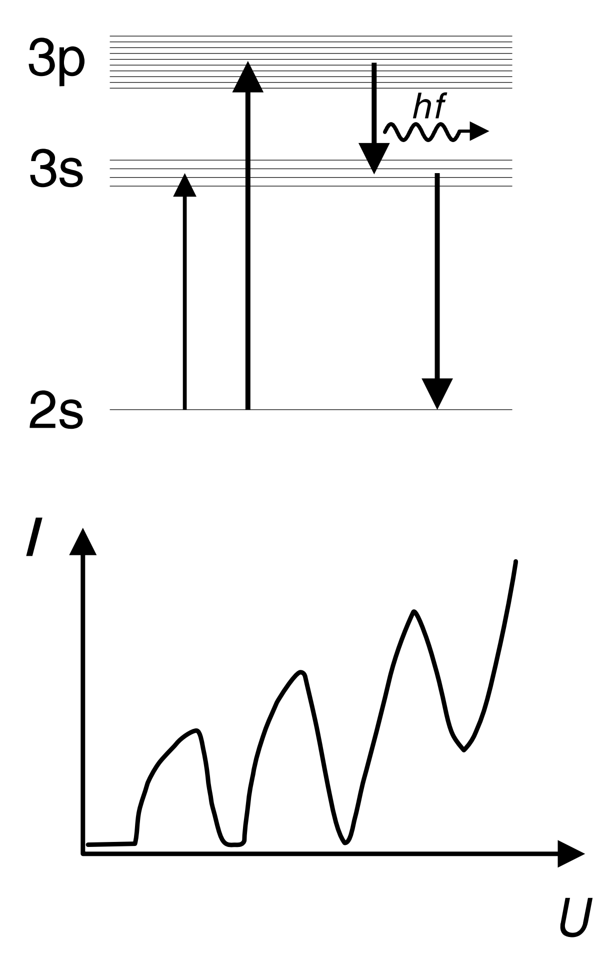
Franck-Hertz experiment with neon

Recording and evaluation using the software “Universal Data Acquisition”

Objects of the experiment

- To record a Franck-Hertz curve for neon via the computer.
- 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.



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

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 (λ = 254 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 3 p-states, which are between 18.4 eV and 19.0 eV above the ground state. The four lower 3 s states in the range from 16.6 eV and 16.9 eV are excited with a lower probability. The de-excitation of the 3 p-states to the ground state with emission of a photon is only possible via the 3 s-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.

Apparatus

1 CASSYpack-E	524 007
1 Disk: Universal Data Acquisition	525 032
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

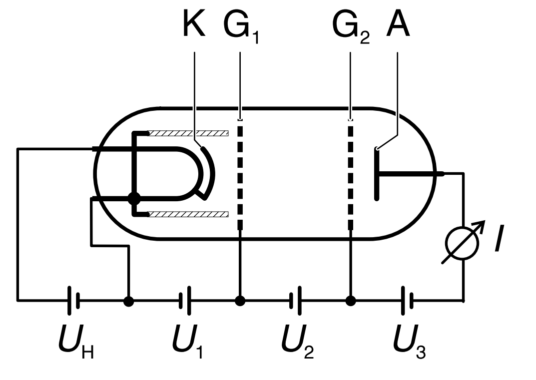
Additionally required:
PC with Windows 3.1. or higher or Windows 95

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 arranged 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 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.

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



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.

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.
– Connect the Franck-Hertz supply unit to CASSY via the 14-pole connector cable **(b)**.

Connect the following inputs and outputs on the Franck-Hertz supply unit and the CASSY interface:

Franck-Hertz supply unit	*CASSY*
Control input	Output X
Voltage U_1	Input A
Voltage U_A	Input B
Voltage $U_2/10$	Input C
Voltage U_3	Input D

Universal Data Acquisition:

The parameters ϑ_S, U_1 and U_3 are set by hand on the Franck-Hertz supply unit, while the voltage U_2 is controlled via the PC and CASSY. For this purpose, a ramp voltage U_X is applied to the control input of the supply unit. For best results, set the rise time of the ramp and the total measuring time to 60 s.

