Faculty of Physics - 3 agosto 2021

modern physics lab course

Frank Hertz Experiment.

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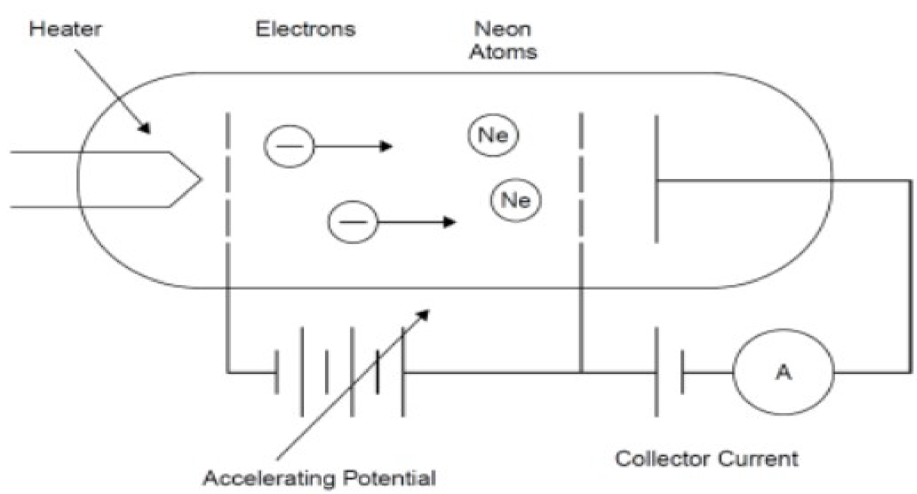
Indice

1 Objective

In this experiment, we will repeat Franck Hertz's experiment and witness energy-loss observations, using neon, and try to interpret the data.
We will see the energy levels in Neon atoms. In the context of modern atomic physics. We will not attempt the spectroscopic measurements, since the emissions are weak and in the extreme ultraviolet portion of the spectrum.

2 Introduction to Frank Hertz theory

The Franck–Hertz experiment demonstrates the fact that energy levels in atoms are indeed quantzaized into discrete levels. Electrons in atoms may be found in discrete energy levels according to Bohr's atomic model. In the Frank Hertz experiment the existence of the same energy levels can be checked by stirring gas atoms by accelerating electrons with electric field. The theory of Frank Hertz clearly shows the quantum nature of atoms. One of the ways to transfer energy between atoms is inelastic collisions by accelerated electrons. Electrons can be ejected from a cathode that is charged with $13.6[V]$ voltage, and accelerated by acceleration voltage V_a to an anode. The anode is built as a grid that the electrons go through, there is an electrode that is charged with stopping voltage V_T . The current between cathode to anode is measured by an amper meter. The electrons collide with the gas molecules inside the Frank Hertz tube , when the electrons are accelerated enough and achieve enough kinetic energy in order to excite the mercury atom , they will perform in-elastic collisions with the mercury atoms and deliver most of their kinetic energy to the atom . As a result , V_T will cause the electrons to stop before the anode, and the current measured will drop down. When we increase V_a the electrons will reach the anode after the collision until they have enough kinetic energy in order to perform two collisions . In the experiment the measurement is current $[A]$ as a function of acceleration voltage $V_a[V]$. From the graph mentioned will see the equal spacing of energy $E_p = e \cdot E_p$ from pick to pick and then obtain the discrete levels of the Neon atoms.



