Related Topics

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

Principle

Electrons are accelerated in a tube filled with mercury vapour. The excitation energy of mercury 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 Hg-tube on plate	09105.10
1	Franck-Hertz oven	09105.93
1	NiCr-Ni thermocouple	13615.01
1	5-pin connecting cable, for Hg-tube	09105.30
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.

**Franck-Hertz experiment
with Hg-tube**

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 operating 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 Hg-tube. You find the specific parameters for your device on a sheet which is enclosed in the package of the Hg-tube. Choose the parameters for U1, U2 and UH as given on that sheet and make sure that the rest is set as shown in Fig. 2. Press the continue button. Now the oven of the Franck-Hertz tube will be heated to 175 °C. Wait another 30 min before start-

Fig. 3: Principle of the measurement.

ing the measurement to make sure that the interior of the tube reaches its final temperature, too. At a particular voltage $U_1 = U_Z$, which is dependent on temperature, a glow discharge between anode and cathode occur through ionisation. Meaningful measurements can therefore only be taken at voltages $U_1 < U_Z$.
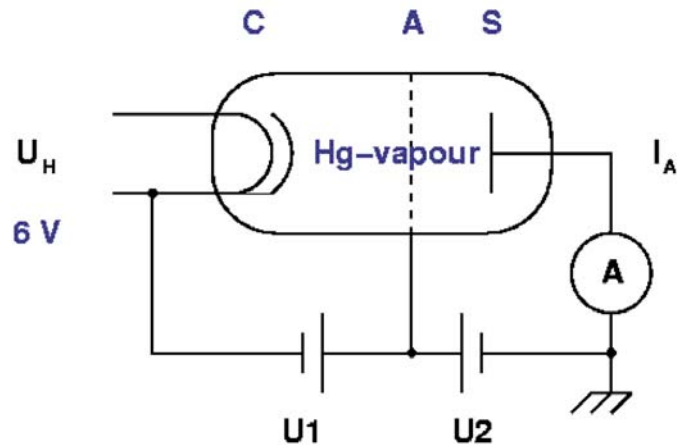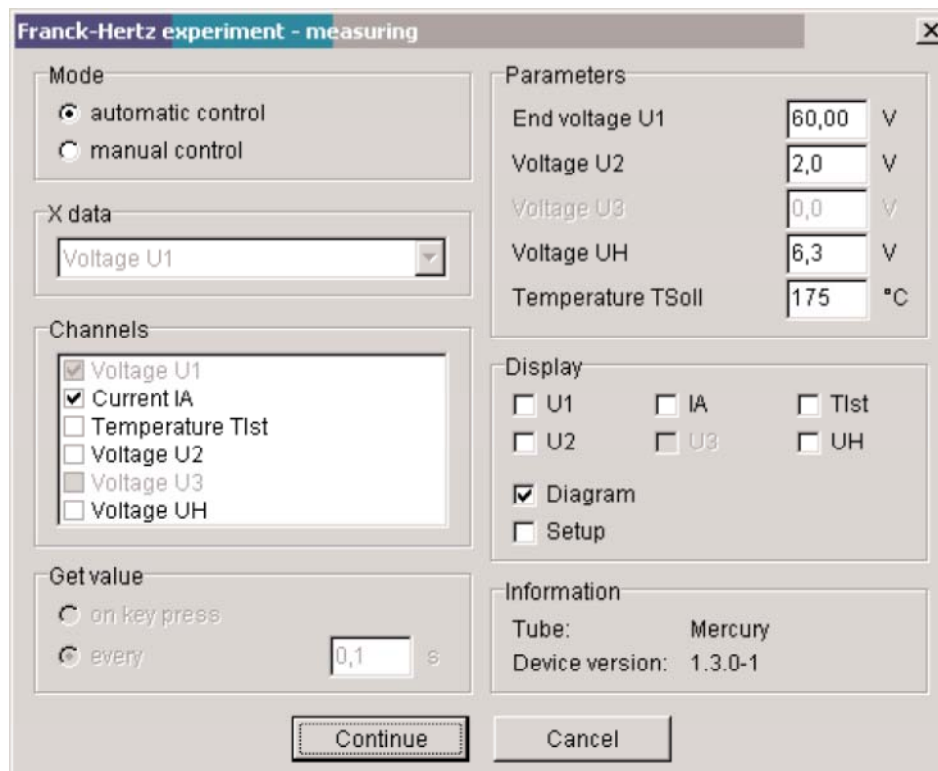

Fig. 2: Measuring parameters.

