SECOND YEAR LABORATORY

THE FRANCK-HERTZ EXPERIMENT

1 Aims

To reproduce the classical experiment that demonstrated that electrons in atoms occupy discrete energy levels.

2 Objectives

1. To record Franck-Hertz curves for both mercury and neon and optimise the signals.
2. To measure the energy characteristics of free electrons for inelastic collisions.
3. To interpret the results as representing discrete energy absorption by the atoms.
4. To gain knowledge about the Labview environment for data acquisition.

3 Principle.

In 1914 James Franck and Gustav Hertz discovered that electrons lost energy in distinct steps when passing through mercury vapour, when they were accelerated through the vapour. Niels Bohr subsequently recognized that this provided evidence confirming his model of the atom. The Franck-Hertz experiment is hence a key experiment that confirmed quantum theory and this was the birth of modern atomic physics.

In this experiment mercury atoms are held in a partially evacuated glass tube at a vapour pressure of ~5 millibar, which is kept constant by temperature control. The experiment investigates the energy loss of free electrons due to inelastic scattering, and thus due to collisional excitation of Hg atoms.

For the inert gas neon, the most probable excitation through inelastic collisions takes place from the 2*p* ground state to the manifold of excited 3*p*-states (see Fig. 1). The four lower 3*s* states can also be excited but have lower probability. De-excitation from the 3*p*-states to the 3*s* states results in photon emission between red and green light, as shown in Fig. 1.

To understand the energy levels of the different atoms you should look at the file on Blackboard for this experiment that is called 'FranckHertz_Grotrian_diagrams.pdf'

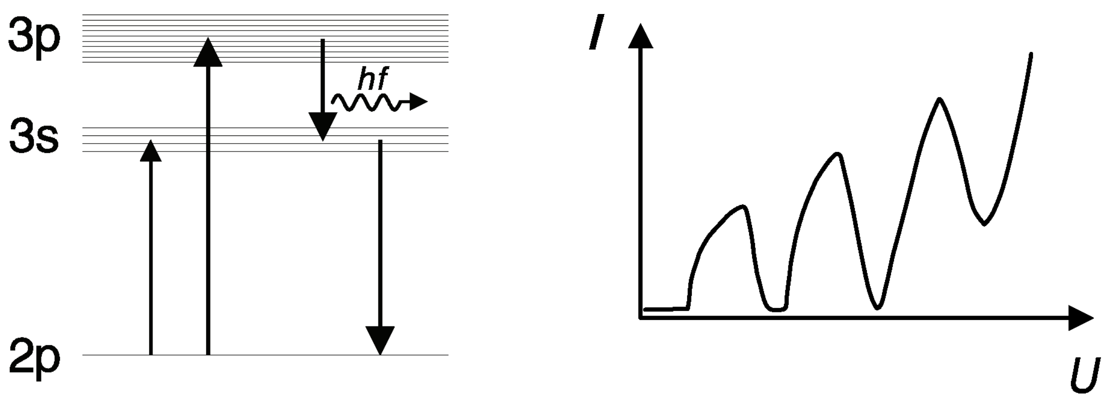

Fig. 1. Left: the energy levels for neon. Right: the electron current flowing to the collector as a function of accelerating voltage in the Franck-Hertz experiment.

4 Apparatus

Details of the Franck-Hertz tube are shown in Fig. 2. The tube contains either low-pressure Hg vapour or Ne gas. Each tube is slightly different in construction but the principles of operation are the same. Electrons are emitted by a hot electrode K (heated by a filament which has potential U_H across it), and this forms a current by applying a voltage difference U_1 between the cathode K and grid G_1. The electrons emerging from G_1 are then accelerated by the potential U_2 set up between grids G_1 and G_2. A braking voltage difference U_3 is applied between G_2 and the collecting anode A (note how the supply is connected in the opposite sense to U_1 and U_2 here). The resultant current returning back to 0V through the anode I is then measured. By fixing U_1 and U_3, minima are seen in the current I as U_2 is increased from 0 to the maximum that can be applied (~80V for Neon). These minima are due to absorption of energy from the electron beam by the atoms, due to inelastic collisions occurring at different distances between G_1 and G_2 as the electrons move along the tube.

