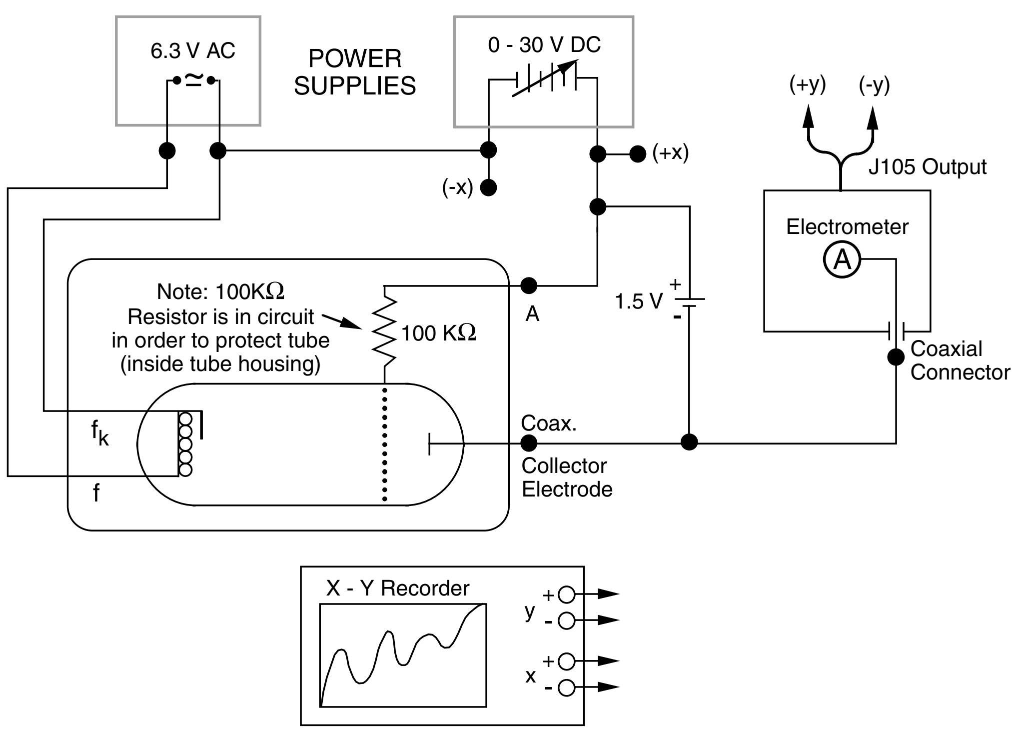
# IM.1. Franck-Hertz Experiment

## 1. Purpose:

Perform the historic Franck-Hertz experiment to demonstrate the existence of discrete energy levels in mercury, and to determine the minimum kinetic energy needed by an electron in order to collide inelastically with a mercury atom.

## 2. Apparatus:

Keithley 600 A Electometer
Power Supply 0 to 40 V DC for accelerating voltage
Power supply or transformer 6.3 V AC for heating of cathode
Franck-Hertz tube with heating oven
1.5 V battery
2 Voltmeters
X Y plotter



## 3. Description of experiment:

The Franck-Hertz tube serves primarily as an enclosed atmosphere of mercury vapor through which electrons are accelerated by means of a variable potential difference so that a range of electron energies is available.

The tube has three electrodes: an indirectly heated cathode as an electron source, a grid - form anode to which the accelerating potential difference is applied, and a plate which serves as an electron collector. A sensitive electroscope is connected to the collector electrode, so that the number of electrons reaching the collector plate may be measured. The mercury atmosphere is kept at the desired pressure by heating the tube in an electric oven, the temperature of the oven being controlled by thermostat.

Between the anode and the collector plate a small constant negative potential of 1.5 volt is applied. This is called the retarding voltage, and makes it necessary for an electron at the grid-anode to have at least 1.5 eV energy in order to reach the collector plate. As shall be shown later this retarding voltage helps to differentiate the electrons having inelastic collisions from those not having collisions.

