

Franck-Hertz experiment using Neon tube

1 Objective

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

2 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 (4.9 eV) 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.

3 Experimental setup

The Franck-Hertz tube is a tetrode with an indirectly heated barium oxide cathode C, 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 cathode 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.

The connecting sockets for the heater, control grid and anode grid voltages are on the base of the instrument (See Fig. 1). The collector current is taken off through the BNC socket at the top end of the screening cylinder. An internal 10 k Ω 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.)

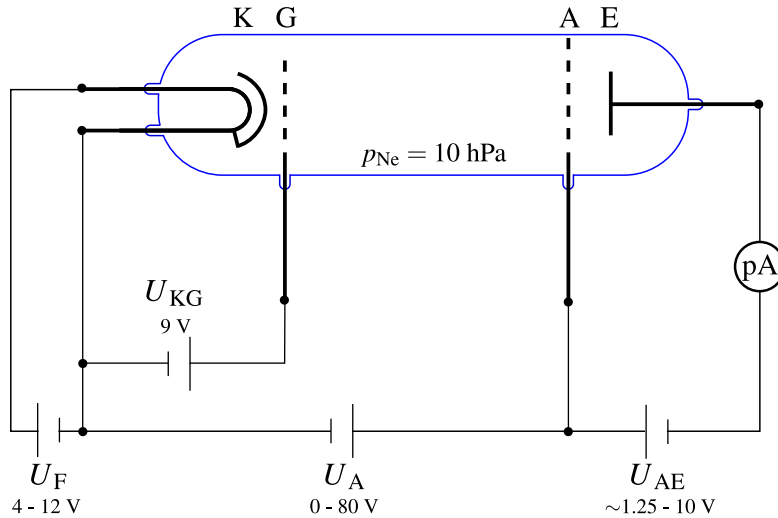


Figure 1: Schematic of set up for measuring the Franck-Hertz curve for neon. (C cathode, G control grid, A anode, E collector electrode)

Table 1: Technical data

| | |
|------------------------------|--------------------------------------|
| Filament voltage | : 4 - 12 V |
| Control voltage | : 9 V |
| Maximum accelerating voltage | : 80 V |
| Counter voltage | : 1.2 - 10 V |
| Approximated tube dimensions | : 130 mm (height) × 26 mm (diameter) |

4 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(a). 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.

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. 2(b). As the acceleration voltage U_A is increased

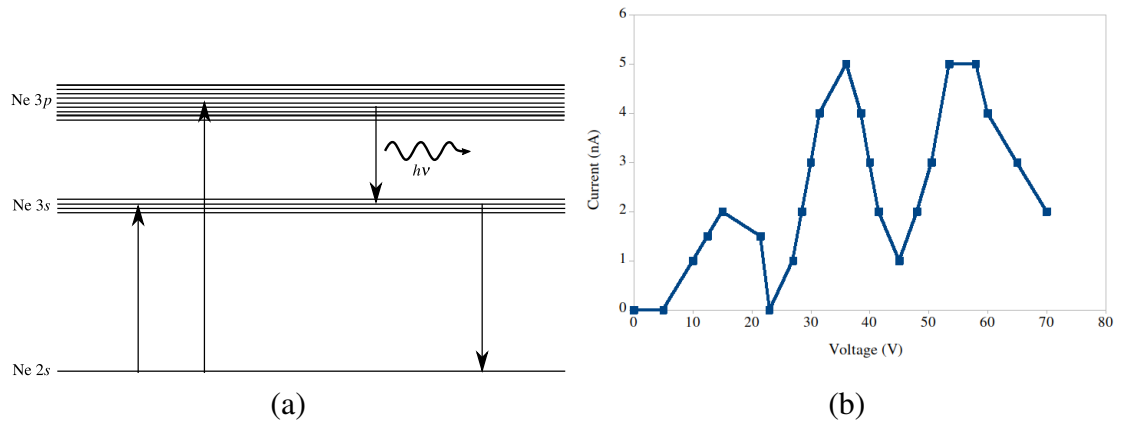


Figure 2: (a) Atomic energy levels of Neon. (b) Sample data obtained from the experiment.

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. 3.