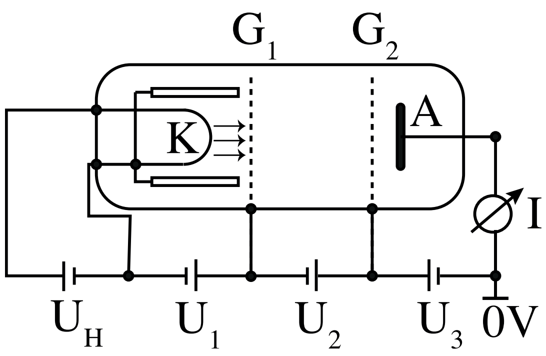

Fig. 2. Schematic of the Franck-Hertz tube.

Figure 3 shows a photograph of the apparatus that is setup on the bench, in this case showing when the neon tube is used.

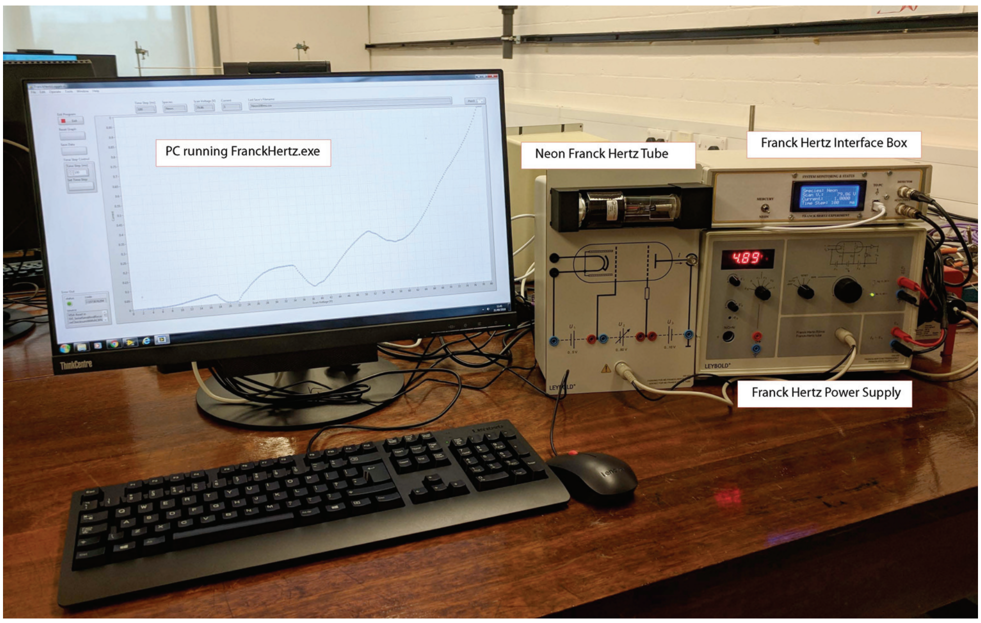

Fig. 3. Photograph of the apparatus using the neon tube, showing the power supply, tube and holder, interface box (set for Neon) and the PC which is running the Labview software.

Figure 4 shows the arrangement when the mercury tube is used. In this case the tube is inserted into the heater, and the thermometer is placed into the heater from the back.

