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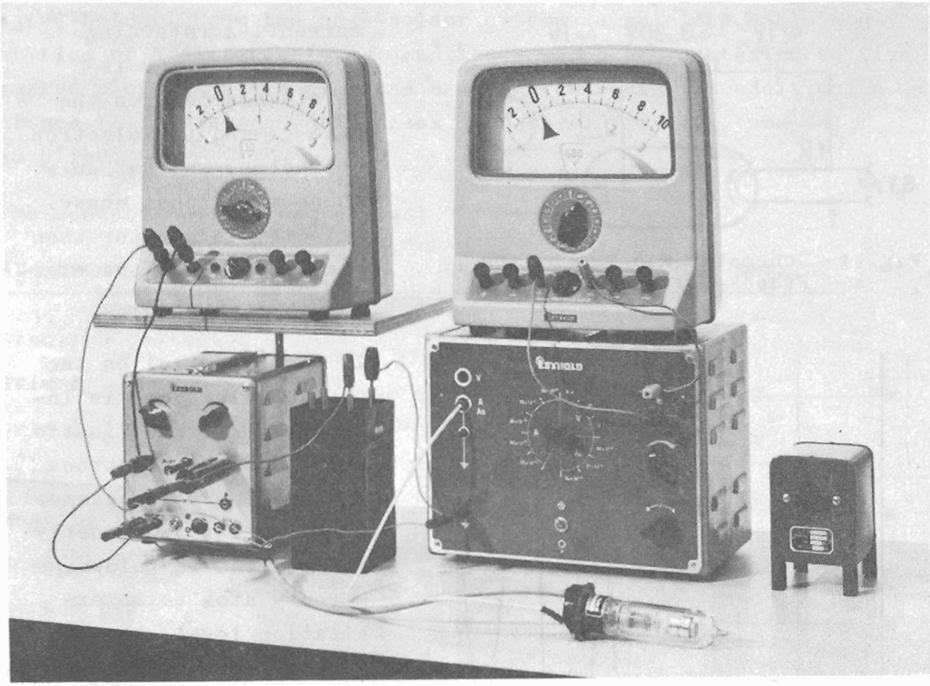
Bulletin 24 E

The Franck-Hertz Experiment



By the introduction of Planck's constant, a new conception utterly different from those of classical physics has been introduced in atomic physics. On the atomic shell, energy is not infinitely divisible, but is arranged into discrete packets or quanta. This important fact, which is so different from customary ways of thinking, can be verified in the Franck-Hertz experiment.

In a tetrode, containing a drop of mercury and heated to 200° C, the electrons issuing from a thermionic cathode are accelerated towards an accelerating grid by an accelerating voltage that should be continuously increased in the course of the experiment.

As long as the voltage V is low enough, the electrons reach the grid g_2 with a maximum velocity which can be calculated from the equation: $eV = \frac{1}{2} mv^2$. Some of these electrons fly through the spacings of the grid and land on the electron collector A, so that they can be recorded by the ammeter after amplification of the current. A retarding potential of 1 V is maintained between the grid g_2 and the electron collector, so that only those electrons, whose velocity is greater than 1 eV, can reach the electron collector A.

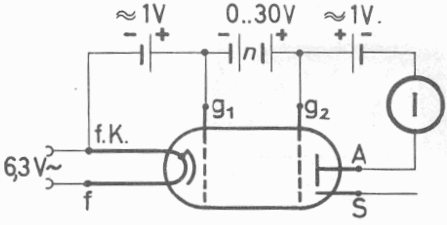


Fig. 1 Schematic diagram of the Franck-Hertz tube

If the potential on the accelerating grid is increased till the kinetic energy of the electrons, $e\,V_0 = 1/2\; m\,v_0^2$, becomes just equal to the energy $h\nu$ required to raise the mercury atom to an excitation level, then the electrons may transfer this energy to the mercury atoms. After such a collision, the electron has lost its velocity. It is no longer able to travel against the retarding potential between A and g_2 and the current decreases.

