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KA6040/41

NEVA	Franck-Hertz-Experiment	6750 984

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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.

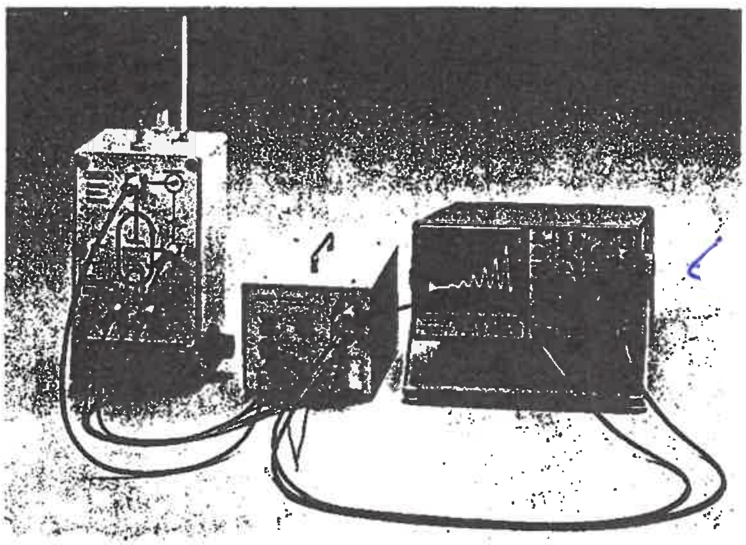

Fig 1 Apparatus set up for the experiment

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 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.

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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° 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.

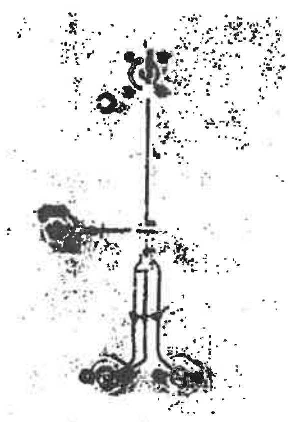
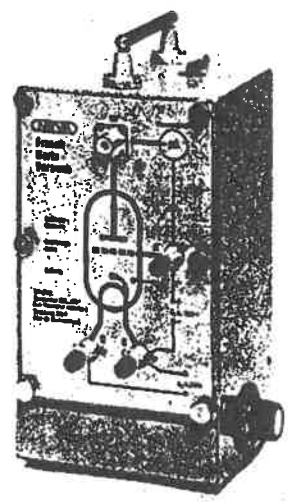


Fig.2 Franck-Hertz-Tube
(mounted on front panel)



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

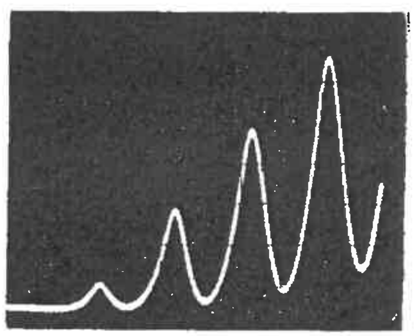
$$\nu = \frac{E}{h} \quad \text{, i.e.} \quad \frac{4{,}9\ \text{eV}}{4.133 \times 10^{-15}\ \text{eVs}} = 1{,}18 \times 10^{15}\ \text{Hz}$$

and the corresponding wavelength is

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

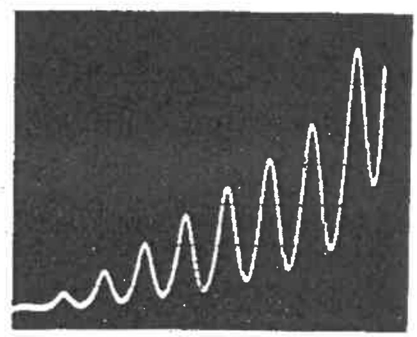
Franck and Hertz verified the presence of this ultraviolet radiation with the aid of a quartz spectrograph.

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 accellerating voltage of about 7 V.



at 150 °C

Fig. 4 Franck-Hertz-Curve



at 180 °C

Fig.5 Franck-Hertz Curve

<u>Procedure for carrying out the experiment</u>

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^{o}) 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 grid-form 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.

