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Physical laboratory 3

Task D The Franck-Hertz experiment

Tasks

1. Observe the influence of the set parameters on the behaviour of the anode current. Choose the correct parameters.
2. Measure the dependence of the anode current on the accelerating voltage and determine the energy of the lowest excitation level of the rare gas in the tube.
3. Measure the optical spectrum emitted from the Franck-Hertz experiment tube and determine the identity of the rare gas.

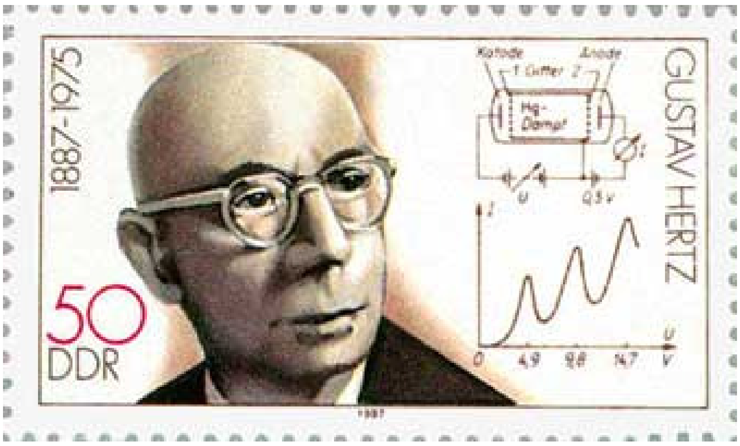

Figure 1: Gustav Hertz.

The principle of the Franck-Hertz experiment

At the beginning of the twentieth century, the new quantum theory was verified mainly using atomic spectra. In 1914 Franck and Hertz experimentally showed, even without using optical spectroscopy, that quantum energy levels of electrons exist and correspond to those determined by the optical emission spectroscopy. Franck and Hertz were awarded the Nobel prize in physics in 1925 for this work.

The original Franck-Hertz experiment is based on the collisions of electrons with mercury atoms. When an atom inelastically collides with an energetic particle, a part of mutual kinetic energy can be transferred to the atom. An electron in such an atom is excited to a higher energy level. For the atom to be excited by an impact of another particle, mutual kinetic energy must

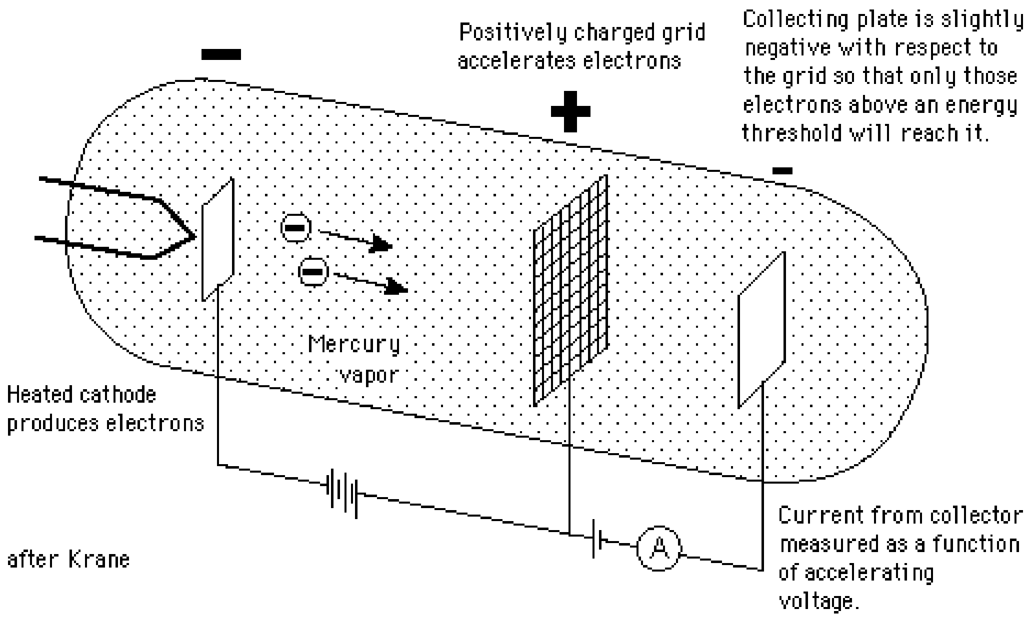

Figure 2: Experimental setup of the original Franck-Hertz experiment.

be higher than the lowest excitation energy of the atom. Only then an inelastic collision can take place. Some time after the excitation (usually a very short time), the excited electron in the atom returns to its base state while emitting one or more photons.