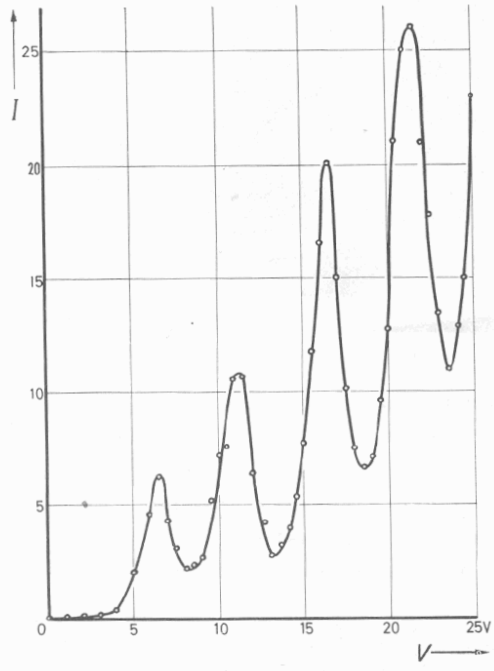


Fig. 2 Current-voltage characteristic of the Franck-Hertz tube

As such a transfer of energy from an electron may take place several times as the voltage on the grid is increased, distinct minima are found in the current-voltage curve. In the voltage range from 1 to 30 V, four such minima are observed. The difference on the abscissa between the minima corresponds to the value of the energy quantum (4.9 eV).

Description of the valve:

The valve has a seven pin base which is inserted into the supplied valve-holder. From the base-holder extends a shielded cable consisting of 5 differently colored leads which are connected to five marked plugs. A sixth flex has a separate sheath. In addition, a bronce foil with connecting flex as a shield for the tube is supplied.

The connections are as follows:

Electrode	Base Pin	Colored Lead	Plug Marking
Electron collector	7	led out separately	A
Grid 2	2	yellow	g_2
Grid 1	10	white	g_1
Cathode	11)	brown	fk
Heating filament	12)		
Heating filament	1	green	f
Screen pin	6	grey	S

The required mercury pressure in the valve is 15 - 20 mm Hg, therefore the entire valve must be kept at a temperature of approx. 200° C in an electric oven (electrical tubular heater 555 81/82). The valve base is separated from the glass envelope by a glass sleeve and remains outside the heater.

The necessary voltages for the valve are as follows:

Heating voltage: 6.3 V
Adjustable D.C. voltages between the grids and the cathode:
0 .... 4 V and 0 .... 30 V.

The grid bias between the electron collector and grid g_2: 1 V.

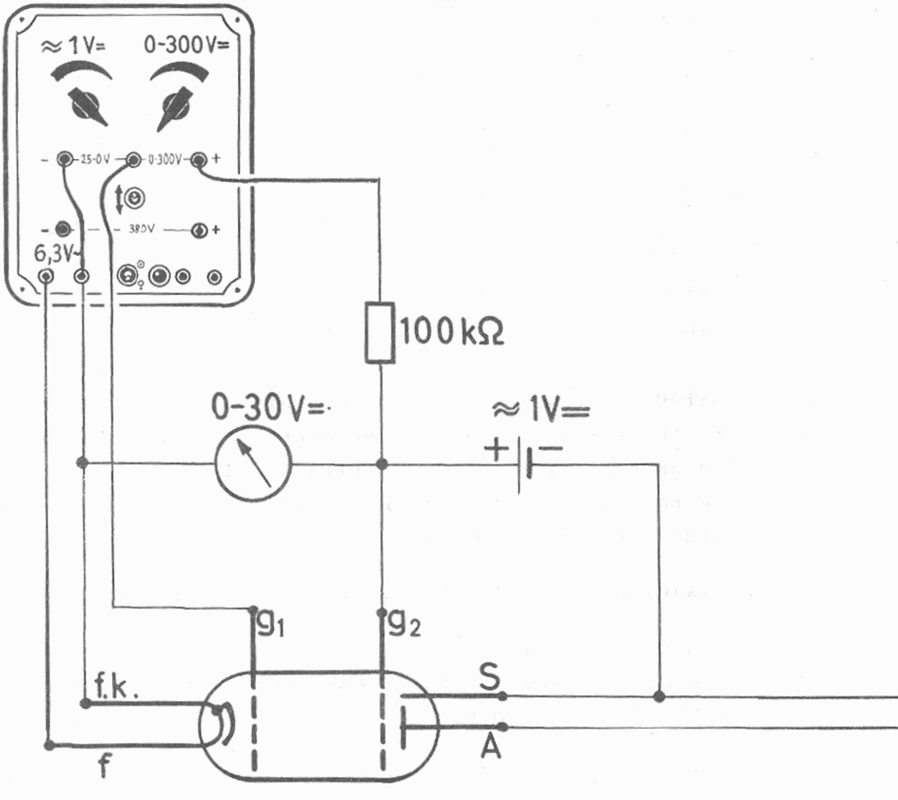
The power-supply (522 33/35) and a small dry battery or one cell of a nickel-cadmium battery have proved to be satisfactory voltage sources.