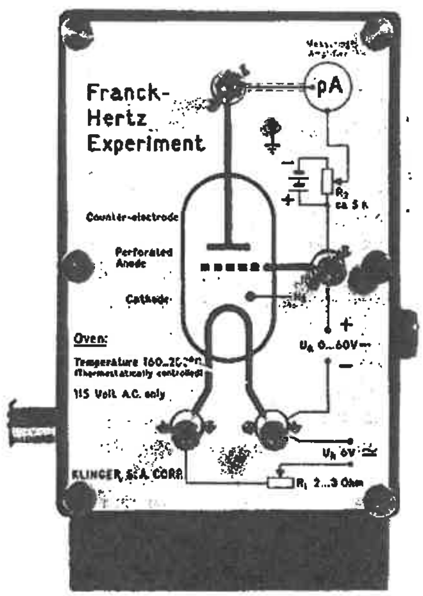
The collisions between electrons and mercury atoms at first take place elastically without significant transfer of energy to the mercury atoms. But when the accelerating voltage has been increased to a sufficient extent,the kinetic energy of the electrons is large enough to excite the mercury atoms just 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.

MARCH 1974

FRANCK-HERTZ TUBE

CAT. NO. KA6040/KA6041

INSTRUCTIONS FOR USE



Design of this Klinger tube is similiar to that originally used by Franck and Hertz to directly measure excitation potentials. This design provides for rigid mounting and stable positioning of the electrodes which insures dependable results. In order to maintain the proper operating temperature, the tube is housed in a thermostatically controlled metal oven.

Description of the tube

1. To avoid deformation of the electric field the tube uses a planoparallel system of electrodes. In order to insure a high probability of collision, the distance between the grid (perforated anode) and the plate (counter electrode) is small whereas the distance between the cathode and grid (perforated anode) is large in comparison to the free path of the electrons.

2. Electrons are emitted thermionically from an indirectly heated cathode. Secondary and reflected electrons are eliminated by a metal diaphragm connected to the cathode.

3. Leakage current along the hot glass wall of the tube is minimized by use of a ceramic feed-through on the plate (counter electrode).

4. The tube is highly evacuated and contains a measured quantity of metalic mercury. When raised to its proper operating temperature the mercury within the tube is in vapor state, thus providing a suitable atmosphere for the measurement of excitation potentials of mercury.

The Oven

To provide proper operating temperature for the tube a 300 watt thermostatically controlled oven is used. The oven also contains a schematic diagram of the tube which clearly indicates and provides means for making all necessary electrical connections.

Operation

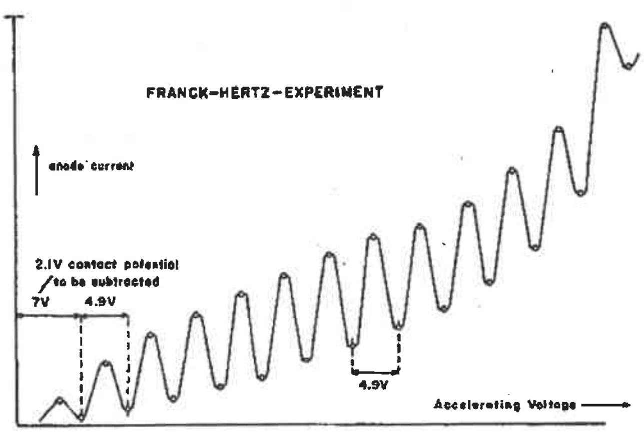
The tube is heated to its proper operating temperature. An accelerating voltage is applied between the cathode and grid (perforated anode). A retarding potential is applied between the grid (perforated anode) and plate (counter electrode). Then the cathode current is adjusted. After the above steps are completed, the accelerating voltage is reset to zero and the tube is ready for use.

As the accelerating voltage increases, more and more electrons are able to surpass the retarding potential and reach the plate (counter electrode). These electrons are recorded as an increasing current. When the accelerating voltage reaches the excitation potential of the mercury atom, an electron colliding with an atom of the mercury vapor will give up a quantum of energy to this atom. These electrons lose velocity to the extent that they cannot surpass the retarding potential and are recorded as a decreasing current.

