Collision Excitation of Atoms
(Franck-Hertz Experiment)

Goal

- Build inelastic and elastic energy models of collisions between electrons and gas molecules.
- Use the Franck-Hertz experiment to investigate atom and electron collisions in Neon.
- Build a model that describes the excitation of neon atoms and the energy lost by electrons during collisions.
- Measure the excitation energies for neon and mercury.

Introduction

The experiment you will do today was first performed, using slightly different equipment, by James Franck and Gustav Hertz in 1914. In 1925 Franck and Hertz received the Nobel Prize in physics for their work.

A. Collisions Between Electrons and Atoms

In the tutorial on the photoelectric effect we examined photons interacting with atoms in a metal. In this tutorial we will look at electrons colliding with gas atoms. We will bombard a gas with electrons whose kinetic energy can be varied. The collisions between the electrons and gas atoms can be either elastic or inelastic.

A-1. Predict the effects elastic and inelastic collisions would have on:

- electrons

- gas atoms

Soon after Bohr presented his atomic model in 1913, Franck and Hertz devised an experiment to demonstrate that:

- atoms can be excited by bombardment with electrons,
- the energy is transferred from the electrons to the atoms in discrete amounts, and
- the amounts of energy transferred are consistent with spectroscopic results.

The apparatus Franck and Hertz used is shown schematically in Figure 1. In our experiment we will use neon as the gas instead of mercury but the process is the same.

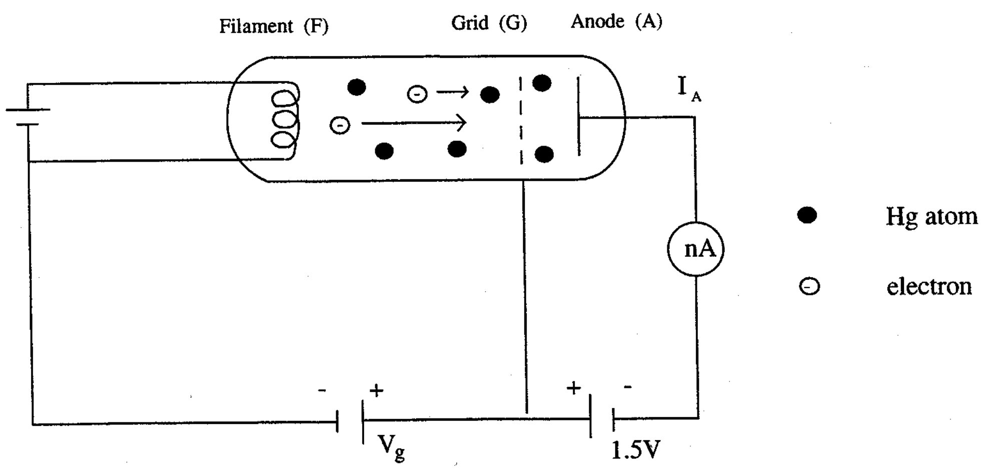


Figure 1. Simplified circuit for the Franck-Hertz experiment

The original Franck-Hertz tube contained droplets of mercury and was baked in an oven so that the mercury vaporized. The hot filament (F) emits electrons thermionically, that is the electrons "boil" off. The grid (G) is at a positive potential with respect to the filament so the electrons are accelerated towards G, and their kinetic energy increases. The potential of G, V_g, can be varied.

A-2. Predict what would happen as V_g is increased.

A-3. Examine Figure 1. What is the potential of the anode with respect to the grid?

A-4. Why do you think the experiment is set up in this way? (We don't expect a good answer at this stage; we will revisit this question after you have collected some data using the apparatus.)

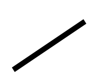
B. The Experiment

Equipment: An electron gun apparatus contained in a glass tube with neon, a specialized power supply, and an oscilloscope.

> **Hints:**
>
> In this experiment it is possible to boil off so many electrons that the current becomes too great for the electronics to handle. You will see this happening if the line on the oscilloscope becomes flat at the top. If this happens, just turn down the heater.
>
> The "Gain" setting on the upper left of the power supply amplifies the current. You may need to adjust it to keep it from overwhelming the electronics.

In this experiment you can control the energy of the accelerated electrons by controlling the accelerating voltage (dial marked U_a). You can also measure the current through the tube. As you increase the accelerating voltage, you will see an increase in the current because the electrons are increasing their kinetic energy. Thus, more of them are passing through the wires each second. However, if the electrons lose energy the current will decrease.

The oscilloscope is measuring and plotting the accelerating voltage on the horizontal axis and the electron current on the vertical axis. The power supply has a switch in the middle of the panel with two options illustrated:

 and 

The first allows you to manually adjust the voltage and the second automatically ramps through the voltage. Select the manual option.

Gradually increase the accelerating voltage and observe changes in the neon tube. As you increase the voltage you should see the neon begin to glow. However, the neon does not glow all the way through the tube. The glow begins at a certain distance from the cathode.

B-1. Think about how the accelerating electrons gain energy and explain why the tube does not glow uniformly.

As you increase the accelerating voltage further, you will see the glowing region increase. Look carefully and you should be able to see a dark band in the middle of the glowing region.

B-2. Explain this observation in terms of the energies of the electrons and the neon gas.

Depending on the values of the various currents and voltages, you may be able to see a second dark band. Try it although it may be difficult to achieve.

B-3. Dial through the accelerating voltage and describe what happens to the current as you increase the voltage.

B-4. How are the changes in current related to the onset or changes in the light emitted by the neon gas?

For the next part of the experiment set the power supply to the “ramp” option. On the oscilloscope, voltage is the horizontal axis while current is displayed vertically.

