2. Theory

According to Bohr's theory, atoms can only remain stable in some specific states (i.e. steady-states). Each of which corresponds to a certain amount of energy, and the steady-state energy is discrete. Atoms can only absorb or release energy equivalent to the energy difference between two discrete states. To excite an atom from the ground state to the first excitation state, the impact energy must be greater than the energy difference between the two states. Franck-Hertz experiment implements the energy exchange for state transitions through the collisions of atoms with electrons of certain energy, which is obtained by applying an accelerating electric field. The process can be represented by using the equation below:

$$\frac{1}{2}m_e v^2 \geq eV_1 = E_1 - E_0$$

where e, m_e, and ν are the charge, mass and speed (before collision) of an electron, respectively; E_1 and E_0 are the energy of the atom at the first excitation and the ground states, respectively; V_1 is the minimum voltage of an accelerating field required to excite the atom from the ground state to the first excitation state, called the first excitation potential of the atom. eV_1 is therefore called as the first excitation potential energy.

The principle of Franck-Hertz experiment is shown in Figure 1. A drop of mercury is contained in a vacuumed tube (F-H tube). After the tube is heated to a certain temperature in a furnace, the liquid mercury becomes vapor and fills the tube. Electrons are emitted from hot cathode K. A relatively low voltage V_{G1K} is applied between cathode K and grid G_1 to control the electron flow entering the collision region. An adjustable accelerating voltage V_{G2K} is applied between grid G_2 and cathode K to accelerate electrons to desired energy. A retarding voltage V_{G2P} is applied between anode P and grid G_2. The electric potential distribution in the F-H tube is shown in Figure 2. When electrons pass through grid G_2, with energy higher than eV_{G2P}, they can arrive at anode P to form current I_P.

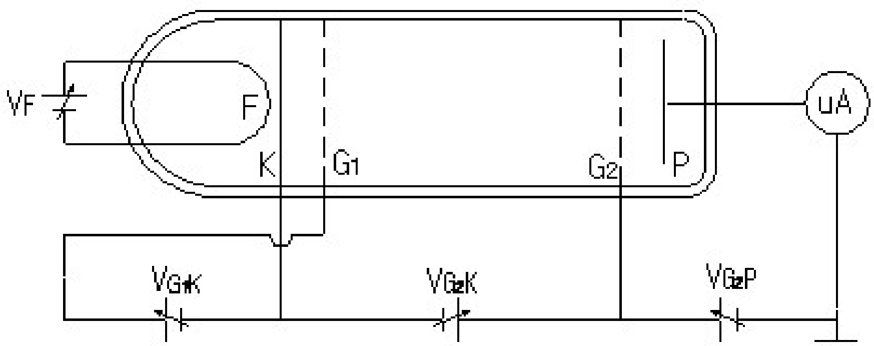

Figure 1 Schematic of Franck-Hertz experiment

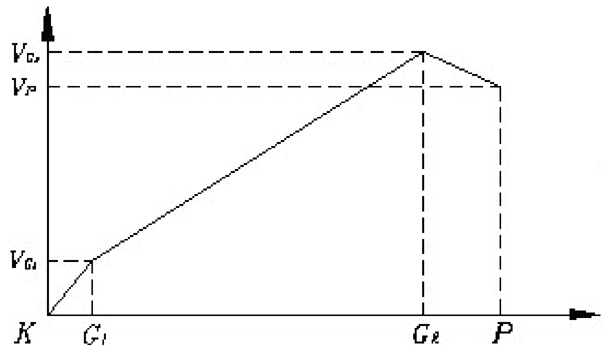

Figure 2 Schematic of potential distribution in the F-H tube

Initially, accelerating voltage V_{G2K} is relatively low and the energy of electrons arriving at grid G_2 is less than eV_{G2P}, so the electrons cannot reach anode P to form a current. By increasing V_{G2K}, the electron energy increases accordingly (the number of electrons with energy higher than eV_{G2P} increases too), so current I_p rises to the point that electron energy is higher than the first excitation potential energy eV_1 and electrons pass energy eV_1 to atoms by inelastic collisions. As a result, electron energy is less than eV_{G2P}, leading to a reduced anode current I_p.

