<u>**The University of Hong Kong**</u>
<u>**Department of Physics**</u>

Physics Laboratory
PHYS3760 Physics Laboratory
Experiment No. PHYS3760-1: Franck-Hertz Experiment

Name:
University No:

Aim:

To study the collisions of electrons with mercury atoms as a function of electron energy. Hence can be determined the first excitation energy of the mercury atom and the contact potential of the electrodes of the tube. This experiment partially demonstrates the quantized (discrete) energy spectrum of atoms as predicted by quantum mechanics.

Background:

In 1914, J. Franck and G. Hertz reported observing discontinuous energy emission when electrons passed through mercury (Hg) vapor, and the resulting emission of the ultraviolet (UV) spectral line (λ = 254 nm) of Hg. A few months later, N. Bohr recognized that their experiment supported his model of the quantized orbits and energies of electron in an atom. The Franck-Hertz experiment showed that an electron must have a certain minimum energy to make an inelastic collision with an atom (we now interpret that minimum energy as the energy of an excited state of the atom). Franck-Hertz were awarded the 1925 Nobel Prize in physics for this work.

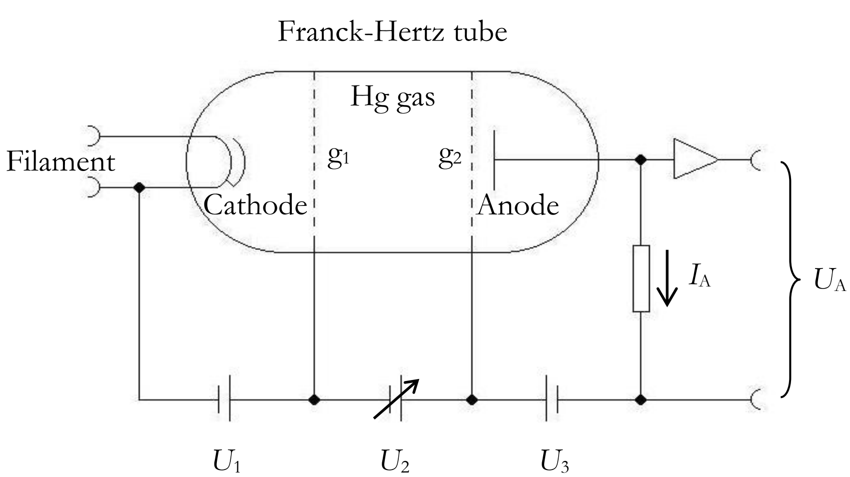

Figure 1. Schematic circuit diagram.

In Fig. 1, electrons from a thermionic filament are accelerated by a voltage U_2 in the Franck-Hertz tube containing Hg vapor (at a pressure of about 15-20 mm Hg). Without energy loss, the energy gained by the electrons on reaching the grid g_2 is eU_2 (in eV). A small retarding voltage U_3 exists between g_2 and the anode. When the energy of the electrons on arriving at g_2 is larger than this retarding voltage, those electrons will be collected and give rise to a current (*i.e.*, anode current I_A). As U_2 is increased, more and more electrons acquire sufficient energy to overcome U_3 and thus I_A rises rapidly. When U_2 reaches a value so that the electron has enough energy to raise a mercury atom from its ground state to an excited state of energy of about 4.9 eV, the electron will transfer all this energy to an Hg atom if it collides with one, and will not have enough energy left to overcome U_3. Thus, at this value of U_2, I_A will drop sharply. I_A will increase again when the electrons are accelerated such that they have enough energy left after a collision to overcome U_3, and then fall again when the electron energy coincides with another energy level of the Hg atom. This gives a direct evidence for the existence of atomic excited states. The states involved are the 6^1S_0 ground state and the 6^3P_1 first excited state. There is in fact a state with slightly lower energy, 6^3P_0, which is not excited in this experiment. The experiment demonstrates that energy absorption by the atom only occurs when the kinetic energy of the colliding electron reaches certain discrete values. This demonstrates that the energy eigenvalues of the atom are quantized (discrete).

Experiment:

Apparatus:

- A mercury Franck-Hertz tube
- A socket for Franck-Hertz tube (DIN connector)
- An electric oven
- A Franck-Hertz control unit
- A NiCr-Ni temperature sensor
- A 2-channel oscilloscope

Set-up

(see Fig. 2)

Figure 2. Set-up.

Procedure:

1. The electrodes are contained in a glass tube (the Hg Franck-Hertz tube), and the voltage leads should be connected to the control unit. This tube, surrounded by a shield, should be placed in the electric oven. Make sure that this shield is well grounded. The temperature of the oven is monitored by a NiCr-Ni thermocouple sensor which should be inserted into the small hole in the wall of the oven.
2. The control unit maintains the temperature at a preset value ϑ_S (180–190°C). Use a fine screwdriver to adjust the ϑ_S-potentiometer if necessary.
3. Set the selector switch to MAN (manual). Set U_1, U_2, and U_3 to zero. Then switch on the control unit.
4. Monitor the oven temperature ϑ. When it has settled down to the preset value, use the oscilloscope to determine the optimum voltage settings as follows. The current I_A (~ 10^{-8}–10^{-9} A) is amplified inside the control unit to produce an output voltage U_A which is proportional to I_A. Connect the outputs U_A and U_2 (actually $U_2/10$ on the panel of the control unit) respectively to the Y- and the X-channels of the oscilloscope (set in X-Y mode). Set the small retarding voltage U_3 in the range of 2–3 V. Set the selector switch to AUTO (automatic). This causes the accelerating voltage to sweep from zero to about 30 V repeatedly. By adjusting the voltage U_1 on the space-charge grid g_1 (which controls the current), a value should be found to produce a pattern of Franck-Hertz current peaks on the oscilloscope. Fine tune U_1 and U_3 to get an optimum trace containing about 5 peaks. These values of U_1 and U_3 are the optimum voltage settings.
5. Now remove the oscilloscope and set the selector switch back to MAN. Measure U_A as a function of U_2 (where U_2 lie in the range 0–30 V) and plot the data. Hence determine the first excitation energy of the mercury atom and the contact potential of the electrodes of the tube from the graph. Also calculate the wavelength corresponding to de-excitation of the Hg atoms. Note the separation between the peaks gives the first excitation energy and the position of the first peak is displaced by the contact potential.

Note that error analysis should be included in the calculations.

References:

1. A.C. Melissinos, *Experiments in Modern Physics* (Academic Press, New York, 1966).
2. D.W. Preston and E.R. Dietz, *The Art of Experimental Physics* (Wiley, New York, 1991).
3. T. Duncan, *Practical Modern Physics* (John Murray, London, 1967).
4. E.E. Anderson, *Modern Physics and Quantum Mechanics* (Saunders, Philadelphia, 1971).