Frank – Hertz Experiment

The Frank-Hertz experiment is significant because it provides somewhat direct evidence for the atomic energy levels in atoms. The idea is this: electrons are liberated from a heated filament by way of a potential difference. The liberated electrons are accelerated through a potential difference (the same potential difference) and obtain an energy given by:

$$K = \tfrac{1}{2} m_e u^2 = eV$$

Where I am using u to represent speed and V to represent electrostatic potential difference.

The liberated electron travels through a gas which can be neon or mercury. In our situation, we will use mercury. After traveling a distance which is given by the "mean free path", on the average the electrons will encounter a mercury atom and have a collision, either elastic or inelastic. It is normally assumed that when the electrons collide inelastically with the mercury atoms, most of the energy from the electron is transferred to result in an atomic excitation of mercury. If the Bohr model (and its successor, the quantum theory of atomic structure) are valid, this transfer of energy will happen only at certain discrete energies which produce an atomic excitation. If we had the capability to observe it, at these particular potential differences, corresponding to transitions between the ground state and excited states in mercury, we should observe light (UV) emitted. We won't here because it is outside our visible range. However, without this observation the evidence that this collision indeed produced a direct atomic excitation is incomplete. Additional collisions will result in additional atomic excitations, namely where an electron collides twice with mercury atoms before reaching the grid. It is thus expected that as potential is increased, multiple dips in the IV curve will be observed at specific intervals.

Brief notes about the transition and notations, included here only for completeness.

It is normally assumed that the transition which is observed will be the lowest excitation in mercury atoms (between the $6^1S_0 \rightarrow 6^3P_0$ states) which corresponds to a transition energy of 4.67eV. The electronic configuration of the ground state of Hg (80) is

$$[1s^2][2s^2 2p^6][3s^2 3p^6][3d^{10} 4s^2 4p^6][4d^{10} 5s^2 5p^6] \cdot 4f^{14} 5d^{10} 6s^2 = \{Xe\} \cdot 4f^{14} 5d^{10} 6s^2$$

However the spectroscopic notation is of the form:

$$n^{2S+1} L_j$$

Here n is the principle quantum number, (similar to the Bohr n), S is the multiplicity. L corresponds to the shell obtained form the principle quantum number: n=(1,2,3,4,5,6,7,8,9,10,...) corresponds to (K,L,M,N,O,P,Q) respectively. J represents the total angular momentum of the atom and is given by $\vec{J} = \vec{L} + \vec{S}$, with L being the total orbital angular momentum and S being the total spin angular momentum.

For non-hydrogenic atoms, $J = L+S, L+S-1, \ldots, |L-S|$

In fact, you will measure transitions that occur with about 4.9 V spacings. This difference has been interpreted as owing to extra energy the electron acquires over a distance of the mean free path. I recommend reference to Am. J. Phys. **74**,(5) : May 2006 for more

information here. For our purposes, we will use the existence of spacings to indicate the validity of the Bohr model as a representative model of atomic structure, although the separations between successive collisions will be more than would be observed if all electronic energy, as calculated by the equation above, were delivered to the atomic excitation.

By changing the potential difference, the electrons are thus enabled to have varying amounts of energy available for the collisions with the mercury atoms. It is observed that the electron current will generally increase with increasing potential difference. However this increase is not smooth and is marked by sudden drops in the “IV” curve.

According to literature published on the Frank-Hertz experiment, the following are observable (although not necessarily by us):
(1) The spacing between minima will increase as potential difference increases. The spacing is not equidistant.
(2) The average spacing observed over moderate potential difference between successive minimina is about 4.89 V which will be larger than the 4.67V corresponding to the first excited state of mercury.

(3) The spacing between minima will show temperature dependence. The implication here is that the process is not purely atomic, but then again the very heart of the experiment links kinetic excitation to atomic excitation so of course the process can not be purely atomic.

About the data treatment

You might think this: why don't we just measure the separation between the peaks and take the average rather than doing a graphical analysis and finding the slope? I want to show you why this is a problem. Assume you have the following data:

Peak 1: v1=x1
Peak 2: v2=x2
Peak 3: v3=x3

The separation between the peaks is then $v2-v1=x2-x1 : v3-v2=x3-x2$.
Ok, so let's find the average separation between the peaks:

$$\text{average separation}=\frac{[x2-x1]+[x3-x2]}{2}=\frac{x3-x1}{2} \quad .$$

What has happened is that you will only with such a calculation have 1 measurement instead of two measurements because, as you can see, the algebra removes the second measurement. There are other similar experiments where this is also true. As an example, you need to be particularly careful when you measure g with a spark tape. The better way to do this is to plot the voltage vs peak number and take the slope from that graph in order to obtain the experimental separation per peak.