

NEVA

Franck-Hertz-Experiment

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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.

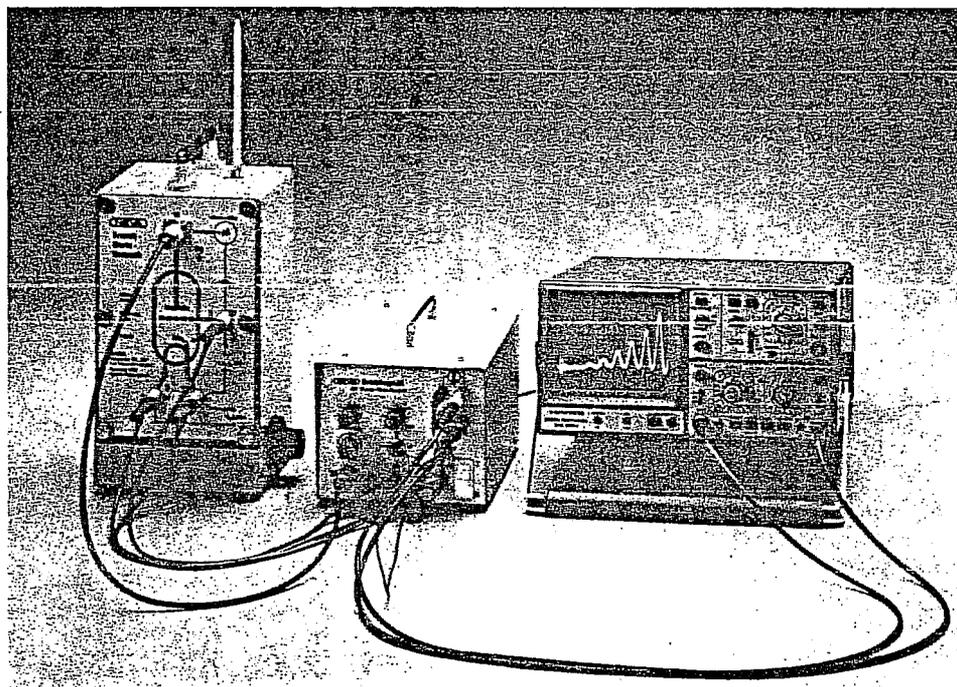


Fig 1 Apparatus set up for the experiment

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. 6756
(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 accelerating 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 2000 C (NEVA no. 4052)

A voltmeter with 3 V DC and 100 V DC measuring ranges.

Miscellaneous connecting leads.

The Franck-Hertz-Tube (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 °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.

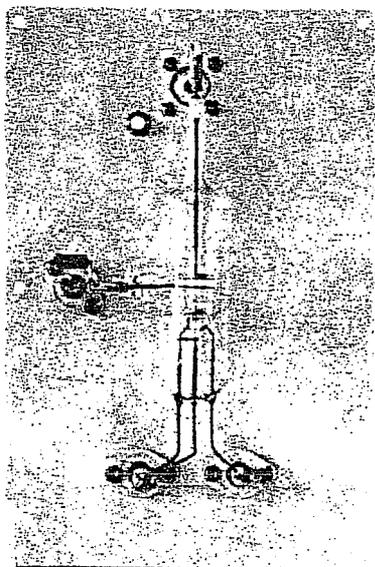
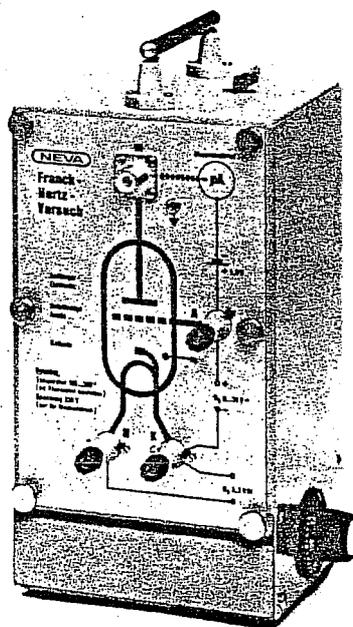


Fig.2 Franck-Hertz-Tube
(mounted on front panel)



The Heating Oven consists of a steelplate cabinet with the dimensions 240 x 160 x 140 mm³. 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 accelerating 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

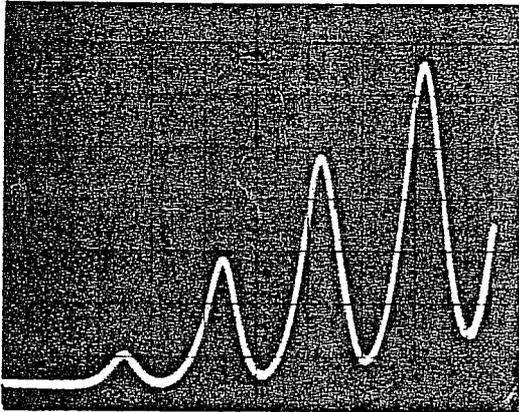
$$\nu = \frac{E}{h}, \text{ i.e. } \frac{4,9 \text{ eV}}{4.133 \times 10^{-15} \text{ eVs}} = 1,18 \times 10^{15} \text{ Hz}$$

and the corresponding wavelength is

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

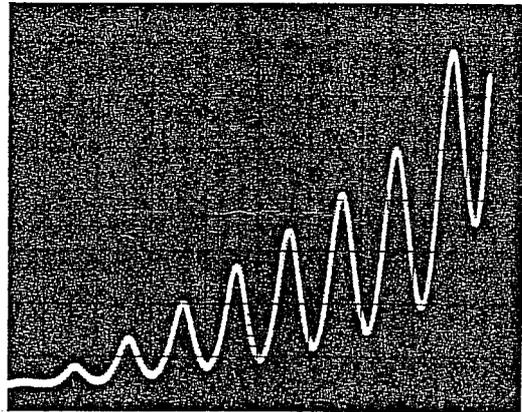
Franck and Hertz verified the presence of this ultraviolet radiation with the aid of a quartz spectrograph.

