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 Franck-Hertz tube is a tetrode with an indirectly heated barium oxide cathode K, a mesh-type control grid G, a mesh-type anode A, and a collector electrode E (see 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 cath-ode and the control grid and between the anode and the collector electrode are both about 2 mm. The tube is supplied already filled with neon gas at a pressure chosen to give an optimum characteristic curve, which is in the region of several hundred Pascal.

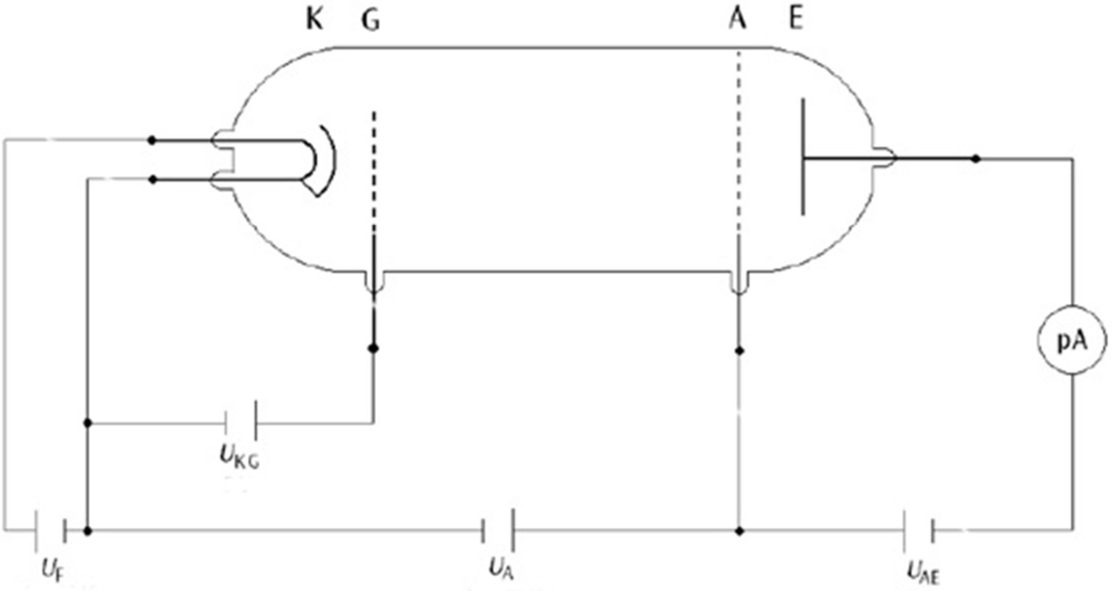

Fig. 1 Schematic of set up for measuring the Franck-Hertz curve for neon (K cathode, G control grid, A anode, E collector electrode)

The connecting sockets for the heater, control grid and anode grid voltages are on the base of the instrument (Fig.1b). The collector current is taken off through the BNC socket at the top end of the screening cylinder. An internal 10 kΩ limiting resistor is permanently built in between the connector sockets for the accelerator (control grid) voltage and the anode voltage. This protects the tube in case there is a spark discharge caused by applying too high a voltage. The voltage loss in this resistor when making measurements is negligible, as the anode current in the tube is smaller than 5 pA. (Thus the voltage loss in the protecting resistor is 0.05 V.)

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

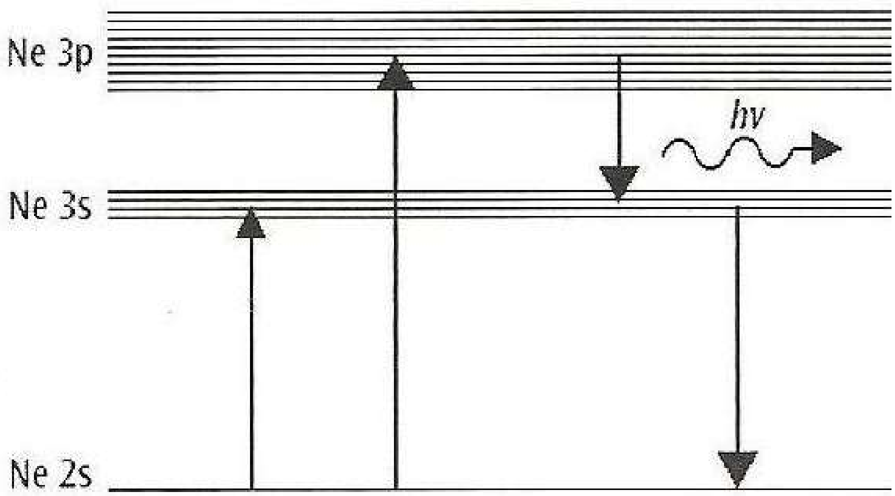

Figure 2: Energy level diagram for Ne

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.

