Experiment 1

Electron Beam Experiments:

Constant B field, Diffraction, and the Frank-Hertz Experiment

In this laboratory session we will do three different types of experiments pertaining to electrons. The first one deals with the motion of an electron in a uniform magnetic field. The other two experiments concern the quantum mechanical properties of electrons: electron diffraction and the Frank-Hertz experiment. There will be one set-up of each experiment in the laboratory and you will rotate through the experiments. The data taking is quite simple, so we might be able to perform all three experiments in one session. If we can't finish them all in one meeting, we can continue next session. Below I describe each experiment separately.

Motion of an electron in a uniform magnetic field

You will be using the "Ealing" apparatus, which consists of a special "vacuum" tube in which a beam of electrons is emitted from a heated filament and attracted toward an anode. The electrons travel through a potential difference of **V** volts. A small amount of mercury vapor is present in the tube so that you can see the electron beam.

A magnetic field can be used to deflect the beam. A set of Helmholtz coils is set up that will produce a relatively uniform magnetic field at the center of the coils. The strength of the magnetic field for these Helmholtz coils is

$$B \approx 7.8 \times 10^{-4} I \ Tesla \tag{1}$$

where I is the current in the coils.

This set-up could be used to measure the ratio of e/m for the electron. Here, we will do something different. We will see if the magnetic force on the electron is proportional to its speed v.

1. Check the connections. If all wire connections are correct, then first turn on the filament voltage to **5 Volts AC**. **Wait at least one minute before turning up the anode voltage**.

2. Turn the anode voltage up slowly until an electron beam becomes visible. With the anode voltage somewhat more than 120 V, adjust the focus for a sharp beam.

3. Increase the Helmholtz coil current till the beam bends into a circular path.

4. Set the coil current to a constant value of around 1.5 amp. With the coil current held fixed, measure the diameter of the beam for at least 5 different anode voltages over as large a range as you can. You should be able to take readings for anode voltages between 100 and 300 Volts.

Data Analysis

We want to examine if the magnetic force is proportional to the electron's speed v. The relevant physics is that the force on an object undergoing uniform circular motion is $F = mv^2/r$, and that the energy acquired by the electron after accelerating through a potential difference of V is $K.E. = eV$.

1. Using these two relationships, show that

$$F \sim \frac{V}{r} \quad (2)$$

$$v \sim \sqrt{V} \quad (3)$$

where V is the anode voltage, and the symbol $\sim$ means "proportional to".

2. Make a graph of V/r versus $\sqrt{V}$. What can you conclude from this graph?

3. If the graph of V/r versus $\sqrt{V}$ yields a straight line, determine the slope of the line. From the value of the slope, what do you obtain for the ratio of e/m?

Electron Diffraction

The apparatus consists of a cathode ray tube (CRT) designed to demonstrate electron diffration. Inside the CRT is an "electron gun" which produces a narrow beam of electrons with a specific energy. The CRT is an evacuated tube. The electrons travel through the tube and pass through a thin layer of graphite (carbon). After passing through the graphite, the electrons land on a luminescent screen. The electrons produce a green pattern (of rings) on the screen.

There is only one parameter to adjust: the accelerating voltage (or anode voltage) V that the electrons experience. If the voltage V is changed, the size of the diameter of the green rings on the screen will also change.

The formation of the rings are consistent with the interference property of the electron. This can be seen by changing the voltage and observing the change in the diameter of the rings. Below are some guidelines for the experiment. The format for the laboratory report is listed at the end of this write up.

Qualitative Observation: Decrease the anode voltage from 4000 volts to 3000 volts.

Question 1. Does the diameter of the rings increase or decrease?

Question 2. Is this is consistent with interference effects and the De Broglie relation: $\lambda = h/p$? Explain your reasoning.

Quantitive Analysis: Vary the anode voltage V and measure the diameters D of the two rings at each voltage setting. Some suggested values for the voltage: 4700, 4000, 3500, 3000, 2000 and 1500. Be careful when measuring the diameters since the tube is curved.

Graph 1. Make a graph of the appropriate powers of V and ring diameter D such that a straight line plot gives insight into the principles of physics. Explain why you chose these values for your axes. You can plot the data for both rings on the same graph.

Question 3. If your points plot in a straight line, what is the slope (with correct units) of the line(s).

Question 4. From the value of your slope, use the known values for the properties of the electron and the geometry of the setup to obtain a value for Plank's constant h.