As we increase the accelerating voltage we should expect the following to happen: Up to a certain voltage, say $V_1$, the plate current will increase as more electrons reach the plate. When we reach $V_1$, we note that the plate current, $I_p$, takes a sudden drop. This is due to the fact that the electrons just in front of the grid-anode have gained enough energy to collide inelastically with the mercury atoms. Having given all their energy to the mercury atom, they do not have sufficient energy to overcome the retarding voltage between grid-anode and collector electrode. This causes a decrease in the plate current $I_p$. Now as the voltage is again increased, the electrons obtain the energy necessary for inelastic collisions before they reach the anode. After the collision, by the time they reach the grid, they have obtained enough energy to overcome the retarding voltage and will reach the collector plate. Thus $I_p$ will increase. Again when a certain voltage $V_2$ is reached we note that $I_p$ drops. This means that the electrons have obtained enough energy to have two inelastic collisions before reaching the grid anode, but have not had enough remaining energy to overcome the retarding voltage. Increasing the voltage again, $I_p$ starts upward until a third value, $V_3$, of the voltage is reached when $I_p$ drops. This corresponds to the electrons having three inelastic collisions before reaching the anode, and so on. The interesting fact is that $V_3 - V_2$ equals $V_2 - V_1$ equals approximately 4.9 volts, which shows that the mercury atom has definite excitation levels and will not accept energy, except in quantized amounts, namely 4.9 electron volts.

When an electron has an inelastic collision with a mercury atom, it gives up all its energy to the atom. This transfer of energy causes one of the outer orbital electrons to be pushed up to the next higher energy level. This excited electron will within a very short time fall back into the ground state level, emitting energy in the form of photons. The original bombarding electron is again accelerated toward the grid anode. We see then that the excitation energy can be measured in two ways: by the method outlined above, or by spectroscopically analyzing the radiation emitted by the excited atom. The latter of these two methods is by far the more difficult to perform.

## 4. Caveat:

*Protect the tube from damage:*

The pressure of the mercury in the tube is a critical factor. If this pressure is too low, the mean free path of the electrons is too great, the probability of collision lowered thus some of the electrons would gain more energy than necessary for an inelastic collision with the mercury atom. If this energy were to equal or exceed the ionization potential of mercury, the mercury would ionize causing a rapid discharge at the plate into the electroscope. The ionization potential of mercury is approximately 10.4 electron volts. The manufacturers of the tube suggest a pressure of 15 to 20 mm of mercury within the tube. This corresponds to a tube temperature of around 180°C. Maintaining the correct temperature of the oven is a critical issue in this experiment. *Never operate the tube at temperatures outside the range* 150°C to 200°C.

*Contact potentials:*

Consideration of contact potentials is also necessary. In simple terms, this means that the accelerating potential is not completely converted into kinetic energy of the electrons: some of it provides the "work function" of the cathode material, i.e. the amount of energy (measured in electron volts) necessary to free the electrons from the cathode. The cathode is coated with a material with a relatively low work function. The collector plate, since it is used merely as electron collector, has a somewhat higher work function. The contact potential is the difference between the work functions, since they are oppositely directed in the electric field, that is, the electric field has to work against the cathode potential but is helped in the case of the collector plate. Thus we should expect that the voltage to the first peak will be greater than the average peak to peak voltage, due to the contact potential. The contact potential can be calculated as the average peak to peak voltage subtracted from the first peak voltage.

## Notes:

1) The data are recorded on a X-Y plotter. The recorder has two inputs (X-axis and Y-axis), both of which have high input impedances, so that they affect the remaining circuit very little. (i.e. the X-Y recorder is equivalent to two voltmeters). In this experiment the X-axis measures the accelerating voltage on $V_a$ between cathode and grid-anode, and the Y-axis measures the plate current. Thus a graph of plate current versus accelerating voltage is obtained directly on the X-Y recorder.

2) When using the X-Y recorder, the electrometer should be operated in the "fast" mode. The mode is determined by a switch on the back of the electrometer.

3) In case the X-Y plotter does not work, you have to use a voltmeter instead, and set the accelerating voltages by hand and record the output voltage (proportional to the current) of the electrometer.

4) A 100 kΩ current limiting resistor is incorporated in the circuit between the connecting

socket for the accelerating voltage and the anode of the tube, in order to protect the tube when a discharge occurs due to excessive accelerating voltage.

## Questions:

1) How would molecular contaminants in the tube affect your results?

2) How might your results be affected by the fact that the peaks are superimposed on a rising background current?

3) How does the current limiting resistor in the accelerating voltage circuit affect your measurement of the accelerating voltage? Do you have to worry about this?