In the Franck-Hertz tube, electrons are emitted from the cathode and form a charge cloud. These electrons are accelerated by the accelerating voltage U_A between the cathode K and anode A. A braking voltage U_{AE} is present between anode A and collector electrode E. Only electrons with sufficient kinetic energy can reach the electrode E and contribute to the collector current. A typical plate current versus accelerating voltage characteristics is shown in Fig. 3. As the

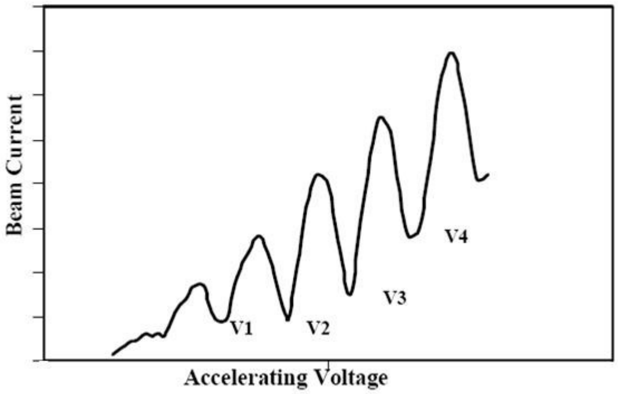

Figure 3: Typical Franck-Hertz curve showing plate current versus accelerating voltage characteristics.

acceleration voltage U_A is increased while U_F, U_{KG} and U_{AE} are held constant, the corresponding collector current initially increases, It reaches a maximum when the kinetic energy of the electrons closely in front of Anode A 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_{AE}. As the acceleration voltage U_A increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from anode A. After collision, they are accelerated once more and, when the acceleration voltage is sufficient, 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_A further maxima of the collector currents are observed. At higher acceleration voltages, we can observe discrete red luminance layers between grid G and anode A as shown in Fig. 4.

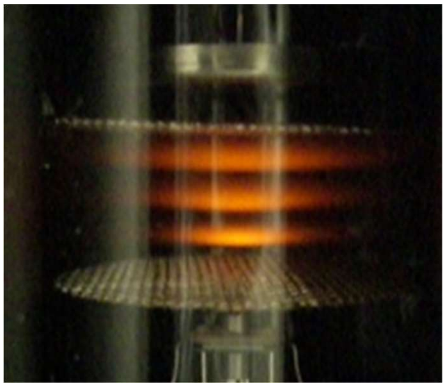

Figure 4: Visible luminescence layers between grids.

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. Put the selector switch in manual mode. (operating unit and neon tube are shown in Figs.5 and 6)
2. Set the all control knobs at extreme anticlockwise position of the Franck Hertz base unit.
3. Connect the Franck Hertz operating unit plug to mains, switch ON the Unit.
4. Gradually increase the filament (heater) voltage U_F till the filament starts glowing. Approximate filament voltage, U_F, 8 V to 9 V, and wait for 3-5 minutes. (observe what happens if the filament voltage is less than 8 V and more than 9 Volt and infer why this is the range suggested)
5. Set U_{KG} at 4 – 6 V and U_{AE} at 4 – 8 V approximately.
6. Keeping the U_F, U_{KG} and U_{AE} fixed, slowly vary the acceleration voltage U_A from 0-80 V and record the corresponding collector 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 U_A constant.
7. Repeat the experiment for different filament voltage U_F, U_{KG}. If required adjust the $U_{AE.}$
8. Analyze the curve to obtain explicit values of the maxima and minima of the curve.
9. This experiment can also be performed using Oscilloscope with Ramp mode.

1 Display
2 Rotary knob for heater voltage
3 Heater voltage output
4 Cathode output
5 Control grid output
6 Rotary knob for control voltage
7 Rotary knob for “minimum accelerating voltage”
8 Accelerating voltage output
9 “Man(ual)”/“Ramp” selector switch
10 Rotary knob for “maximum accelerating voltage”
11 Output “accelerating voltage/10”
12 Ground socket
13 F/H signal output
14 Rotary knob for F/H signal amplitude
15 F/H signal input
16 “Polarity of reverse bias” selector switch
17 Rotary knob for reverse bias
18 Power switch (back side)

Fig.5 Frank Hertz operating unit

1 BNC connector
2 Screening cylinder with observation window
3 Franck-Hertz tube
4 Base with connector sockets

Fig.6 Neon tetrode tube with connectors

Observations:

Table.1: U_F = … ,U_{KG} = …., U_{AG} = …..

Accelerating voltage, U_A (V)	..	..	..	..
Collector current (nA)			..	..

Graph: Plot collector current ~ accelerating voltage. Determine the distance between two consecutive maxima and calculate the excitation energy. Find the average excitation energy in eV.

References:

1. American Journal of Physics, **56(8)**, August 1988.
2. D. Halliday and R. Resnick: Fundamental of Physics, New York, John Wiley, 3rd 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.