Related Topics

Energy quanta, quantum jumps, electron collision, excitation energy, Bohr’s shell model.

Principle

Electrons are accelerated in a tube filled with neon gas. The excitation energy of neon is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

Equipment

1	Franck-Hertz operating unit	09105.99
1	Franck-Hertz neon-tube with housing	09105.40
1	5-pin connecting cable, for Ne tube	09105.50
1	Shielded BNC-cable, l = 75 cm	07542.11
1	RS 232 data cable	14602.00
1	Franck-Hertz software	14522.61
	PC, Windows® 95 or higher	

Additional equipment:

1	Oscilloscope, 30 MHz, 2 channels	11459.95
2	Adapter, BNC-socket/4mm plug pair	07542.27
2	Screened cable, BNC, l = 75 cm	07542.11

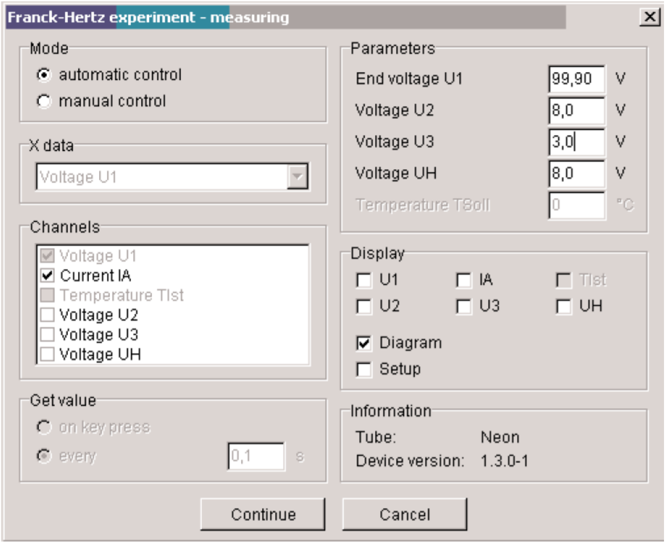
Fig.1: Set-up for the Franck-Hertz experiment with PC.

Tasks

- Record the countercurrent strength I in a Franck-Hertz tube as a function of the anode voltage U.
- Determine the excitation energy E from the positions of the current strength minima or maxima by difference formation.

Set-up and Procedure

Set up the experiment as shown in Fig. 1. For details see the operating instructions of the unit 09105.99. Connect the Cobra3 Basic Unit to the computer port COM1, COM2 or to USB port (use USB to RS232 Adapter Converter 14602.10). Start the measure program and select Cobra3 Franck-Hertz experiment Gauge. The window “Frank-Hertz-experiment – measuring” (see Fig. 2) appears. The optimum parameters are different for each Ne-tube. You find the specific parameters for your device on a sheet which is enclosed in the package of the Ne-tube. Choose the parameters for U1, U2, U3 and UH as given on that sheet and make sure that the rest is set as shown in Fig. 2. Press the continue button.



Franck-Hertz experiment - measuring

Mode
● automatic control
○ manual control

X data: Voltage U1

Channels
☑ Voltage U1
☑ Current IA
☐ Temperature Tist
☐ Voltage U2
☐ Voltage U3
☐ Voltage UH

Get value
○ on key press
● every 0,1 s

Parameters
End voltage U1 99,90 V
Voltage U2 8,0 V
Voltage U3 3,0 V
Voltage UH 8,0 V
Temperature TSoll 0 °C

Display
☐ U1 ☐ IA ☐ Tist
☐ U2 ☐ U3 ☐ UH
☑ Diagram
☐ Setup

Information
Tube: Neon
Device version: 1.3.0-1

Fig. 2: Measuring parameters.

Theory and evaluation

Niels Bohr introduced the planetary model of the atom in 1913: An isolated atom consists of a positively charged nucleus about which electrons are distributed in successive orbits. He also postulated that only those orbits occur for which the angular momentum of the electron is an integral multiple of $h/2\pi$, i.e. $n*h/2\pi$, where n is an integer and h is Planck’s constant. Bohr’s picture of electrons in discrete states with transitions among those states producing radiation whose frequency is determined by the energy differences between states can be derived from the quantum mechanics which replaced classical mechanics when dealing with structures as small as atoms. It seems reasonable from the Bohr model that just as electrons may make transitions down from allowed higher energy states to lower ones, they may be excited up into higher energy states by absorbing precisely the amount of energy representing difference between the lower and higher states. James Franck and Gustav Hertz showed that this was, indeed, the case in a series of experiments reported in 1913, the same year that Bohr presented his model. Franck and Hertz used a beam of accelerated electrons to measure the energy required to lift electrons in the ground state of a gas of mercury atoms to the first excited state (see experiment 5.1.03-11). In present experiment a tube filled with neon gas is used.