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 accelerating 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 accelerating voltage and opposing voltage are correct. The negative pole of the accelerating voltage must be connected to the cathode socket K (bottom right). If you are using separate voltage sources (accelerating 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 accelerating 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 accelerating 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 function of the accelerating 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 10Ω) such that the collector electrode current is of the order 10^{-10} A with 50 V accelerating 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 $10 \text{ k}\Omega$ 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 $10\text{ k}\Omega$ current limiting resistor is permanently incorporated between the connecting socket for the accelerating 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 $5\text{ }\mu\text{A}$ (voltage drop across the safety resistor less than $0,05\text{ V}$).

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 accelerating voltage (U_b), so that the electrons fly through the grid-form anode and then against an opposing voltage of $1,5\text{ V}$ 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 ($-1,5\text{ V}$). Thus the current reading given by the measuring amplifier become smaller. When the accelerating 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 accelerating voltage.

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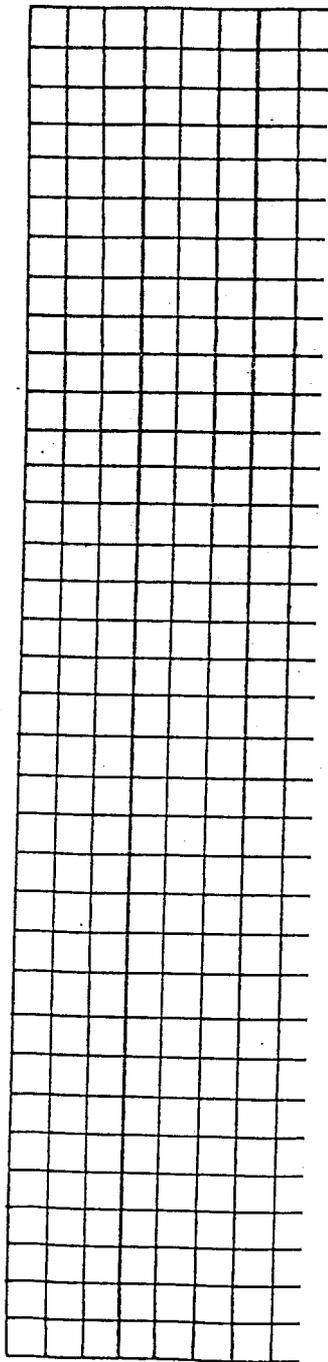
Franck-Hertz-Röhre mit Queckberfüllung

Artikelnummer: 6751,00
 Röhrennummer: 02
 Heizstrom: 277 mA
 Steuerung: 8V
 Gegenspannung: 1,3 V
 Temperatur: 220 °C

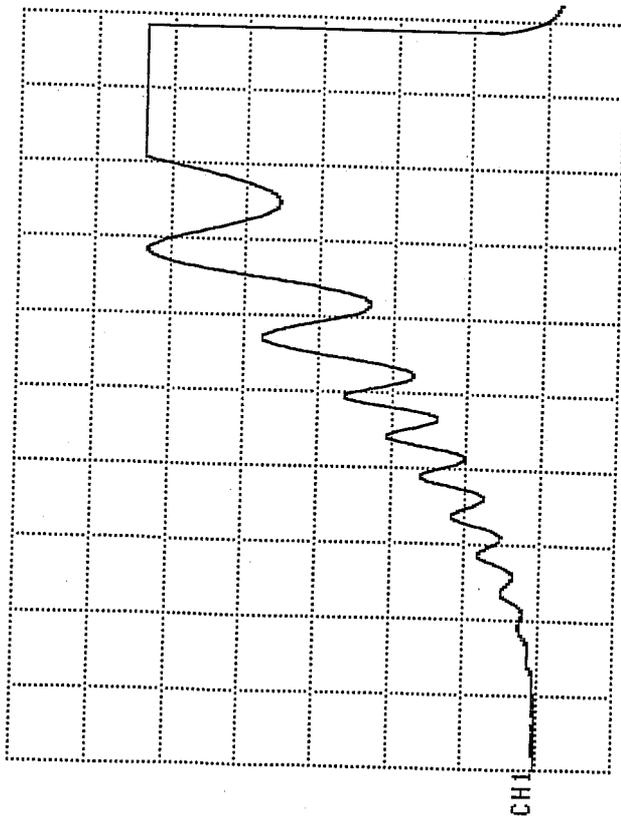
Schreiberrablenkung:
 X-Ablenkung: 0,5 V/cm
 Y-Ablenkung: 2 -0,5 V/cm

geprüft am:
 Prüfer:

F. J. ...

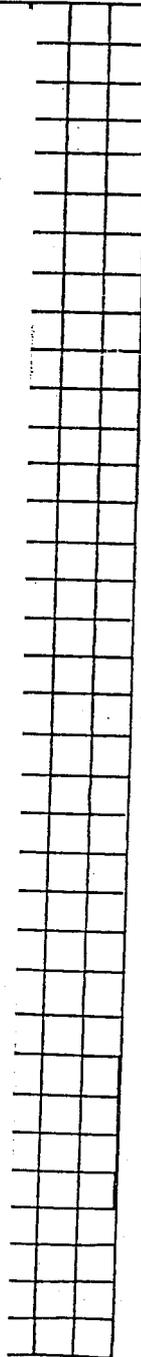
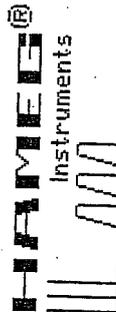


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 TIME: 11:57:46
 SIGNALPARAMETER:
 CHI - VOLTS/DIV:
 TIMEBASE-SEC/DIV:



PRINTERPARAMETER:
 ZOOMRANGE - CHI:0-9
 HARDCOPY SOURCE : HM 205-3

REMARKS:



X

This unit provides all voltages required for carrying out the Franck-Hertz experiment and also contains a highly sensitive DC amplifier for measuring the collector current. The set-up of apparatus for the experiment becomes very simple with the aid of this unit. It is merely necessary to make four connections to the Franck-Hertz tube and to link up the measuring units.

