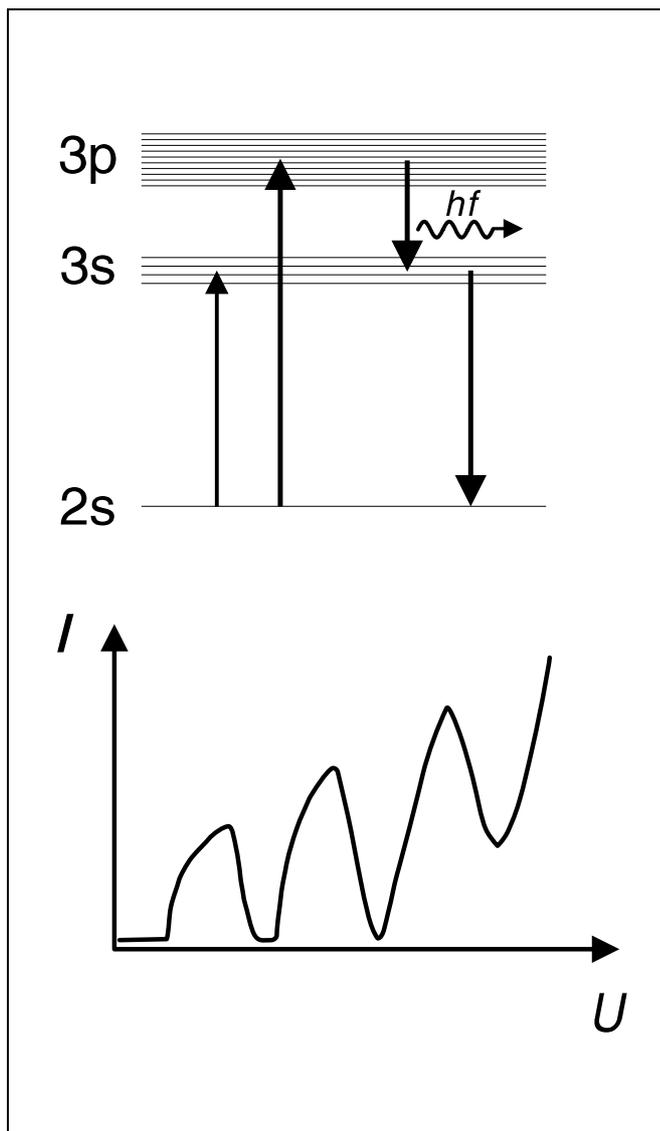


## Franck-Hertz experiment with neon

Recording with the oscilloscope, the XY-recorder and point by point

### Objects of the experiment

- To record a Franck-Hertz curve for neon.
- To measure the discontinuous energy emission of free electrons for inelastic collision.
- To interpret the measurement results as representing discrete energy absorption by neon atoms.
- To observe the Ne-spectral lines resulting from the electron-collision excitation of neon atoms.
- To identify the luminance phenomenon as layers with a high probability of excitation.



### Principles

As early as 1914, *James Frank* and *Gustav Hertz* discovered in the course of their investigations an “energy loss in distinct steps for electrons passing through mercury vapor”, and a corresponding emission at the ultraviolet line ( $\lambda = 254 \text{ nm}$ ) of mercury. As it is not possible to observe the light emission directly, demonstrating this phenomenon requires extensive and cumbersome experiment apparatus.

For the inert gas neon, the situation is completely different. The most probable excitation through inelastic electron collision takes place from the ground state to the ten 3p-states, which are between 18.4 eV and 19.0 eV above the ground state. The four lower 3s-states in the range from 16.6 eV and 16.9 eV are excited with a lower probability. The de-excitation of the 3p-states to the ground state with emission of a photon is only possible via the 3s-states. The light emitted in this process lies in the visible range between red and green, and can thus be observed with the naked eye.