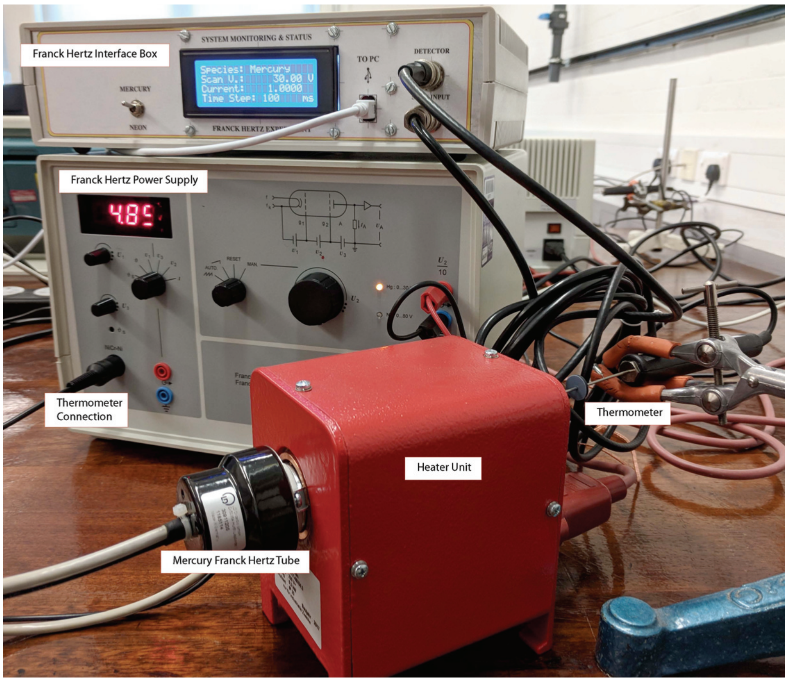

Fig. 4. Photograph of the heater for the Hg tube, showing the power supply, tube and holder, interface box (set for Hg) and the thermometer connection. NOTE that the thermometer must be inserted into the heater, NOT between the heater and the Mercury tube or damage can occur.

4.1 Experiments with Mercury.

The experimental setup for mercury is shown in figures 3 - 5. For measurements the mercury tube must be at a temperature from ~145°C - 180°C, which is controlled by the thermometer inserted in the hole in the heating chamber, and which is connected to **b** in fig 7. Each tube operates with slightly different conditions, and so you will need to find the best temperature to give the clearest signal (this is typically around 170°C). With the unit switched off, turn switch **d** to 'reset', and then switch the unit on. This sets the voltage U_2 to be zero. Check the temperature setting is initially set to $\theta_S \sim 170°C$ and then allow the apparatus time to reach this temperature before taking any measurements.

You should load the programme 'FranckHertzLogger.exe' on the computer, which is located in the folder 'C:/Physics Vi Master/Franck Hertz/'. This will then engage the Labview programme specifically written for this experiment, which talks with the interface unit shown in figure 3. The front panel switch on the unit should be set to Mercury (see figure 4), and this will also be displayed on the LCD screen on the interface box. This screen also shows the measured voltage U_2, as well as the current (which has been scaled to read from 0 to 1) and the time step as selected by the interface programme.

Note that the current reading has been scaled for the measurements. Typically a reading of 1.0 on the unit corresponds to a current of around 12 nA (this depends on the individual tubes).

Figure 5 shows a schematic of the Labview front panel for this experiment, and the figure caption details how this interface operates. The data is saved as a comma-deliminated file

(Excel readable). The example here shows a scan for Hg. The results for Neon are similar but have added complexity which you will need to think about.

Note also that if you select a fast data accumulation time, the interface box will not show the output signals, however data will still be sent to the Labview programme (see figure 6).

