

Experiment 2

Frack-Hertz Experiment Physics 2150 Experiment 2 University of Colorado¹

Introduction

The Franck-Hertz experiment demonstrates the existence of Bohr atomic energy levels. In this experiment you will determine the first excitation potential of Argon contained in a Franck-Hertz tube and use this value to compute Planck's constant.

Theory

During the late nineteenth century, a great deal of evidence accumulated indicating that radiation was absorbed and emitted by atoms only when the radiation had certain discrete frequencies. The evidence provided by the photoelectric effect also suggested that light of a given frequency ν was transmitted in quanta, each quantum being associated with an energy $h\nu$. There was some discussion at the time as to whether this quantization was entirely a characteristic of light or whether quantization also occurred in atomic structure. In order to resolve such questions it was necessary to "look at" atoms with a probe that did not involve light. This investigation was, at least in part, the motivation for the Franck-Hertz experiment in 1914, which used electrons rather than light to explore the structure of atoms. The results of the experiment provided a strong confirmation for the Bohr theory of quantized atomic states.

The experiment consists of observing the energy losses of electrons that collide with argon atoms. If the internal energy of an atom has a unique value so that the distribution and motion of the electrons cannot be changed, then when an atom is hit by an electron, the atom must recoil as a whole. That is, despite its fairly loose and open structure consisting of a nucleus and electrons, the atom must behave much as a rigid elastic sphere. The electron will bounce off the atom as a ping-pong ball would off a bowling ball, losing a very small fraction of its initial kinetic energy. The fraction thus lost is given by the ratio of the mass of the electron to the mass of the atom. Thus, even after a thousand collisions with mercury atoms, the electron will lose less than 1% of its initial energy.

Suppose that on the other hand, a moving electron were to collide with a stationary electron. It could then lose all of its energy in one collision. If an electron collides with an electron which is bound in an atomic state of definite energy and which can only make a transition to some other state of definite energy, then only if

¹ Experimental apparatus and instructions come from *Lambda Scientific*:
www.lambdasys.com

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the incident electron has an energy equal to this energy difference can all of the incident electron's energy be lost in a single collision. The Franck-Hertz experiment demonstrates this type of collision and shows that such energy losses occur only for very special values of the energy of the incident electrons.

To excite an atom from the ground state to the first excitation state, the impact energy must be greater than the energy difference between the two states. The Franck-Hertz experiment implements the energy exchange for state transitions through the collisions of atoms with electrons of certain energy, which is obtained by applying an accelerating electric field. This process is represented by using the equation below:

$$\frac{1}{2}m_e v^2 \geq eV_1 = E_1 - E_0 \quad (1)$$

where e , m_e , and v are the charge, mass and speed (before collision) of an electron, respectively; E_1 and E_0 are the energy of the atom at the first excitation and the ground states, respectively; V_1 is the minimum voltage of an accelerating field required to excite the atom from the ground state to the first excitation state, called the first excitation potential of the atom. eV_1 is therefore called as the first excitation potential energy.

The results of the experiment indicate that the electrons in mercury atoms can exist only in a discrete set of energy states. Furthermore, the energy of the state discovered by electron bombardment corresponds to the energy of the photons that are absorbed by mercury atoms. Thus, the results of the Franck-Hertz experiment solidly supported Bohr's suggestions as to the nature of atoms. This result is so fundamental that, even though it is now familiar, it is worthwhile to repeat the experiment and obtain a graphic display of the phenomenon.

Experimental Apparatus

Consider the diagram/schematic of the Franck-Hertz tube (F-H tube), in the figure below:

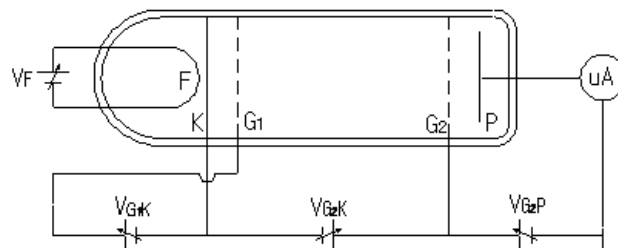


Figure 1: Schematic of Franck-Hertz experiment

In an argon-filled tube electrons are emitted from hot cathode K. A relatively low

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voltage V_{G1K} is applied between cathode K and grid G_1 to control the electron flow entering the collision region. An adjustable accelerating voltage V_{G2K} is applied between grid G_2 and cathode K to accelerate electrons to desired energy. A braking voltage V_{G2P} is applied between anode P and grid G_2 . The electric potential distribution in the F-H tube is shown in Figure 2. When electrons pass through grid G_2 , with energy higher than eV_{G2P} , they can arrive at anode P to form current I_p .

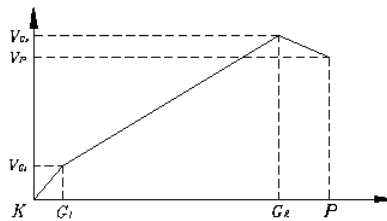


Figure 2: Schematic of potential distribution in the F-H tube 1

Initially, the accelerating voltage V_{G2K} is relatively low and the energy of electrons arriving at grid G_2 is less than eV_{G2P} , so the electrons cannot reach anode P to form a current. By increasing V_{G2K} , the electron energy increases accordingly (the number of electrons with energy higher than eV_{G2P} increases too), so current I_p rises to the point that electron energy is higher than the first excitation potential energy eV_1 and electrons pass energy eV_1 to atoms by inelastic collisions. As a result, electron energy is less than eV_{G2P} , leading to a reduced anode current I_p .

