# Franck-Hertz experiment with a Hg-tube

| | | |
|---|---|---|
| Physics | Modern Physics | Quantum physics |
| Chemistry | Physical chemistry | Atomic structures & properties |

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| easy | 1 | 10 minutes | 10 minutes |

PHYWE excellence in science

# General information

## Application

PHYWE excellence in science

Hg Franck-Hertz tube

The Franck-Hertz experiment on electron-mercury collisions demonstrates the quantum behavior of atoms and proves the existence of discrete stationary energy levels in atoms. The experiment is limited to the determination of the energy required to excite the first energy levels of mercury atoms.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

## Other information (1/2)

PHYWE excellence in science

**Prior knowledge**

When an isolated atom absorbs an electron with right amount energy, it is excited from a ground state to a higher energy state. It generally remains in the excited state for a short time before emitting a photon and making a transition to a lower energy state. The transition of electron between the levels only occurs, if the amount of absorbed or emitted energy is exactly equal to the energy difference between the two levels.

**Scientific principle**

Electrons are accelerated in a tube filled with mercury vapour. The excitation energy of mercury is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

## Other information (2/2)

PHYWE excellence in science

**Learning objective**

To verify the concept of quantization of energy transfer in non-elastic electron-atom collisions.

**Tasks**

1. Record the countercurrent strength $I$ in a Franck-Hertz tube as a function of the anode voltage $U$.
2. Determine the excitation energy from the positions of the current strength minima or maxima by difference formation.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

## Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

Ensure the temperature of the tube do not exceed 300°C to avoid damaging the tube by a runaway discharge

## Theory (1/4)

Niels Bohr introduced the planetary model of the atom in 1913: An isolated atom consists of a positively charged nucleus about which electrons are distributed in successive orbits. He also postulated that only those orbits occur for which the angular momentum of the electron is an integral multiple of $h/2\pi$, i.e. $n * h/2\pi$, where $n$ is an integer and $h$ is Planck's constant.

Bohr's picture of electrons in discrete states with transitions among those states producing radiation whose frequency is determined by the energy differences between states can be derived from the quantum mechanics which replaced classical mechanics when dealing with structures as small as atoms.

It seems reasonable from the Bohr model that just as electrons may make transitions down from allowed higher energy states to lower ones, they may be excited up into higher energy states by absorbing precisely the amount of energy representing difference between the lower and higher states.



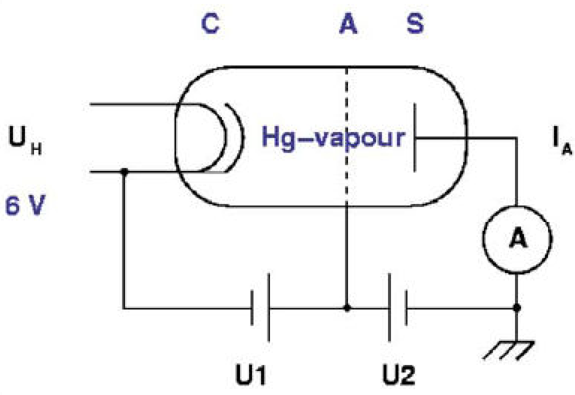
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

# Theory (2/4)

PHYWE excellence in science

James Franck and Gustav Hertz showed that this was, indeed, the case in a series of experiments reported in 1913, the same year that Bohr presented his model. Franck and Hertz used a beam of accelerated electrons to measure the energy required to lift electrons in the ground state of a gas of mercury atoms to the first excited state.

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with mercury vapour and are scattered by elastic collision with mercury atoms. From an anode voltage $U_1$ of 4.9 V, however, the kinetic energy of the electrons is sufficient to bring the valence electron of the mercury to the first excitation level $6^3P_1$ by an inelastic collision.




Principle of the measurement

# Theory (3/4)

PHYWE excellence in science

Because of the accompanying loss of energy, the electron can now no longer traverse the opposing field between anode A and counter electrode S: the current $I$ is at a minimum. If the anode voltage is now increased further, the kinetic energy of the electron is again sufficient to surmount the opposing field: the current strength $I$ increases.

