

10/62

Instruction Sheet

Cat.No. 555 80

555 81

555 82

555 83

Franck-Hertz tube

Electric oven, 220 V

Electric oven, 110 V

Shielded cable

1. Franck-Hertz tube (555 80)

The Franck-Hertz tube is used for demonstrating inelastic collisions between slow electrons that have a kinetic energy of 4.9 electron volts, and mercury atoms. It is a four-electrode valve with indirectly heated cathode, and contains a drop of mercury.

The tube is fitted with a seven-pin valve base. Fig. 1 illustrates the tube wiring as viewed from the pins.

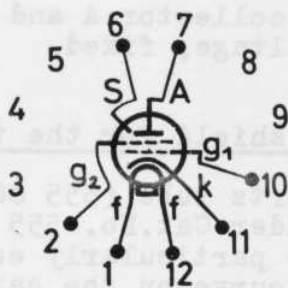


Fig. 1

The tube contains the following coaxial, cylindrical electrodes (Fig. 2), from the shell inwards: Collector A, grid g_2 (accelerator grid), grid g_1 (space charge grid), cathode k, heater filament f.

In addition, a short pin marked screen S is fused into the glass press of the tube between the supply wires of A and g_2 . Its purpose is to prevent leakage currents between these electrodes

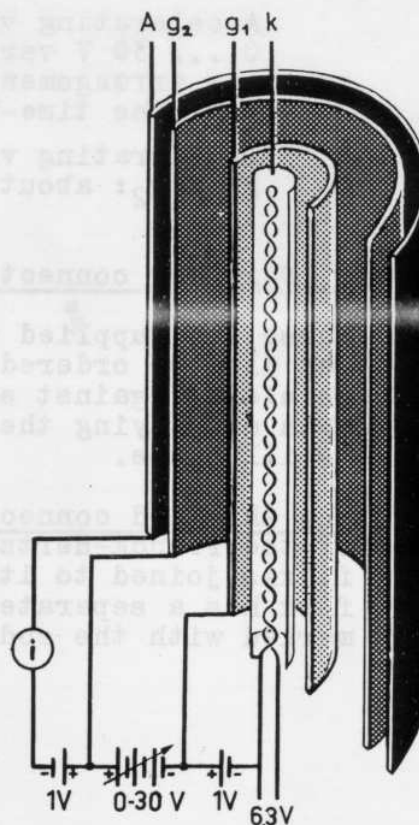


Fig. 2

and so it is grounded when the tube is in operation.

During the experiment, a mercury vapour pressure of 5 to 20 Torr must be maintained in the Franck-Hertz tube. Therefore, the entire tube must be kept at a temperature of about 150°C to 200°C . The electric oven is a convenient means of heating the tube. The plastic valve base which is separated by a glass collar from the Franck-Hertz tube proper remains outside the oven.

When the vapour pressure is too low, not all 4.9 eV electrons will deliver their energy leading to ionization and to an undesirable gas discharge. The same effect may be caused by too large an electron current. Therefore, the Franck-Hertz tube may only be operated with very small collector currents of the order of several times 10^{-9} A. This requires a sensitive current-indicating and measuring device, such as the measuring amplifier (532 01) with the moving coil instrument (531 64. or 531 86), or amplifier (580 00) with the school cathode ray oscilloscope (575 15C).

The Franck-Hertz tube requires the following operating voltages:

Cathode heating: 6.3 V

Space charge grid voltage across grid g_1 and cathode k:
0 ... 4 V variable steady voltage

Accelerating voltage across grid g_2 and cathode k:
0 ... 30 V variable steady voltage, or, in the case of the arrangement with oscilloscope, saw-tooth voltage from the time-base of the oscilloscope.

Decelerating voltage across collector A and accelerator grid g_2 : about 1 V steady voltage, fixed.

2. Shielded connecting cable and shield for the tube

These are supplied with Franck-Hertz tube (555 80.); they may also be ordered separately under Cat.No. 555 83. Shielding against stray fields is particularly essential when displaying the Franck-Hertz curve on the cathode ray oscilloscope.