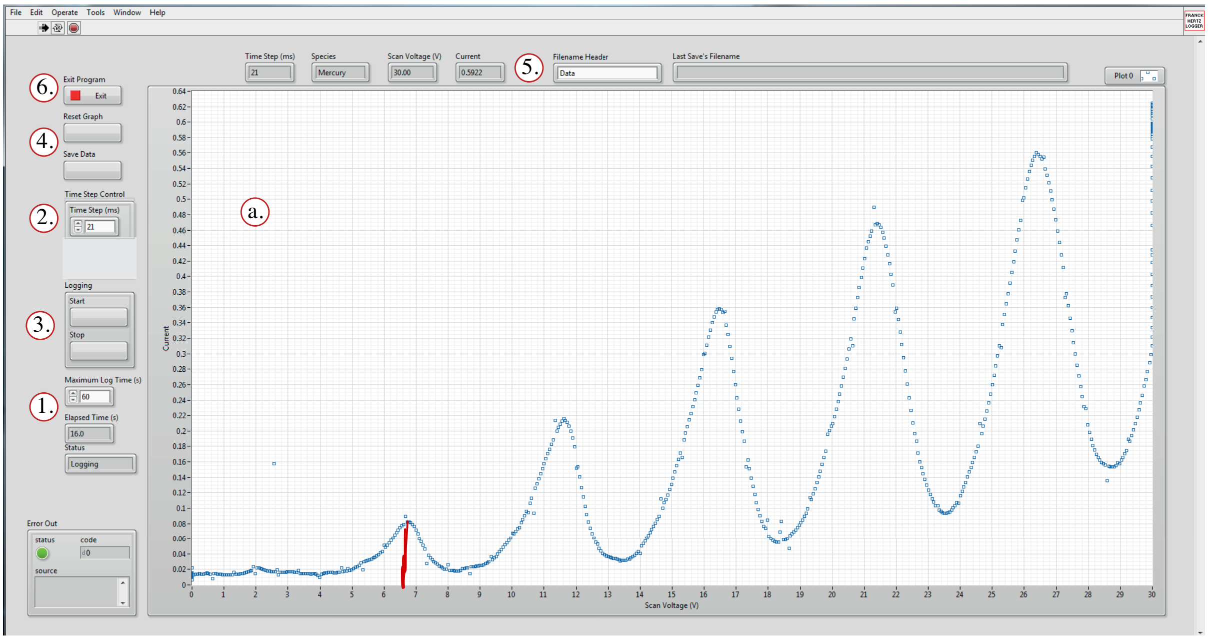

Fig 5. Labview front panel for the Franck Hertz experiment. 1. Time for experimental run (default is 60 s, so you may need to change this). 2. Time step for data measurement. The minimum time-step is 5 ms, however this should be adjusted for your apparatus to produce a good set of data readings. 3. Start and stop buttons for measurements. 4. Reset graph & save data buttons. 5. Filename header for saving data (input any changes here). 6. Exit Labview programme. a. Graph of current against U_2 voltage.

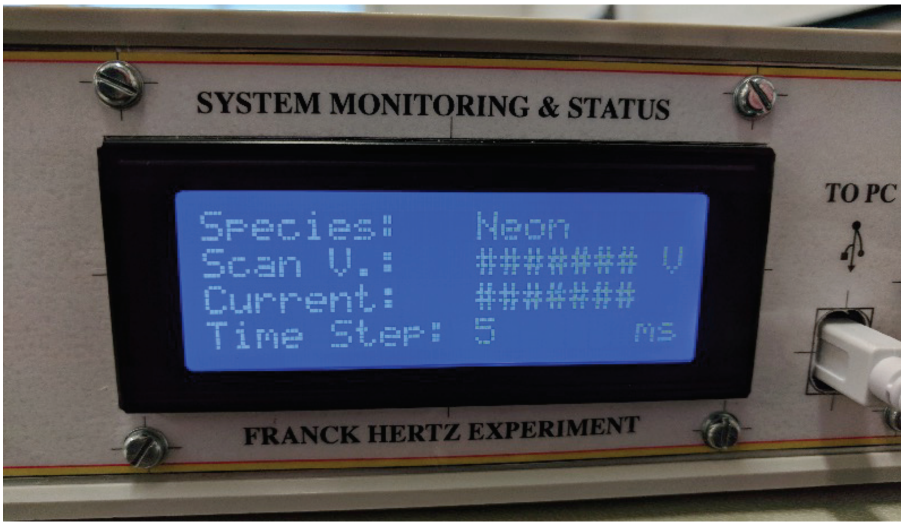

Fig 6. Front panel of the interface unit for fast data collection. The screen does not show the data in this case as the LCD screen cannot respond quickly enough, however the results are still sent to the Labview programme in the normal way.