Compared to the distance between cathode and grid (perforated anode) the free path of the elctrons is small. Electrons which have collided inelastically are able to regain more energy in the electric field. Some of these electrons are able to reach the plate (counter electrode) and are indicated by an increasing current. Plate current continues to increase as the accelerating voltage is increased until the electrons reach the second excitation level and lose their energy a second time.

Energy transfers such as these take place several times as the accelerating voltage increases and are indicated by distinct current maxima and minima. In the voltage range from 0 to approximately 60V, as many as 13 minima are observed. Measurement of these minima which occur in steps of 4.9V with increasing accelerating voltage give a direct measurement of the excitation potentials for mercury.
The first peak however, occurs at about 7 volts because of the additional energy of 2.1V required to remove an electron from the cathode.

Fig. 2



Franck-Hertz Experiment

Set up the apparatus as indicated in Figure 3.

Insert the thermometer to the 76 mm immersion mark.

Plug in the oven and adjust the thermostat so that the oven maintains a temperature of 180° C $\pm$ 5° C.

Adjust the rheostat to its maximum value.

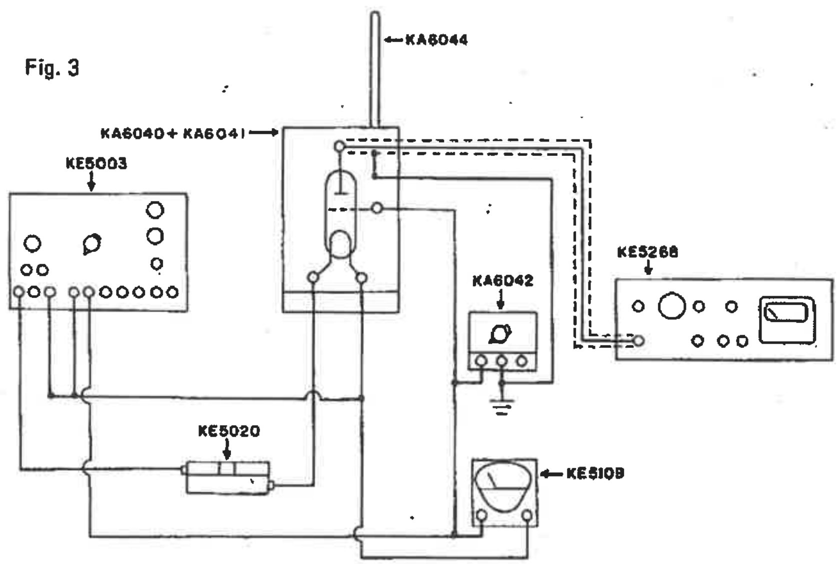
Turn on the amplifier and power supply. Increase the grid voltage to 50 volts. Set the range control on the ampliflier to 1 x 10^{-9} amperes. Set the retarding potential at 1 volt.

Slowly increase the filament current, by adjusting the rheostat, so that a current of approximately 0.75 x 10^{-9} amperes is indicated on the amplifier meter. Note: Fine adjustment of the amplified current is made by varying the retarding potential. Decrease the accelerating voltage to zero. The apparatus is now ready for use.

Slowly increase the accelerating voltage. Record this voltage and the corresponding current measured on the amplifier meter. A plot of this current vs. the accelerating voltage should yield a curve similar to Figure 2.

To clearly define the minimas which occur at lower voltages it may be necessary to increase the amplification.

Fig. 3



WIRING DIAGRAM FOR FRANCK-HERTZ EXPERIMENT

ORDERING DATA

KA6040	Franck-Hertz tube filled with mercury
KA6041	Thermostatically-controlled oven
KA6041R	Repair of the Franck-Hertz tube
KA6044	Thermometer
KE5020	Rheostat, 2 ohms, 6 amps with cover
KA6042	Voltage divider
KE5003	Universal DC power supply
KE5109	DC meter
KA6043	Set of 13 leads

For measuring of small currents an amplifier with a current indicator, sensitivity 10^{-9} - 10^{-10} A, is satisfactory.

