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The Franck-Hertz-experiment (1913, Nobel Prize 1926) with the well-defined periodic and equidistant maxima and minima of the collector electrode current when exciting the mercury resonance line at 253.7 nm wavelength, is undoubtedly one of the most impressive experiments to demonstrate and verify the quantum theory. This experiment provides direct proof for the truth of the concepts of quantum theory.

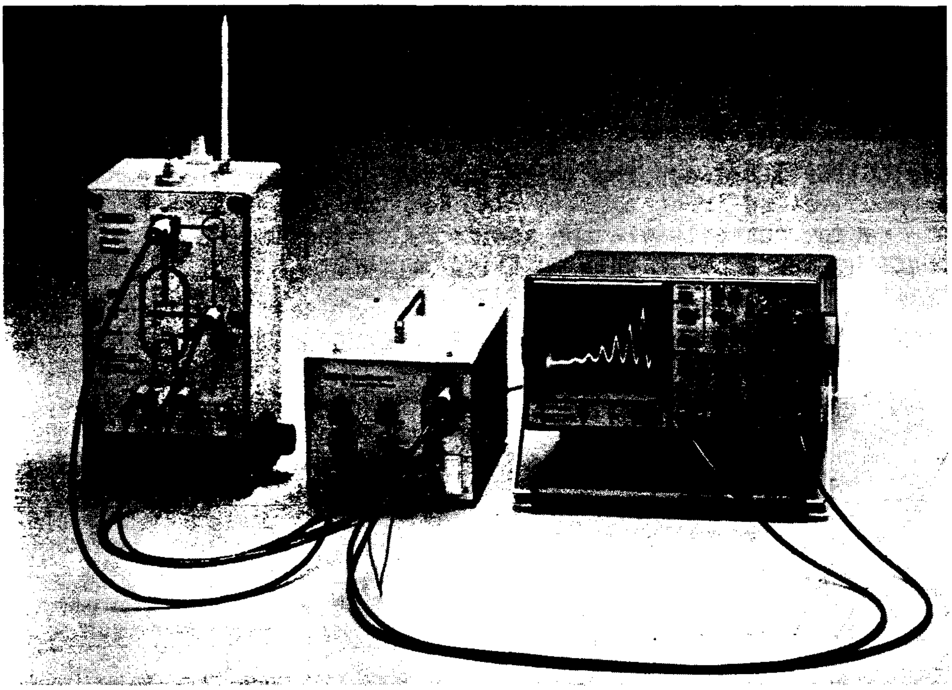


Fig 1 Apparatus set up for the experiment

The following apparatus is required for carrying out the experiment :

Franck-Hertz-Tube No. 6751, on a
Front Panel No. 6753, in an
Oven No. 6752
Operating Unit for Franck-Hertz-Experiment No. 6749
(This unit provides all voltages required and contains also a DC-amplifier.)

The experiment can be alternatively carried out with the following equipment:
A 6,3 V DC or AC voltage source (cathode heating voltage) and 0 to +70 V continuously variable DC voltage source (as accellerating voltage), e.g. Mains Rectifier Unit 5211
A measuring amplifier, current sensitivity to 10^{-11} A (NEVA No.7212) with shielded connecting cable (NEVA No.7256) and read-out meter.

A DC voltage source of about 1,5 V as opposing voltage (pocket lamp battery or accumulator with voltage divider).

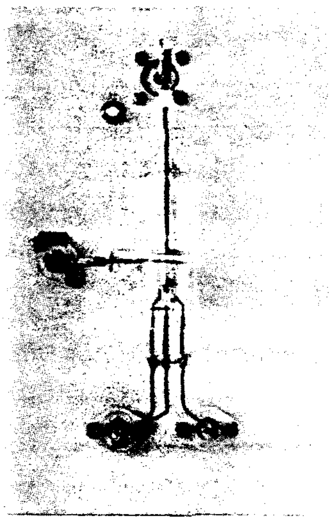
A thermometer reading up to 200^{o} C (NEVA no. 4052)
A voltmeter with 3 V DC and 100 V DC measuring ranges.
Miscellaneous connecting leads.

The <u>Franck-Hertz-Tube</u> (No.6751) is a three-electrode tube with indirectly heated oxide-coated cathode, grid-form anode and collector electrode. The electrodes are arranged in plane-parallel manner. The distance between the cathode and the anode (8 mm) is large compared with the mean free path length in the mercury vapour atmosphere (at 180 ^{o}C) in order to ensure a high collision probability. On the other hand, the separation between the anode and the collector electrode is small.

During manufacture the tube is provided with a highly activated contact getter and exhausted to high vacuum. The getter is effective for a long time, so that no deterioration of the characteristics through energy-consuming molecular gases takes place when operating the tube.