By continuously increasing V_{G2K}, anode current I_p rises again until the electrons regain energy eV_1. Due to the inelastic collisions between electrons and atoms for the second time, anode current reduces again. By increasing V_{G2K} from low to high, multiple inelastic collisions occur between electrons and mercury atoms leading to multiple rise/fall cycles as shown in Figure 3, where V_o is eV_1 and V_c is contact potential.

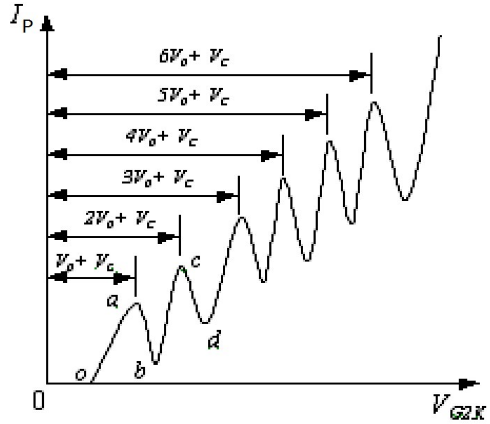

Figure 3 Relationship curve of anode current I_p and accelerating voltage V_{G2K}

For mercury atoms, the voltage difference between adjacent valleys or peaks as shown in Figure 3 is the 1st excitation potential of an mercury atom, which proves the discontinuity of mercury atomic energy states.

The absorbed energy of the mercury atom will be released through electron transition to lower state, giving off a strong emission spectral line corresponding to an energy of eV_1. According to published literatures, the measured mercury atom resonance line is 254 nm (or 4.9 eV). Using the acquired 1st excitation potential, Planck's constant h can be calculated based on the formula: $h = eV_1\lambda / c$, where e=1.602×10^{-19} C, λ=254 nm, and c=3× 10^8 m/s.

In the above experiment of measuring the first excitation potential of mercury atoms, the temperature of the F-H tube is relatively high that results a high vapor pressure of mercury and high density of mercury atoms, so that the free path of electrons is relatively short and the probability of electrons colliding with mercury atoms is high, which makes the electrons kinetic energy can hardly exceed 4.9 eV.

In order to measure the higher excitation state of the mercury atom, the kinetic energy of the electron must be greater than 4.9 eV. Therefore, the mean free path of the electron must be increased firstly, so that the electron obtains a higher kinetic energy before colliding with the mercury atom. This can be achieved through the two actions: (1) lower the temperature of the F-H tube (to be 100 °C ~ 130 °C) to reduce the density of mercury atoms, and (2) modify the wiring connections of the F-H tube with the controller.

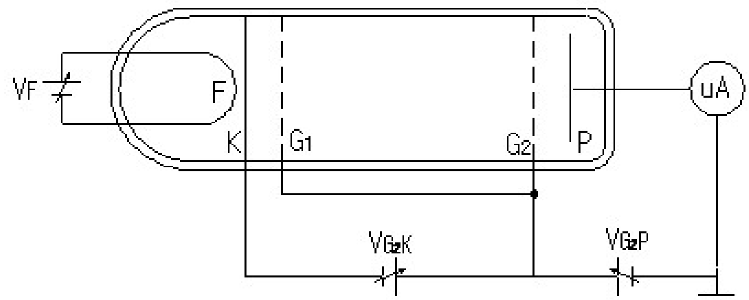

Figure 4 Wiring schematic for measuring excitation potentials of higher levels.

As shown in Figure 4, the accelerating voltage V_{G2K} is applied to the grid G_1 by connecting grids G_1 and G_2 together (or applying a fixed small voltage (e. g. 1 V) in between G_1 and G_2) to form a collision zone. The retarding zone is still between G_2 and P. This way, the electrons are accelerated to a high kinetic energy within a short distance between K and G_1 to reduce the probability of collision.

Various parameters should be adjusted to achieve the best working conditions for measuring excitation potentials of higher levels, such as the temperature of the F-H tube, the filament voltage and the retarding voltage.

