Franck-Hertz experiment

Related topics
Energy quanta, quantum jumps, electron collision, excitation energy.

Principle and task
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

Franck-Hertz tube on plate	09085.00	1
Franck-Hertz oven	09085.93	1
Power supply unit for F.-H.tube	09086.01	1
Power supply, 0...600 VDC	13672.93	1
DC measuring amplifier	13620.93	1
Voltmeter 5/15 V DC	07037.00	1
COBRA-interface 2	12100.93	1
PC COBRA data cable RS 232, 2 m	12100.01	1
Softw. COBRA xyt-recorder, 4 CH.	14250.51	1
PEK electrol. capacitor 100 mmF/35 V	39105.25	2
Digital thermometer	07030.00	1
Thermocouple NiCr-Ni, 500 C max.	13615.02	1
Screened cable, BNC, l 750 mm	07542.11	2
On/off switch	06034.01	1
Connecting cord, 500 mm, red	07361.01	2
Connecting cord, 750 mm, red	07362.01	3
Connecting cord, 250 mm, blue	07360.04	2
Connecting cord, 250 mm, red	07360.01	2
Connecting cord, 500 mm, blue	07361.04	2
Connecting cord, 750 mm, blue	07362.04	1
Connecting cord, 2000 mm, red	07365.01	2
Connecting cord, 2000 mm, blue	07365.04	2

Problems
To record the countercurrent strength I_S in a Franck-Hertz tube as a function of the anode voltage U_A. To determine the excitation energy E_A from the positions of the current strength minima or maxima by difference formation.

Set-up and procedure
Set up the experiment as shown in Figs. 1 and 2. To generate an anode voltage U_A which increases with time, the power supply unit for F.-H. tube is used, which is powered from a constant voltage source (50 V, power supply unit 0…600 V-).

As long as *S* is closed, the anode voltage is about 0.5 V. Opening *S* causes the voltage to increase in a logarithmic way. The setting voltage of the power supply, at 0 to 12 V, is too high for the countervoltage U_S and is therefore reduced by a voltage divider in the power supply unit for F.-H. tube.

When U = 12 V, then

$$U_S \simeq 3\text{ V}.$$

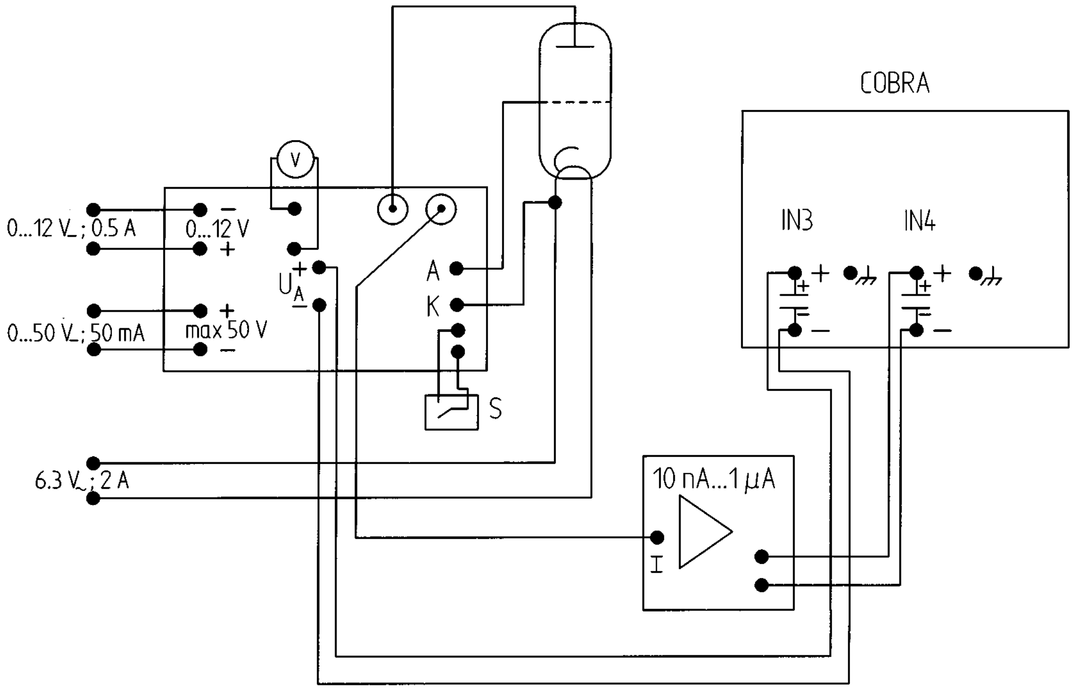
The countervoltage can now be set between 0 and 3 V.

