

## Franck-Hertz experiment using Neon tube

### Objective:

Study of quantized excitation of Neon atoms by inelastic scattering and determine the excitation energy.

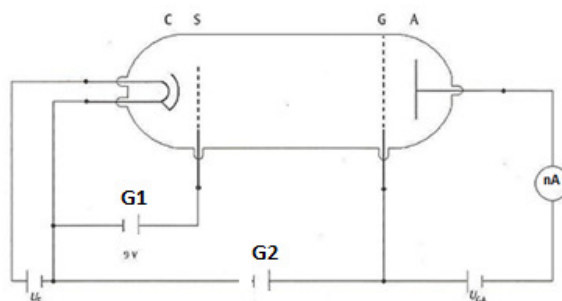
### Introduction:

Franck and Hertz described the first observation of quantized excitation in 1914; one year after Bohr published his theory of the hydrogen atom with its concept of quantized energy states. They discovered that electrons moving through the Hg vapour with an energy equal to or greater than a certain critical value (4.9eV) can excite the 253.6 nm line of Hg. Electrons with less than the critical merely bounce off elastically when they collide with Hg atom and fail to excite any electromagnetic radiation at all. This experiment provided crucial evidence in favor of Bohr Theory.

In this experiment excitation of Ne atoms is studied by inelastic collision with electrons. The electrons emitted from the indirectly heated cathode of a tetrode filled with neon vapors are accelerated. The excited atoms emit visible light that can be viewed directly. The excitation energy of neon is determined from the distance between the equidistant maxima of the electron current in variable opposing electric field.

### Experimental set up:

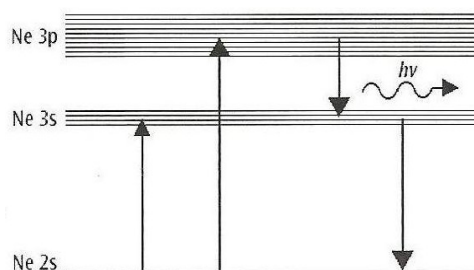
The set up uses a tetrode as a Franck-Hertz tube. It has an indirectly heated barium oxide cathode (C), two mesh-type grids (control grid S and anode grid G) and an anode (A) as shown in Fig. 1. The electrodes are in a plane-parallel configuration. The distance between the control grid and the anode grid is about 5 mm, and the distances between the cathode and the control grid and between the anode grid and anode are about 2 mm each. The tube is filled with neon gas at a pressure chosen to give an optimum characteristic curve, which is in the region of several hundred Pascals.



**Figure 1:** Franck-Hertz tube filled with Ne (C: cathode, S: control grid, G: anode grid, A: anode).

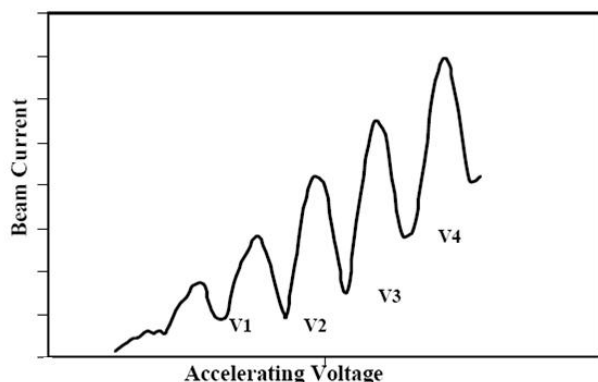
### Theory:

Neon atoms are excited by inelastic collision with electrons emitted by the cathode in a Frank-Hertz tube. The cathode in the tube is heated by a filament to emit electrons in a process called thermionic emission. After absorbing energy from collisions, electrons in Ne atoms are excited and subsequently de-excited to produce a visible glow in the gas that can be viewed directly. The energy level diagram for Ne is shown in Fig. 2. The most probable excitation through inelastic electron collision takes place from the ground state to the ten 3p-states, which are between 18.4 eV and 19.0 eV above the ground state. The four lower 3s-states in the range from 16.6 eV and 16.9 eV are excited with a lower probability. The de-excitation of the 3p states to the ground is only possible via the 3s-states. The 3p-3s transition leads to emission of a photon. The light emitted in this process lies in the visible range between red and green, and can thus be observed with the naked eye.



