Franck-Hertz Experiment in Neon/Hg

Equipment

Franck-Hertz tube (Ne or Hg) & Operating Unit
Analog oscilloscope
Many Banana cables; 1 BNC cables; 2 BNC-Banana Plug connector
Graphing paper

Theory

This experiment will demonstrate the 1926 Nobel Prize Winning Franck-Hertz Experiment. The existence of discrete energy levels in atoms is demonstrated by the Franck-Hertz experiment.

An anode and cathode are placed in a tube which contains Neon/Hg gas. Electrons emitted from the cathode are accelerated toward the grid and thus their kinetic energy increases linearly with distance. Two collision processes happen in tube. Firstly, the electrons suffer *elastic collisions* with the neon atoms; these are collisions in which the sum of the kinetic energies of the electron and of the gas atoms is conserved. In such collisions, the electron loses a very small fraction of its energy. Therefore the electron has a kinetic energy approximately equal to eV, where ΔV is the potential difference between grid and cathode. The small retarding voltage (~0.5 V) does not prevent them from being collected at the anode, provided that $\Delta V > 0.5$ V. If, on the other hand, an electron suffers an *inelastic collision* with a gas atom in which it lost nearly all its energy, it will be turned around by the retarding field between the grid and node and will not participate in the anode current I.

As the voltage difference between the cathode and grid is increased, the anode current increases until a critical voltage is reached, at which point the current decreases sharply. We interpret this decrease to be the result of inelastic collisions that evidently occur as soon as the electron kinetic energy K reaches a threshold energy. An electron with this KE loses all its energy to an atom, exciting an electron in the atom from one discrete energy level to a higher one. The result is a dip in the anode current. As the voltage is further increased to 0.5 V + the exciting potential, an electron has sufficient energy to overcome the retarding voltage, even after making on inelastic collision. When V becomes 2 x (exciting potential), an electron can make two inelastic collisions, and another dip in the anode current curve occurs. By measuring the distance between "dips" we can measure the critical potential to excite an electron in the neon atom.

Another important result from this experiment is the light of a corresponding wavelength is observed to come from the tube as soon as V becomes greater than the exciting potential. Evidently, when an electron in a neon atom is excited to an energy level above its normal energy level, it returns to its normal state by radiating light.

The concepts of quantum theory are verified as several well-defined minima can be observed on your oscilloscope screen, as the electrode current produced by the control unit excites the neon resonance line.

The apparatus consists of a neon-filled (Hg-filled) Franck-Hertz tube in a housing; a control unit with power supplies, reverse voltage source and DC preamplifier; and a shielded cable with BNC connectors.

Experimental Set-up

- If using the Hg tube, turn the heating oven on the side panel of tube to 150-200°C. WARNING: the Hg tube gets very hot!!!
- The indirectly heated cathode (green knob) requires a warm-up time of about 90 seconds after you switch on the operating unit for the Ne/Hg tube.
- Connect the color coded outputs of the operating unit with the color coded inputs of the Ne / Hg tube.
- Connect the FH signal (M) from the tube with a BNC cable to operating unit.
- Connection to oscilloscope:
  BNC-Bananan Plug adapter: RED is **signal** input; BLACK is **ground**.
  X-axis, signal Channel 1: from V_a/10 on Ne unit or U_B/10 on Hg unit
  Y-axis, signal Channel 2: From (V+) on Ne unit or FH signal y-out on Hg unit;
  From ground of operating unit to ground of Channel 2 and Channel 1.
- Oscilloscope settings:
  Time: X-Y axis
  Channel 1& 2 on DC mode
  Adjust Volts/Div so that the graph fills the screen (see figure 2).

Procedure 1:

- Set switch to Ramp position
- Increase the acceleration voltage (starting from 0 volts), while reducing the "gain" setting, to keep the output reading within the meter range. Adjust the heater for the filament (= electron flux) for optimum results.
- A current on the order of 10nA then flows from the collector electrode to the anode. Amplification gain (on the operating unit) or current sensitivity (on the measurement amplifier) should then be set to suitable levels.
- Quantitatively sketch the graph from the oscilloscope on graphing paper. Include the grid lines; label the axis; importantly: provide the correct scale for the x-axis;
- From the graph and using the x-scale, determine the ionization potential for Ne / Hg.

Procedure 2:

- Switch to manual for the acceleration voltage on the operating unit.
- Darken room
- Slowly turn the acceleration voltage to medium
- Observe the tube and adjust the heating current for optimal results.
- Vary acceleration voltage
- Take note of your observations as the voltage varies.

CAUTION: KEEP THESE CRITERIA IN MIND

The collector electrode is negative with respect to the anode; be sure that the polarity of any indicators on the measurement amplifier are correct.

The emission current in the tube and therefore the collector current are influenced by the heating current. The heating current must be set (appropriate level when the bias is within the range 6 - 8 V) so that no independent discharge occurs at an acceleration of 70 V (recognizable by red light between the cathode and control grid).

A limiting resistor (kW) at the anode terminal of the tube prevents overloading. Even if an impact ionization discharge occurs in the tube as a result of excessive voltage, the tube will not be damaged.

The countervoltage between anode and collector electrode should be set between 6 and 10 V so that the minima (maximum number = 3) in the current/voltage curve are clearly recognizable. If the countervoltage is too high, a decreasing characteristic line occurs in some cases with negative collector current.