Some useful information

A diffraction maximum occurs when $sin\theta = \lambda/d$ where d is the spacing of the slits.

There are two relevant spacings between the carbon atoms: $d_1 \approx 1.2$ Angstroms, and $d_2 \approx 2.1$ Angstroms.

The distance from the screen to the thin layer of carbon is $L \approx 13.5$ cm.

If an electron traverses a voltage difference of V, the work done by the electric field is eV. Since there are no other forces involved, $eV \approx mv^2/2$. Also, $p \approx mv$.

Note: the non-relativistic expressions above are justified since the energy the electron obtains is at most 4700 eV. The mass-energy of the electron is around 511000 eV. The kinetic energy is therefore less than 1% of the electrons rest mass so the non-relativisitic expressions of $mv^2/2$ and $p = mv$ are fairly accurate.

Frank-Hertz Experiment

The apparatus consists of a tube filled with a gas, which in our case is neon. At one end of the tube there is a source of electrons. The electrons that are produced are accelerated through a potential difference of V volts (applied voltage) and can reach the other end of the tube. The electrons that arrive at the other end are collected and the current (anode current) that they can produce is measured. The two measurements that we will consider are the applied voltage V and the anode current I.

Check if the tube is connected correctly by examining the schematic of the set-up. Guidelines for the experiment are listed below. The format for the laboratory report is at the end.

Qualitative Observation: Increase the applied voltage slowly and observe the anode current.

Question 1. As you increase the applied voltage, does the anode current suddenly change? Describe what you observe and explain the phenomena.

Quantitative Analysis: Increase the applied voltage in increments of 2 volts and record the anode current.

Graph 1. Make a graph of anode current versus applied voltage. Note the voltages where the anode current decreases. Estimate the average difference in these voltages. What property of neon are you determining?

Question 2. Next to this write-up (on my home page) is a file of ionization energies for the neutral atoms. Discuss how your results compare with the value listed for neon.

Experiment 1 Report

Motion of an electron in a uniform magnetic field

1. Display your data table of anode voltage V, radius r, V/r, and $\sqrt{V}$.
2. Show your calculations that demonstrate that $F \sim V/r$ and $v \sim \sqrt{V}$.
3. Show your plot of V/r versus $\sqrt{V}$, and explain what conclusion you can draw from the plot.
4. If the plot of V/r versus $\sqrt{V}$ yields a straight line, determine the ratio of e/m from the value of the slope.

Electron Diffraction

1. Describe what happens when the anode voltage was increased from 3000 to 4000 volts? (i.e. Do the diameter of the rings increase or decrease?

2. Using De Broglie's relation: $\lambda = h/p$ derive a formula that relates the anode voltage V to the diameter of the ring. See "useful information" above.

3: Display your data table of anode voltage V and ring measure diameter D for the two rings.

4. Guided by the formula you derived make a graph of the appropriate powers of V and ring diameter D such that a straight line plot gives insight into the principles of physics. Explain why you chose these values for your axes. You can plot the data for both rings on the same graph.

5. If your points plot in a straight line, what is the slope (with correct units) of the line(s).

6. From the value of your slope, use the known values for the properties of the electron and the geometry of the setup to obtain a value for Plank's constant h. Show your work.

Frank Hertz Experiment

7. As you increase the applied voltage, what does the anode current do? Describe what you observe and explain the phenomena.