Top: Simplified term diagram for neon.  
Bottom: The electron current flowing to the collector as a function of the acceleration voltage in the Franck-Hertz experiment with neon

**Apparatus**

1 Franck-Hertz tube, Ne . . . . .	555 870
1 Holder with socket and screen for 555 870 . . . . .	555 871
1 Connecting cable to Franck-Hertz tube, Ne . . . . .	555 872
1 Franck-Hertz supply unit . . . . .	555 88

*Recommended for optimizing the Franck-Hertz curve:*

1 Two-channel oscilloscope 303 . . . . .	575 211
2 Screened cables BNC/4 mm . . . . .	575 24

*Recommended for recording the Franck-Hertz curve:*

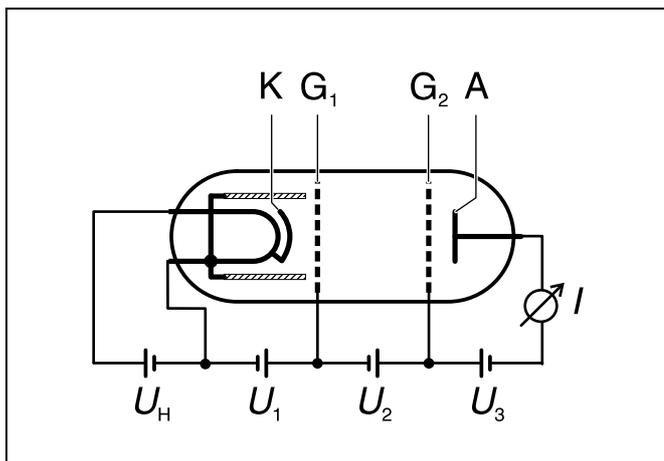
1 XY-Yt recorder SR 720 . . . . .	575 663
Connecting leads	

An evacuated glass tube is filled with neon at room temperature to a gas pressure of about 10 hPa. The glass tube contains a planar system of four electrodes (see Fig. 1). The grid-type control electrode  $G_1$  is placed in close proximity to the cathode K; the acceleration grid  $G_2$  is set up at a somewhat greater distance, and the collector electrode A is set up next to it. The cathode is heated indirectly, in order to prevent a potential differential along K.

Electrons are emitted by the hot electrode and form a charge cloud. These electrons are attracted by the driving potential  $U_1$  between the cathode and grid  $G_1$ . The emission current is practically independent of the acceleration voltage  $U_2$  between grids  $G_1$  and  $G_2$ , if we ignore the inevitable punch-through. A braking voltage  $U_3$  is present between grid  $G_2$  and the collector A. Only electrons with sufficient kinetic energy can reach the collector electrode and contribute to the collector current.

In this experiment, the acceleration voltage  $U_2$  is increased from 0 to 80 V while the driving potential  $U_1$  and the braking voltage  $U_3$  are held constant, and the corresponding collector current  $I_A$  is measured. This current initially increases, much as in a conventional tetrode, but reaches a maximum when the kinetic energy of the electrons closely in front of grid  $G_2$  is just

Fig. 1: Schematic diagram of the Franck-Hertz tube, Ne



sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage  $U_3$ .

As the acceleration voltage  $U_2$  increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from grid  $G_2$ . After collision, they are accelerated once more and, when the acceleration voltage is sufficient, again absorb so much energy from the electrical field that they can excite a neon atom. The result is a second maximum, and at greater voltages  $U_2$  further maxima of the collector currents  $I_A$ .

At higher acceleration voltages, we can observe discrete red luminance layers between grids  $G_1$  and  $G_2$ . A comparison with the Franck-Hertz curve shows them to be layers with a higher excitation density.

**Preliminary remark**

The complete Franck-Hertz curve can be recorded manually.

For a quick *survey*, e. g. for optimizing the experiment parameters, we recommend using a two-channel oscilloscope. However, note that at a frequency of the acceleration voltage  $U_2$  such as is required for producing a stationary oscilloscope pattern, capacitances of the Franck-Hertz tube and the holder become significant. The current required to reverse the charge of the electrode causes a slight shift and distortion of the Franck-Hertz curve.

An XY-recorder is recommended for *recording* the Franck-Hertz curve.

**a) Manual measurement:**

- Set the operating-mode switch to MAN. and slowly increase  $U_2$  by hand from 0 V to 80 V.
- Read voltage  $U_2$  and current  $I_A$  from the display; use the selector switch to toggle between the two quantities for each voltage.

**b) Representation on the oscilloscope:**

- Connect output sockets  $U_2/10$  to channel II (1 V/DIV) and output sockets  $U_A$  to channel I (2 V/DIV) of the oscilloscope. Operate the oscilloscope in XY-mode.
- Set the operating-mode switch on the Franck-Hertz supply unit to "Sawtooth".
- Set the Y-position so that the top section of the curve is displayed completely.

