Franck-Hertz experiment using Neon tube

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The Franck–Hertz experiment probes quantized electronic excitation of atoms by measuring the current of electrons transmitted through a low-pressure gas as a function of accelerating voltage. In this experiment, a Franck–Hertz tetrode tube was used to record collector current versus accelerating voltage. The equidistant peaks in the characteristic curve were analyzed to obtain the excitation energy of the neon atom. From the averaged peak separations we obtain an excitation energy of $\Delta E_{\text{avg}} = (18.3 \pm 0.1)\,\text{eV}$, which is close to the accepted Neon (3s $\to$ 3p) manifold ($\approx$ 18.4–19eV). The results provide a compact and convincing demonstration of discrete atomic energy levels and the utility of collision spectroscopy for measuring them.

I. OBJECTIVE

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

II. INTRODUCTION

The Franck–Hertz experiment demonstrates that atoms have quantized electronic energy levels that absorb energy only in discrete quanta by observing the variation of the electron collector current as the accelerating potential is swept. Electrons emitted from a heated cathode are accelerated and suffer elastic or inelastic collisions with atoms. When an electron transfers a well-defined amount of its kinetic energy to an atom (inelastic collision), the collector current shows characteristic minima and maxima. The voltage spacing between successive maxima and the excitation energy of the target atom is:

$$E_{\text{ex}} \approx e\,\Delta U, \tag{1}$$

where ΔU is the mean spacing (in volts) between successive collector-current peaks and e is the elementary charge.
Historically, it is one of the key experiments supporting Bohr's model and the quantization of energy levels (Franck and Hertz, 1914).

THEORY

Neon gas — electronic structure and exitation levels [1]

Neon (Z=10) has a closed-shell ground configuration $1s^2\,2s^2\,2p^6$. Excitations of interest in Franck–Hertz experiments promote an electron to $3s$ or $3p$ orbitals, yielding configurations of the general form $2p^5\,3s$ or $2p^5\,3p$ (i.e., a hole in $2p$ plus an excited electron). These configurations split into multiple atomic terms due to spin–orbit and electrostatic interactions; term symbols in the ${}^{2S+1}L_J$ notation classify these levels (where S is total spin, L total orbital angular momentum and J total angular momentum). Selection rules (electric dipole) require $\Delta S = 0$ and typically $\Delta L = \pm 1$, so only certain transitions are optically allowed.

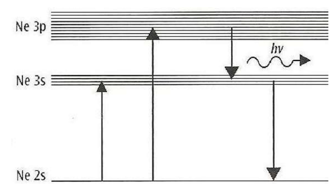

FIG. 1. Energy level diagram for Ne

The most probable excitation occurs from the ground state to the ten 3p-states (between 18.4 eV and 19.0 eV), while the four lower 3s-states (in between 16.6 eV and 16.9 eV) excites with a lower probability. Also, as shown in figure 1 the 3p-3s transition leads to emission of a photon which lies in the visible range between red and green.

Accelerating potential, elastic and inelastic scattering

Two types of collision occurs when electrons are accelerated by the accelerating voltage (U_A) :

1. **Elastic scattering:** the electron changes direction but retains (to first order) its kinetic energy; elastic collisions primarily broaden the angular and energy distribution and do not remove electrons from the transmitted beam.

2. **Inelastic scattering:** when the electron kinetic energy reaches an allowed excitation energy of the atom, it can excite the atom and lose energy equal to a transition quantum. After such a collision the slowed electron may not overcome the retarding potential at the collector and thus produces a drop in collector current.

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Repeated maxima and minima in the collector current occur because, as the accelerating voltage increases, electrons can undergo 1, 2, 3, ... inelastic collisions before reaching the collector; peaks therefore appear when electrons have just enough energy to reach the collector after k inelastic events. The voltage spacing between successive peaks corresponds, to good approximation, to the lowest excitation energy of the atom (see Eq. 1).

Experimental setup [1]

The Franck-Hertz Experiment employs a tetrode tube to study electron collision and energy quantization in gases (as in figure 2). The setup includes the following components:

1. Indirectly Heated Barium Oxide Cathode (K)
2. Control Grid (G)
3. Anode Grid (A)
4. Collector Electrode (E)

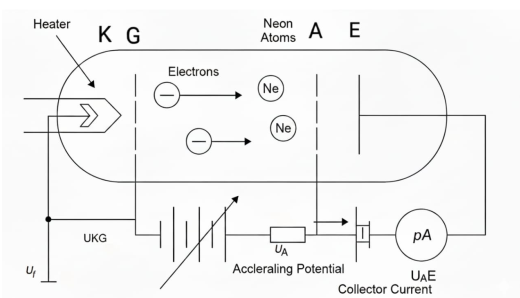

FIG. 2. Schematic for Set up for measuring Franck-Hertz curve for neon

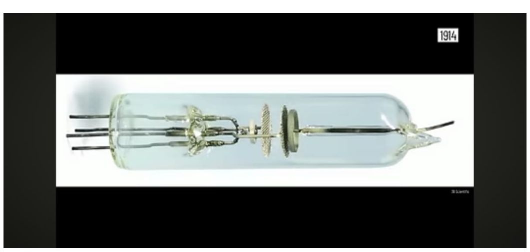

FIG. 3. Frank-Hertz tube

The tube is supplied already filled with neon gas. Also, the distance between the control grid and the anode grid is approximately 0.5 cm while the distance between cathode and control grid, and between anode and collector electrode is approximately 0.2 cm each.

III. OBSERVATION

The observation tables are attached at the last of the report. There are four tables attached, but out of four only three tables are plotted. For table 3, the value of U_{AE} is large due to which negative I_C were obtained. All plots were generated with the Python code available at [2].

