Atomic and nuclear physics

Atomic shell

Franck-Hertz experiment

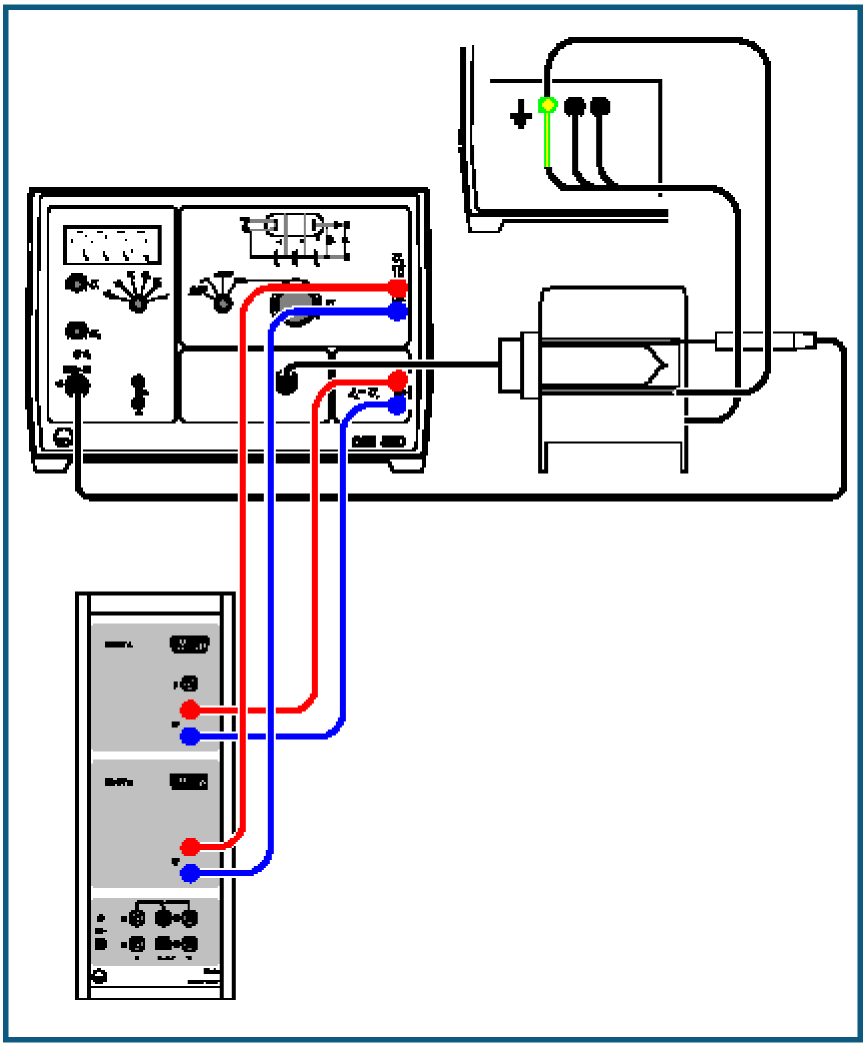
Franck-Hertz experiment with mercury - Recording and evaluation with CASSY

Description from CASSY Lab 2

For loading examples and settings, please use the CASSY Lab 2 help.

CASSY Lab 2 (2013-06-07)

Franck-Hertz experiment with mercury



can also be carried out with Pocket-CASSY

Experiment description

In 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line (λ = 254 nm) of mercury. Just a few months later, Niels Bohr recognized this as evidence confirming his model of the atom. The Franck-Hertz experiment is thus a classic experiment for confirming quantum theory.

In this experiment, the acceleration voltage U_2 is increased from 0 to 30 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 mercury atoms (E_{Hg} = 4.9 eV) 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 mercury 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 mercury atom. The result is a second maximum, and at greater voltages U_2 further maxima of the collector current I_A.