By continuously increasing V_{G2K} , anode current I_p rises again until the electrons regain energy eV_1 . Due to the inelastic collisions between electrons and atoms for the second time, anode current reduces again. By increasing V_{G2K} from low to high, multiple inelastic collisions occur between electrons and Argon atoms leading to multiple rise/fall cycles as shown in Figure 3.

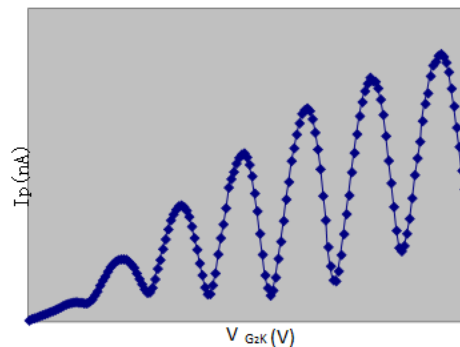


Figure 3: Relationship curve of anode current I_p and accelerating voltage V_{G2K}

For argon atoms, the voltage difference between adjacent valleys or peaks as shown in Figure 3 is the first excitation potential of an argon atom, which proves the

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discontinuity of argon atomic energy states.

The absorbed energy of the argon atom will be released through electron transition to lower state, giving off a strong emission spectral line corresponding to an energy of eV_1 . The argon atom resonance line is 106.7 nm (or 11.62 eV). Using the acquired first excitation potential, Planck's constant h can be calculated based on the formula:

$$h = \frac{eV_1\lambda}{c} \quad (2)$$

where $e = 1.602 \times 10^{-19}$ C, $\lambda = 106.7$ nm, and c is the speed of light.

Procedure

You will first need to set up the oscilloscope to record a plot of the current vs. grid voltage trace. The x-axis of the plot will represent the value of V_{G2K} and the y-axis represents the current I_P . Turn on the scope by pressing the button on the top of the case. On the oscilloscope press the following sequence of keys:

DISPLAY -> FORMAT -> XY

Doing so will plot the inputs of channel one and two versus each other, rather than plotting the signal versus time as you may be used to when using an oscilloscope. Use the Volt/Div knob to adjust channel one and two to 1.00 V/div and 50.0 mV/div respectively. Set the sample rate to 1 GS/S. You will also need to store the trace on the screen. Our digital scopes allow us hold the trace for different amounts of time: 0s, 1s, 5s, and Infinity. Press the PERSIST button to toggle through the different options and select "Infinity". To erase the trace toggle through the items on the PERSIST menu once again. Take some time to get used to the digital oscilloscope before taking data if you have never used one before. ☺

Next, we need to set up the Franck-Hertz apparatus. Before turning the apparatus on, ensure **all knobs are turned fully counterclockwise (i.e. in their zero positions)**. Turn on the apparatus by locating the power switch on the back of the apparatus near the power cord input. Now we need to set up the potential distribution as depicted in figure 2. The manufacturer has values posted on the apparatus for *nearly* ideal values for V_F (filament voltage), V_{G1} (also called V_{G1K}), and V_P (also called V_{G2P}). Set these three to the posted values by toggling the display and adjusting the voltage. You will vary V_{G2} (also called V_{G2K}) from 0-90 Volts to observe the trace on the scope.

You are now ready to begin taking data. Increase V_{G2} and observe what happens on the scope. You should observe a plot similar to figure 3. If you don't you may need to adjust the Volts/div scaling on channels one and two, or double check you have V_F , V_{G1} , and V_P set appropriately. **Record the value of V_{G2} for which you observe a peak/maximum and a trough/minimum in current.** You can use the

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scope in conjunction with the current readout on the apparatus to hone in on the maximum or minimum. For each trace you should get about 7 peaks and 6 troughs. **Record V_{G2} peak and trough values for four trials. Take a picture or make a sketch of a typical trace for your lab report.**

The first excitation potential of Argon is obtained by taking the difference in two adjacent peak measurements or two adjacent trough measurements. This should result in 6 measurements based on the peak data and 5 measurements based on the trough data. You can do the subtraction by hand or use the `Differences[...]` function in Mathematica. Once you have ensemble at least 40 first excitation potentials of Argon **compute the mean, standard deviation, and standard deviation on the mean** for this ensemble. Report your measurement. **Describe what is going on inside the tube at a maximum and a minimum.** Then use **equation 2 to compute Planck's constant.** (Or if you've done the photoelectric effect experiment you can compute h/e and compare your two values made in completely different ways ☺!!)

Next, lets **make a histogram of the excitation potential data** to do a little exploratory statistics. The snippet of code below will help you make a bare-bones histogram with a normal distribution over the top:

```
hist = Histogram[data, "PDF"]
prob = Plot[(2*Pi*sigma)^(-1/2)*Exp[-(x-
mean)^2/(2*sigma^2)],{x,xmin,xmax},PlotRange -> All]
Show[hist,prob]
```

The values of σ and mean are the standard deviation and mean you calculated earlier. Be sure to modify this snippet so that you have labeled axes and a title. You may also wish to look up the documentation for the `Histogram[...]` command. Make some pithy observations about your histogram especially regarding error.