The shielded connecting cable has a socket fitting the base of the Franck-Hertz tube. Five of the differently coloured flexes joined to it have a common metallic sheath. A sixth flex has a separate sheath. The plugs on the flexes are marked with the code letters for the electrodes:

Electrode	Letter on plug	Flex colour
filament	f	green
filament + cathode	fk	brown
grid 1	g ₁	white
grid 2	g ₂	yellow
screen pin	S ↓	grey
collector	A	led out separately

Fig. 3 shows the wiring of the socket, as seen from the socket side.

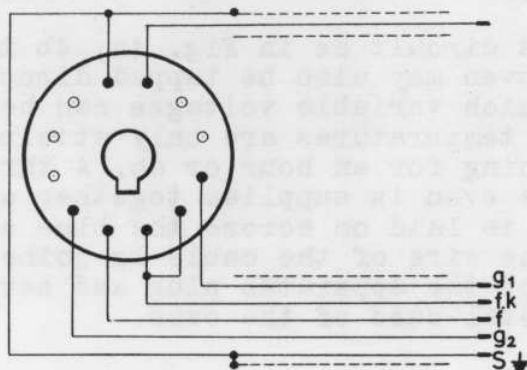


Fig. 3

The sheaths for both cables (shown by a dashed line in Fig.3) are joined to the plug S ↓ together with the screen pin: this plug is grounded in operation.

The shield for the tube is a bronze foil 10 cm x 14 cm in size, with connecting flex, and serves the purpose of shielding the Franck-Hertz tube against stray fields from the electric oven. To this end, the shield foil is laid round the glass of the tube like a sheath, and must not come into contact with plastic base of the tube which might otherwise become too hot. The foil must be earthed.

3. Electric oven, operated from the 220 V (555 81) or 110 V (555 82) A.C. mains

This ceramic oven has a cylindrical heating chamber of about 37 mm clear width and about 100 mm length. When connected to the mains voltage marked on it, it will attain its maximum admissible operating temperature (about 600° C) after about 1 hour, and its consumption is about 200 W.

In the Franck-Hertz experiment, the oven must never be operated at full power, as the Franck-Hertz tube (555 80) is only resistant to temperatures of up to 200° C. Therefore, the oven must be connected to the mains through a potentiometer and a voltmeter.

Fig. 4a shows the circuit for connecting the 220 V - oven (555 81) to the 220 V A.C. mains through a 320 ohm rheostat (537 23). The oven voltage is set at about 90 - 100 V.

Fig. 4b shows the corresponding circuit for the 110 V - oven (555 82) where connection to the 110 V A.C. mains is made through a 110 ohm rheostat (537 24). In this case, the oven must be operated at about 40 V.

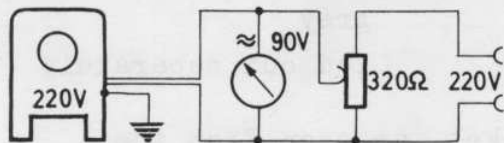


Fig. 4a

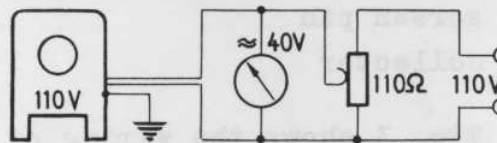


Fig. 4b

Instead of using a circuit as in Fig. 4a, 4b the operating voltages for the oven may also be tapped directly from a switch panel on which variable voltages can be adjusted and read. Steady oven temperatures are only attained after the oven has been running for an hour or so. A three-wire cable for connecting the oven is supplied together with it. The operating voltage is laid on across the blue and black plug. The red plug on the wire of the cable is joined to the earthing contact of the apparatus plug and serves the purpose of earthing the metal case of the oven.