The power supply section delivers:

1. The accelerating voltage

U_b = DC voltage, continuously variable from 0 to 60 V (switch " U_b " in setting -).

2. The filament heating voltage for the tube

U_H = AC voltage up to 8 V.

The filament current is adjustable from 270 mA to 350 mA.

3. The opposing voltage U_G = DC voltage of about 1.5 V .

Furthermore, for displaying the Franck-Hertz curve on the screen of a cathode ray oscilloscope:

4. A sawtooth waveform accelerating voltage U_b with amplitude adjustable from 0 to 90 V pp (switch " U_b " in setting ).

5. Voltage for X-deflection on the oscilloscope = halfwave voltage obtained by halfwave rectification, adjustable from 0 to 10 V pp .

The DC amplifier consists of two cascaded operational amplifiers (integrated circuits), the first of which is connected as electrometer amplifier. The current to be measured is applied to the non-inverting input. The input impedance is 2.2 M Ω . The gain can be adjusted with a variable negative feedback resistance. The subsequent second operational amplifier further amplifies the signal and inverts it.

The output display voltage is proportional to the measured current. 1 V output voltage corresponds to an input current of 1×10^{-8} A in the minimum sensitivity setting (control knob to the left as far as it will go), and to an input current of 2×10^{-10} A in the maximum sensitivity setting. Any voltmeter reading up to 10 V can be used as output display. It is not necessary to match the meter. The output voltage can be loaded up to 30 mA and is short circuit proof.

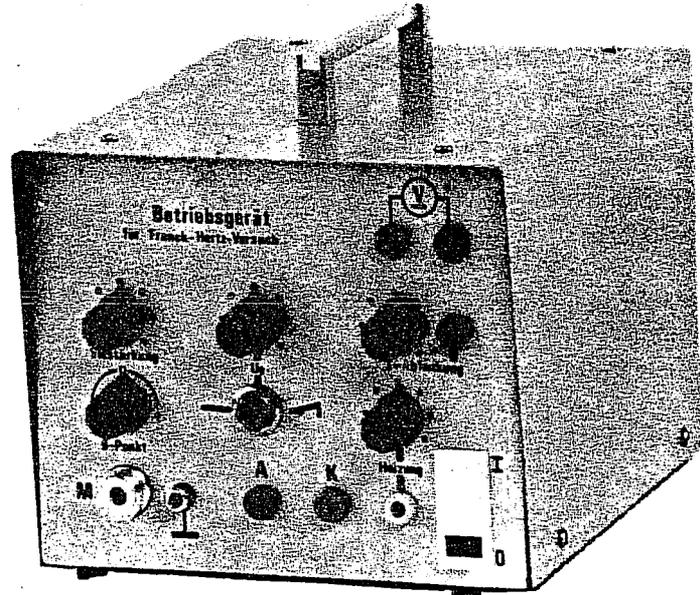


Fig.1

Set-Up of Experiment :

Connect-up as shown in Fig.2. The voltages are connected as follows:

U_b to the sockets K (-) and A (+)

U_H to the sockets K and "filament heating"

U_G to the socket A (+) and to ground (chassis) (-)

A shielded line (No. 7213) must be used for the connection from the collector electrode to the amplifier input. The display meter (1 V full scale deflection) is connected to the sockets at the top right (the red socket is +). The voltmeter for indicating the accelerating voltage (range 30 V DC or 100 V DC) is connected to the sockets K and A.