Equipment list

1	Sensor-CASSY	524 010 or 524 013
1	CASSY Lab 2	524 220
1	Hg Franck-Hertz tube	555 854

1	Socket for Hg Franck-Hertz tube	555 864
1	Electric oven, 230 V	555 81
1	Franck-Hertz supply unit	555 880
1	Temperature sensor NiCr-Ni	666 193
2	Pairs of cables, 100 cm, red and blue	501 46
1	PC with Windows XP/Vista/7/8	

Experiment setup (see drawing)

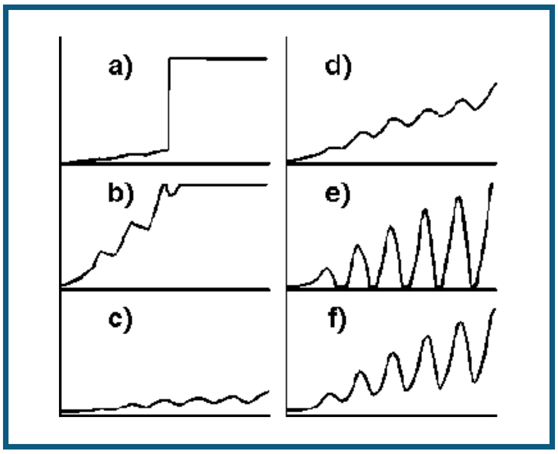
- Make sure the Franck-Hertz supply unit is switched off.
- Connect the heating oven via the 4-mm safety sockets on the rear of the supply unit. In particular, ensure that the yellow and green plug is connected to the yellow and green safety socket (earth).
- Additionally, connect the copper lead of the copper sleeve with 4-mm plug to the green-yellow safety socket (to screen the Franck-Hertz tube from interference fields).
- Connect temperature sensor to the "NiCr-Ni" DIN socket and Franck-Hertz tube to the "Franck-Hertz tube" DIN socket of the supply unit.
- Insert the temperature sensor in the corresponding blind hole of the heating oven as far as it will go and slide the Franck-Hertz tube with copper sleeve into the oven.
  Note: If the thermal contact of the temperature sensor is poor, the measured oven temperature will be too low, resulting in overheating of the tube.
- Turn the operating-mode switch to RESET and switch on the supply unit (after a few seconds, the LED indicator for mercury (Hg) changes from green to red).
- Check the default setting ϑ_S = 180 °C and wait until the operating temperature is reached (LED indicator changes from red to green; the temperature ϑ first reaches a maximum, and then declines to the final value).

If the indicator in the display flashes:

- There is a mistake in the setup for temperature measurement (see the Instruction Sheet).
- Connect voltage input A for the Sensor-CASSY to output U_A for the voltage proportional to the collector voltage and the voltage input B of Sensor-CASSY at output U_2/10 for the acceleration voltage.

Carrying out the experiment

- Load settings
- Set the driving potential U_1 = 1.5 V and the braking voltage U_3 = 1.5 V and record the Franck-Hertz curve in the "Ramp" operating mode. To do this, start the measurement by pressing and immediately set the operating mode switch to "Ramp". The measurement is automatically stopped after 15 s, then return the operating mode switch to RESET.



1) Optimizing ϑ

If the Franck-Hertz curve rises abruptly (a) and you can see a gas discharge in the Franck-Hertz tube through the insertion opening of the oven (blue glow):

- Immediately turn the operating-mode switch to RESET and wait until the setup reaches the operating temperature.
- If necessary, raise the set value ϑ_S using the screwdriver potentiometer (e.g. by 5 °C) and wait a few minutes until the system settles into the new thermal equilibrium.

2) 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 = 30 V and the top of the Franck-Hertz curve is cut off (b):

- Reduce U_1 until the curve steepness corresponds to (d).

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

- Increase U_1 until the curve steepness corresponds to (d).

If the Franck-Hertz curve is flat even after increasing U_1:

- Reduce the set value ϑ_S for the oven temperature using the screwdriver potentiometer.

3) 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 (d):

- Alternately increase first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (f).

If the minima of the Franck-Hertz curve are cut off at the bottom (e):

- Alternately reduce first the braking voltage U_3 and then the driving potential U_1 until you obtain the curve form shown in (f).

The Hg Franck-Hertz tube in the experimental example was measured using the parameters U_1 = 2.58 V, U_3 = 1.95 V und ϑ_S = 180 °C.

Evaluation

The recorded curve is evaluated by drawing vertical lines or peak centers to find the distance between the subsequent maxima. In the experimental example, an average value of U_2 = 5.07 V is found. This corresponds to an energy transfer ΔE = 5.07 eV.

The value found in the literature for the transfer energy of the mercury atoms from the basic state 1S0 to the first 3P1 state is E_{Hg} = 4.9 eV.

The position of the first maximum is determined through the contact voltage of the electrode materials used and the driving potential U_1. The larger distance between the maxima of higher order is caused by superposition of the Franck-Hertz curve by the characteristic tube line.