**Figure 2:** Energy level diagram for Ne

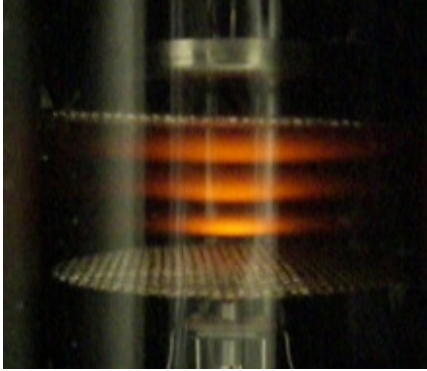
In the Franck-Hertz tube, electrons are emitted from the cathode and form a charge cloud. These electrons are accelerated by the driving potential  $G1$  between the cathode and control grid  $S$ . A braking voltage  $U_{GA}$  is present between  $G$  and anode  $A$ . Only electrons with sufficient kinetic energy can reach the anode and contribute to the collector current. A typical plate current versus accelerating voltage characteristics is shown in Fig. 3. As the acceleration voltage  $G2$  is increased while  $U_F$ ,  $G1$  and  $U_{GA}$  are held constant, the corresponding collector current initially increases, It reaches a maximum when the kinetic energy of the electrons closely in front of grid  $G2$  is just sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current



**Figure 3:** Typical Franck-Hertz curve showing plate current versus accelerating voltage characteristics.

reaches a maximum when the kinetic energy of the electrons closely in front of grid  $G2$  is just sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current

drops off dramatically, as after collision the electrons can no longer overcome the braking voltage  $U_{GA}$ . As the acceleration voltage  $U_2$  increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from grid G2. After collision, they are accelerated once



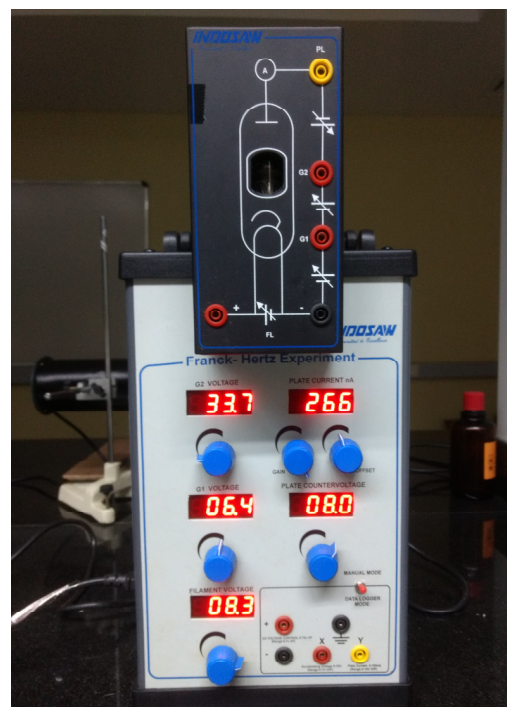
**Figure 4:** Visible luminescence layers between grids.

more and, when the acceleration voltage is sufficient, they again absorb so much energy from the electrical field that they can excite a neon atom. The result is a second maximum, and at greater voltages  $U_2$  further maxima of the collector currents are observed. At higher acceleration voltages, we can observe discrete red luminance layers between grids G1 and G2 as shown in Fig. 4.

Franck and Hertz used their data to measure the threshold voltage  $V$  at which the photons appeared and then derived a value for Planck's constant  $h/2\pi = (eV/c)\lambda$  which agreed with the values previously obtained by Planck, Einstein and Bohr from Blackbody radiations, Photoelectric effect and Hydrogen spectrum respectively. This was a striking confirmation of new quantum theory.