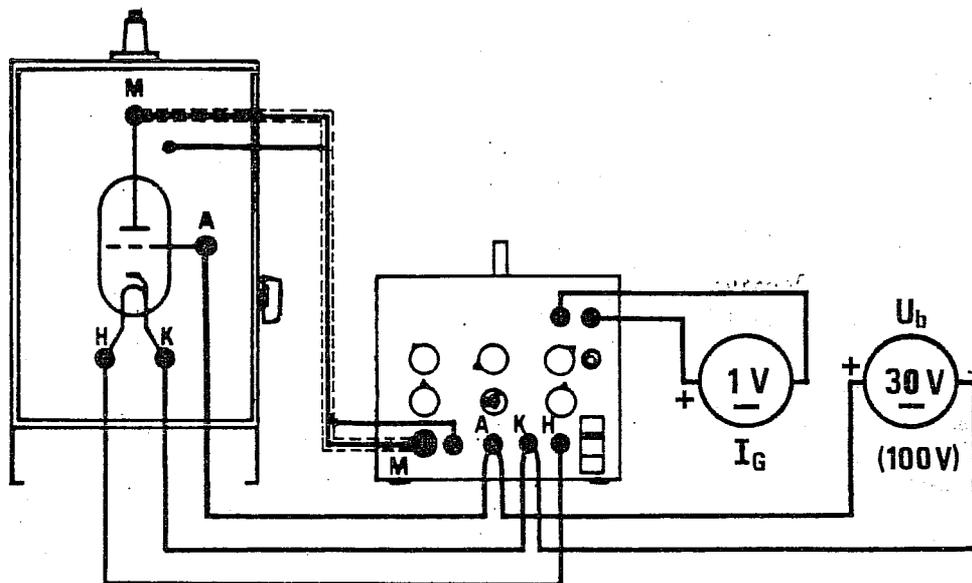


Fig. 2

Carrying out the Franck-Hertz Experiment

1. Set the oven to the desired temperature (e.g. 170°C).
2. Switch-on the operating unit.
3. Set switch U_b to position "-" .
4. Set control U_b to 0 Volts .
5. Set the control knob "filament heating" to about midway.
6. Set to maximum sensitivity with the "gain" control knob (turn to the right as far as it will go).
7. Adjust the "zero" control knob such that the meter reading at the amplifier output is zero.

Then slowly increase the accelerating voltage, reducing the gain setting thereby to keep the output reading within the meter range.

The indicated collector current shows equidistant minima as a function of the accelerating voltage. It may be possible to improve the form of the curve by changing the cathode temperature (with the "filament heating" control knob).

Tracing the Franck-Hertz curve on the screen of a cathode ray oscilloscope

Set-up :

1. Connect the oscilloscope according to Fig.3
(X-deflection = external, Y-deflection = 1 V/cm).
2. Adjust the length of the timebase with the control "X-deflection".
3. Set switch U_b to position .
4. Slowly increase the sawtooth voltage amplitude with the control knob U_b .

The Franck-Hertz curve appears on the cathode ray tube screen (Fig.4). If necessary, improve display by judiciously adjusting the "gain" control and the cathode temperature "filament heating". Adjust the accelerating voltage such that no self-sustained discharge takes place in the tube, because the curve would be destroyed by collision ionization.

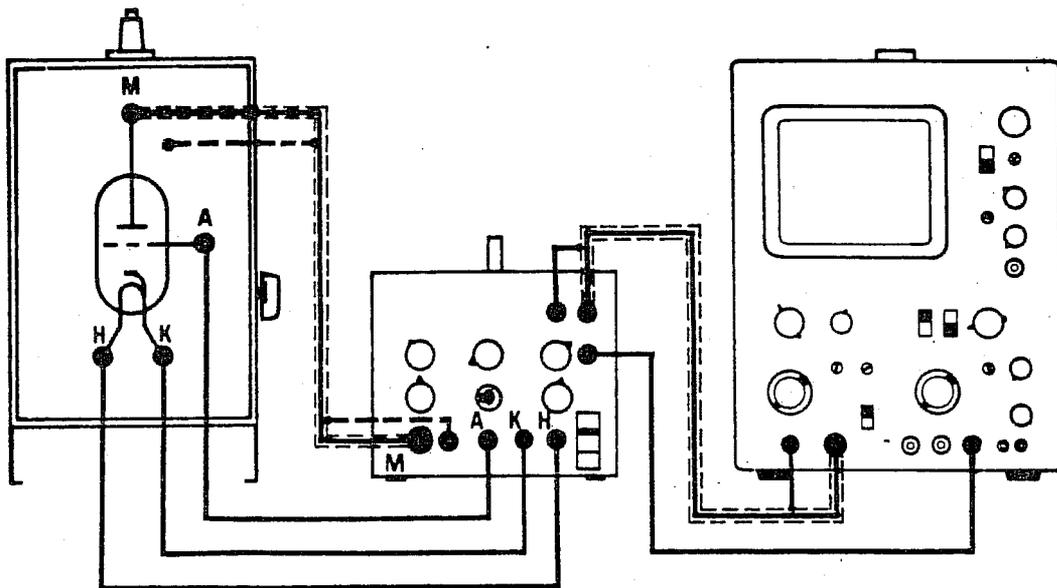


Fig. 3

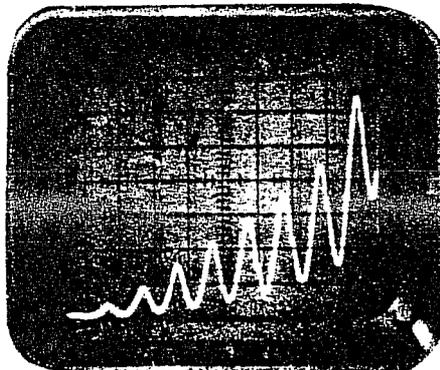


Fig. 4

FRANCK-HERTZ EXPERIMENT

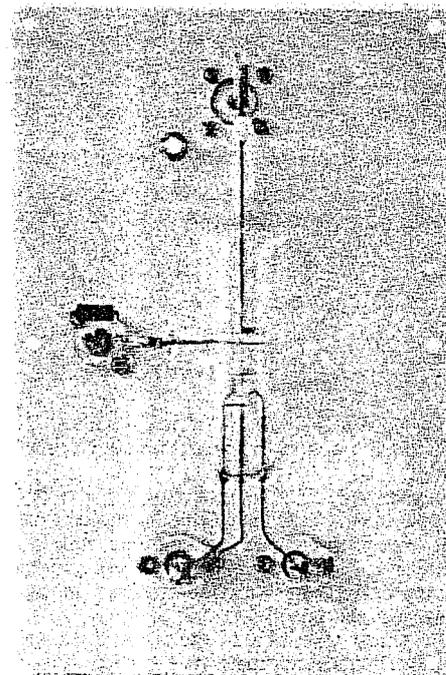
The Franck-Hertz experiment (1913; Nobel Prize 1926) with the well-defined periodic and equidistant maxima and minima of the collector electrode current when exciting the mercury resonance line at 253.7 nm wavelength, is undoubtedly one of the most impressive experiments to demonstrate and verify the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

