

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: Electrometer (Keithley 600A)

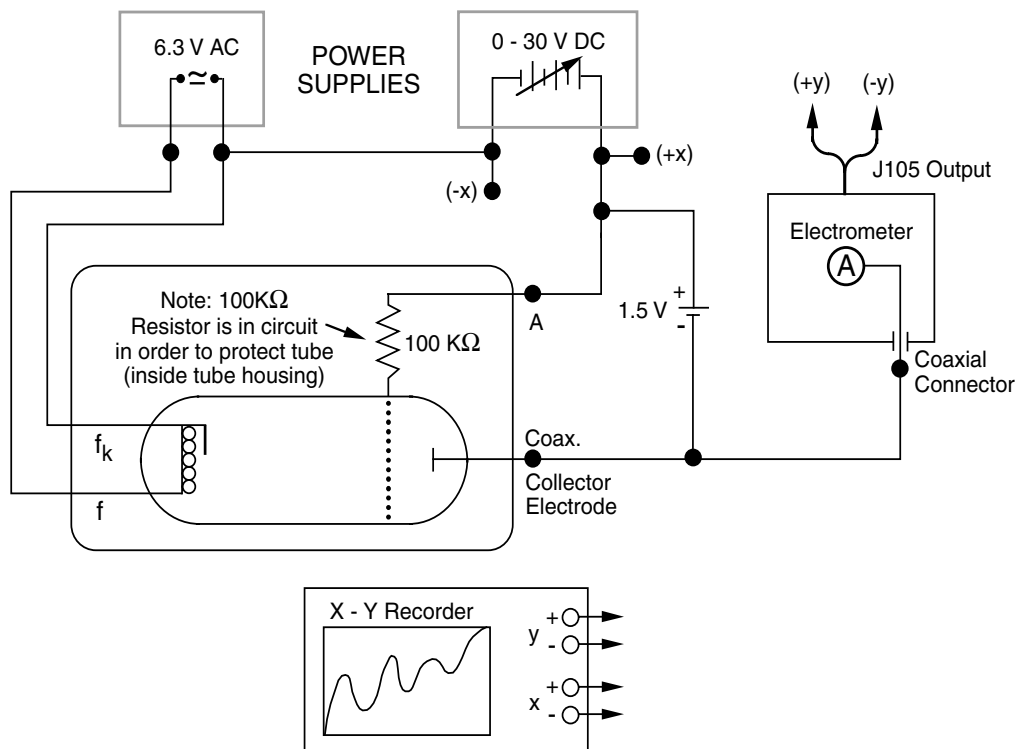
Power Supply 0 to 40 V DC for accelerating voltage

Power supply or transformer 6.3 V AC for heating of cathode

Franck-Hertz tube with heating oven

1.5 V battery

2 Voltmeters



3. Description of experiment:

The Franck-Hertz-Tube is an evacuated glass cylinder with three electrodes which contains a drop of highly purified mercury. The tube is mounted inside a thermostat-controlled oven which allows heating the tube so as to evaporate part of the mercury. The tube has three electrodes: an indirectly heated oxide-coated cathode as an electron source, a grid-form anode and a plate which serves as an electron collector. A variable potential difference is applied between the cathode and the anode so that electrons emitted from the cathode can be accelerated to a range of electron energies. 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. The distance between the cathode and the anode is large compared with the mean free path length in the mercury vapor atmosphere (at 180°C) in order to ensure a high collision probability. On the other hand, the separation between the anode and the collector electrode is small.

Between the anode and the collector plate a small constant negative potential of 1.5 volt ("retarding potential") is applied. The resulting electric field between anode and collector electrode opposes the motion of electrons to the collector electrode, so that electrons which have kinetic energy less than 1.5eV at the grid-anode cannot reach the collector plate. As will be shown later this retarding voltage helps to differentiate the electrons having inelastic collisions from those that don't.

A sensitive electrometer is connected to the collector electrode, so that the current due to the electrons reaching the collector plate may be measured. 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 lost 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, the kinetic energy lost to the atom 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 spectral analysis of 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 the inelastic collision with the mercury atom that we want to observe. If the electron energy were to equal or exceed the ionization potential of mercury (10.4 eV), the mercury would ionize causing a rapid discharge at the plate into the electroscopes. 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.* After turning on the oven, wait for about 10 minutes before applying the accelerating voltage. This is to ensure sufficiently high mercury vapor pressure for collisions to happen frequently (on the PHYWE oven, set the thermostat to 6). 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.

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.

Questions:

- (1) Should you use the positions of the peaks or of the valleys to determine the excitation energy? Or both? -- Explain.
- (2) How might your results be affected by the fact that the peaks are superimposed on a rising background current?
- (3) Why are the peaks and valleys smeared out rather than sharp?
- (4) How would increasing the temperature affect your observations? Would there be a higher or lower background current? Sharper or less sharp peaks? More peaks?
- (5) 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?
- (6) How would molecular contaminants in the tube affect your results?