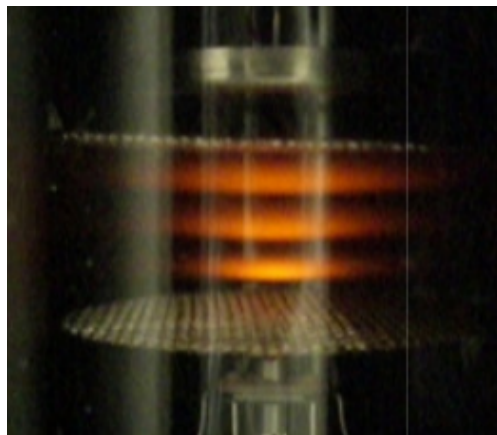


Figure 3: Luminance layers visible in the Franck-Hertz tube.

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.

5 Procedure

1. Put the selector switch in manual mode. (Operating unit and neon tube are shown in Fig. 4 and Fig. 5)

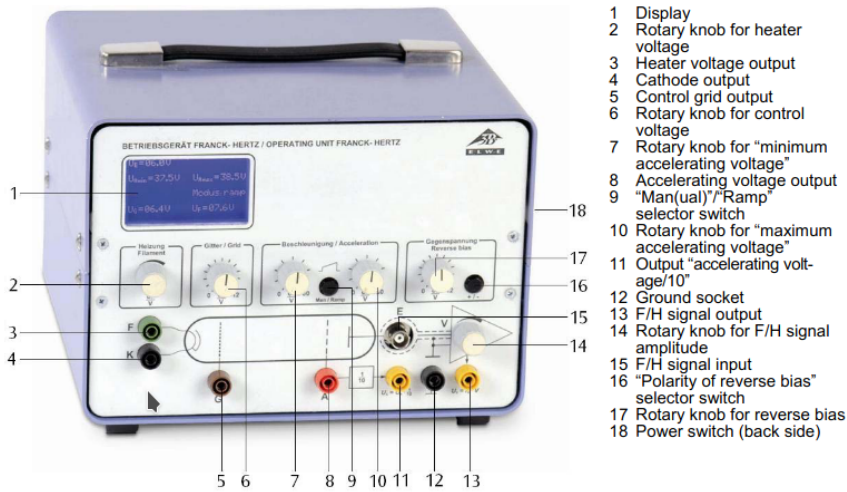


Figure 4: Franck-Hertz operating unit connections.

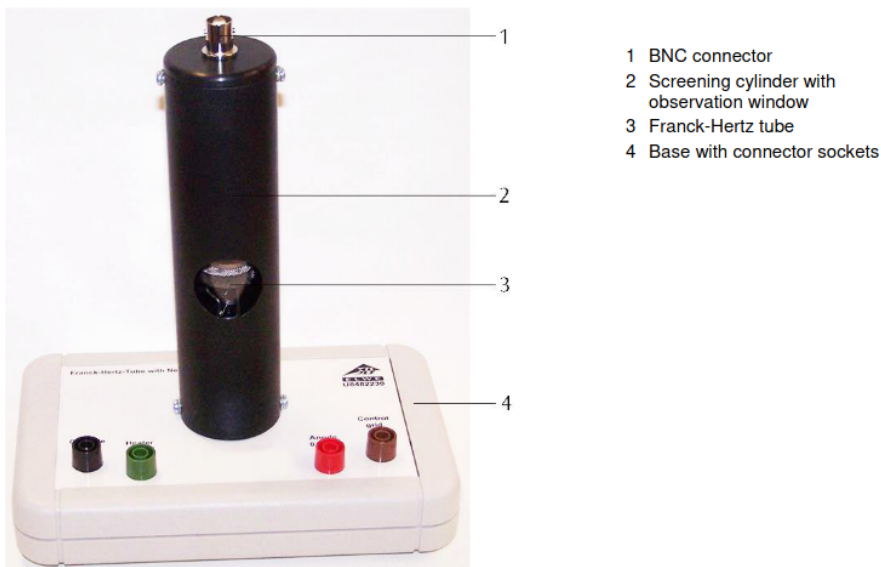


Figure 5: Franck-Hertz tube connections

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.

5. Set U_{KG} at 4 - 6 V and U_{AE} at 4 - 8 V approximately. Fig. 3: Visible luminescence layers between grids.
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.

6 Observations

U_F =
 U_{KG} =
 U_{AG} =

| Sl. No. | Accelerating voltage, U_A (V) | Collector current (nA) |
|---------|---------------------------------|------------------------|
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| | | |
| | | |
| | | |

7 Graph

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

8 Precautions

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

References

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