0.5 V should be set for the measurement initially.

The current I_S generated by the elctrons striking the counter electrode S is in the range 10^{-9} A (Fig. 3). It is amplified and connected to IN4 of COBRA.

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

Fig. 2: Wiring diagram for the Franck-Hertz experiment.



Now heat the oven of the Franck-Hertz tube to approx. 160 °C (the thermocouple is near the counter electrode not touching the housing of the oven). Sufficient mercury will have vaporised after 15–20 minutes for the apparatus to be ready for use. Set the DC amplifier to I and 0.1 µA (or 10 nA…10 µA).

Software handling

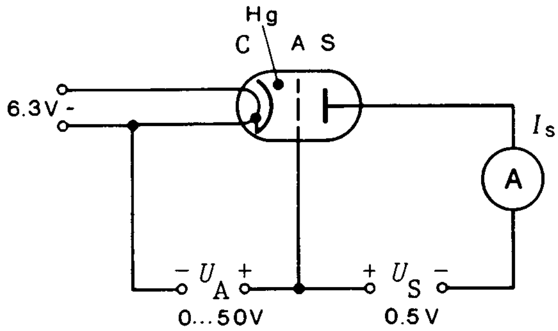
– Type COBRA “Enter” and xyt “Enter” to start the programme.
– Make sure COBRA is connected to the COM socket which has been selected by the programme.
– Settings:
– <Parameters> <Channels>
  Channel 1: free
  Channel 2: free
  Channel 3: 1. xy-x
  Channel 4: 1. xy-y
  <ok>
– <Parameters> <Display><Channel 3>
  Offset: 0.000
  Factor: 1.000
  Minimum: 0.000
  Maximum: 60.000
  unit: Volt
  Type of scale: Linear
  Setting: 100 Volt
  <ok>
– <Parameters> <Display><Channel 4>
  Offset: 0.000
  Factor: 1.000
  Minimum: 0.000
  Maximum: ≈0.06
  (depends on temperature and individual characteristics of the Franck-Hertz-tube)
  unit: Volt
  Type of scale: Linear
  Setting: 100 mV
  <ok>
– <Parameters> <COBRA-Settings>
  Measuring time: 60.000 (or 100.000)
  Time units: s
  Trigger conditions: no analog trigger condition
  Trigger channel: 1
  Trigger threshold in Volt: 0.000
  <ok>
– <Measure> <Measure><ok>
  Open the switch S.
  Hit any key to start the measurement.
  After 60 s (or 100 s) the measurement data is transfered to the computer automatically.

At a particular voltage $U_A = U_Z$, which is dependent on temperature, a glow discharge between anode and cathode occur through ionisation. Meaningful measurements can therefore only be taken at voltages $U_A < U_Z$.

Theory and evaluation

The elctrons 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.

Fig. 3: Principle of the measurement.