KA6040 - Franck-Hertz tube filled with mercury 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 (8mm) is large compared with the mean free path length in the mercury vapor atmosphere (at 180°C) in order to ensure a high collision probability. On the other hand, the separation between the anode and the collector electrode is small. **\$517.00**

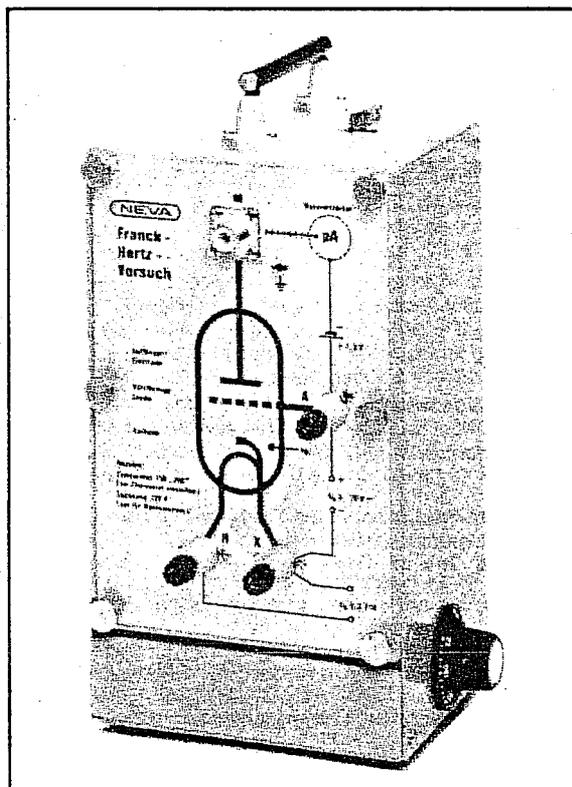
The envelope wall between the anode and the collector electrode carries a vacuum-proof sealed-in protective ring made of sintered carborundum, to prevent leakage currents via the ionically conducting hot glass wall. The tube contains a drop of highly purified mercury.

This new Franck-Hertz tube is not interchangeable with any other tube type formerly supplied for the same application. Tube KA6040 is supplied already mounted inside the thermostatically-controlled oven and contains the necessary resistors.

As an additional feature, the tube can be repaired when the filament burns out, provided the glass form is returned intact. This repair can be made at approximately two-thirds the original purchase price.



KA6040 - Franck-Hertz Tube
(mounted on front panel)



KA6041 - Heating oven consists of a steel-plate cabinet heated with chrome-nickel spirals mounted in a ceramic former on the floor of the oven. The power consumption is 400 Watts. A rheostat which can be adjusted from the exterior serves for setting and stabilizing the oven temperature. The spiral heater and the bimetal contact are electrically shielded with a wire net so that the measurements are not disturbed by the switching surges of the heating oven. **\$648.00**

Ordering Data:

KA6040 - Franck-Hertz tube, mercury filled, for observation of quantum transitions due to electron collisions with mercury atoms. **\$517.00**

KA6041 - Thermostatically-controlled oven for tube KA6040. **\$648.00**

KA6040R - Repair of the Franck-Hertz tube KA6040. Only tubes with burned out filaments can be repaired by us. All orders for KA6040R must be accompanied by the defective tube. **\$420.00**

KA6042 - Voltage divider, a potentiometer mounted on stand, regulated by a knob with provision to clamp a 1.5 volt flashlight battery. **\$40.00**

KA6043 - Set of leads with plugs and special coaxial cable. **\$75.00**

KH2235 - Thermometer, range -10° to +200°C. **\$13.00**

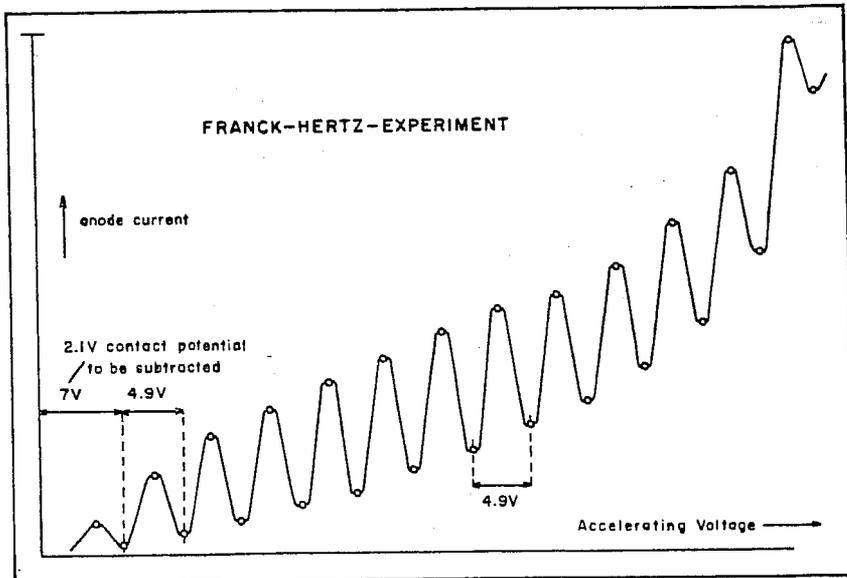
KA6045 - Operating unit for Franck-Hertz experiment (combination power supply and DC amplifier). **\$1220.00**

The above set of equipment for the Franck-Hertz experiment is suitable for student laboratory work and is most dependable. As an amplifier and current indicator any other instrument can be used.