For demonstrations in large lecture room:

KE5221	Measuring amplifier of highest stability
KE5204	Demonstration multirange meter

Or, for student laboratory work:

KE5268
Measuring amplifier with built-in meter to measure current down to 10^{-10} ampere.

This instrument features 17 ranges from 10 ma to 0.1 nanoampere in 1X and 3X steps. Minimum detectable current is approximately 2 picoamperes.

Typical applications: Measurement of current in the Franck-Hertz tube; measurement of current in the Planck's constant phototube; determination of currents in diodes, transistors, vacuum-tube grids; measurement of insulation resistance, capacitor leakage, etc. May be used for either rack or bench mounting.

Coaxial cable for use with the Franck-Hertz experiment is included.

NOTE: If any instability occurs at the highest amplification range, it will be found helpful to shield the input plug to the Franck-Hertz tube by wrapping a strip of aluminum foil around the plug and input jack; the foil should be grounded, of course. The polarity of the connections to the filament of the Franck-Hertz tube is quite critical and should be carefully checked if maxima are not well defined. The right-hand terminal of the tube must be connected to the -50 volt terminal on the power supply.

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By further voltage increase, the neon line 5852 AS appears in the tube. The glow around the cathode changes from red to yellowish-red and the current drops to minimum value. The blue glow of mercury disappears almost completely because the collisions between electrons and atoms of neon are no more elastic, but with exchange of energy. For direct exciting of mercury, the pressure Hg is too low and the probability of collision, therefore, is very small. The average free path of electrons in Hg-vapour at room temperature is longer than the distance between the cathode and anode.

By further increase of voltage, the current again increases, reaching the peak at 21.5 volt (ionization potential of neon). The minimum of the current occurs now at 22.5 volt and after that, the current increases again; however, due to formation of space charges no more peaks are observed.

The following accessories are necessary:

K4301	Tube filled with mercury and neon mounted on insulating board	$ 60.00
K4302	Regulated power supply, 0 - 300 Volt	90.00
K4303	Measuring Instrument, range: 0 - 100 microamps	30.00
K4304	Variable rheostat 2 Ohms, 6 Amps	17.00
K4305	Spare tube filled with mercury and neon	45.00
K4306	Set of 14 leads with banana plugs	17.60

Reference:

R.W.Pohl: Optik und Atomphysik,9-th edition,page:223-225

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VISUAL, ELECTRICAL AND SPECTROSCOPIC DEMONSTRATIONS OF THE FRANCK-HERTZ EXPERIMENT

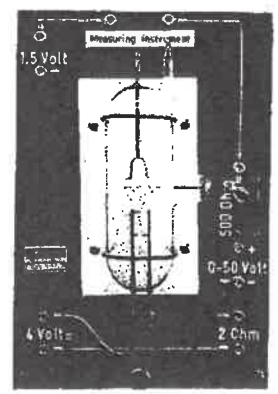
We are taking the opportunity to introduce a new Franck-Hertz experiment. This new apparatus makes it possible to demonstrate optically, by means of characteristic spectral lines as well as electrically the transitions which result from the inelastic collisions of electrons with atoms of mercury and neon.

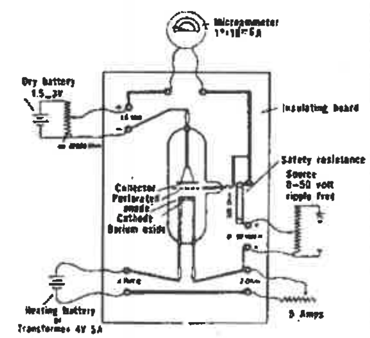
The experiment is much simpler than the classic Franck-Hertz experiment previously supplied by us. The construction of the tube is very rigid and dependable and requires only a micro-ammeter with sensitivity 10^{-6} ampere per division as a current indicator.

Franck-Hertz tube filled with mercury and neon.

The tube filled with a mixture of mercury and neon allows to demonstrate at room temperature the maxima and minima due to inelastic collisions of electrons with mercury and neon atoms. The transitions can be observed visually in form of a characteristic color change and also spectroscopically, by observation of spectral lines. By increasing of the acceleration voltage, it is possible with an ordinary microammeter, (sensitivity 10^{-6} amperes) to demonstrate electrically a voltage current curve with a few maximas and minimas. The tube contains a directly heated cathode with a barium oxide spot, perforated anode and a collector electrode.