From an anode voltage 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_S 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_S increases. When U_A = 2×4.9 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_S/U_A 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_A between anode and cathode is represented by

$$U_A = U + (\phi_A - \phi_C),$$

where U is the applied voltage, and ϕ_A and ϕ_C the work function voltages of the anode and cathode respectively. As the ecxitation energy E_A 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_S/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_A is 4.9 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E_A} = 253 \text{ nm, where}$$

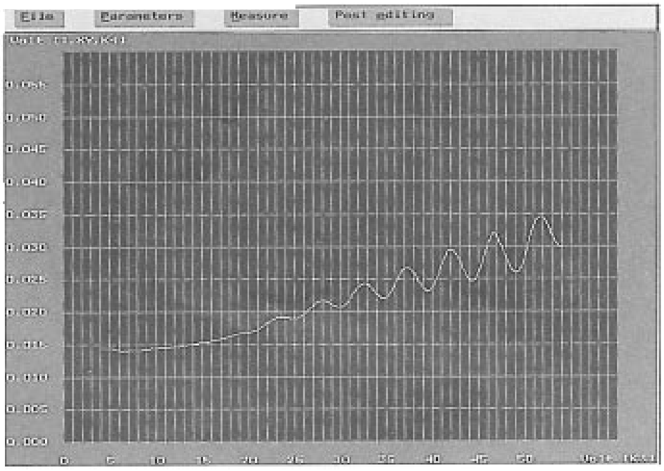
$$c = 2.9979 \cdot 10^8 \ \frac{m}{s}$$

and

$$h = 4.136 \cdot 10^{-15} \text{ eV},$$

and thus lies in the UV range.

Fig. 4: Example of a Franck-Hertz curve recorded with T = 160 °C, U_S = 1 V, DC ampl. = 0.1 µA.



Determination of I_s:

The following equation is valid:

$$\frac{10 \text{ V}}{0.1 \ \mu\text{A}} = \frac{\text{xV}}{\text{y}\mu\text{A}}$$

$$\text{y}\mu\text{A} = \frac{\text{xV} \cdot 0.1 \ \mu\text{A}}{10 \text{ V}}$$

with:

0.1 µA	setting of the DC amplifier
10 V	maximum voltage of the output of the DC amplifier
xV	voltage recorded by IN4 of COBRA
yµA	I_s-current in µA

In this case:
xV = 0.01 mA ≙ 0.0001 nA

For our evaluation we determine the voltage values of the minima. From the differences between these values we obtain the excitation energy E_A of the mercury atom by taking an average.

By evaluating the measurements in Fig. 5 we obtained the value

$$E_A = 4.93 \text{ eV} \pm 0.08 \text{ eV}.$$

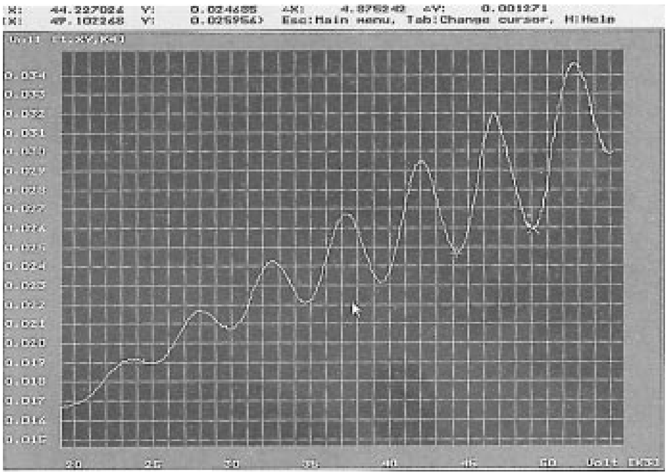
Evaluation of the curve:

– <Post editing><Zoom>
<Enter coordinates via mouse>
Click the upper left corner of the zoom window by means of the left mouse button, hold the button and move the mouse to the lower right corner.

– <Post editing><Δx/Δy Measurement>
Recorder 1.xy <ok>

Move the cursors to neighboring minima of the Franck-Hertz-curve. (Fig. 5)

Fig. 5: Zoomed Franck-Hertz curve.



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.
- It is recommended that on reaching the optimum oven temperature (this depends on the Franck-Hertz tube used) the heater is switched off and recording of the curve is started immediately.
- 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.
- The experimental set-up in the classical version is shown in Fig. 6. The interface related articles COBRA interface 2 (12100.93), PC COBRA data cable RS232, 2 m (12100.01) and Software COBRA xyt-recorder, 4CH (14250.51) have to be replaced by a xyt recorder (11416.97). Ref. no for the experiment with xyt-recorder 25103-01.