**c) Recording with the XY-recorder:**

- Connect output sockets  $U_2/10$  to input X (0.5 V/cm) and output sockets  $U_A$  to input Y (1 V/cm) of the XY-recorder.
- Set the operating-mode switch on the Franck-Hertz supply unit to RESET.
- Adjust the zero-point of the recorder in the X and Y direction and mark this point by briefly lowering the recorder pen onto the paper.
- To record the curve, set operating-mode switch to "Ramp" and lower the recorder pen.
- When you have completed recording, raise the pen and switch to RESET.

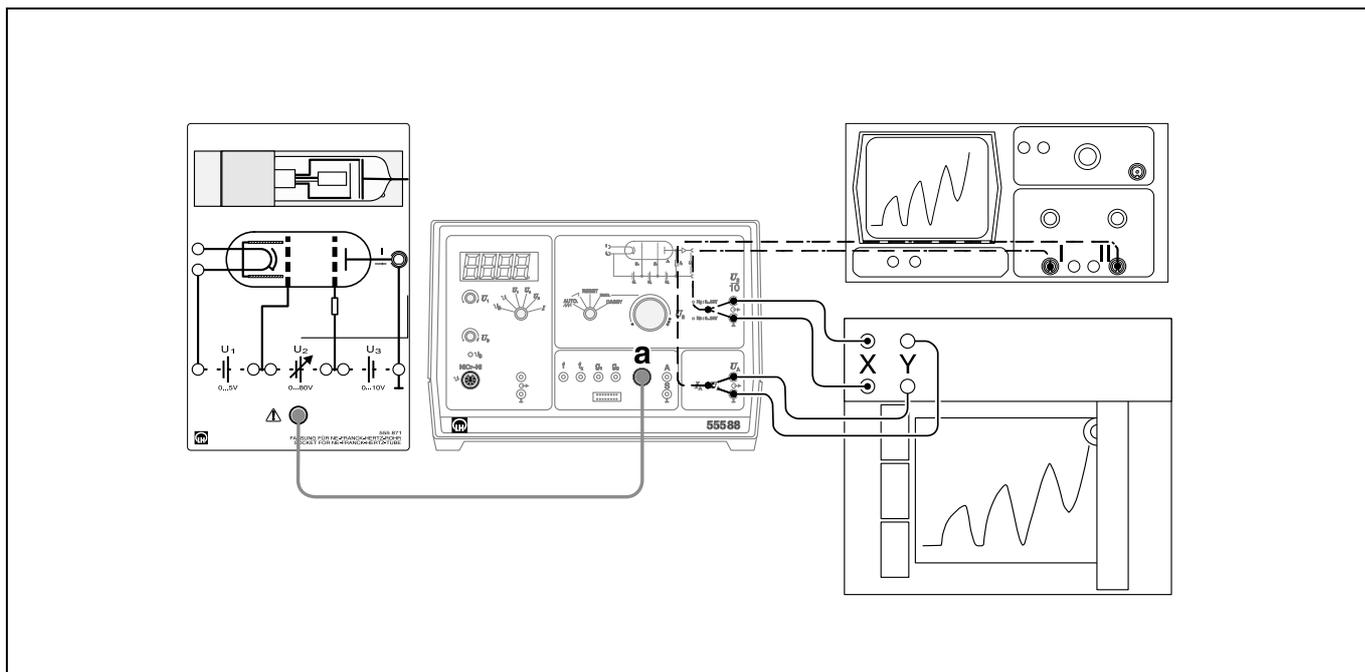


Fig. 2: Experiment setup for Franck-Hertz experiment with neon

## Setup

Fig. 2 shows the experiment setup.

### First:

- Insert and secure the Franck-Hertz tube in the holder and connect it to socket (a) on the Franck-Hertz supply unit via the connecting cable.

### Optimizing the Franck-Hertz curve:

- Set the driving potential  $U_1 = 1.5 \text{ V}$  and the braking voltage  $U_3 = 5 \text{ V}$  and record the Franck-Hertz curve (see preliminary remark).

#### a) Optimizing $U_1$ :

A higher driving potential  $U_1$  results in a greater electron emission current.

If the Franck-Hertz curve rises too steeply, i.e. the overdrive limit of the current measuring amplifier is reached at values below  $U_2 = 80 \text{ V}$  and the top of the Franck-Hertz curve is cut off (Fig. 3a):

- Reduce  $U_1$  until the curve steepness corresponds to that shown in Fig. 3c.

If the Franck-Hertz curve is too flat, i.e. the collector current  $I_A$  remains below  $5 \text{ nA}$  in all areas (see Fig. 3b):

- Increase  $U_1$  until the curve steepness corresponds to that shown in Fig. 3c.
- If necessary, optimize the cathode heating as described in the Instruction Sheet for the Franck-Hertz supply unit.