FRANCK-HERTZ EXPERIMENT

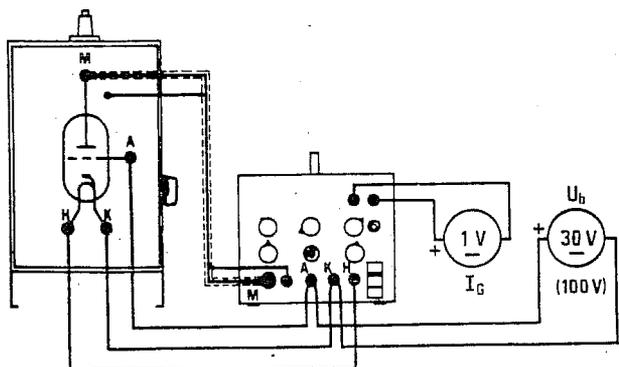
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The front panel carries the ceramic-insulated connecting sockets for the tube. The collector electrode is connected to a UHF-type jack to which the shielded lead to the measuring amplifier is connected. The symbolic designation of the tube is marked on the front panel in bold line 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.

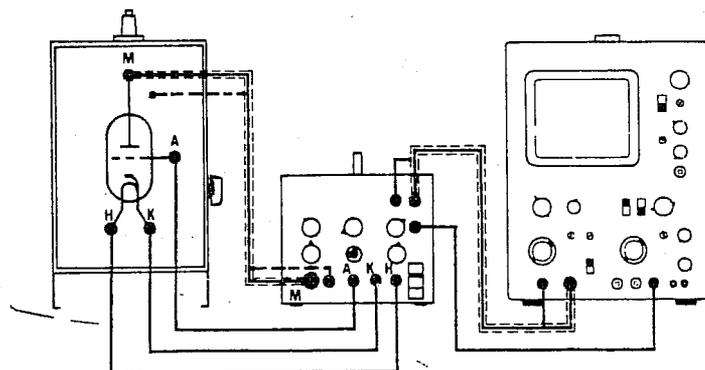


KA6045 - Operating Unit for Franck-Hertz Experiment.

This unit provides all voltages required for the Franck-Hertz experiment and also contains a highly sensitive DC amplifier for measuring the collector current. Setup of the Franck-Hertz experiment becomes very simple when using this unit. Only four connections have to be made and the measuring instruments connected up. The operating unit also permits recording of the Franck-Hertz curve with an oscilloscope. A sawtooth waveform accelerating voltage is produced in the unit for this purpose and the collector current is amplified so that signal voltages up to 10 V are available for vertical deflection. The DC amplifier has an input resistance of 2.2 MΩ. When set to maximum sensitivity, a collector current of 5×10^{-11} A produces a signal output voltage of 1 V. Any voltmeter reading up to 10 VDC may be used as output indicator. Matching of the meter is not necessary. The amplifier can also be used in other experiments for measuring small currents and voltages. Case dimensions: 160 mm x 132 mm x 210 mm. **\$1220.00**



Experimental setup using a meter to observe current maxima and minima.



Setup using an oscilloscope to record Franck-Hertz curve.

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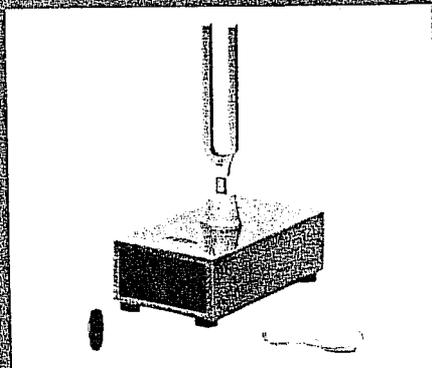
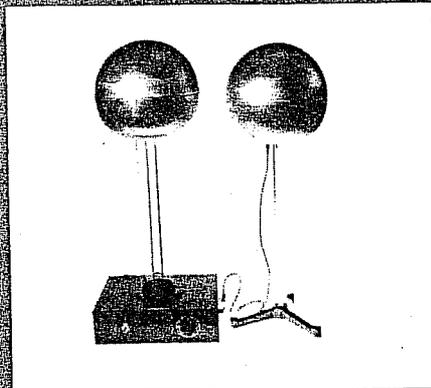
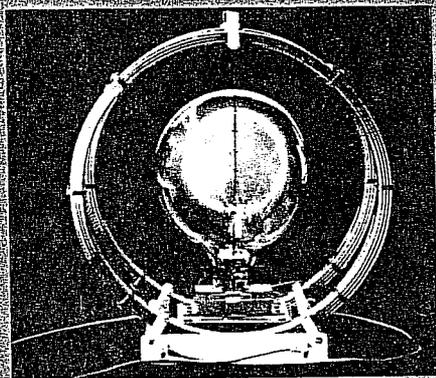
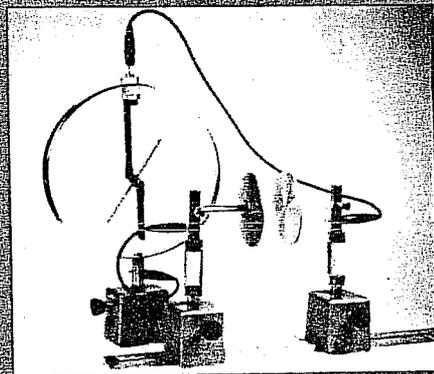
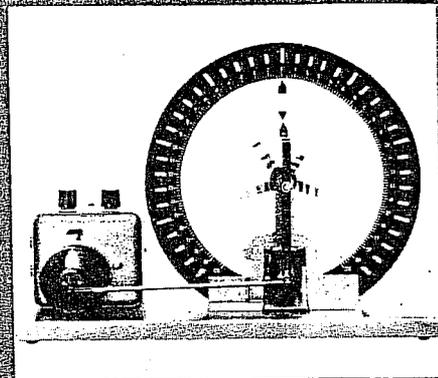
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Dieses Gerät liefert alle zur Durchführung des Franck-Hertz-Versuches erforderlichen Spannungen und enthält einen hochempfindlichen Gleichstromverstärker zur Messung des Auffängerstromes. Verwendet man dieses Betriebsgerät, so wird der Versuchsaufbau denkbar einfach. Es sind nur vier Verbindungen zur Franck-Hertz-Röhre herzustellen und die Meßgeräte anzuschließen.