IV. DATA ANALYSIS

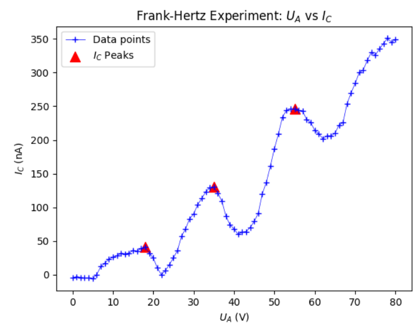

FIG. 4. I_C vs U_A for $U_f = 8.2$V, $U_{KG} = 5.8$V, $U_{AE} = 4.4$V

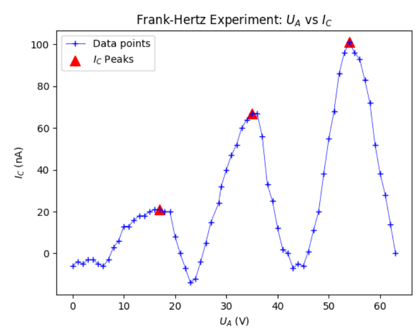

FIG. 5. I_C vs U_A for $U_f = 8.4$V, $U_{KG} = 5.0$V, $U_{AE} = 6.0$V

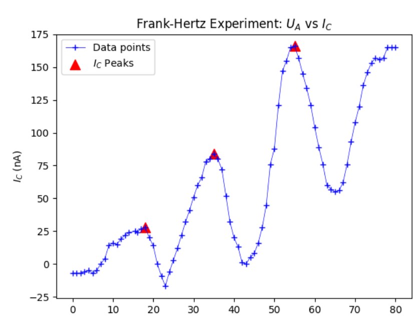

FIG. 6. I_C vs U_A for $U_f = 8.7$V, $U_{KG} = 4.8$V, $U_{AE} = 5.6$V

For table 1,

$$\Delta U_1 = (35 - 18)V = 17V$$

$$\Delta U_2 = (54 - 35)V = 19V$$

For table 2,

$$\Delta U_3 = (35 - 17)V = 18V$$

$$\Delta U_4 = (54 - 35)V = 19V$$

For table 4,

$$\Delta U_5 = (35 - 18)V = 17V$$

$$\Delta U_6 = (55 - 35)V = 20V$$

The mean voltage spacing is

$$\Delta U_{\text{avg}} = \frac{17 + 19 + 18 + 19 + 17 + 20}{6} = \frac{110}{6} \approx 18.33 \text{ V}$$

The average excited energy of the neon comes out to be:

$$E_{\text{avg}} = e\,\Delta U_{\text{avg}} = 18.33eV$$

A. Error Analysis

The least count of the device is 0.1 V. So, maximum error in ΔU is $\delta(\Delta U) = \sqrt{(0.1)^2 + (0.1)^2} = 0.14$ V ≈ 0.1 V

Hence, the average excited energy of the neon will be

$$E_{\text{avg}} = e\,\Delta U_{\text{avg}} = (18.3 \pm 0.1)eV$$

V. RESULTS AND DISCUSSION

The variation of collector current I_C with accelerating voltage U_A exhibits a series of periodic maxima and minima, characteristic of inelastic collisions between electrons and the Neon atoms inside the Franck–Hertz tube. Each drop in current corresponds to electrons losing a fixed quantum of energy by exciting the Neon atoms to higher electronic states.

From the measured voltage spacings between successive peaks, the average excitation potential was determined as

$$\Delta U_{\text{avg}} = (18.3 \pm 0.1) \text{ V},$$

which corresponds to an excitation energy of

$$E_{\text{exc}} = (18.3 \pm 0.1) \text{ eV}.$$

This value is in close agreement with the accepted literature values of 18.4–19.0 eV for the excitation of Neon atoms into the $3p$ states. In addition to the electrical measurement, visible luminous bands were observed in the tube between the grids when the accelerating voltage exceeded the threshold. These correspond to radiative de-excitations from the $3p \to 3s$ transitions of Neon, which emit photons in the visible spectrum. This optical confirmation reinforces the evidence of discrete atomic energy levels. But for the table 3, the value of $U_{AE} = 7.6$ V is much higher than $U_{KG} = 4.8$V and that's why the I_C observed is negative which shows the backward flow of electrons. Hence, the graph of table 3 is not shown in the report. Also, in the plot of table 2, last 17 data points were ignored because those points were distorted (giving a small peak) which may be due to fluctuations in the retarding potential, nonlinearities in the sweep voltage, or electrical noise.

Overall, the experiment successfully verified the quantization of Neon atomic states. The measured excitation energy is consistent with theoretical expectations, and the periodic behavior of the current provides direct support for the Franck–Hertz model of electron–atom interactions.

VI. CONCLUSION

The Franck–Hertz experiment provides a straightforward demonstration of quantized atomic excitations. By measuring the voltage spacing between current maxima one obtains the excitation energy of the target atom within experimental uncertainty. It also links collision physics and spectroscopy: measurement of the periodic structure in the collector current provides a direct, model-independent determination of atomic excitation energies, while spectroscopic the identity of the excited states. The experiment also highlights practical issues such as the role of vapour pressure, tube temperature and instrument calibration.

[1] School of Physical Sciences, NISER Bhubaneswar, Franck–hertz experiment: Laboratory manual, `https://www.niser.ac.in/sps/assets/files/msc/Franck-Hertz_experiment_manual2024.pdf` (2024), accessed: 2025-10-02.

[2] A. Arya, Codify, `https://github.com/Anuj-Arya1/Codify.git` (2025).