Franck-Hertz Experiment

1. Introduction:

Niels Bohr introduced the planetary model of the atom in 1913. According to Bohr's model, an isolated atom consists of a positively charged nucleus about which electrons are distributed in successive orbits. He also postulated that only those orbits are possible for electrons for which their angular momentum the is an integral multiple of $h/2\pi$ where 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 Bohr model that just as electrons may make transition 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.

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.

In this experiment, students will be provided with mercury and neon tubes and are required to

(i) Record the counter current strength in a Franck-Hertz tube as a function of anode voltage.

(ii)Prove Bhor's postulate of discrete energy levels for electrons in an atom.

(iii) Calculate Excitation energy E_a between ground and excited states of electrons in both mercury and Ne atoms.

2. Franck-Hertz Experimental Setup:

Fig 1. Franck-Hertz neon tube experimental set-up

Fig 2. Franck-Hertz mercury tube experimental set-up

The equipment that is on the left hand side of Fig. 1 and 2 is the Franck-Hertz control unit. The equipment that is in the middle of Fig. 1 and 2 is the respective tube. In Fig. 2, the mercury tube is being encased in a heating oven. For more information about the Franck-Hertz control unit, please refer to Annex A. For information on the safe usage of the neon and mercury tube, please refer to Annex B.

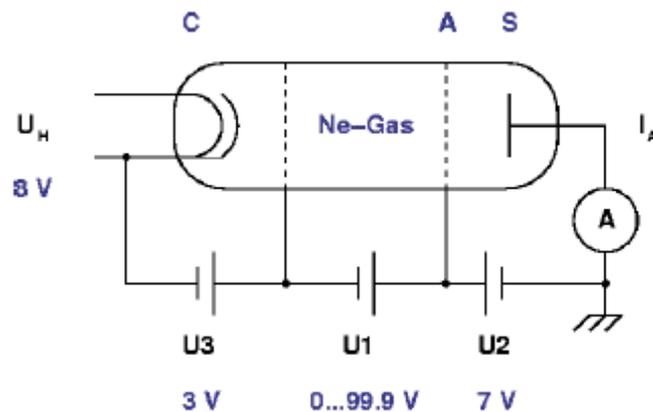## 3. Franck-Hertz Neon Tube experiment

Fig 3. Schematic of the Franck-Hertz neon tube

3.1 Principle of measurement

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with neon gas and are scattered by elastic collision with neon atoms. The electrons are being detected in the form of anode current, I_A.

For an anode voltage U_1 of for example 16.8V, the kinetic energy of the electrons is sufficient to bring the valence electron of the neon to the first excitation level by an inelastic collision. 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_A is at a minimum.

If the anode voltage is being increased further, the kinetic energy of the electron is sufficient to surmount the opposing field and I_A increases again. When U1 = 2 x 16.8V, the kinetic energy is so high that two atoms in succession can be excited by the same electron. Hence we obtain a second minimum. The graph of I_A against U_1 thus shows equidistant maxima and minima as shown in the theoretical graph in Fig 4.
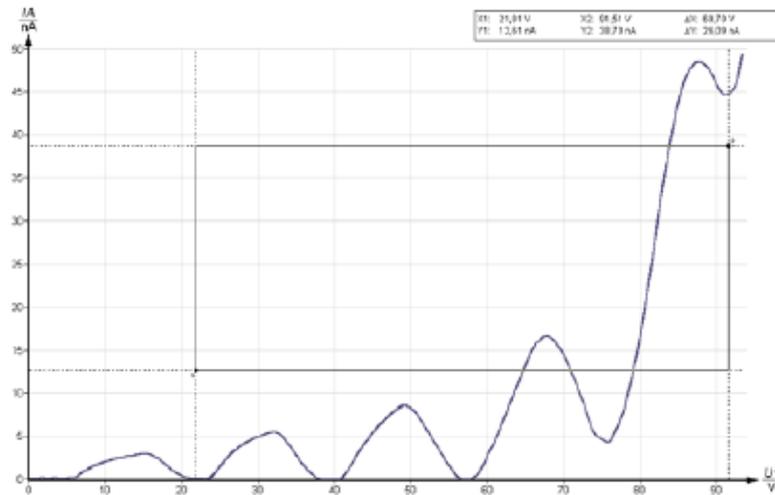