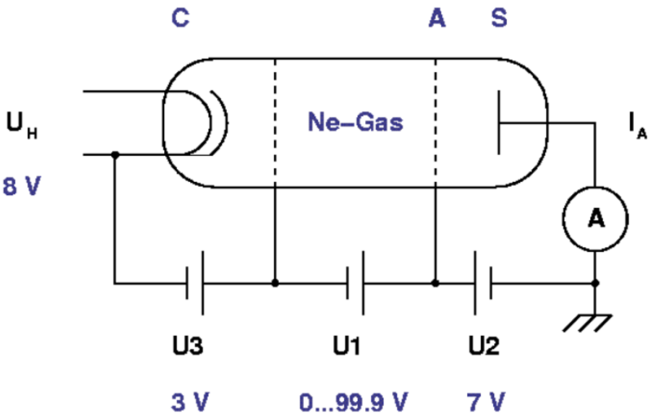


Fig. 3: Principle of the measurement.

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with neon gas (Fig. 3) and are scattered by elastic collision with neon atoms. From an anode voltage U_1 of 16,8 V, however, the kinetic energy of the electrons is sufficient to bring the valence electron of the neon to the first excitation level by an inelastic collision. Because of the accompanying loss of energy, the electron can now no longer traverse the opposing field between anode A and counter electrode S: the current I is at a minimum. If we now increase the anode voltage further, the kinetic energy of the electron is again sufficient to surmount the opposing field: the current strength I increases. When U_1 = 2·16.8 V the kinetic energy is so high that two atoms in succession can be excited by the same electron: we obtain a second minimum (Fig. 4). The graph of I/U_1 thus shows equidistant maxima and minima.

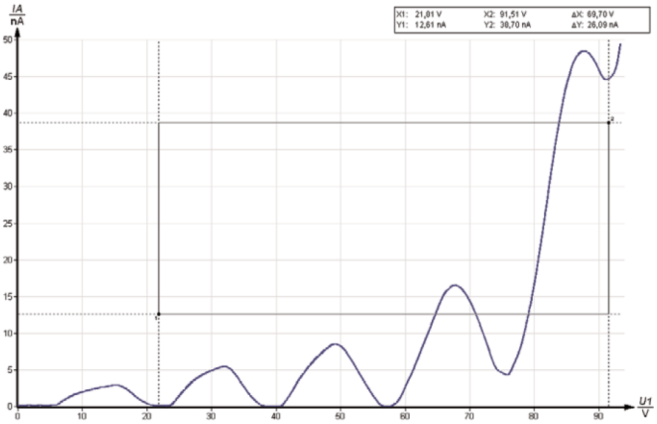


Fig. 4: Example of a Franck-Hertz curve recorded with Netube.

These minima are not, however, very well-defined because of the initial thermal distribution of the electron velocities. The voltage U_1 between anode and cathode is represented by

$$U_1 = U + (\Phi_\mathrm{A} - \Phi_C)$$

where U is the applied voltage, and Φ_A and Φ_C the work function voltages of the anode and cathode respectively. As the excitation energy E is determined from the voltage differences at the minima, the work function voltages are of no significance here. According to the classical theory the energy levels to which the mercury atoms are excited could be random. According to the quantum theory, however, a definite energy level must suddenly be assigned to the atom in an elementary process. The course of the I/U_A curve was first explained on the basis of this view and thus represents a confirmation of the quantum theory. The excited neon atom again releases the energy it has absorbed, with the emission of a photon. When the excitation energy E is 16.8 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E} = 73.8\, nm$$

where $c = 2.9979 \cdot 10^8 \frac{m}{s}$ and $h = 4.136 \cdot 10^{-15}$ eV.

For our evaluation we determine the voltage values of the minima. From the differences between these values we obtain the excitation energy E of the neon atom by taking an average. By evaluating the measurements in Fig. 4 we obtained the value

$$E = (17.4 \pm 0.7)\ \text{eV}.$$