Der Spannungsteil liefert :

1. Die Beschleunigungsspannung U_b = Gleichspannung von 0 bis 60 V stetig regelbar (Schalter " U_b " in Stellung \rightarrow)
2. Die Heizspannung für die Röhre U_H = Wechselspannung bis 8 V. Der Heizstrom ist regelbar von 270 mA bis 350 mA.
3. Die Gegenspannung U_G = Gleichspannung ca. 1,5 V.

Außerdem zum Aufzeichnen der Franck-Hertz-Kurve mit einem Elektronenstrahl-Oszillograf.

4. Eine sägezahnförmige Beschleunigungsspannung U_b = Amplitudenhöhe einstellbar von 0 bis 90 Vss (Schalter " U_b " in Stellung \swarrow).
5. Spannung für X-Ablenkung am Oszillograf = Halbwellenspannung durch Einweggleichrichtung von 0 bis 10 Vss regelbar.

Der Gleichstromverstärker besteht aus zwei hintereinandergeschalteten Operationsverstärkern (IC), von denen der Erste als Elektrometerverstärker geschaltet ist. Der Meßstrom wird am nichtinvertierenden Eingang zugeführt. Der Eingangswiderstand ist $2,2 \text{ M}\Omega$. Die Verstärkung kann an einem veränderlichen Gegenkopplungswiderstand eingestellt werden. In dem nachgeschalteten OV wird das Signal weiter verstärkt und invertiert.

Die Anzeigespannung ist proportional zum Meßstrom. 1 V Anzeigespannung entspricht bei kleinster Empfindlichkeit (Drehknopf ganz links) einem Meßstrom von $1 \cdot 10^{-8} \text{ A}$ und bei größter Empfindlichkeit einem Meßstrom von $2 \cdot 10^{-10} \text{ A}$. Als Anzeigeelement kann jeder Spannungsmesser bis 10 V verwendet werden. Eine Anpassung des Instruments ist nicht erforderlich. Die Anzeigespannung ist bis 30 mA belastbar und kurzschlußfest.

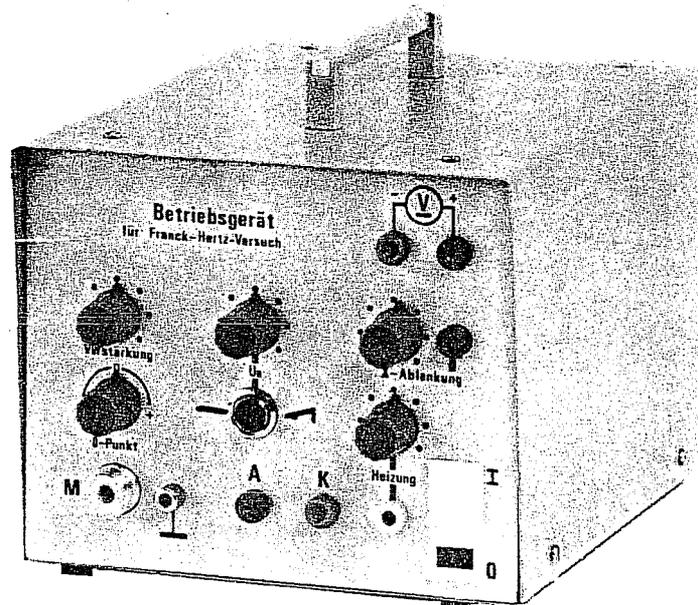


Abb. 1

Versuchsaufbau :

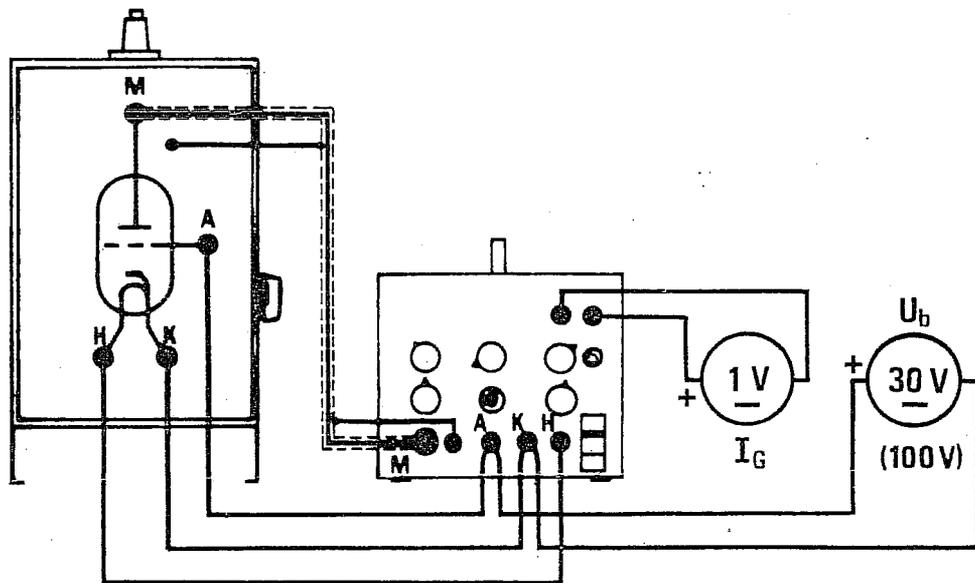
Die Verbindungen sind nach Abb. 2 herzustellen. Dabei liegen die Spannungen