3 Theoretical background

As early as 1914, James Franck and Gustav Hertz discovered in the course of their investigations an energy loss in distinct steps for electrons passing through mercury vapor and a corresponding emission at the ultraviolet line (λ= 254 [nm]) of mercury. They performed this experiment that has become one of the classic demonstrations of the quantization of atomic energy levels. They were awarded the Nobel Prize for this work in 1925. In the experiment we will investigate the process by which the electrons are accelerated in an electric field due to two electrodes that are in a tube field with low pressure neon gas. The kinetic energy of the electrons increases in their motion toward the anode because they apply electrical voltage (Acceleration voltage). When the energy of the electron exceeds the excitation energy of neon atoms, inelastic collisions between the electrons and the neon atoms are possible - the electrons transfer some of there kinetic energy to the neon atoms, which causes a decrease in the current between the two electrodes in the tube. The purpose is to see whether the amount of energy delivered to the neon atoms in the tube is random or constant. We will see that in a certain energy the neon gas will observe some of the kinetic energy of the electrons and emit visible light with a certain wave length.The energy required to raise an electron in an atom of Neon from the elemental level to the excitation level is equal to the energy of a photon at the specific wavelength. The expectation is to see photons emission in orange or red color with wave length 600 - 700 [nm]. Neon has about 10 energy levels in the range between 18.3 and 19.5 $[eV]$. The energy of a photon in the excitation level is:

$$E_p = h \cdot v = \frac{h \cdot c}{\lambda_p}$$