4. Implementation of the experiment, using the measuring amplifier

a) List of apparatus

Franck-Hertz tube	555 80A
Electric oven, 220 V or 110 V	555 81 or 82
Rheostat, 320 ohms or 110 ohms	537 23. or 24.
Voltmeter, 90 V~ or 40 V~, for instance, universal moving coil instrument	531 55
Measuring amplifier	532 01
Moving coil instrument 300 μ A = 60 mV = for instance, large demonstration type multirange meter	531 86
or large moving coil instrument	531 64.
Power pack, 6.3 V~, 0 ... 4 V =, 0 ... 300 V =	522 35
Voltmeter, 30 V = for instance, large demonstration type multirange meter	531 86
or large moving coil instrument with multiplier resistor, 30 V	531 64 /80
Accumulator, about 1 V, for instance	522 70
Precision resistance, 110 kohms	536 25

- b) The Franck-Hertz tube should be sheathed with the metal shield and inserted into the oven as deeply as possible.
- c) According to Figs. 4a, or 4b, a rheostat should be used to regulate the voltage across the electric oven to 90 V in the case of the 220 V-oven and to about 40 V in the case of the 110 V-oven.
- d) The measuring amplifier should be switched on and its sensitivity control set at zero.

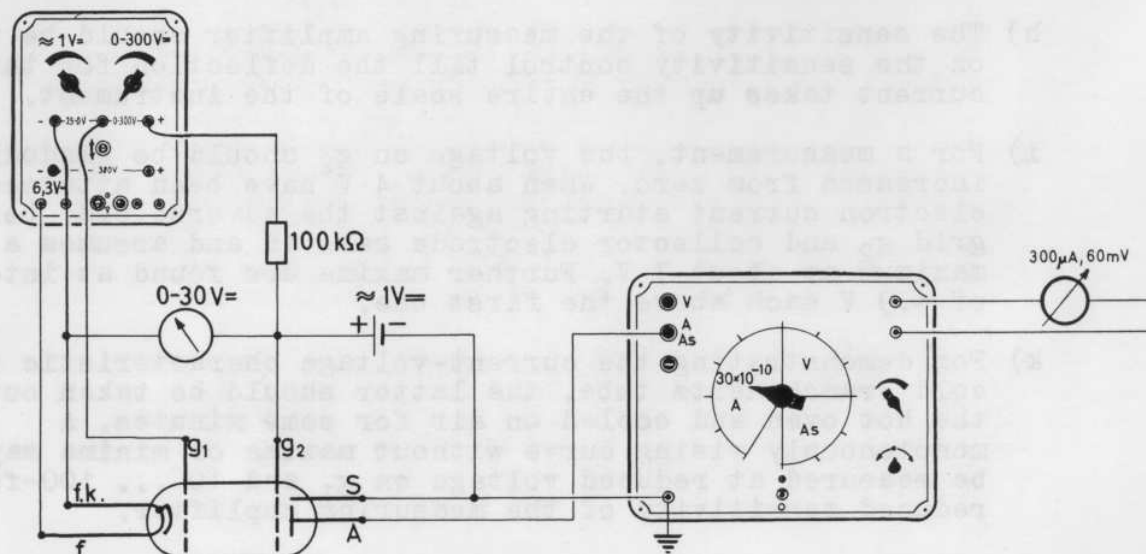


Fig. 5

- e) For arrangement and connections see Fig. 5.

The power supply should be switched off while wiring up the arrangement. The voltmeter, 30 V =, has two functions. As a component of a voltage divider circuit, it supplies voltages between 0 and 30 V to grid g_2 when voltages between 0 and 300 V are adjusted on the power supply. At the same time, it indicates the p.d. between g_2 and the cathode. If a different circuit is used, a resistance of about 100 kohms must be in series with grid g_2 to limit the current in the event of a possible gas discharge.

The collector current is supplied to the current input of the measuring amplifier.

- f) About 1 hour after heating up the oven and the measuring amplifier, the cathode heating (6.3 V) should be switched on. At this stage, there should be no p.d. across the cathode and grids.
- g) After heating has been continued for about 1 minute, the correct voltage for g_1 will be found. This voltage determines the space charge about the cathode and thus the emission current. In order to find this voltage on g_1 , the measuring amplifier should be set at 30×10^{-10} A, the sensitivity control turned up to about three quarters, and the accelerating voltage on g_2 brought to about 30 V. Then the voltage on g_1 should be gradually increased, at the same time constantly keeping an eye on the instrument connected

to the measuring amplifier. The current will grow slowly and steadily at first, till it suddenly begins to rise steeply. This is a sign that a gas discharge is taking place, and the voltage on g_2 must be brought back to zero at once. The gas discharge is also recognized from a bluish luminescence in the Franck-Hertz tube. The voltage on g_1 should be decreased somewhat and the process repeated, till there is no gas discharge even at 30 V in spite of the fact that a large emission current flows. This voltage is generally about 1 V.