The tube is mounted on a board made from insulating material with binding posts connected to the electrodes of the tube. The board can be used in a horizontal or vertical position.





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INSTRUCTIONS FOR USE

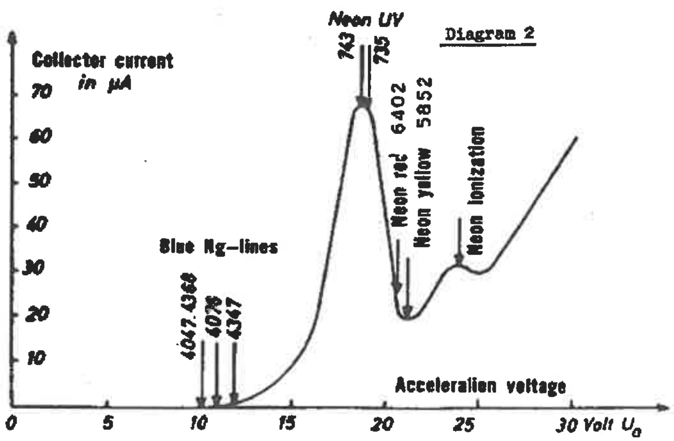
Operation:- The current for the filament is supplied by a 4 Volt battery or a transformer through a variable resistor of 2 ohms. The voltage drop on the filament should be .6 to .7 volt, the current: 3A. Before adjusting the right voltage of the filament, set the variable resistor at the maximum value.

Connect the circuit as shown in the diagram. The power supply which delivers fine regulated voltage between 0 and 50 volt with 15 mA maximum current is placed on the right side of the board. The voltage divider with a 3 volt battery which supplies the counter voltage to the collector, should be connected to the binding posts on the left side of the board. As a current indicator, a microammeter 10^{-6} A per division is recommended. The voltage between the cathode and the anode should be measured with a high resistance voltmeter. From the measured voltage, 2½ volt as a contact potential between barium cathode and anode made of iron should be subtracted.

Diagram 2 shows current voltage characteristic in the Franck-Hertz tube filled with mercury and neon mixture.

The only critical feature in this experiment is the temperature of the cathode. To adjust the temperature of the filament, the following procedure is recommended:- Adjust the position of the rheostat so that the temperature of the cathode appears glowing dark-red (the room should be darkened). As the accelerated voltage is slowly increased from 0 to 30 volts, we can see by approximately 10 volts a pale blue glow of the mercury. By acceleration of 18 volts, a deep dark red glow of the neon. By further increase of the voltage, the dark red color changes to yellowish. The temperature of the cathode should be adjusted so that the passage of the blue mercury glow to the dark red appears distinctively.

Diagram 2



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Evaluations of the results: By slow increase of the acceleration voltage, we observe the following visual, spectroscopic, and electrical phenomena:

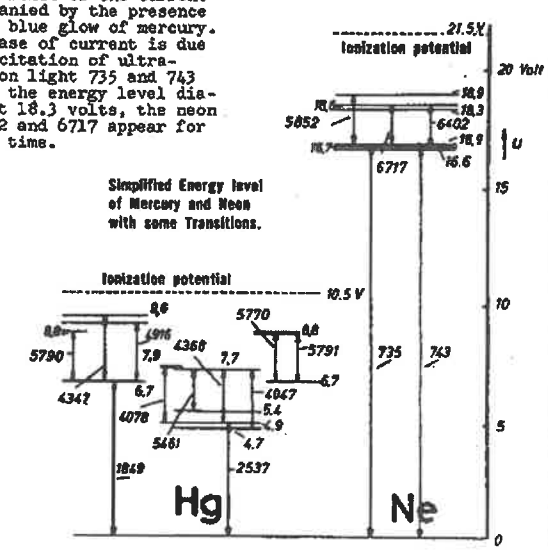
1. Voltage between 0 and 7: Complete darkness in the discharge tube, no sign of glow visible. Current smaller than 10^{-6} amperes.