To begin, set U_1 and U_3 both to 1.5V (*what will the energy of the electrons be at the anode in this case, assuming there are no collisions?*). You should draw a potential energy curve for the electrons as they move from the emitting filament K to the anode A, and discuss this with

qU_1

your demonstrator (*What do you expect the energy of the electrons to be just as they are emitted from the hot filament? What about the spread of energies they might have?*).

Set switch **d** to 'auto' and observe the current as a function of U_2 on the screen. Experiment with different values of U_1 and U_3 to sharpen up the final curve that you obtain (thinking about the changes to your potential energy curve that you are making), at which time you can record the data to file (remember to set the switch back to 'reset' to set the voltage U_2 back to zero). Measure the U_2 value for each of the minima that you obtain. From your data, calculate the excitation energy of mercury, as well as the associated uncertainty in your measurement.

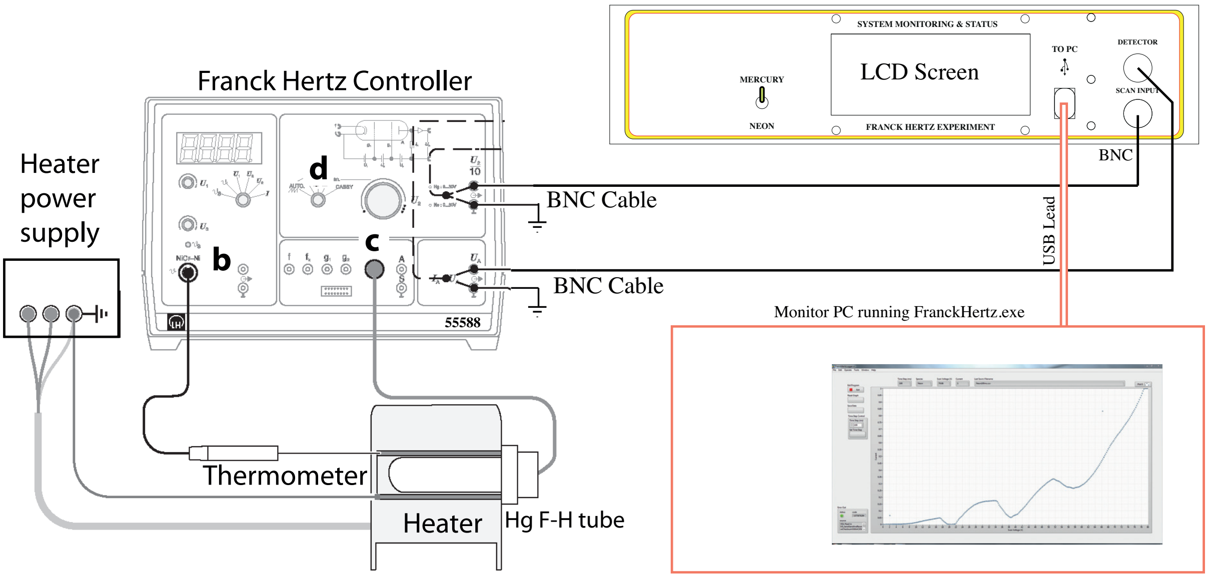

Fig. 7. Setup for mercury.

4.2 Experiments with Neon.

The experimental setup for neon is shown in fig. 8. Since neon is a gas at room temperature, you do not need to control the temperature of the tube for this target to perform the same type of measurement as for mercury. Once again, experiment with different values of U_1 and U_3 to sharpen up the final curve that you obtain, and draw appropriate potential energy curves for the experiments as you do this. *Note that for some tubes it may not be possible to obtain all of the minima at the same time, however you should always try to get at least 2 minima on any set of readings so that you can measure the difference between them.*

From your data try to ascertain the minima for the less probable transition 2*p* to 3*s* in neon.