#### b) Optimizing $U_3$

A greater braking voltage  $U_3$  causes better-defined maxima and minima of the Franck-Hertz curve; at the same time, however, the total collector current is reduced.

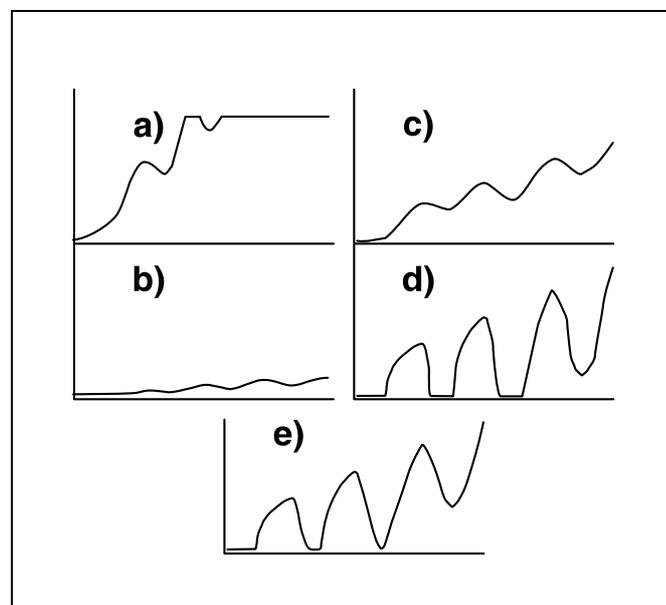
If the maxima and minima of the Franck-Hertz curve are insufficiently defined (see Fig. 3c):

- Alternately increase first the braking voltage  $U_3$  (maximum  $18 \text{ V}$ ) and then the driving potential  $U_1$  until you obtain the curve form shown in Fig. 3e.

If the minima of the Franck-Hertz curve are cut off at the bottom (see Fig. 3d):

- Alternately reduce first the braking voltage  $U_3$  (maximum  $18 \text{ V}$ ) and then the driving potential  $U_1$  until you obtain the curve form shown in Fig. 3e.

Fig. 3: Overview for optimizing the Franck-Hertz curves by selecting the correct parameters  $U_1$  and  $U_3$



### Carrying out the experiment

#### a) Franck-Hertz curve:

- Record the Franck-Hertz curve (see preliminary remark).

#### b) Light emission:

- Set the operating mode switch to MAN.
- Optimize the acceleration voltage  $U_2$  until you can clearly see a red-yellow luminance zone between grids  $G_1$  and  $G_2$ .
- Additionally, find the optimum acceleration voltages for two or three luminance zones and log these values.

#### b) Light emission:

$$U_1 = 2.06 \text{ V}$$

$$U_3 = 7.94 \text{ V}$$

The luminance layers are zones of high excitation density. They can be compared directly with the minima of the Franck-Hertz curve. Their spacing corresponds to an acceleration voltage  $U_2 = 19 \text{ V}$ . Therefore, an additional luminance layer is generated each time  $U_2$  is increased by approx.  $19 \text{ V}$  (see table 1).

Table 1: Number  $n$  of the luminance zones in relation to the acceleration voltage  $U_2$

n	$U_2$
1	30 V
2	48 V
3	68 V

### Measuring example and evaluation

#### a) Franck-Hertz curve:

$$U_1 = 2.06 \text{ V}$$

$$U_3 = 7.94 \text{ V}$$

The distance between the vertical lines (these were placed by eye on the main points of the maxima) has an average value of  $\Delta U_2 = 18.5 \text{ V}$ . This value is much closer to the excitation energies for the 3p-levels of neon ( $18.4 - 19.0 \text{ eV}$ ) than to the energies of the 3s-levels ( $16.6 - 16.9 \text{ eV}$ ). Thus, the probability of excitation to the latter due to inelastic electron collision is significantly less.

The substructure in the measured curve shows that the excitation of the 3s-levels cannot be ignored altogether. Note that for double and multiple collisions, each combination of excitation of a 3s-level and a 3p-level occurs.

### Supplementary information

The emitted neon spectral lines can be observed easily e.g. with the school spectroscope (467 112) when the acceleration voltage  $U_2$  is set to the maximum value.

Fig. 4: Franck-Hertz curve for neon (recorded using an XY-recorder)