– In the Windows program group “CASSY”, double-click on the icon labeled “Franck-Hertz” or open the file fh.lhw in the File menu to load the pre-defined measuring example, and change and expand the measuring, evaluation and control settings as follows:

Menu “Channels → Inputs → Analog Input … ”

Input A
Quantity = Voltage UA, Range = 0 V ... 10 V
Input C
Quantity = Voltage UC, Range = 0 V ... 10 V
Input D
Quantity = Voltage UD, Range = 0 V ... 10 V

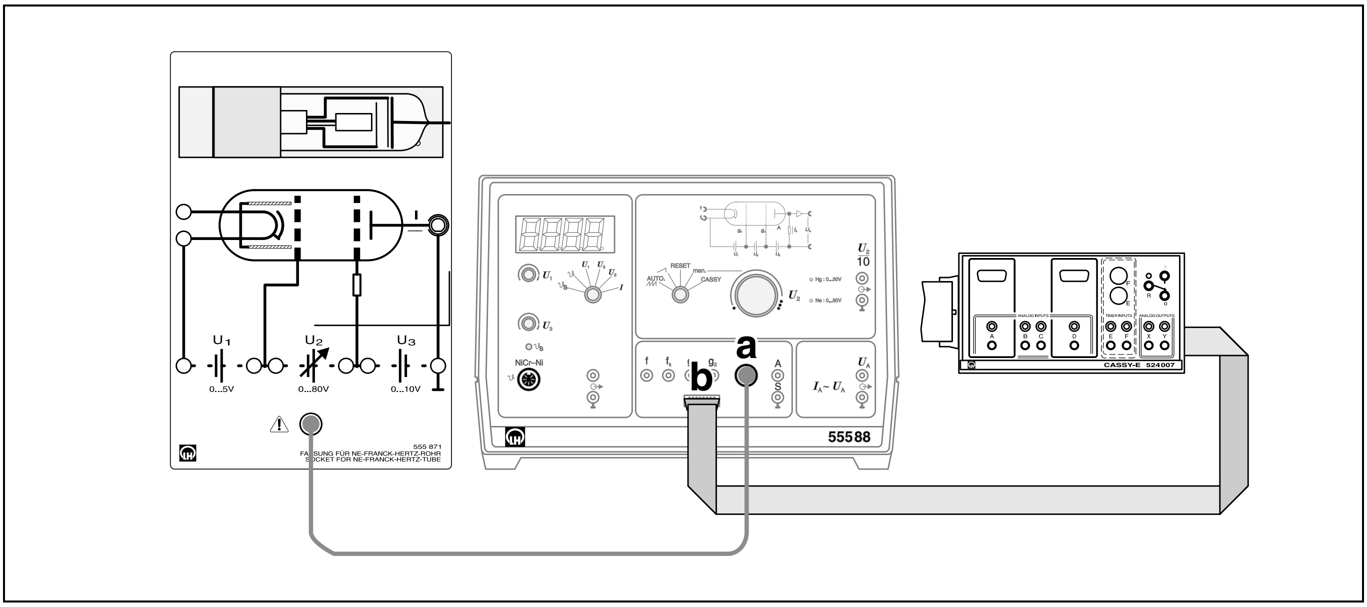


Fig. 2: Experiment setup for Franck-Hertz experiment for neon

Menu "Channels → Outputs → Analog Output … "

Output X
Quantity = Voltage UX,
Formula: = 8 * (shift(t/60)-(t>60)

Menu "Channels → Formula …"

Quantity = Driving Potential
Symbol = U1, Unit = V,
Range = 0 V … 10 V, Formula = UA
Quantity = Acceleration voltage
Symbol = U2, Unit = V,
Range = 0 V … 80 V, Formula = 10*UC
Quantity = Braking Voltage
Symbol = U3, Unit = V,
Range = 0 V … 10 V, Formula = UD

Optimizing the Franck-Hertz curve:

– Set the driving potential U_1 = 1.5 V and the braking voltage U_3 = 5 V and turn the operating-mode switch to CASSY.
– Delete the existing measurement data with "Del".
– Press the spacebar to start recording of the Franck-Hertz curve, and "Ctrl+Space" to stop recording.

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 V and the top of the Franck-Hertz curve is cut off (Fig. 3 a):

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

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

– Increase U_1 until the curve steepness corresponds to that shown in Fig. 3 c.
– 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.