If the acceleration voltage is slowly raised from an initial value of zero, a reduction in collector current occurs starting at about 20 V. This is accompanied by the appearance of a glowing red layer at the anode. As the anode voltage is raised further, the collector current decreases and the glow movers toward the cathode. The collector current reaches a minimum when the glowing layer detaches from the anode. As the anode voltage is raised, a dark zone appears, followed by a second glowing layer (at about 40 V). In all, a maximum of two dark zones may be observed (layered positive column).

These layers are created as follows: Electrons emerging from the cathode begin their trajectory at a velocity close to zero, and are all accelerated by the same field, meaning that they also all reach the energy necessary for excitation in the same cross section. Excitation therefore occurs in a layer. In the process, however, all of the electrons lose their energy, begin again with a velocity close to zero, and so on. The layers naturally become blurred after a series of such cycles due to immediate statistical scattering of the excitation sites, and the column gradually becomes homogeneous again.

For exact evaluations of the current/voltage relationship the iron/barium contact potential of 2.5V must be subtracted from the acceleration voltage value.

The voltage difference between the first and second maximum indicates which excited state the electron is excited to. You will find that this value is consistent with the energy diagram for neon. The transitions between these two groups of excited states lie in the visible region, and are responsible for the appearance of glowing layers. This light is accessible to spectroscopic evaluation, and contains several strong spectral lines in the yellow and red regions. The transitions to the ground state lie in the far ultraviolet, and therefore cannot be studied.

For Your Labreport:

- An introduction including theory and relevant formulas for this lab and description of the experiment.
- A sketch of the experimental set-up and the cable connections to the oscilloscope.
- The procedure for the experiment including an explanation of why you perform each task
- The oscilloscope’s graph for Hg / Ne onto graph paper; label axis with correct units, zero level for x-axis, and the correct scale for x-axis.
- Include the ionizaton energy for Hg / Ne and how you derived that value.
- Describe the observations from procedure 2 and include an explanation in your own words using theory as to why you observed this occurance.

Questions:

- Explain in words what is plotted on your graph / oscilloscope? Why does the Franck-Hertz signal (FH signal) shows dips for certain accelation voltages?
- Lets assume the distance between cathode and control grid is 1 cm, and the distance between contral grid and anode is 0.25cm.
  A) Draw a sketch of the electrical potential as a function of distance for an acceleration voltage of 20V and a reverse bias of 2V.
  B) Draw a sketch of the kinetic energy of an electron as a function of distance in the above potential, as it undergoes inelastic collision with the gas (Ne/Hg).
- Why do you see light from the Neon / Hg tube? How is it created. Explain.
- Why does the light from the tube has a vertical pattern?

Conclusion:

- Write a short conclusion mentioning your result and discussing possible sources or error.
- Add comments and remarks regarding the lab and its write-up for improvement.

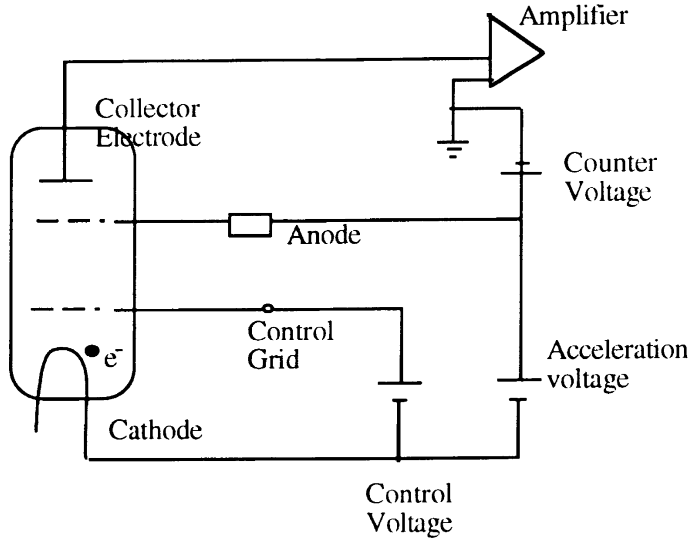

Figure 1

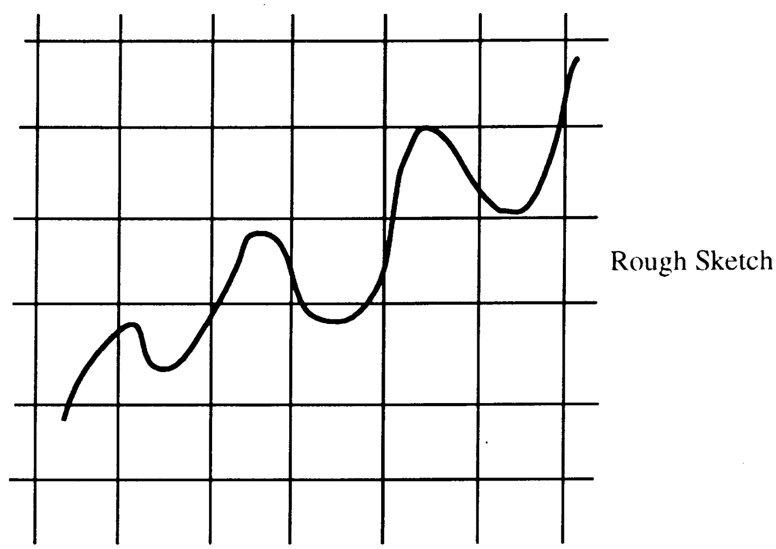

Figure 2