When $U_1 = 2x4.9V$, the kinetic energy is so high that two atoms in succession can be excited by the same electron: the second minimum is obtained. The graph of $I/U_1$ thus shows equidistant maxima and minima. These minima are not, however, very well-defined because of the initial thermal distribution of the electron velocities. The voltage $U_1$ between anode and cathode is represented by

$$U_1 = U + (\Phi_A - \Phi_C)$$

where *U* is the applied voltage, and *A* and *C* the work function voltages of the anode and cathode respectively.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

## Theory (4/4)

As the ecxitation energy $E$ is determined from the voltage differences at the minima, the work function voltages are of no significance here.

According to the classical theory the energy levels to which the mercury atoms are excited could be random. According to the quantum theory, however, a definite energy level must suddenly be assigned to the atom in an elementary process. The course of the $I/U_A$ curve was first explained on the basis of this view and thus represents a confirmation of the quantum theory.

The excited mercury atom again releases the energy it has absorbed, with the emission of a photon. When the excitation energy $E$ is 4.9 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E} = 253\,nm$$

where $c = 2.9979 \cdot 10^8\ ms$ and $h = 4.136 \cdot 10^{-15}\ eV$ and thus lies in the UV range.



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

# Equipment

| Position | Material | Item No. | Quantity |
|---|---|---|---|
| 1 | Franck-Hertz Hg-tube on plate | 09105-10 | 1 |
| 2 | Franck-Hertz control unit | 09105-99 | 1 |
| 3 | Franck-Hertz oven for Hg-tube | 09105-93 | 1 |
| 4 | Thermocouple NiCr-Ni, -40..1300°C | 13615-01 | 1 |
| 5 | Connecting cord for Franck-Hertz Hg-tube | 09105-30 | 1 |
| 6 | Software Measure Franck-Hertz experiment | 14522-61 | 1 |
| 7 | Converter USB - RS232, active | 14602-10 | 1 |
| 8 | Data cable, plug/ socket, 9 pole | 14602-00 | 1 |
| 9 | Screened cable, BNC, l = 750 mm | 07542-11 | 1 |



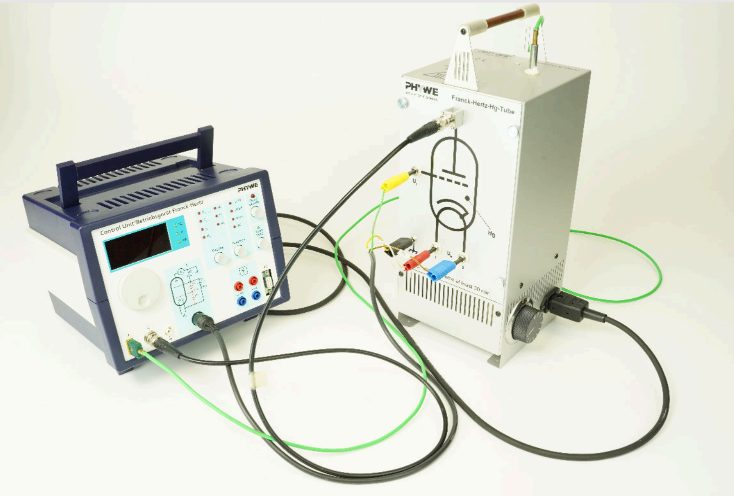
PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE excellence in science

# Setup and procedure

## Setup

PHYWE excellence in science



Experiment setup

For details, see the operating instructions of the unit 09105.99. Connect the operating unit to the computer port COM1, COM2 or to USB port (use USB to RS232 Adapter Converter 14602.10).



PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

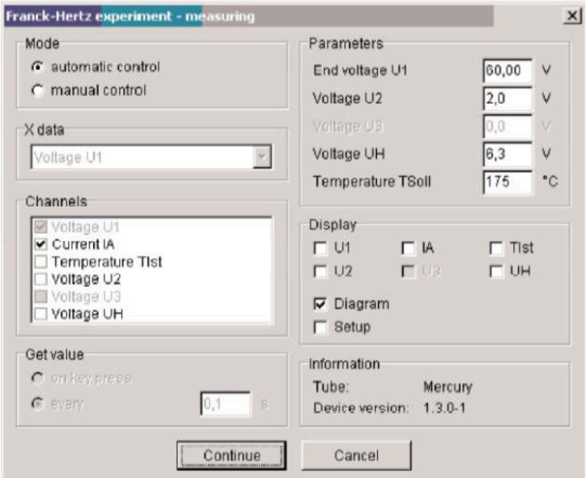
## Procedure (1/2)

PHYWE excellence in science

Start the measure program and select Cobra3 Franck-Hertz experiment Gauge. The window “Frank-Hertzexperiment – measuring” appears.

The optimum parameters are different for each Hg-tube. The specific parameters for the device can be found on a sheet which is enclosed in the package of the Hg-tube. Choose the parameters for U1, U2 and UH as given on that sheet and make sure that the rest is set.

Press the continue button. Now the oven of the Franck-Hertz tube will be heated to 175 °C.




Measuring parameters

## Procedure (2/2)

PHYWE excellence in science

Wait another 30 min before starting the measurement to make sure that the interior of the tube reaches its final temperature, too.

At a particular voltage $U_1 = U_z$ , which is dependent on temperature, a glow discharge between anode and cathode occur through ionisation.

Meaningful measurements can therefore only be taken at voltages $U_1 < U_z$.

Analyze the curve to obtain explicit values of the maxima and minima of the curve.



PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

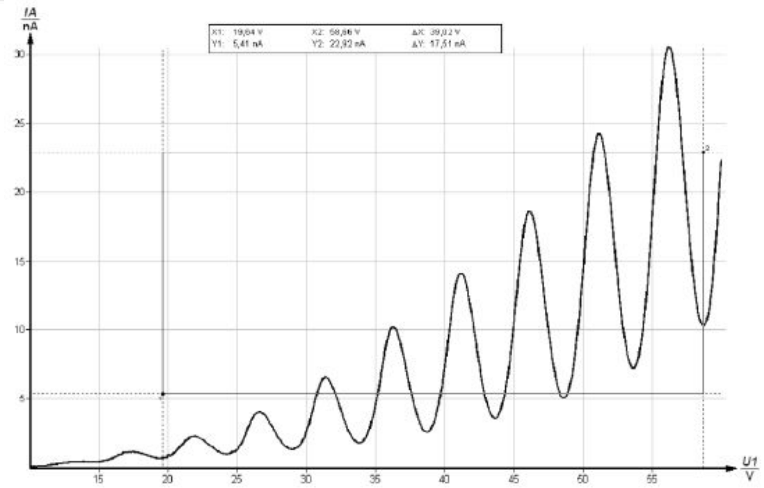
## Evaluation (1/2)

PHYWE excellence in science

For the evaluation, the voltage values of the minima are determined.

From the differences between these values, the excitation energy *E* of the mercury atom by taking an average is obtained:

$E = (4.86 \pm 0.09) eV$




Example of a Franck-Hertz curve recorded with T = 175°C and $U_2 = 2V$

## Evaluation (2/2)

PHYWE excellence in science

Fill in the blanks:

In the Franck-Hertz experiment for mercury tubes, the ______ between the minima in a Franck-Hertz curve ______ linearly with the number of minimum due to the additional ______ of electrons over the mean ______ after the excitation energy has been reached, but before inelastic collisions with atoms occur.

- increase
- spacings
- free path
- acceleration

Check



PHYWE excellence in science
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

| Slide | Score / Total |
| --- | --- |
| Slide 16: Frank-Hertz curve | 0/4 |

**Total Score** 0/4

Show solutions

Retry



PHYWE excellence in science

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de