To measure the current (approx. 10^{-9} A.) the measuring amplifier (532 01) in connection with the demonstration multirange meter (531 86 or 87) can be used.

The experimental procedure:

a) The Franck-Hertz tube is put into the oven.

b) The temperature of the tubular heater is adjusted by a variable resistor (rheostat, 320 ohms, 537 23, at 220 V mains voltage, or rheostat, 110 ohms, 537 24, at 110 V mains voltage) in such a way, that there are 40 - 50 V on the terminals of the 110 V heater and 80-100 V on the terminals of the 220 V heater (Fig. 3).



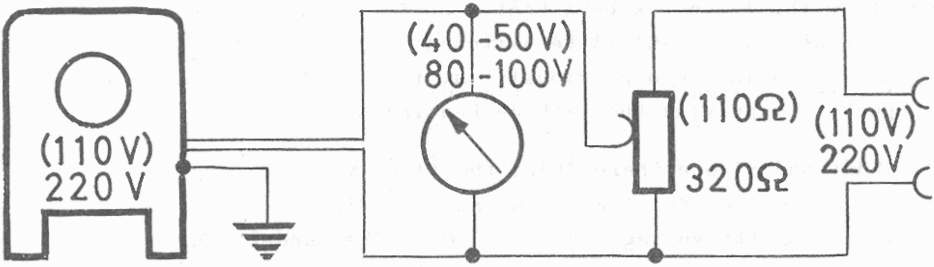


Fig. 3 Circuit of the tubular heater
(The figures in brackets refer to 110 V mains voltage)

c) The measuring amplifier is switched on and the sensitivity is set to zero.

d) The connections should be made according to the circuit diagram on fig. 4.

The voltage supply must be switched off while wiring up. The voltmeter (531 86) should be switched to the 30 V range and has the following additional function: As a member of a potential divider, it supplies voltages from 0 - 30 V to grid g_2, when the power-supply is set to 0 - 270 V. If another indicating instrument is used, a resistor of at least 10 000 ohms must be inserted in the circuit for grid g_2 in order to limit the current in case of a gas discharge in the valve.

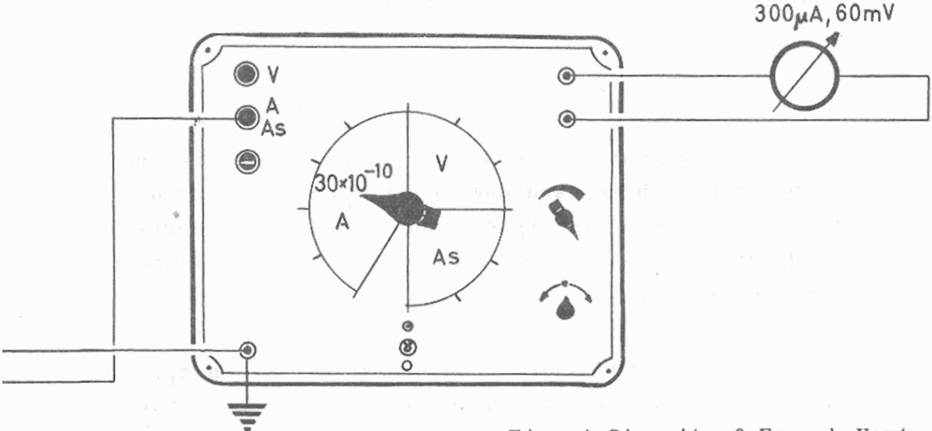


Fig. 4 Circuit of Franck-Hertz tube

e) After the valve has been heated up for about 1/2 hour, the cathode heating should be switched on, the potentials on g_1 and g_2 having been previously set to zero so that the power pack is supplying the cathode heating only.