Franck and Hertz used an experimental apparatus similar to that shown in figure 2 to bombard vapours of different gasses with electrons of variable energy. The electrons are emitted by a hot cathode, and they are electrically accelerated towards a grid. A small potential difference is kept between the grid and a collecting electrode (collector) to decelerate electrons after passing the grid. The collector current rises with the increasing accelerating voltage only in a specific region. A steep decrease in the collector current is observed after exceeding a particular value of the

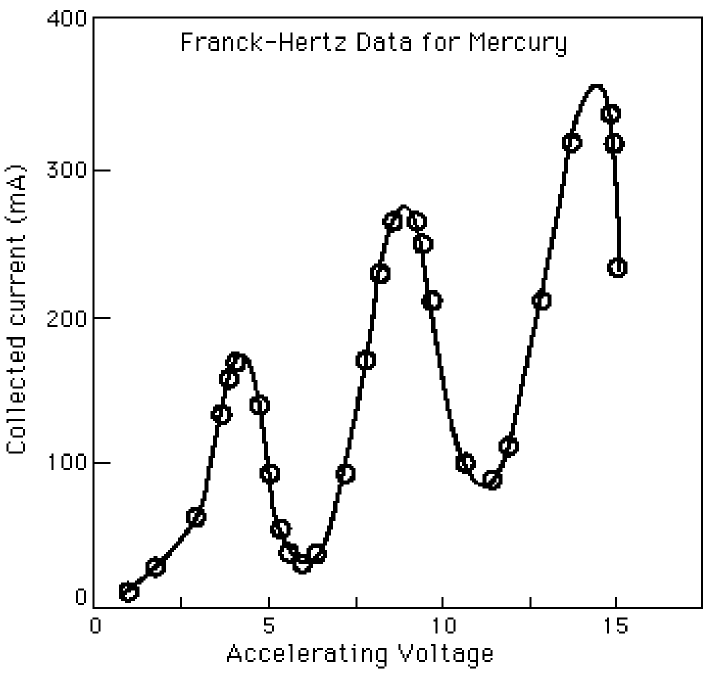

Figure 3: The dependence of the collector current on the accelerating voltage for mercury.

accelerating voltage. Inelastic collisions occur near the grid as electrons gain the energy of the lowest excitation level of the studied gas at that region by the accelerating field. The electrons lose their energy after undergoing the inelastic collision, and they are unable to overcome the potential difference between the grid and the collector. In such a case, the electron does not reach the collector, but it lands on the grid instead. Consequently, the collector current steeply decreases.

An example of such measurement for mercury vapour is shown in figure 3. It was seen that the dependence of the collector current on the accelerating voltage shows several drops repeated after approximately 4.9 V. Inelastic collisions occurred near the grid at the accelerating voltage of 4.9 V, at which the electrons reached the lowest excitation energy of mercury. The collector current sharply decreased. Each electron could undergo two such consecutive collisions at the accelerating voltage of 9.8 V. The first one happened approximately halfway between the cathode and the grid and the second one near the grid itself. Both collisions resulted in the excitation of mercury to the lowest excitation level. Therefore it is evident that the Franck-Hertz experiment allows for the measurement of only the lowest excitation energy level of an atom. Nevertheless, it was the first experiment proving the existence of discrete atomic levels without using optical spectroscopy, and therefore it was significant for quantum physics.

Experimental setup

Figure 4 shows the experimental setup of the Franck-Hertz experiment we will use in the laboratory. A hot cathode C, two grids G_1 and G_2 separated by the distance L and anode A are placed inside a vacuum tube. The small voltage U_1 between the cathode C and the first grid G_1 serves for the stabilisation of the experiment. The accelerating voltage U_2 between the grids G_1 and G_2 is used to set the kinetic energy of the electrons. The electrons are then decelerated by the voltage U_3 between the grid G_2 and the anode A. If the electron undergoes an inelastic collision

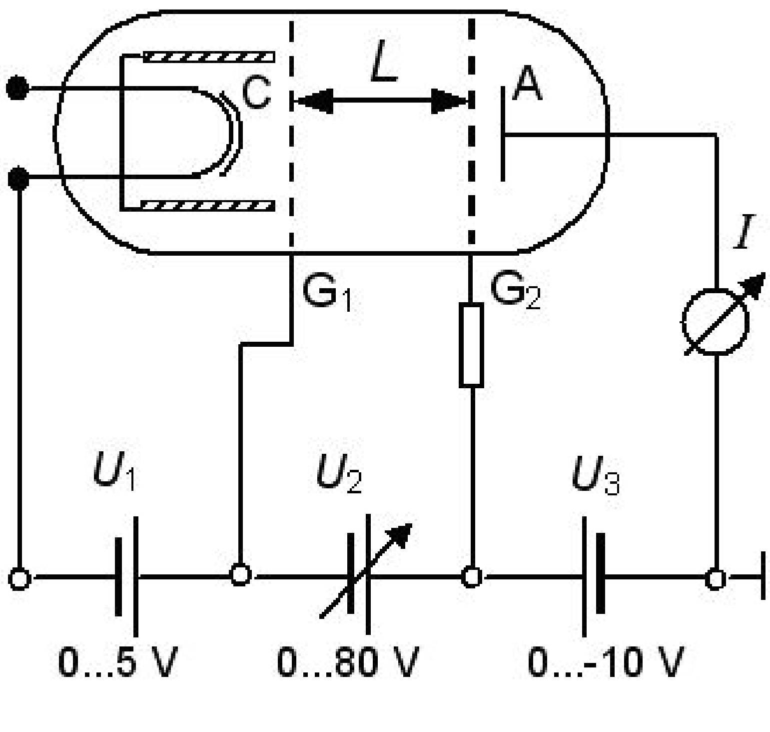

Figure 4: Experimental setup of the Franck-Hertz experiment in the laboratory.