3. Structure and Specifications

A. <u>Structure</u>

This apparatus consists of a main electronic unit for the control and measurement of voltage and current, a temperature controller and a furnace for heating mercury filled tube. A picture of the apparatus is shown in Figure 5.

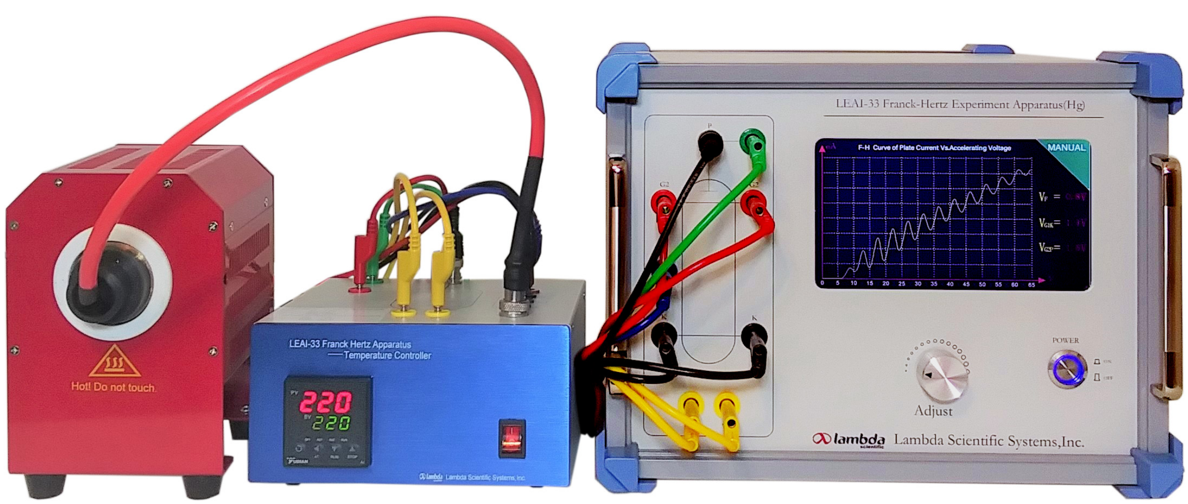

Figure 5 A photo of the apparatus

B. Specifications

1. Supplied voltages for Frank-Hertz tube:

   a. Filament voltage V_F: DC 0～6.5 V, adjustable.

      Filament temperature has a significant impact on the emission coefficient of cathode. The breakdown voltage of the tube reduces with an increase in anode P current. A low temperature cathode causes a narrow velocity distribution of emitted electrons, thus reducing current I_P, and elevating breakdown voltage.

   b. Grid voltage V_{G1K}: DC 0～12 V, adjustable.

      It is used to eliminate the electron accumulation effect near the cathode and control the intensity of the electron flow emitted by the cathode. If V_{G1K} is too high, it will reduce the electron flow entering the collision region leading to a reduced anode current I_P. Because the cathode emission coefficient varies from tube to tube, V_{G1K} should be optimized in the experiment.

   c. Accelerating voltage V_{G2K}: DC 0～99 V, adjustable.

      The upper limit of this voltage is not to result in a breakdown of the tube.

   d. Retarding voltage V_{G2P}: DC 0～15 V, adjustable.

      It prevents low energy electrons near grid G_2 from reaching anode P. Higher V_{G2P} results in lower I_P.

   ***Note**: A set of voltages will be shown on the back panel of the apparatus for reference settings, but these settings should be optimized in actual experiment.

2. Micro current measurement range: 0.001 nA - 1.999 uA, accuracy ±1%.

3. Four sets of voltages and F-H curve are displayed on a 7-inch LCD screen. Display resolution 1024×600;

4. Dimensions of F-H mercury tube: diameter 18 mm, height 50 mm.

5. Working mode:

   Manual measurement: record data point by point;

Automatic measurement: system increases the accelerating voltage step by step while measure and record plate current; under this mode, the system periodically outputs the measurement data to the built-in LCD screen to display the curve, or the data can be export to a PC via USB cable and then the results can be further graphed and analyzed by using other graphic software.

6. Peaks of F-H curve: more than 10 with mercury tube 160 ℃ - 220 ℃.