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 the energy amount that is 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 not be less 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. The electron energy 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 v are the charge, mass and speed (before collision) of an electron, respectively. E_1 and E_0 are the energy of an atom at the 1st excitation state and the ground state, respectively. V_1 is the minimum voltage of the accelerating field required to excite the atom from the ground state to the 1st excitation state, which is called as the first excitation potential of the atom. eV_1 is therefore called as the 1st excitation potential energy.

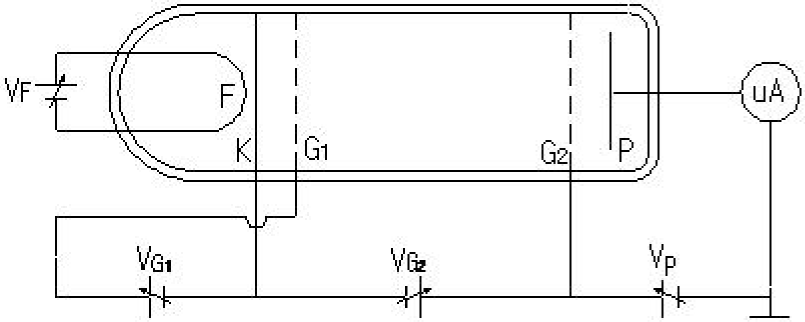

Figure 1 Schematic of Franck-Hertz experiment

The principle of the Franck-Hertz experiment is shown in Figure 1. In an Argon-filled Franck-Hertz tube (F-H tube), electrons are emitted from hot cathode K. A relatively low voltage V_{G1} is applied between cathode K and grid G_1 to control the electron flow entering the collision region. An adjustable accelerating voltage, V_{G2}, is applied between grid G_2 and cathode K to accelerate electrons to desired energy. A braking voltage V_p 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, they can arrive at anode P to form current I_p if their energy is higher than eV_p.

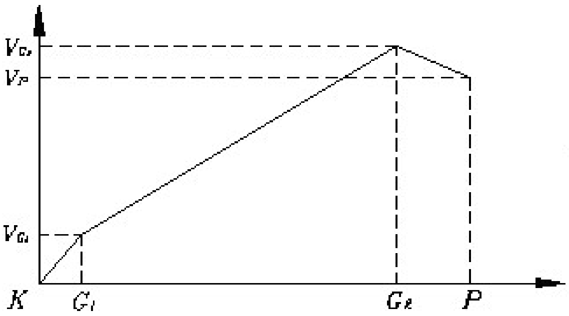

Figure 2 Schematic of potential distribution in the F-H tube

At the beginning, accelerating voltage V_{G2} is relatively low, the energy of electrons arriving at grid G_2 is less than eV_p, so the electrons cannot reach anode P to form a current. By increasing V_{G2}, the electron energy increases accordingly, so does current I_p. As a result, the electrons with energy larger than the 1st excitation potential energy pass energy amount eV_1 to the argon atoms by inelastic collisions, and subsequently their residual energy is less than eV_p, resulting in a decrease in anode current I_p.

By continuously increasing V_{G2}, anode current I_p increases again. The electrons regain energy over the 1st excitation potential energy and then lose energy amount eV_1 to argon atoms due to the second inelastic collision, leading to the second decline in anode current. By continuously increasing V_{G2}, multiple inelastic collisions occur between electrons and Argon atoms. There will be multiple rise/fall cycles on the I_P~V_{G_2} curve, as shown in Figure 3.

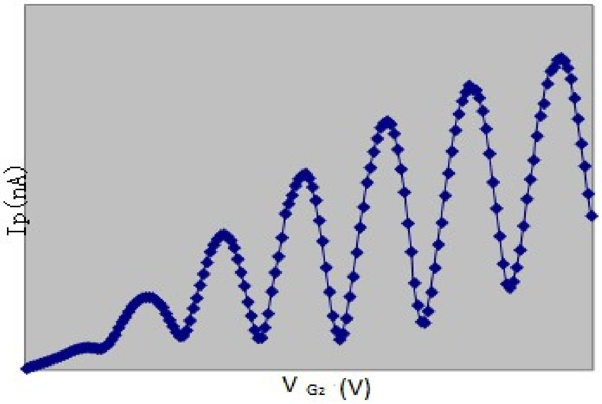

Figure 3 Relationship curve of anode current I_p with accelerating voltage V_{G_2}

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

The absorbed energy of the argon atom will be released through electron transition to lower state, and therefore a strong emission spectral line can be found that is corresponding to an energy of eV_1. According to published literatures, the measured argon atom resonance line is 106.7 nm (or 11.62 eV). Using the acquired 1st excitation potential, Planck's constant h can be calculated based on the formula: $h = eV_1\lambda / c$, where $e=1.602\times10^{-19}$ C, $\lambda=106.7$ nm, and $c=3\times10^{8}$ m/s.