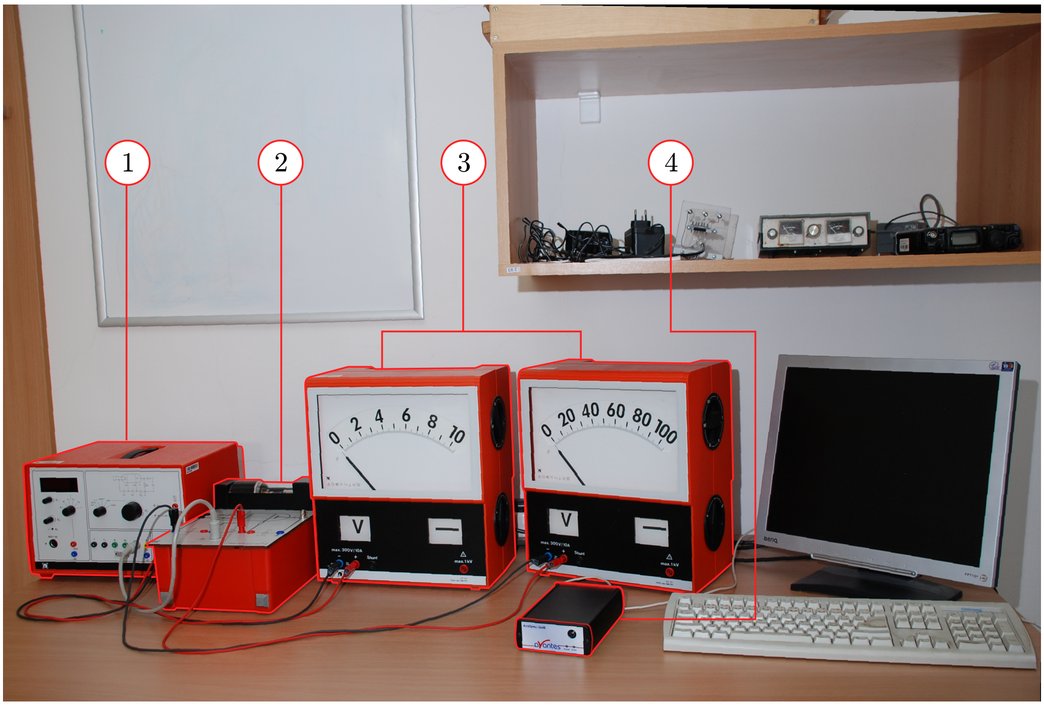

Figure 5: Measurement apparatus: 1 - Power source, 2 - Vacuum tube, 3 - Voltmeters, 4 - Avantes spectrometer.

near the second grid G_2, the decelerating voltage U_3 can cause the electron to land on the grid G_2 rather than on the anode A. The tube is filled with a rare gas. Voltages U_1 and U_3 can be set to constant values, voltage U_2 can be set to a constant value or generated in a saw-shape.

Experimental procedure

- Work in the regime where U_2 is generated in the saw-shape and study the effect of voltages U_1 and U_3 on the general shape of the measured anode current. At first set different values of U_3 (keep U_1 constant) and observe the I=f(U_2) dependence. Do not note the specific data. Rather make conclusions from your observations and support them based on the physics applied in the experiment. Repeat the same for constant U_3 and different U_1.
- Choose at least one suitable combination of U_1 and U_3. Measure the I=f(U_2) dependence for chosen combination of U_1 and U_3.
- Determine the energy of the lowest excitation level of the rare gas in the tube. Familiarise yourselves with the lowest excitation energy levels of rare gases before the laboratory. These can be found, e.g. on the pages of the National Institute of Standards and Technology in the Atomic spectra database subsection (`http://www.physics.nist.gov/PhysRefData/contents.html`). Compare your results with the tabulated data and identify the present gas. You can find the spectroscopic notation using roman numerals. Numeral I denotes a neutral atom, numeral II denotes a singly ionised atom, numeral III a doubly ionised atom etc. For example, neutral helium atoms are denoted He I.
- Finally, measure the optical spectra of the gas by the available spectrometer. Verify your gas identification based on the spectral line database (e.g. from the National Institute of Standards and Technology). You can do this by comparing the positions of the measured intensive spectral lines with the tabulated positions.