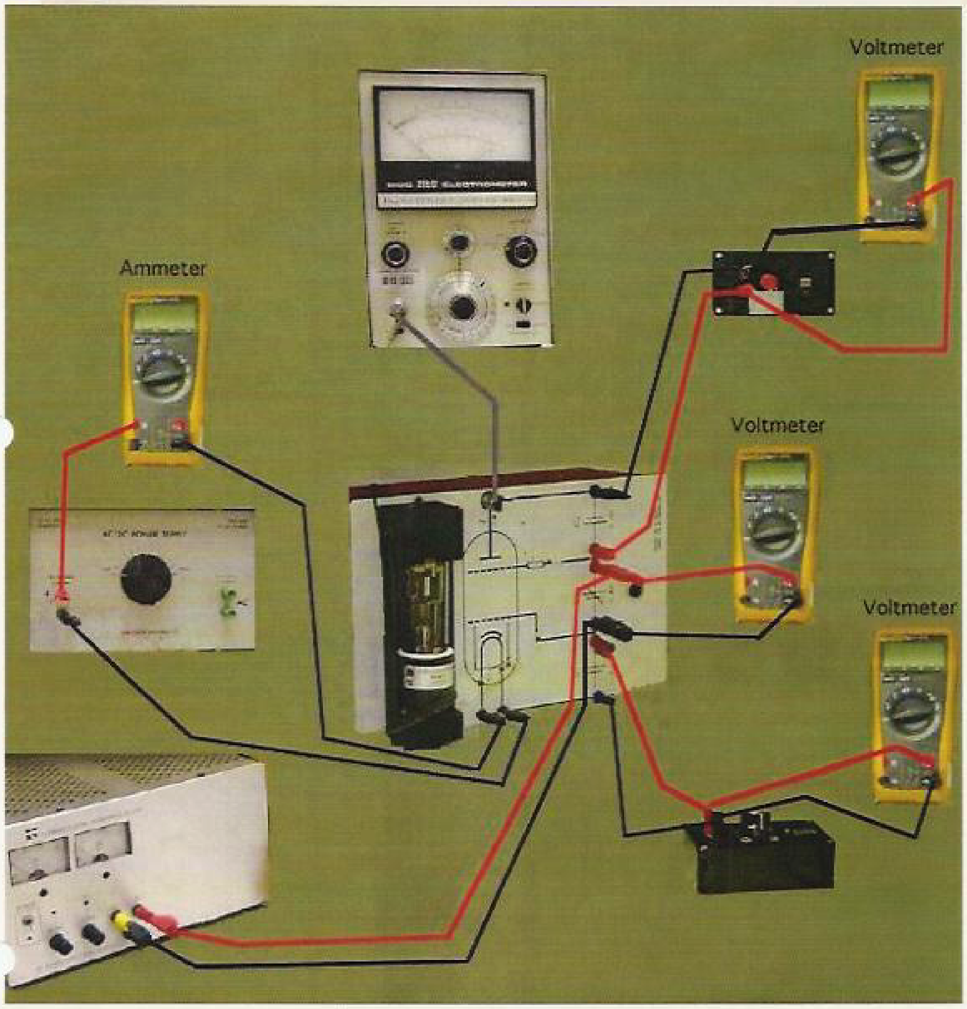
8: Display a table of your data of applied voltage and anode current.

9. Make a graph of anode current versus applied voltage. Note the voltages where the anode current decreases. Estimate the average difference in these voltages. What property of neon are you determining?

10. Next to this write-up (on my home page) is a file of ionization energies for the neutral atoms. Discuss how your results compare with the value listed for neon.

NEON FRANCK-HERTZ

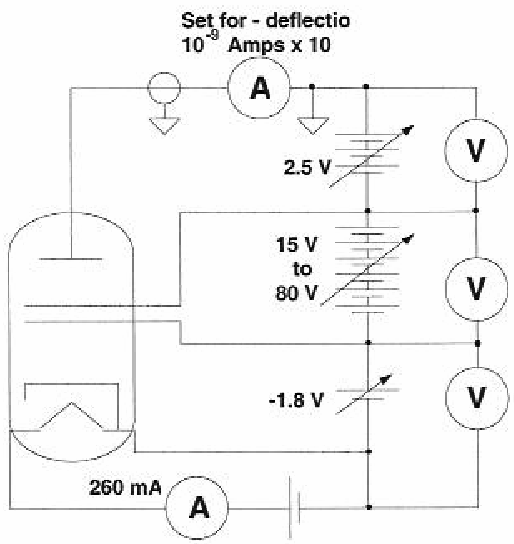
CONNECTIONS



Collisions = 19 eV
optical transition about 1.9 eV

Experiment #5
The Neon Franck-Hertz Experiment

Read about the Franck-Hertz experiment in your text. Use the neon Franck-Hertz apparatus (circuit diagrammed below) to obtain a graph of current versus voltage. The excitation energy of neon is not the same as that of mercury



As the main power supply voltage increases minima are observed in the anode current (measured in the top ammeter above). With each minimum a new, sharp layer of glowing neon atoms are observed. Plot a graph of anode current versus applied voltage. Measure the average difference in the voltage between current minima (or between current maxima) to obtain the quantum of energy that neon atoms cam absorb. Compare it with the energy emitted by the neon as light. Is it the same? Should it be?