From thet we will expect to get E_P in the range of 18.3-19.5 $[eV]$.

$$h = 6.62607004 \cdot 10^{-34} \, [\frac{m^2 \cdot kg}{s}]$$

is Planck's constant.

$$c = 2.9979 \cdot 10^{18} \ \ [\frac{ang}{s}]$$

$v[Hz]$ is the frequency and $\lambda_p \ \ [m]$ is the wave length .

The kinetic energy of an electron is:

$$K_e = e \cdot V_a$$

$e = 1.60217662 \cdot 10^{-19} \, [C]$ - the charge of the electron and V_a is the acceleration voltage.

When an electron with kinetic energy less than E_p (excitation energy level) [eV] strikes a Neon atom, the collision between the electron and the mercury atom can only be an elastic collision. The ratio between the electron mass and the neon is $\kappa = \frac{M_{ne}}{m_e} = 3.9 \cdot 10^4$, because of the large ratio between the masses of a neon atom and an electron, there will be almost no change in the kinetic energy of the electron after an elastic collision. If the energy of the electron will be greater then E_{neon} [eV] the collision will be non elastic collision. When an electron with an energy greater than E_p [eV] strikes a neon atom, the electron will give the neon atom a dose of energy of E_p [eV] which "bounces" an electron of the neon atom from the ground level to the stimulus level. The electron is naturally comes back to the ground state after a very short time while emitting a photon in a light wave of $\lambda_p[m]$.

4 Equipment and system orientation

The equipment used:
1. Tunable DC (Constant Voltage) Power Supply
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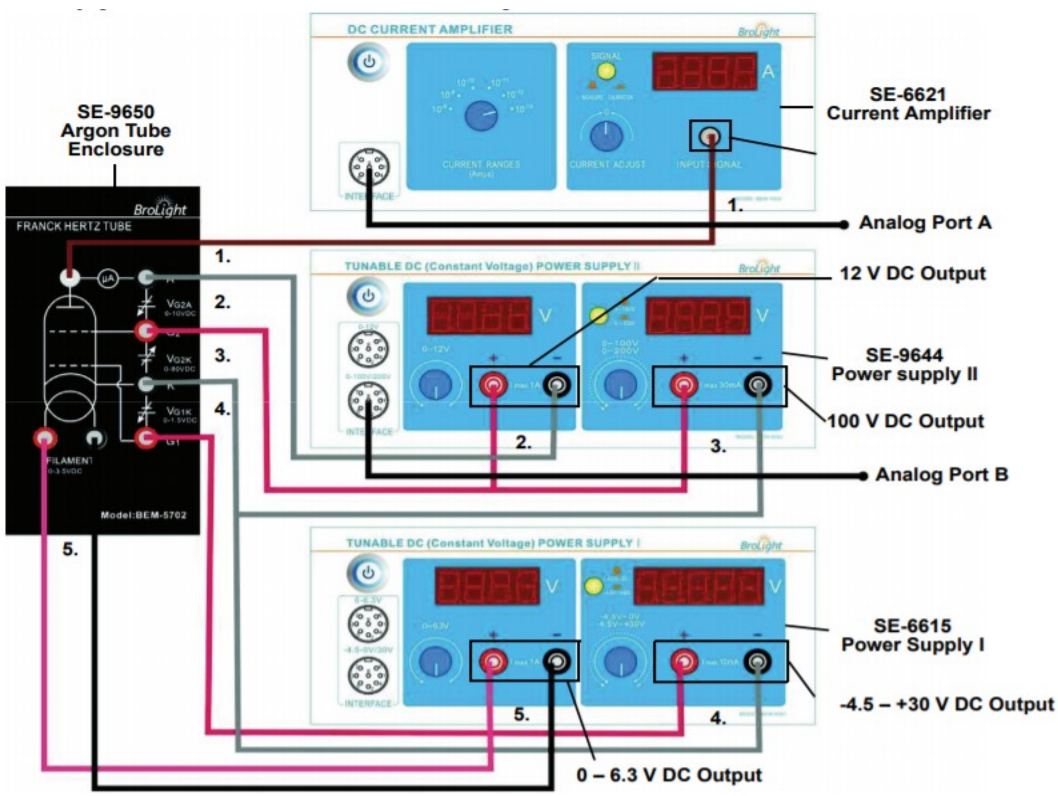
3. DC Current Amplifier SE-6621
4. Neon Tube Enclosure with Neon Tube SE-9650
5. Connecting cable, 850 mm, red EM-9740 Set of 5
6. Connecting cable, 850 mm, black EM-9745 Set of 5
7. Power Cord - 3
8. BNC Cable - 1
9. 8-pin DIN Extension Cable UI-5218