Fig. 4 Theoretical graph for Franck-Hertz Neon tube

3.2 Experimental steps with Ne-tube:

1. Connect the Neon tube with the Frank-Hertz Control unit.

2. Switch on the energy source to the Franck-Hertz Neon tube setup.

3. Change the control on the Franck-Hertz Control unit to PC mode.

4. Switch on the computer and activate the "Measure" program on the computer desktop.

5. Click the record function of the program and change the specification according to the following:

$$U_1 = 99.90V$$

$$U_2 = 8.0V$$

$$U_3 = 3.0V$$

$$U_H = 8.0V$$

6. Repeat the experiment for atleast 3 different values of U_2.

7. Save the data in the format for generating the report.
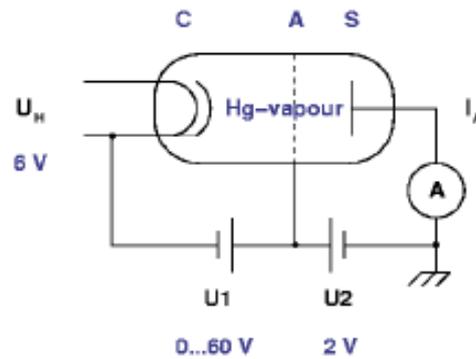
4. Franck-Hertz Mercury Tube experiment

Fig. 6 Schematics of the Franck-Hertz mercury tube

4.1 Principle of experiment

The mercury tube is housed inside the Franck-Hertz oven. The mercury tube must be heated in order to obtain an adequate mercury vapor density for the experiment. Similar to Ne-tube, here also the electrons emitted by the thermionic cathode are scattered by elastic collision with mercury atoms. The mercury atoms will be excited to the first excitation level 6 $^3P_1$ and this will result in the subsequent rise and fall of I_A.

4.2 Experimental steps

1. Switch on the energy source to the Franck-Hertz Mercury tube setup. Ensure that the rotary switch on the oven is turned to the maximum.

2. The mercury tube device should be heated up on the highest setting for about 10 minutes before the experiment. Be careful to avoid touching the mercury tube device as it will be very hot.

3. Change the control on the Franck-Hertz Control unit to PC mode.

4. Switch on the computer and activate the "Measure" program on the computer desktop.

5. Click the record function of the program and change the specifications according to the following:

$$U_1 = 60.00V$$

$$U_2 = 2.0V$$

$$U_3 = 0.0V$$

$$U_H = 6.0 \text{ V}$$

Temperature = 175°C

6. Repeat the experiment for different values of U_2.

7. If the collection current is too high then the measurement will be interrupted automatically by control unit after 7 sec. To protect the tube from being damaged.

8. Generally, oven temperatures around 175^0C is used. However, in some circumstances better experimental results can be obtained at slightly lower temperatures (160^0C) or at slightly higher temperatures (190^0C).

9. Save the data in the format for generating the report.

Franck-Hertz control unit
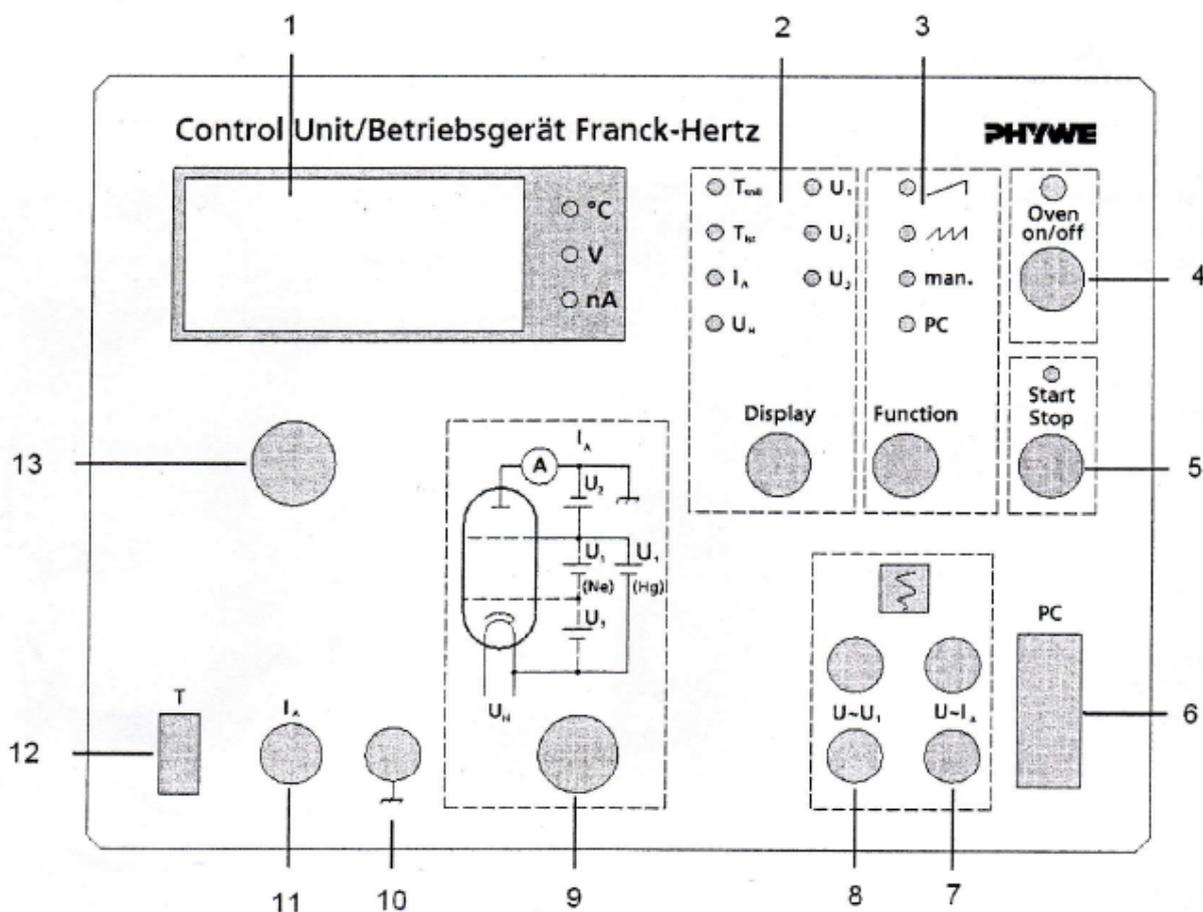
Display component of Franck-Hertz control unit