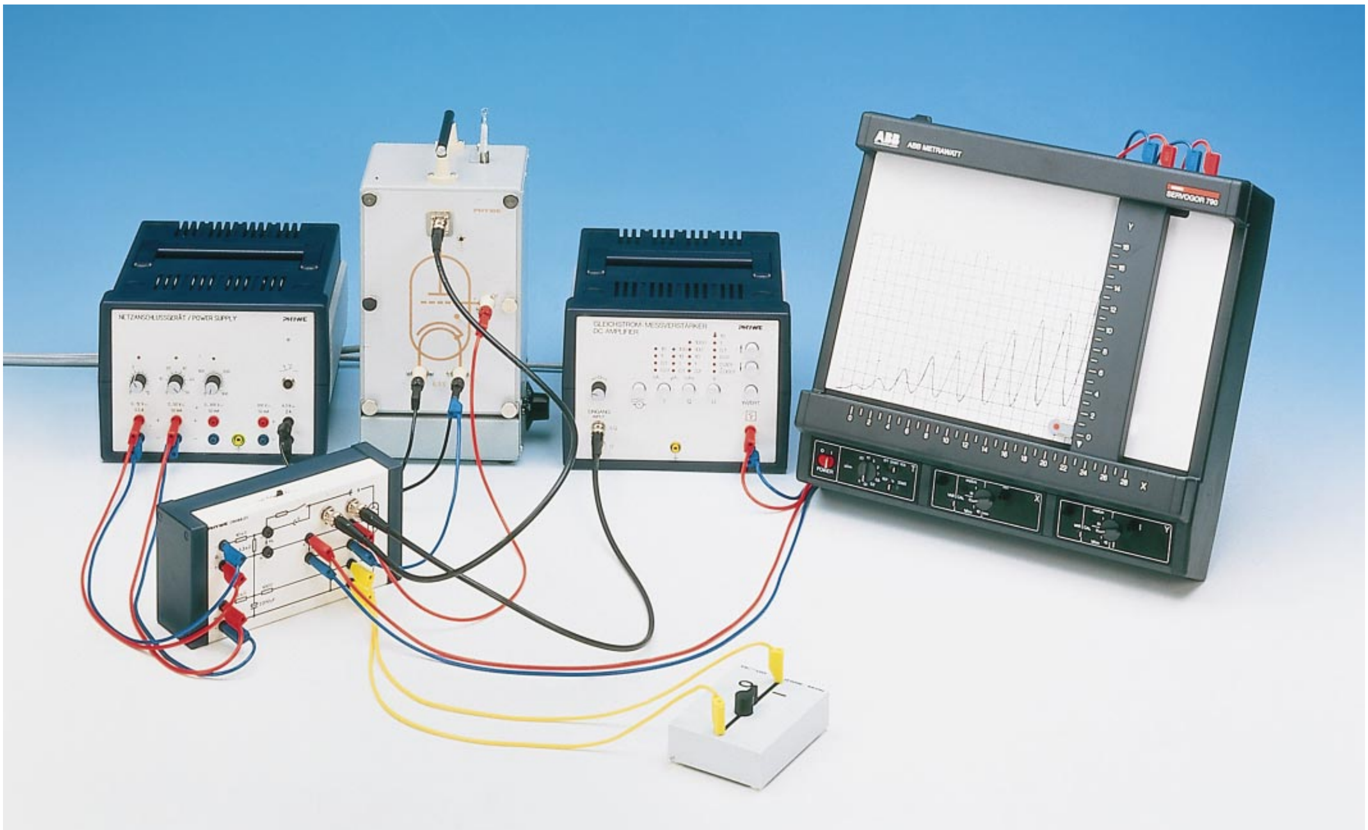


Fig. 6: Set-up for the Franck-Hertz experiment with xyt-recorder.