2. Voltage increased to 10 volts: In the vicinity of the cathode, a pale blue glow of the mercury vapour. Spectroscopically, the mercury lines 4347 and 4368 are identified.

By further increase of voltage, increase of current gives the first peak at 17 volts. Even at the low pressure of mercury (10^{-3} Torr at room temperature), the mercury vapour can be excited to emit light in the presence of neon which acts as colliding gas. At low voltage, many collisions between electrons and neon atoms are elastic collisions. Due to the longer paths of the electrons, the probability of ionization of mercury atoms is greater.

3. At 17 volts:

Strong decrease of the current is accompanied by the presence of a pale blue glow of mercury. The decrease of current is due to the excitation of ultraviolet neon light 735 and 743 AE. (See the energy level diagram.) At 18.3 volts, the neon lines 6402 and 6717 appear for the first time.



ENERGY LEVEL DIAGRAM

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Franck-Hertz-Experiment

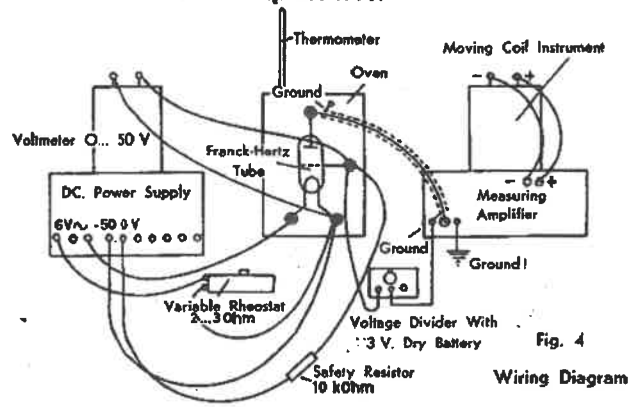

Fig. 4

Wiring Diagram

ORDERING DATA

K4307	Franck Hertz tube filled with mercury	$ 50.00
K4308	Thermostatically controlled oven	45.00
K4304	Variable rheostat 2.4 ohms, 7.5 Amps to regulate the current in the cathode	17.00
K4310	Voltage divider for the counter electrode	9.50
K4302	DC Power supply - 300 Volt with increments every 50 Volt and fine adjustment within each 50 Volt. Filament voltage 4 and 6.3 Volt, 6 Amps. For operation with 115 Volt, 60 cy.	90.00
K4314	DC Meter, Range 50 Volt	22.50
K4313	Set of leads with plugs and special coaxial cable	18.85

For measuring of small currents an amplifier with a current indicator, sensitivity 10^{-9} - 10^{-10} A, is satisfactory. For laboratory use we recommend:

K4309	Universal measuring amplifier	$ 272.00
53155	Moving coil instrument AC, DC, with ranges from 1 mA - 6 A and 0.1 Volt - 300 Volt	68.50

For demonstrations in large lecture room:

53201	Measuring amplifier	$ 385.00
53186	Demonstration multirange meter	260.00

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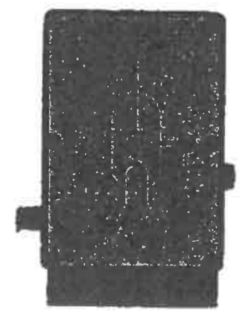
NEW IMPROVED FRANCK-HERTZ TUBE



The tube construction is similar to the original tube used by Franck and Hertz. Rigid mounting and stable position of the electrodes assures dependable results (13 maxima can be obtained). The tube is housed in a thermostatically-controlled metal oven.

Description of the tube

1. The tube has a planoparallel system of electrodes in order to avoid deformation of the electric field. The distance between the anode and the counter electrode is small in comparison to the average free path of electrons whereas the distance between the cathode and perforated anode is large in comparison to the free path of electrons to assure the highest probability of collisions.

2. A platinum ribbon with small Barium-oxide spot serves as a direct heated cathode. A diaphragm connected with the cathode limits the current and eliminates secondary and reflected electrons, making the electric field more uniform.

3. In order to avoid current leakage along the hot glass wall of the tube, a protective ceramic ring is fused in glass as a feed-through to the counter electrode.

4. The tube is highly evacuated and coated inside with getter which absorbs traces of air during the manufacturing process and acts as absorbent during the entire lifetime of the tube and prevents any changes in performance.