The envelope wall between the anode and the collector electrode carries a vacuum-proof sealed-in protective ring made of sintered carborundum, to prevent leakage currents via the ionically conducting hot glass wall. The tube contains a drop of highly purified mercury.

A 6,3 V DC or AC voltage source is required for heating the cathode. The heater current should be at least 0,3 A.



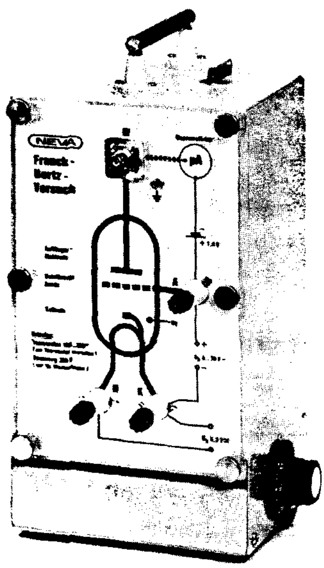


Fig.2 Franck-Hertz-Tube
(mounted on front panel)

The <u>Heating Oven</u> consists of a steelplate cabinet with the dimensions 240 x 160 x 140 mm^3. The oven is heated with a tubular radiator mounted on the floor of the oven. The power consumption is 400 Watts. A bimetal switch which can be adjusted with a control knob from the exterior serves for setting and stabilizing the oven temperature.

The oven heater may be connected only to an AC supply, otherwise arcing would damage the bimetal contact.

The resulting current curve as a function of the accellerating voltage is shown in Fig 4 and 5.

The current minima are spaced at intervals of 4,9 V, showing that the excitation energy of the mercury atoms is 4,9 eV.

The spectral frequency corresponding to this energy is

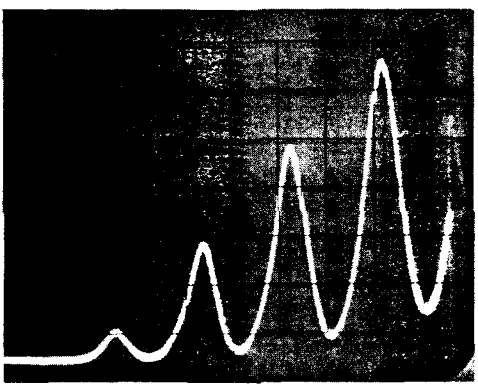
$$v = \frac{E}{h} \quad , \text{ i.e. } \frac{4{,}9 \text{ eV}}{4.133 \times 10^{-15} \text{ eVs}} = 1{,}18 \times 10^{15} \text{ Hz}$$

and the corresponding wavelength is

$$\lambda = \frac{c}{v} = 253{,}7 \text{ nm.}$$

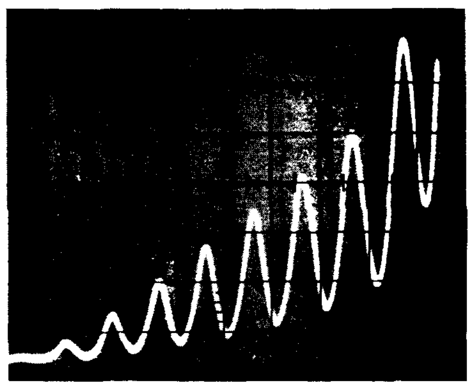
Franck and Hertz verified the presence of this ultraviolet radiation with the aid of a quartz spectrograph.

Note : A contact potential of about 2 V exists between the cathode and the anode of the tube, so that the first current minimum is found for an applied accellerating voltage of about 7 V.



at 150 °C

Fig. 4 Franck-Hertz-Curve



at 180 °C

Fig.5 Franck-Hertz Curve

Procedure for carrying out the experiment

Connect the heating oven to a grounded AC mains power point with the aid of the provided mains cable. Set the bimetal contact switch to the desired temperature. The temperature can be read on the thermometer inserted to the center of the oven. This temperature will be reached after a warm-up time of 10 to 15 minutes (e.g. 170 °C). The temperature set in this manner is automatically held constant (even if the oven is switched off and then re-used after a long idle period).

Establish the connections to the operating unit (respectively to the voltage sources and to the measuring amplifier) according to Fig 1 and the markings on the front panel. A shielded cable (No. 7256) must be used for the connection from the collector electrode to the amplifier input. Make sure that the polarities of the accellerating voltage and opposing voltage are correct. The negative pole of the accellerating voltage must be connected to the cathode socket K (bottom right). If you are using separate voltage sources (accellerating voltage, cathode heating voltage and opposing voltage) they must be floating to ground (no galvanic connection to ground or chassis), because the apparatus is already grounded via the measuring amplifier.