Number label	Definition
1	Three digit digital display with optional display of either temperature T, anode current I_A or voltage U_H, U_1, U_2 or U_3
2	Display pushbutton for selection of the quality to be displayed
3	Function pushbutton for selection of a function from "ramp", "saw tooth", "manual control" or "PC control"
4	Oven on/off pushbutton for activation of the Hg oven heating. When the light indicator is blinking, the oven is heating and the temperature inside the oven is increasing. When the light indicator is not blinking, the oven is not heating and the temperature constant.

5	Start/stop pushbutton for initiating or stopping measurement.
6	9-pin D-SUB socket RS 232 for the connection of the Control Unit to the serial interface of a computer.
7	Pair of 4mm sockets for analog input: Voltage proportional to the anode current.
8	Pair of 4mm sockets for analog input: Voltage proportional to the accelerating voltage
9	DIN socket for supplying voltage (U_H, U_1, U_2 and U_3) to the tube connected
10	GND connector
11	BNC socket "I_A": Input for anode current measurement
12	Temperature input T: Thermocouple socket, to which a NiCr-Ni thermocouple with DIN pin can be connected
13	Rotary switch for adjustment of temperature (T_{nom}) and voltages (U_H, U_1, U_2 and U_3)
14	Grounded socket for the plug that supplies voltage to the temperature-regulating Franck-Hertz oven for the mercury tube

1. Franck-Hertz Neon tube

   (1) As a consequence of the neon ions produced during the operation of the Franck-Hertz neon tube, ignition is observed in the form of a glow discharge at a critical acceleration voltage. The collection current then suddenly increases and can exceed the highest current measurement range on the amplifier. Therefore, when the discharge occurs, the acceleration voltage should be immediately reduced until the discharge disappears. If Franck-Hertz Control Unit is used then the tube power supply is switched off automatically after 7 sec to avoid the discharges.

   (2) The discharge of the tube may cause the tube to be damaged.

2. Franck-Hertz Mercury tube

   (1) The oven housing and the screws on the front panel will be at the current set temperature during operation and may therefore be very hot. The carrying handle and the socket on the Franck-hertz tube may be quite hot, particularly under extended operation under the oven. After all measurements, switch the oven off and leave it for at least 15mins to cool down before further operation.

   (2) As a consequence of the mercury ions produced during the operation of the Franck-Hertz neon tube, ignition is observed in the form of a glow discharge at a critical acceleration voltage. The collection current then suddenly increases and can exceed the highest current measurement range on the amplifier. Therefore, when the discharge occurs, the acceleration voltage should be immediately reduced until the discharge disappears. If Franck-Hertz Control Unit is used then the tube power supply is switched off automatically after 7 sec to avoid the discharges. The discharge of the tube may cause the tube to be damaged.

   (3) Don't set the heating voltage U_H too high to avoid the discharges.

   (4) If the discharge occurs at acceleration voltage which is too low, the oven temperature should be increased or the heating voltage U_H should be decreased. The higher the oven temperature, the higher the voltage at which the tube ignites. Also, the mean collection current and, correspondingly, the absolute value of its maxima decrease with increasing oven temperature.

   (5) The first maxima on the current/voltage curve can be best found at low oven temperatures. Generally, oven temperatures of around 175°C are used. However, in some circumstances, better experimental results can be obtained at slightly lower temperatures (down to 160°C) or at higher temperatures (up to 190°C).

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