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.

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with mercury vapour (Fig. 3) and are scattered by elastic collision with mercury atoms. From an anode voltage U_1 of 4.9 V, however, the kinetic energy of the electrons is sufficient to bring the valence electron of the mercury to the first excitation level 6 $^3P_1$ 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 $U_1 = 2 \times 4.9$ 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. 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

$$U_1 = U + (\Phi_A - \Phi_C)$$

where U is the applied voltage, and A and C the work function voltages of the anode and cathode respectively. As the ecxitation 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 mercury atom again releases the energy it has absorbed, with the emission of a photon. When the excitation energy E is 4.9 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E} = 253 \ nm$$

where $c = 2.9979 \cdot 10^8 \frac{m}{s}$ and $h = 4.136 \cdot 10^{-15}$ eV and thus lies in the UV range.

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 mercury atom by taking an average. By evaluating the measurements in Fig. 4 we obtained the value

E = (4.86 ± 0.09) eV.

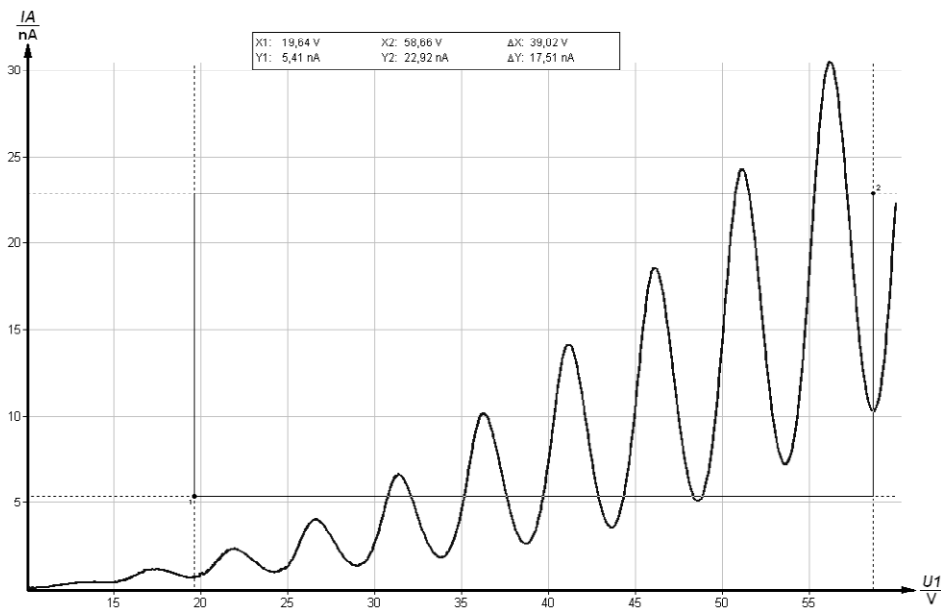Fig. 4: Example of a Franck-Hertz curve recorded with T = 175°C and U2 = 2 V.

Notes

- Generally speaking the first minima are easier to observe at low temperatures. On the other hand, we obtain a larger number of minima at higher temperatures, as the ignition voltage of the tube is raised to higher values.
- Due to oven temperature variations slightly different levels of collection current may be obtained for repeated measurements at the same acceleration voltage. However, the position of the maxima remains unaffected.
- When the bimetallic switch switches the oven on and off, there is a change of load on the AC mains, causing a small change in the set acceleration voltage. This should be noted if the switching takes place just when the curve is being recorded.
- The position of the maxima for the collection current remains unchanged when the reverse bias changes, but the position of the minima are displaced a little. The level of the mean collection current decreases with increasing reverse bias.