The indirectly heated cathode requires a warm-up time of about 90 seconds after applying the heater voltage. Thereafter slowly increase the accellerating voltage commencing from 0 Volts. A current then flows from the collector electrode to the anode and this current is indicated by the measuring amplifier. The magnitude of this current is of the order of 10^{-10} A The current sensitivity of the measuring amplifier must be set accordingly. The polarity of the collector electrode is negative with respect to the anode. Correct corresponding polarity must be observed for the meter connected to the output of the measuring amplifier.

The collector electrode current as a function of the accellerating voltage shows periodically recurrent and equidistant maxima and minima, whereby the minima are spaced at intervals of 4,9 V. A contact potential of about 2 V exists in the tube between the cathode and the anode, so that the first current minimum lies at about 7 V.

Figs. 4 and 5 show the collector electrode current as a funkction of the accellerating voltage. The form of the curve depends strongly on the oven temperature. At low temperatures (around 150°) the first minima are developed more strongly but the curve rises rapidly (Fig.4). The tube thereby strikes at about 30 V. With increasing oven temperature progressively more minima are obtained and the curve remains confined in a narrow current range. But the first minimum is then less pronounced and may even cease to be detectable.

The emission current in the tube and thus the collector electrode current are affected by the cathode temperature. If the current is too small the cathode heater voltage may be increased (e.g. to 8 V). The heater current must then be adjusted with a rheostat or rotary potentiometer control (about 10 Ω) such that the collector electrode current is of the order 10^{-10} A with 50 V accellerating voltage. The heater circuit resistor must be placed in series with the connection to the left-hand heater connecting socket (H). The heater voltage for the cathode may also be taken from an accumulator.

A 10 kΩ resistor in the anode circuit of the tube prevents overloading of the tube. The tube is thus not endangered even if a discharge by collision ionization takes place in it due to excessively high applied voltage. Thus it is possible to observe the luminous discharge with a spectroscope and to verify from the spectrum that the gas filling is mercury vapour.

The Franck-Hertz-tube is mounted on the rear side of the front panel in such a manner that the entire tube including the connecting wires is heated to a constant temperature. This is absolutely essential, because the vapour pressure of the mercury is always determined by the temperature of the coldest point of the tube.

The front panel carries the ceramic-insulated connecting sockets for the tube. The collector electrode is connected to a BNC-type jack to which the shielded lead to the operating unit (measuring amplifier) is connected. The symbolic designation of the tube is marked on the front panel in bold lines and the connections are specified with thinner lines. The oven possesses two windows through which the tube and the heater spirals can be observed. The coverplate of the oven carries a hole for inserting the thermometer which is held in position with a clamp spring.

A 10 kΩ current limiting resistor is permanently incorporated between the connecting socket for the accellerating voltage and the anode of the tube. This resistor protects the tube in case a main discharge strikes in it when excessively high voltage is applied. For normal measurements the voltage drop across this safety resistor may be ignored, because the working anode current of the tube is smaller than 5 µA (voltage drop across the safety resistor less than 0,05 V).

The front panel with the tube can be taken off after releasing the six milled screws, so that the oven can also be used for other purposes (e.g. for the sodium fluorescence experiment).

Description of the Experiment

In the Franck-Hertz experiment, the energy transitions which are produced by collisions between electrons and mercury atoms are observed.
The tube contains a small amount of mercury, some of which vaporizes when the tube is heated in the oven. A mercury vapour pressure of about 20 millibar is obtained at 180° C. The oxide-coated heated cathode emits electrons. The kinetic energy of these electrons increases with increasing accellerating voltage (U_b), so that the electrons fly through the gridform anode and then against an opposing voltage of 1,5 V to the collector electrode. A current of the order of 10^{-10} A flows from the collector electrode to the anode and is indicated with the measuring amplifier.

The collisions between electrons and mercury atoms at first take place elastically without significant transfer of energy to the mercury atoms. But when the accelerating voltage has been increased to a sufficient extent,the kinetic energy of the electrons is large enough to excite the mercury atoms just in front of the grid-form anode. The electrons thereby lose their kinetic energy and are no longer able to reach the collector electrode against the braking voltage (-1,5 V). Thus the current reading given by the measuring amplifier become smaller. When the accellerating voltage is further increased, the collision zone moves progressively closer to the cathode and the electrons which are braked by collision are reaccelerated and can reach the collector electrode again, until their kinetic energy has become so large that they can be braked by a second non-elastic collision with a mercury atom. This energy transfer reappears periodically with progressively increasing accellerating voltage.

Attention :

Take care of supplying the **Heating Oven** with the correct AC supply. You find the value of the AC supply (110 or 220 VAC) on a plate beside the supply cable entry.

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