Look for visible light from de-excitation of the electron excited 3*p* state to the 3*s* states in neon for a range of U_2 voltages (you will need to look carefully to see this). You should see a series of parallel orange lines inside the tube, with these lines moving between G_1 and G_2 as you increase the voltage. Can you explain what it is you are seeing?

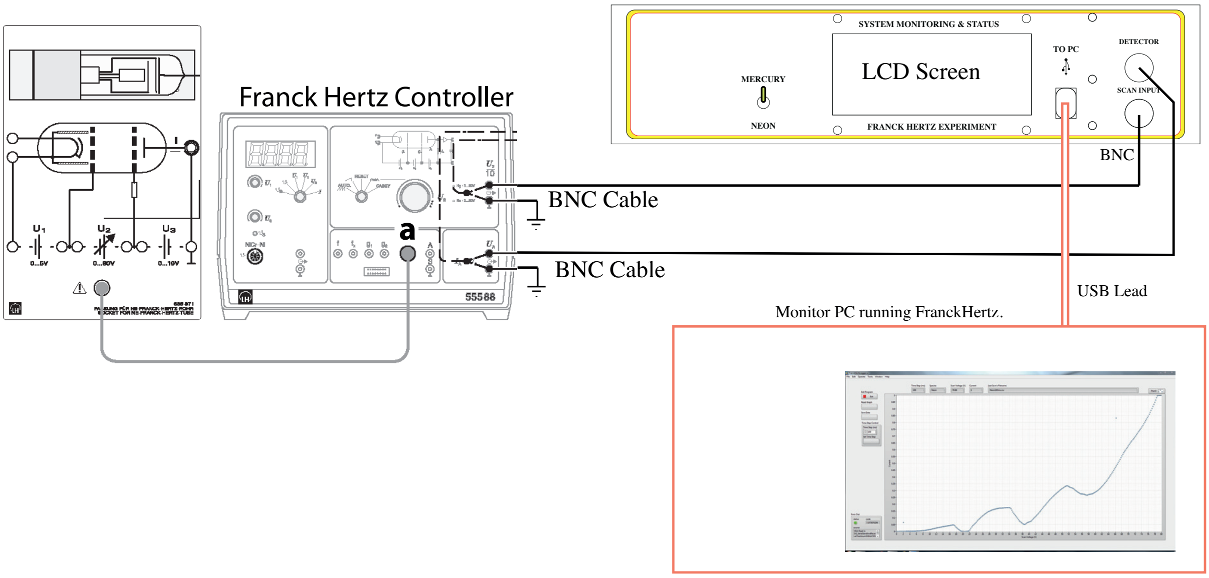

Fig. 8. Experimental setup for neon.

5 Questions

How are the minima in Fig. 1 related to the energy states of the atoms? You should look at a Grotrian diagram of both Hg and Ne (which is very complex) to understand what you see in the experiments. Discuss these with your demonstrator so that you can understand the differences between the atoms that are being excited.

What are the accurate energy differences for all transitions measured in the present experiment (a good source to find out this information is NIST)?

The fine-structure states in these atoms are not resolved in the present apparatus. What is their origin in the atoms?

6 Bibliography

B.H. Bransden and C.J. Joachain, *Physics of Atoms & Molecules*, 2nd edition, Prentice Hall ISBN 0582 35692 X; Library of Congress catalogue number: QC173.B677

F. A. Jenkins and H. E. White, *Fundamentals of Optics*, 4th edition.

Apparatus redesigned & script rewritten by Professor Andrew Murray and Dr Matthew Harvey, Sept 2021.

Original script written by Professor John Meaburn, March 2007.