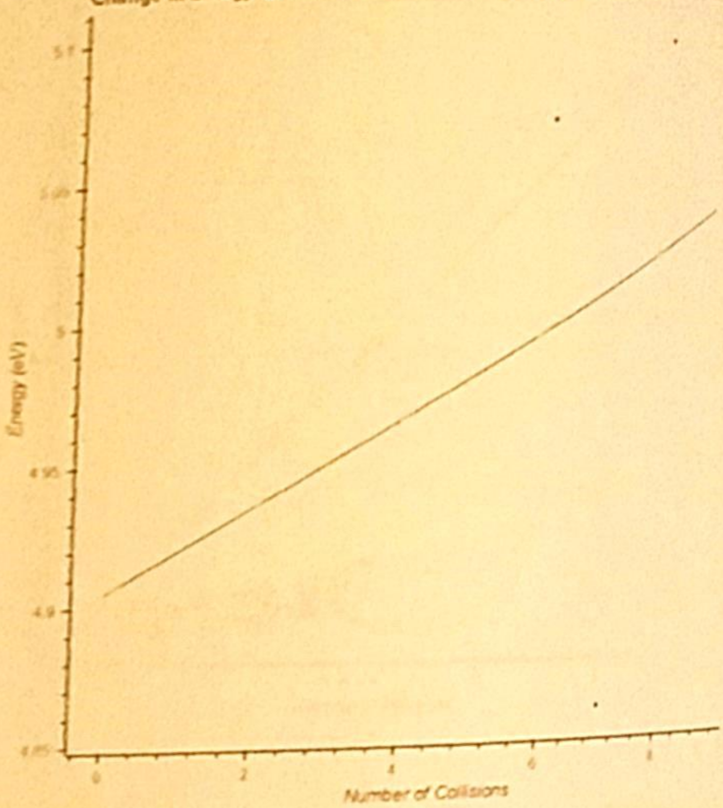

Change in Energy vs Number of Collisions: Curve Fit (447K)



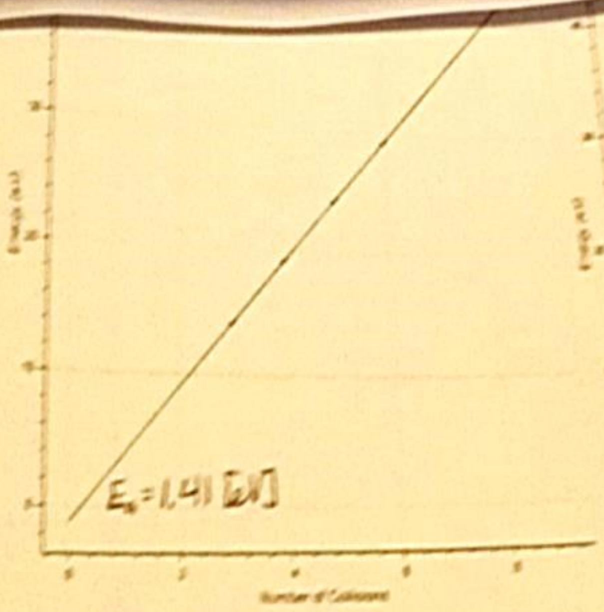

Change in Energy vs Number of Collisions: Curve Fit (462K)