### Procedure

1. The Neon tube unit is mounted on the 4mm socket provided on the top of the Franck Hertz base unit as shown in Fig. 5.
2. Put the toggle switch in manual mode.
3. Set the all control knobs at extreme anticlockwise position of the Franck Hertz base unit.
4. Connect the Franck Hertz base unit plug to mains, switch ON the Unit.
5. Now set the filament voltage,  $U_F$ , at 8.2V to 8.5 V approx, and wait for 3-5 minutes.



**Figure 5:** Franck-Hertz set up

6. Set  $G_1$  at 6 - 8V and  $U_{GA}$  at 7 - 9V approximately.
7. Set the GAIN knob at maximum position (extreme clockwise direction) and adjust the plate (anode) current to zero using OFFSET knob.
8. Keeping the  $U_F$ ,  $G_1$  and  $U_{GA}$  fixed, slowly vary the acceleration voltage  $G_2$  and record the corresponding plate current.

**Note:** Sometimes due to double and multiple collisions of electrons and combinations of excitation of 3S level and 3P level, there may be small variations in plate current measured in nano-ampere. In such case, take the mean of minimum and maximum readings keeping  $G_2$  constant.

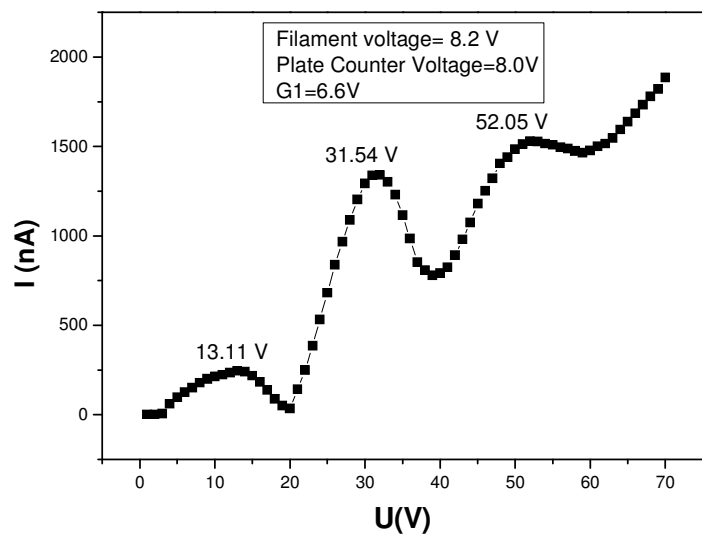
9. Repeat the experiment for different filament voltage,  $G_1$  or  $U_{GA}$ . After setting all the parameters, switch on the ON/OFF switch before taking the readings.
10. Analyze the curve to obtain explicit values of the maxima and minima of the curve.

**Observations:**

**Table.1:**  $U_F = \dots$  ,  $G_1 = \dots$  ,  $U_{GA} = \dots$

Accelerating voltage, $G_2$ (V)	..	..	..	..
Plate current (nA)			..	..

**Graph:** Plot plate current ~ accelerating voltage. A sample graph is shown in Fig. 6. Determine the distance between two consecutive maxima and calculate the excitation energy. Find the average excitation energy in eV.



**Figure 6:** Sample graph

**Precautions:**

1. Vary all the knobs slowly.
2. Filament voltage should never exceed 8.5V.

**References:**

1. American Journal of Physics, **56(8)**, August 1988.
2. D. Halliday and R. Resnick: Fundamental of Physics, New York, John Wiley, 3<sup>rd</sup> edition 1988, pp. 491-492.
3. R. Eisberg and R. Resnick: Quantum physics of Atoms, Molecules, Solids, Nuclei and Particles, pp 107-110 (F-H effect in Hg), pp 407-409(contact potential, thermionic emission).
4. D. W. Preston and E. R. Dietz: the art of Experimental Physics, Experiment 6, pp 197-208.