The Oven

The oven consists of a steel cabinet, 24 x 16 x 15 cm, containing a heating element which uniformly heats the tube and all connections leading to the tube. The heating element is mounted on the bottom of the housing; its consumption is 300 watt.

The temperature in the cabinet is kept constant by a thermostat which can be regulated from the outside. A hole in the top of the cabinet is provided for the thermometer.

Operation

After the tube has reached a constant temperature, the cathode is heated to a dark red glow and thereafter a DC voltage is applied between the anode and the cathode. A retarding regulated potential 0-3 volt is applied, between the counter-electrode and the anode (Fig. 2). As the accelerating voltage increases, all the electrons which are able to surpass the retarding potential will reach the counter electrode and will be recorded by the current indicator; as soon as the energy of electrons reaches the excitation level of the gas (in this particular case Hg), a quantum of energy is given to the atoms, and the electrons lose the velocity to the degree that it cannot surpass the retarding potential between the anode and the counter-electrode. The current decreases and is recorded on the graph as minimum.

Since the free path of electrons is small compared with the distance between the cathode and the anode, the electrons which slowed down due to inelastic collision, regain new energy in electric field, the current increases until the electrons reach the second excitation level and lose their energy the second time.

As such a transfer of energy from an electron may take place several times as the voltage on the anode increases, distinct current maxima and minima are obtained. In the voltage range from 0 to approximately 60 V, 13 such minima are observed. The difference on the abscissa between the minima corresponds to the value of the energy quantum (4.9 eV). The first peak occurs at about 7 volts because of contact potential between barium cathode and anode made of iron, approx. 2.5 volt.

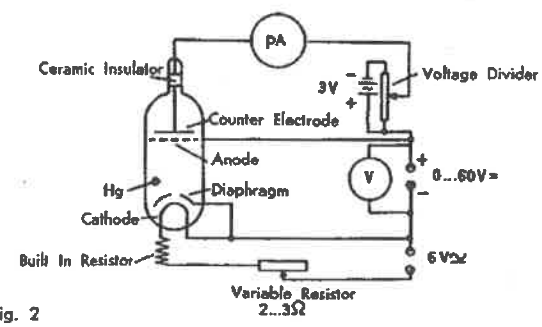


Fig. 2

The Experimental Procedure:

The diagram of connections is shown on Fig. 2. Set the position of the sliding rheostat to its maximum value. Switch on the measuring amplifier, power supply and the heater. It takes about 20 minutes to reach the proper temperature. (In that time, the measuring amplifier also reaches stabilization.) The temperature of the cabinet should be adjusted to 180° C ± 5° C.

Set the sensitivity of the measuring amplifier at 10^{-9} A., the retarding potential at 1.5 volt and raise the acceleration potential to 50 volts. Now, move the slide of the variable rheostat to slowly increase the current in the cathode until the current indicator shows $2 \cdot 10^{-9}$A (full deflection). Immediately after, turn down the voltage on the anode to zero.

At this stage, the apparatus is ready for taking measurements:

Increase very slowly the voltage, read the currents and voltages and record it on the diagram as shown on Fig. 3.

To clearly define the maximas which occur at lower voltages, it may be necessary to increase the amplification to 10^{-10} Amp.

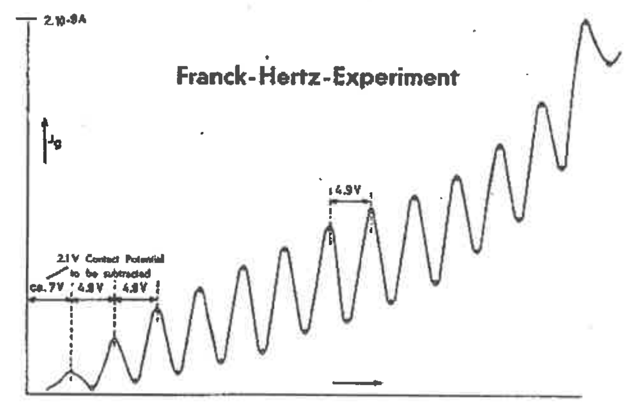


Fig. 3