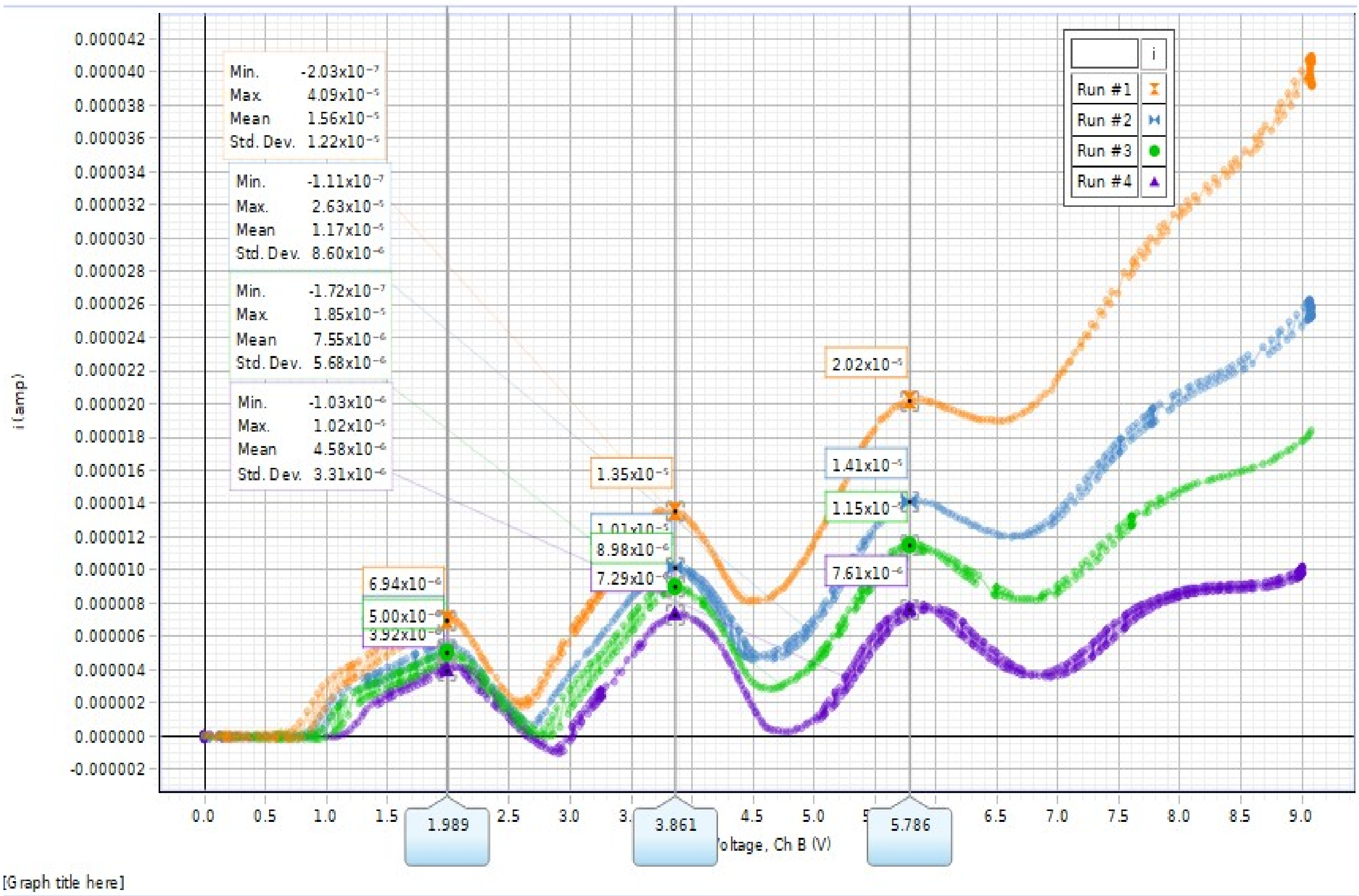


5 Experiment flow

The cathode voltage and stopping voltage remained constant throughout every measurement. The acceleration voltage is changed up to $75[V]$, there is a total of 4 measurements. The difference between measurements is the stopping voltage.

6 Results

From the graph below we can see the behavior of the electrons in the Neon tube. As the current reaches the different picks in the graph, the amount of the kinetic energy of the electrons is getting close to the energy required to create the non elastic coalitions with the Neon atoms and then the current drops until it reaches zero.The current will keep going from pick to pick until it will reach saturation. Measuring the width from pick to pick for every measurement we get $\Delta V_a = Const[eV]$. With this constant we can calculate the wave length of the emitted photon.



The output Voltage in the voltage supply is divided by 10 - $V_a = \frac{V_{out}}{10}$ as it is written in the manual of the AC supplier.

7 Discussion

The energy of the electron is equal to:

$$E_p = h \cdot v[eV]$$

and the wavelength:

$$\lambda_p = \frac{c}{v}$$

So by the previous equations and the data we measured we can find the wavelength:

$$\lambda_p = \frac{c \cdot h}{e \cdot V}$$

Error will be calculated through the direct error of the voltage measurement:

$$\Delta E = e \cdot \Delta V_a$$

$$\Delta \lambda_p = \frac{c \cdot h}{e \cdot V_a^2} \cdot \Delta V_a$$

with all of the above we can calculate the values and we get:

Results				
ΔV_a	λ_p	E_P	$\Delta\lambda$	ΔE_p
19.350 [V]	640.3000 [nm]	1.9350 [eV]	$\pm$ 1.6545 $\cdot 10^{-8}$ [m]	$\pm$ 0.0967 [eV]
18.955 [V]	653.6430 [nm]	1.8955 [eV]	$\pm$ 1.7241 $\cdot 10^{-8}$ [m]	$\pm$ 0.0947 [eV]
19.155 [V]	646.8180 [nm]	1.9155 [eV]	$\pm$ 1.6883 $\cdot 10^{-8}$ [m]	$\pm$ 0.0957 [eV]
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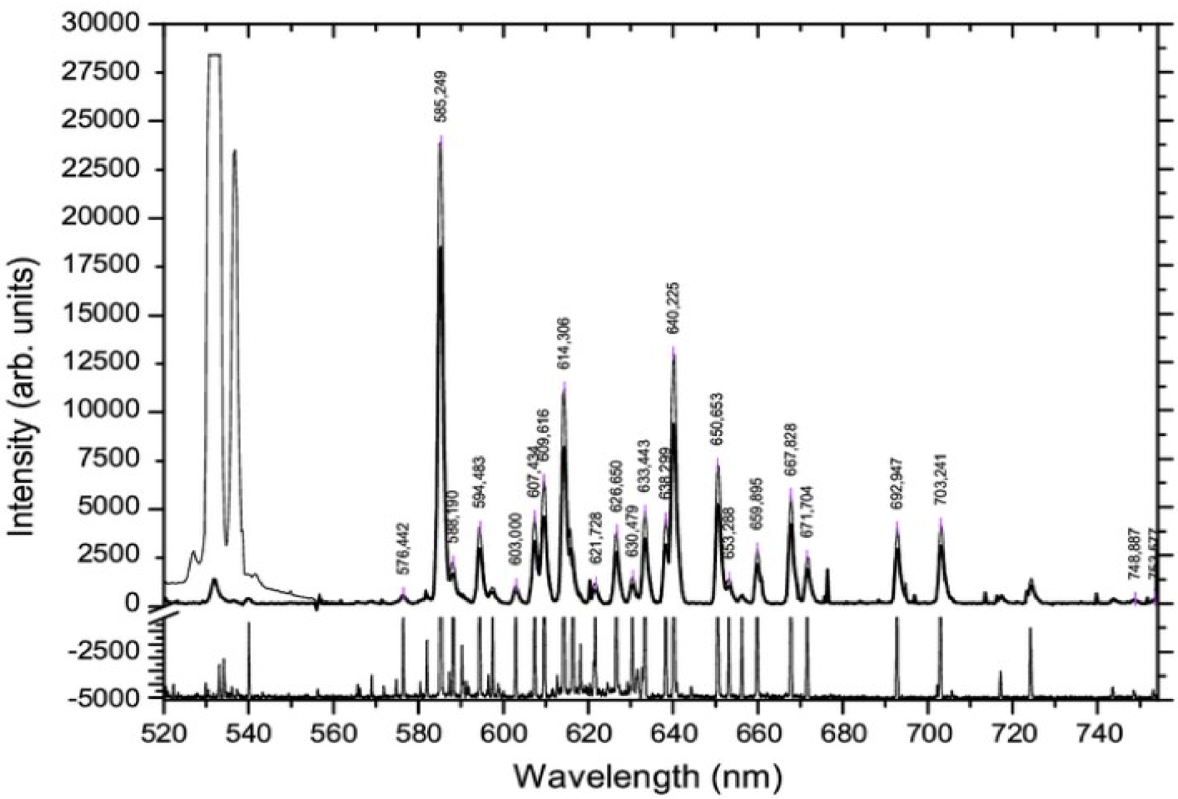
The average wave length is: $\lambda = 646.89475 \pm 10.688[nm]$ This results is the wave length of the color Orange.
The average energy value will be $E_P = 1.9145[eV] \pm 0.0957$ Calculation of the theoretical value of the energy we get:

$$E_{theoretical} = \frac{hc}{\lambda_p} = 4.136 \cdot 10^{-15} \frac{2.99 \cdot 10^8}{646.89475 \cdot 10^{-9}} = 1.9116eV$$

The theoretical value we got corresponds with the measured one.

In the graph below we can see the emission spectrum of neon in visible light. One can notice that the wave length $\lambda = 646.89475 \pm 10.688[nm]$ is in the range of the spectrum of Neon.



8 Conclusion

In this experiment we used frank Hertz theory to showed that the behavior of matter is quantum. The energy levels of atoms are discreet. The position of the peaks in the graph is raised as the acceleration voltage increased. This is due to the fact that more electrons manage to overcome the stopping voltage. In this experiment we performed measurements of the excitation energy, wave length of the emission. We checked The stop voltage, The accelerating voltage and the heating current of the cathode and plotted the results. From these experimental results we will conclude that as we expected these energies are properties of the material being measured, in this case Neon gas. Beyond examining the excitation energies, we also compared their numerical values, which we calculated. In each of the experimental stages (and which have very close values) to the literary values and we got a good match, so we succeeded Meet the purpose of the experiments and measure these values.