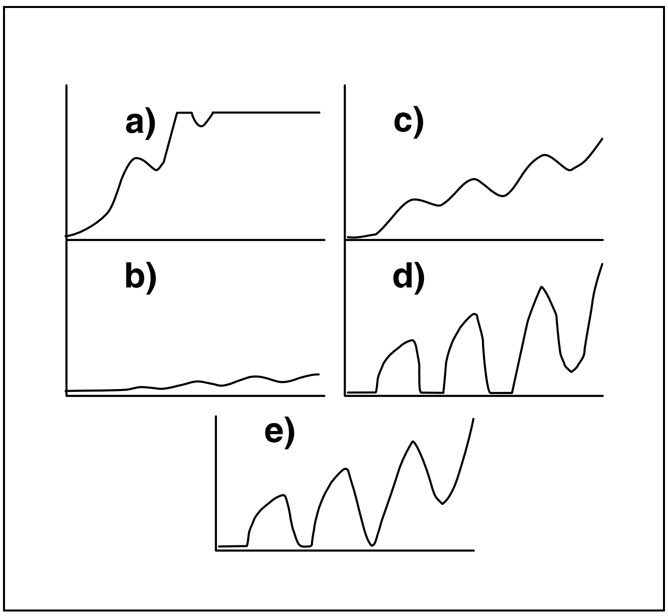
If the maxima and minima of the Franck-Hertz curve are insufficiently defined (see Fig. 3 c):

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

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

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

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:

– Delete the existing measurement data with “Del”.
– Press the spacebar to start recording of the Franck-Hertz curve, and ”Ctrl+Space” to stop recording.
– Click on the menu point *“Evaluations → Set Marker → Vertical Line”* to mark the first maximum of the Franck-Hertz curve.
– Click on the menu point *“Evaluations → Set Markers → Text”* once more and position the suggested text on the line.
– Mark the remaining maxima in the same way.
– Select the menu command *“File → Save As”* and save your data under a different file name.

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.

Measuring example and evaluation

a) Franck-Hertz curve:

U_1 = 2.00 V

U_3 = 7.94 V

The distance between the vertical lines in Fig. 4 has an average value of ΔU_2 = 18.5 V. This value is much closer to the excitation energies for the 3 p-levels of neon (18.4 – 19.0 eV) than to the energies of the 3 s-levels (16.6 – 16.9 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 3 s-levels cannot be ignored altogether. Note that for double and multiple collisions, each combination of excitation of a 3 s-level and a 3 p-level occurs.

b) Light emission:

U_1 = 2.00 V

U_3 = 7.94 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 V. Consequently, an additional luminance layer is generated each time U_2 is increased by approx. 19 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

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.

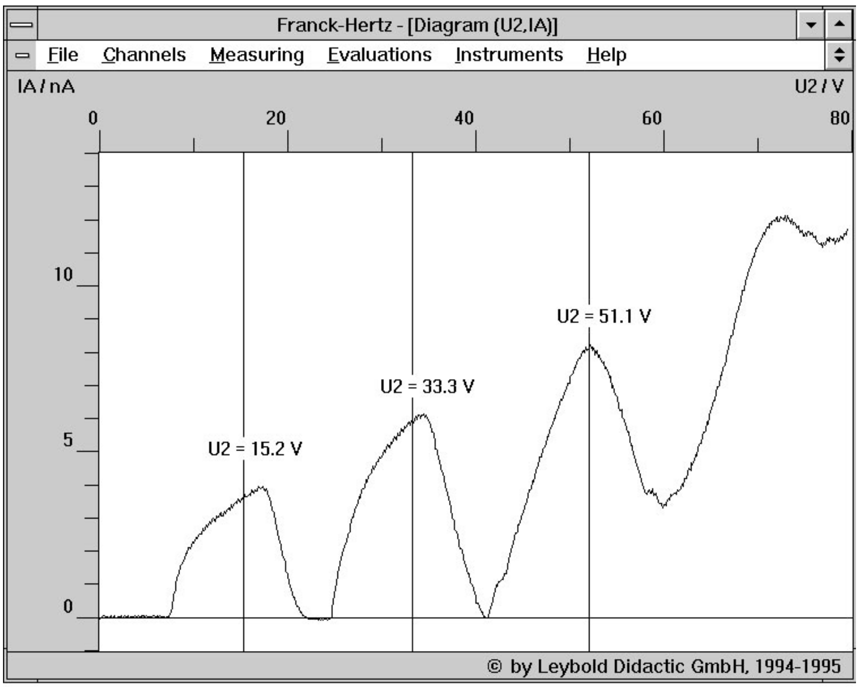


Fig. 4: Franck-Hertz curve for neon (recorded using an XY-recorder)