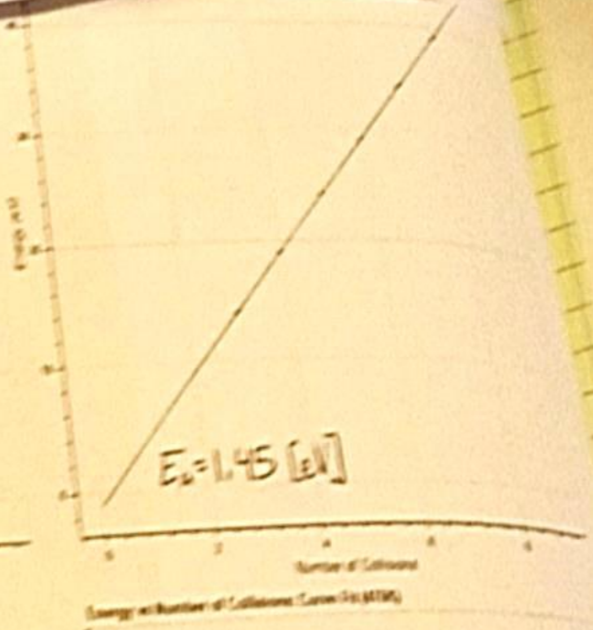


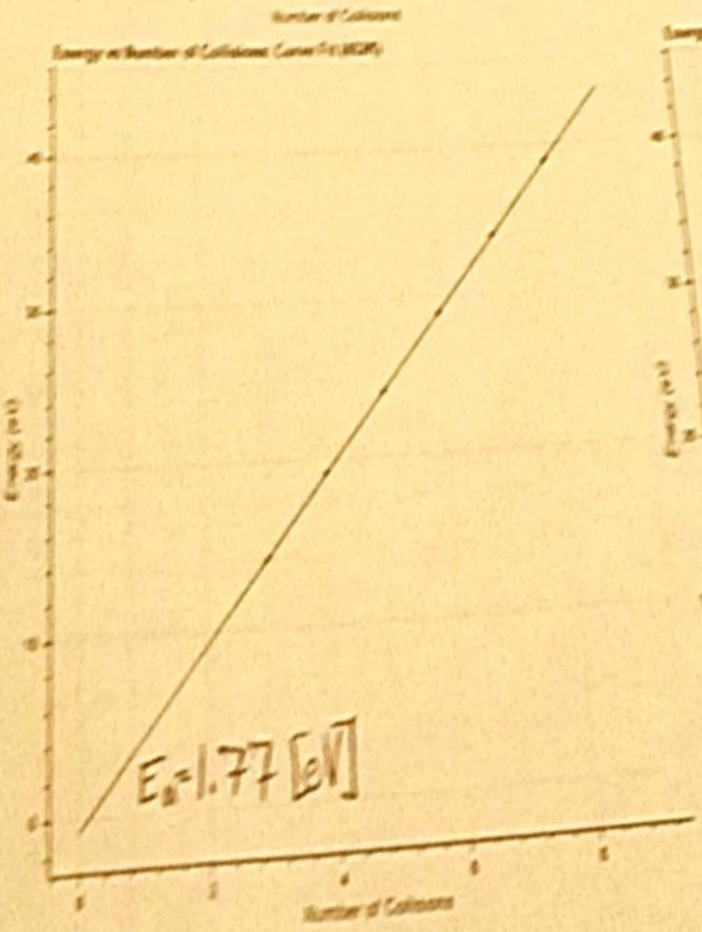

Change in Energy vs Number of Collisions: Curve Fit (476K)

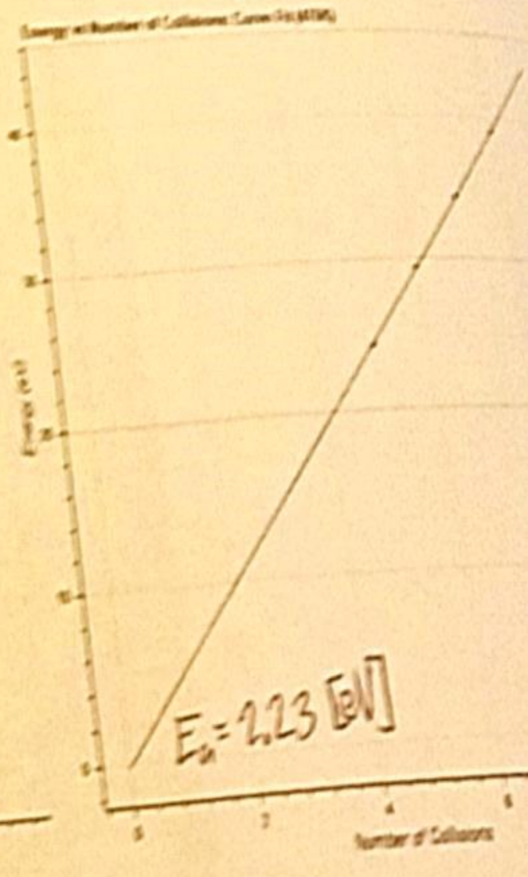



Incorrect Fits below ↻


$E_b = 1.41$ [eV]


$E_b = 1.45$ [eV]


$E_b = 1.77$ [eV]


$E_b = 2.23$ [eV]

Franck-Hertz
Setup