f) About one minute thereafter, the right voltage for g_1 can be determined: Set the measuring amplifier at 30×10^{-10} A and bring the voltage on g_2 to 30 V. Then under continuous observation of the ammeter the voltage on g_1 should be increased with caution. The current will rise slowly and steadily. If ever the current increases rapidly, a gas discharge has taken place, and the voltage on g_2 must be brought down to zero immediately. The voltage on g_1 should then be lowered and the procedure should be repeated until the gas discharge does not occur with 30 V on grid 2,while the greatest possible emission current flows. This voltage is in general approx. 1/2 - 1 V.

g) Restore the sensitivity of the amplifier in such a way, that the deflection covers the scale. Now the arrangement is ready for taking measurements.

h) The voltage on grid 2 is gradually increased, beginning from zero. As soon as approx. 4 V is reached, the electron current starts and reaches a maximum at about 7 V. Further maxima can be found at intervals of 4.9 V each.

(The fact that the first maximum is at 7 V and not at 4.9 V as would be expected, is due to the contact potential).

Special points:

a) The Franck-Hertz tube contains metallic mercury. After the valve has been transported, there is a danger that some mercury has been retained between the electrodes, and may cause a short-circuit. The start of operation without pre-heating could therefore endanger the valve.

b) Well-defined minima depend, apart from the grid bias on g_1, and the adjustment of the amplifier, above all on the temperature of the electric oven (tubular heater).

If the valve has been overheated, the emission current is small, and maxima and minima can hardly be recognized or seen at all.

For checking purposes remove the valve from the oven and let it cool off for approx. 30 seconds. Then, if the valve was overheated before, maxima can be found. In this case, the oven must be operated at a lower voltage.

When the valve is not sufficiently heated, the emission current is large and the maxima, especially those of a higher order, can hardly be seen. Due to low mercury pressure in the valve, discharge can take place even at small voltages. When this is the case, the valve must be heated to a higher temperature. However, the voltage on the oven must in no case exceed 60 V on the 110 V oven and 100 V on the 220 V oven.

In general, the adjustment of the heating temperature is not difficult. One should change the temperature of the heater only after one has ascertained that there is no mistake in the connection and that the facts observed are really in accordance with one of the two cases.

Apparatus required for the experiments:

555 80 1 Franck-Hertz tube

At 220 V mains voltage:

555 81 1 Electric oven (electrical tubular heater), 220 V A.C.

537 23 1 Rheostat, 320 ohms

or, at 110 V mains voltage:

555 82 1 Electric oven (electrical tubular heater), 110 V A.C.

537 24 1 Rheostat, 110 ohms, 2.5 A

531 55 1 Universal moving coil instrument

522 35 1 Power supply, 130, 220 or 240 V A.C.; 50 c/s

or:

522 33 1 Power supply, 110 V A.C.

536 25 1 Resistance coil, 100 000 ohms

531 86 1 Demonstration multirange meter

522 70 1 Nickel-cadmium accumulator, 3 cells; 3.6 V 11 Ah

For small current measurements:

532 01	1	Measuring amplifier
531 86	1	Demonstration multirange meter
or:		
531 81	1	Demonstration millivolt-microammeter

For more detailed information on the experiments described see Leybold Physics Leaflets.

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BONNER STRASSE 504 · ✉ 195 · ☏ KÖLN [0221] 20561 · 08882815 · LEYBOLDVAK KÖLN

Printed in Germany · 1-7-64 · Graph.Betrieb Heinz Kasper, Köln