The Franck-Hertz Experiment

Introduction

Before 1913, the common thinking was that electrons existed in an atom around the nucleus, bound by any amount of energy. However, in 1913, Neils Bohr and Ernest Rutherford introduced the Bohr-Rutherford model of the atom, which proposed that electrons could only exist at quantized/discrete energy levels. This model helped bring about the advent of our understanding of the quantum nature of atoms but, at the time, wasn't directly supported by experimental tests.

In 1914, James Franck and Gustav Hertz presented an experiment to test claims of the Bohr-Rutherford model that electrons in an atom exist at quantized energy levels. This was the first experiment to test and confirm predictions of the model and helped establish it as a key lead-in to the fully quantum description of atoms.

The experiment is conducted with a mercury vapour tube, an anode, and an electron accelerator (a hot cathode). The pressure within the vapour tube is very low because the vapour pressure of mercury is about a thousand times lower than air. Electrons are then accelerated through the mercury vapour towards the anode, which is kept at a small, negative reverse-bias voltage in order to ensure that only sufficiently energetic electrons reach the anode. Any electrons that reach the anode produce a current that we can then measure. This current is proportional to the kinetic energy of the electrons that hit the anode. The accelerating voltage can be adjusted so that the electrons have higher or lower kinetic energies. The convenience is that, by definition, an electron put through an accelerating voltage of 1V will receive 1eV of energy, which means the accelerating voltage you set is roughly equal to the average kinetic energy of the electrons in electron Volts (eV).

Side question: *What is the point of the reverse-bias on the anode? Why don't we want any and every stray electron to reach it?*

Equipment

- Franck-Hertz control interface
- Franck-Hertz mercury oven
- Oscilloscope
- Various cables

Exercise 1

For this lab, the experiment itself is straightforward and simple to conduct. So rather than tell you exactly what you're looking for and how to find it, you must determine this for yourself. Read the introduction section now, if you haven't already. This lab will also require some researching on your part.

While the apparatus is in operation, energized electrons will pass through the mercury vapour. Obviously, there will be some collisions between the electrons and mercury atoms. Use what you know about the classical model and the Bohr-Rutherford model to come up with testable predictions for each model. **Hint:** What does each model say about the energy imparted onto the mercury atoms from each collision? What would this mean for the resulting kinetic energy of the electrons?

Try to sketch your prediction for what the kinetic energy of the electrons would look like as a function of the accelerating voltage after passing through the mercury vapour and reaching the anode under the classical model. Do this again for your predictions under the Bohr-Rutherford model. To help you out, the photon emitted when mercury transitions from the first excited state to the ground state has a wavelength of 254nm. What energy in electron volts does this correspond to? Make both predictions for accelerating voltages ranging from 0 to 50V.

Exercise 2

Now that you have your prediction, you will use the provided equipment to test it.

Start by turning on the oven unit. Set the temperature to around 200°C. Connect the oven to the control interface using ports A, K, F, and E and the compatible cables for each. The control interface should already be connected to the oscilloscope. It should just be turned on.

Ensure that the filament voltage starts at around 7.5V (you may turn it up to at most 10V during the experiment if you want) and the reverse bias is set to about 1.5V. The minimum of the accelerating voltage should remain at 0V, feel free to vary the maximum between 0 and 80V. The light coming from the mercury oven should be a pale bluish-green when it's functioning properly. In a brightly lit environment, you might not even see the pale light given off by the equipment, so don't be concerned if it isn't visible. If you see it turn to a bright white, this means your accelerating voltage is too high and you have begun ionizing the mercury; turn down the accelerating voltage when this happens as it can throw off your results.

Side Question: *What is the benefit of using specifically a ramp accelerating voltage instead of something else, such as a sine wave or a set DC signal?*

With the apparatus in operation, determine a way to test your predictions. Justify your methods.

This experiment has very reliable and precise results. If you find you are having significant difficulties finding these results, ask your TA or lab coordinator for advice.

Once you have made a measurement confirming one of the models, discuss the physical and historical significance of what you observed.

Are there any differences between what you predicted and what you observed? Explain what may have caused these differences.