B-5. Sketch below what you see on the screen. Be sure to include values for the current and voltage.

Adjust the accelerating voltage, oven temperature, and gain so you can see the maximum number of peaks.

B-6. Record the peak number for several different voltages in the table below.

Peak Number	Accelerating Voltage

Table 1. Data Table of Peak Number and Accelerating Voltages

C. Analysis – Putting It All Together

C-1. Using your observations of the glowing neon, the sketch you made and the table of peak voltages, describe what is happening when the electrons collide with the neon gas. You should refer to the predictions you made in questions A-1 and A-2 and resolve any differences.

C-2. What does the minima in electron current mean? Describe how these minima are related to the quantized energy levels in the neon atom.

C-3. The dips occur regularly in a plot of current versus voltage. Using your sketch and the table of values, determine the excitation energy of the neon gas.

C-4. The dips in the oscilloscope plot of current versus voltage are not perfectly sharp. Why is this the case?

C-5. Why is the first peak at about 30V instead of 19V?

C-6. Using the energy diagram provided in Appendix A, determine the most likely transitions resulting from the collision excitation of neon.

Below is a table showing the peak number and the accelerating voltage for a typical Franck-Hertz tube using mercury vapor instead of the neon you used here.

Peak number	Accelerating voltage (V)
1	6.7
2	11.5
3	16.5
4	21.25
5	26.25

Table 2. Table of Typical Results Using a Mercury Vapor Tube

C-7. Calculate the excitation energy of mercury and the corresponding wavelength of light emitted.

C-8. Determine the work function of the filament in this experiment.

C-9. Now that you have collected some data, explain why the anode is set at a lower potential compared to the cathode.

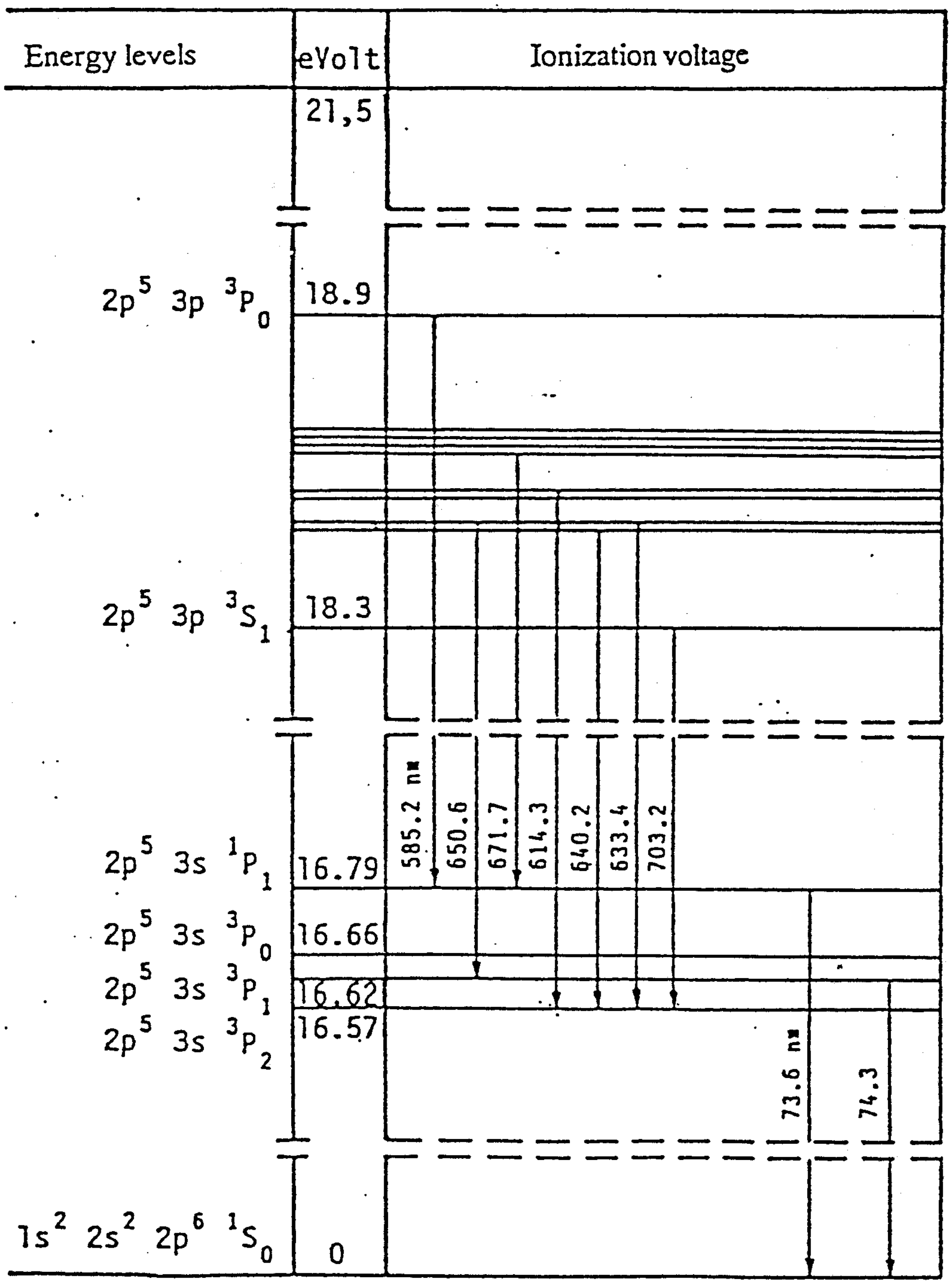


Figure 2. Partial energy diagram of neon