- h) The sensitivity of the measuring amplifier should be varied on the sensitivity control till the deflection for this current takes up the entire scale of the instrument.
- i) For a measurement, the voltage on g_2 should be gradually increased from zero. When about 4 V have been attained, an electron current starting against the adverse p.d. between grid g_2 and collector electrode sets in and assumes a maximum at about 7 V. Further maxima are found at intervals of 4.9 V each above the first one.
- k) For demonstrating the current-voltage characteristic of the cold Franck-Hertz tube, the latter should be taken out of the hot oven and cooled on air for some minutes. A monotonously rising curve without maxima or minima may then be measured at reduced voltage on g_1 and 10 ... 100-fold reduced sensitivity of the measuring amplifier.

5. The experiment with the cathode ray oscilloscope

- a) The entire Franck-Hertz curve may be displaced on the oscilloscope as a standing wave picture, when the accelerating voltage changes periodically, say at mains frequency.
- b) List of apparatus:

Franck-Hertz tube	555 80A
Electric oven, 220 V or 110 V	555 81 or 82
Rheostat, 320 ohms or 110 ohms	537 23 or 24
School cathode ray oscilloscope	575 15
Amplifier	580 00
Power pack	522 35B
Accumulator, 6 V, for instance	522 73
Accumulator, about 1 V, for instance	522 70
Rheostat, 230 ohms	537 18A
Rotary potentiometer, 100 kohms	537 85
- c) The Franck-Hertz tube in its shield is inserted into the oven as far as possible. The shield is earthed.

- d) The electric oven is connected to a source of voltage of about 90 V or about 40 V, as shown in Figs. 4a or 4b. The casing of the oven is grounded by means of the red plug.
- e) Arrangement and connections are as in Fig.6. It is quite essential to arrange the appliances clearly and well spaced from one another, and to wire them up in a tidy manner. Otherwise there may be considerable interferences due to stray A.C.'s.

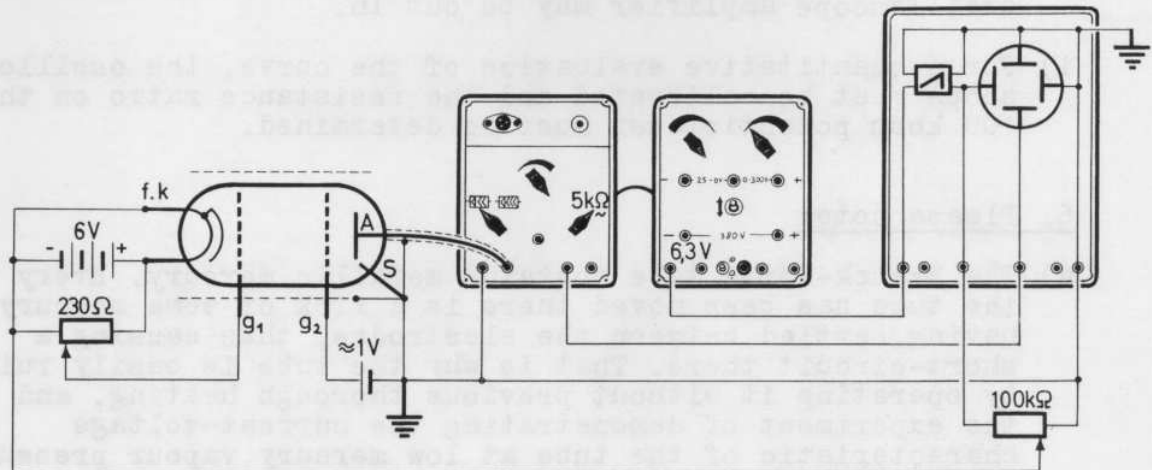


Fig. 6

The 6 V accumulator is used to heat the thermionic cathode and to provide the voltage for the space charge grid g_1 . The polarity must be noted.