U_b an den Buchsen K (-) und A (+)

U_H an den Buchsen K und "Heizung"

U_G an der Buchse A (+) und an Masse (-)

Für die Verbindung Auffängerelektrode - Verstärkereingang ist eine abgeschirmte Leitung (Nr. 7213) zu verwenden. Das Anzeigeinstrument (1 V Vollaus-
schlag) wird an den Buchsen rechts oben angeschlossen (rote Buchse +). Der Spannungsmesser für die Beschleunigungsspannung (30 V - bzw. 100 V -) liegt an den Buchsen K und A.



Durchführung des Franck-Hertz-Versuchs

1. Heizofen auf die gewünschte Temperatur (z.B. 170°C) einstellen.
2. Betriebsgerät einschalten.
3. Schalter U_b auf "-".
4. Regler U_b auf 0 Volt
5. Drehknopf "Heizung" etwa in die Mitte stellen.
6. Größte Empfindlichkeit am Drehknopf "Verstärkung" einstellen. (ganz nach rechts).
7. Drehknopf "0-Punkt" so einstellen, daß am Anzeigeinstrument keine Spannung angezeigt wird.

Die Beschleunigungsspannung wird dann langsam erhöht und die Verstärkung so weit zurückgedreht, daß die Anzeigespannung im Meßbereich des Anzeigeinstrumentes liegt.

Der angezeigte Auffängerstrom weist in Abhängigkeit von der Beschleunigungsspannung äquidistante Minima auf. Die Kurvenform kann evtl. durch Änderung der Katodentemperatur (am Drehknopf "Heizung") verbessert werden.

Aufzeichnen der Franck-Hertz-Kurve mit einem Elektronenstrahl-Oszillograf.

Aufbau :

1. Oszillograf nach Abb. 3 anschließen.
(X-Ablenkung = extern, Y Ablenkung = 1 V/cm)
2. Länge der Zeitachse am Regler "X-Ablenkung" einstellen.
3. Schalter U_b auf \swarrow
4. Sägezahnspannung am Drehknopf U_b langsam erhöhen.

Auf dem Bildschirm erscheint die Franck-Hertz-Kurve (Abb. 4). "Verstärkung" und Katoden-"Heizung" evlt. nachstellen. Die Beschleunigungsspannung ist so einzustellen, daß in der Röhre keine selbständige Entladung auftritt, denn durch Stoßionisation wird die Kurve gestört.

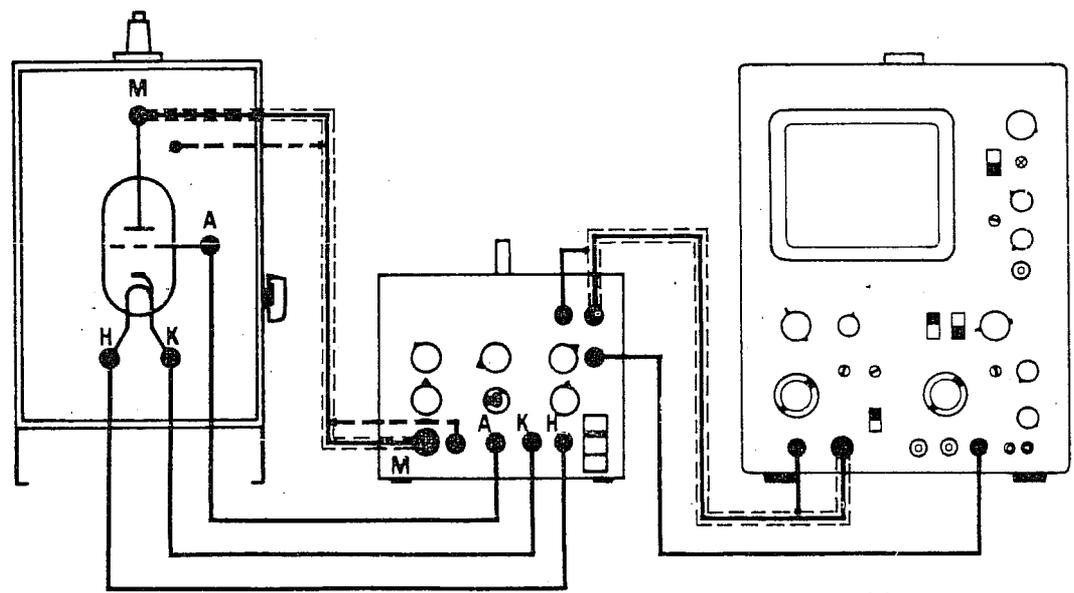


Abb.2

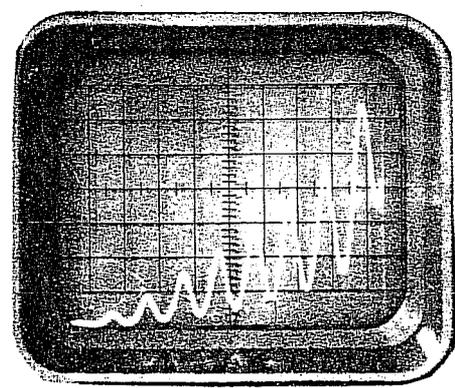


Abb.3