The periodically alternating accelerating voltage between grid g_2 and cathode k is derived from the time-base of the oscilloscope through a high-resistance potentiometer (100 kohms).

The time-base of the oscilloscope is synchronized by injecting mains frequency signal of about 6 V, which may be derived from the socket in the lower left-hand corner of the power supply (the other socket is grounded through the amplifier circuit).

One uses the amplifier output for A.C. and high resistance loads (5 kohms \sim). Only the left-hand one of the pair of output sockets need be connected to the vertical deflecting plate of the oscilloscope. The right-hand one is grounded through the rest of the assembly.

- f) Cathode heating, oscilloscope and amplifier are switched on about 1 hour after heating up the oven. It would be too early yet to start regulating the voltage across the grids and the cathode. The amplifier is used as a two-stage amplifier, the amplifier potentiometer is turned up fully.
- g) After heating up for about 1 minute, the accelerating voltage may be cut in up to about half by means of the 100 kohm potentiometer. Higher voltages should be avoided lest the tube might be damaged by a gas discharge. The

voltage on the space charge grid g_1 is gradually increased on the 230 ohm rheostat while constantly keeping an eye on the oscilloscope screen. When the current suddenly starts to grow rapidly, so that a sharp upward bend occurs in the curve, it is an indication that a gas discharge has set in, and the voltage must be reduced at once.

- h) Should the vertical amplitude of the curve be too small, a larger amplification factor may be used. To this end, all three stages of the amplifier and also the built-in oscilloscope amplifier may be cut in.
- i) For a quantitative evaluation of the curve, the oscilloscope must be calibrated and the resistance ratio on the 100 kohm potentiometer must be determined.

6. Please note:

- a) The Franck-Hertz tube contains metallic mercury. Every time the tube has been moved there is a risk of some mercury having settled between the electrodes, thus causing a short-circuit there. That is why the tube is easily ruined by operating it without previous thorough heating, and the experiment of demonstrating the current-voltage characteristic of the tube at low mercury vapour pressure should only be carried out after the determination at high vapour pressure.
- b) The emission current and the incipience of ionization by collision depend not only upon the space charge about the cathode, but also on the mercury vapour pressure and, therefore, on the temperature of the tube. Thus, if it shows that regulating the voltage on grid g_1 does not suffice, the temperature of the tube must be varied.
- c) With an overheated tube, the emission current will be small and maxima and minima are difficult or impossible to recognize. Small voltages on g_1 have no effect, current only begins to flow when there are some volts on g_1 . As a check, the tube should be taken out of the oven and allowed to cool off for about 30 seconds. If the tube had been overheated previously, the current will now be observed to grow and maxima will appear. To eliminate this fault, the oven should be allowed to cool off somewhat and then operated at smaller voltages.
- d) If the tube is too cool, the emission current will be large. Maxima and minima, especially those of a higher order, are faint or absent. Should the vapour pressure in the insufficiently heated tube be too low, there will be a tendency for gas discharge to develop. In order to prevent these, the voltage on g_1 must be reduced so considerably, that the emission current becomes too small and likewise drops below 10^{-9} A. In this case, the tube must be heated up more. However, the voltage on the oven must not exceed 120 V under any circumstances (that is, 60 V in the case of the 110 V-oven).

In general, the experiment presents no difficulties when heating as set out in section 3. The heating voltages should, therefore, not be altered unless one has made sure, after the experiment has failed, that no error has been made in the wiring, and that the set of symptoms observed agrees with one of the two discussed above. The tube might easily be ruined by randomly increasing the oven temperature.

- e) The Franck-Hertz tube should, if possible, not be left to lie in the hot oven for hours on end, lest the vacuum be deteriorated by outgassing metal- and glass parts.
- f) The voltage across grid g_2 and cathode k should not exceed 30 V, otherwise ionization by collision might develop.
- g) A detailed description of the experiment, its evaluation and explanation is found in Leybold's Physics Leaflets, 3rd series. DC 535.352;a. Transitions in the electron shells of atoms are excited by electron impact.