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The Franck-Hertz Experiment Phy 344

Introduction:

This 1914 experiment demonstrated that the collisions of electrons with atoms have a special property. Often, electrons simply collide elastically with atoms; such collisions obey the standard laws for conservation of energy and momentum. However, in special cases an electron can also lose a specific and large amount of its kinetic energy in a violent, inelastic collision which leaves the atom in an "excited state." The extra energy of the excited state can thus be measured electrically by measuring the properties of the scattered electrons.

The discovery that the inelastic collisions always absorbed exactly the same amount of energy confirmed a prediction about atoms made by Neils Bohr. Rutherford had discovered that the positive charge inside an atom was confined to a tiny "nucleus;" the atom presumably had a cloud of electrons surrounding the nucleus. Bohr's view was that the electrons which were "bound" inside the atom were in very well defined orbits, in the sense that only orbits with precisely defined orbital energies and orbital angular momenta were allowed.

These atomic electrons are not the colliding electrons of Franck and Hertz; in fact, Bohr's model was designed to account for the spectrum of *light* emitted by atoms. Only certain specific colors or frequencies of light were emitted by excited atoms; in Bohr's model the different colors emitted to the quantum jumps of an electron from excited orbits down to less excited orbits. Bohr was able to account for the measurements in hydrogen quantitatively, using the correspondence between the frequency of light and the energy of a photon $E = h\nu$ originally proposed for the photoelectric effect.

If Bohr's model were correct, then inelastic collisions of extra particles with an atom would only reveal very precisely defined energy losses for the extra particle. These energies would correspond to quantum jumps of the atomic electrons from low energy states *up* to more excited states. But this was only a prediction - no purely *electrical* experiment before that of Franck and Hertz had revealed quantum states. So Franck and Hertz showed that Bohr's model, that was designed to account for optical properties, had predicted unexpected electrical effects. This is exactly what a theory is supposed to do if it is useful.

The Franck-Hertz effect is observed using a vacuum diode. A vacuum diode is simply a vacuum tube with two electrodes. One electrode called the *cathode* is usually heated, so that electrons "leak off" into the vacuum. A voltage is applied between the cathode and the second electrode, called the *anode*. If the polarity of the voltage is correct, the electrons emitted from the cathode are accelerated by the electric field and subsequently collected at the anode.

For observing the Franck-Hertz effect a small amount of mercury is placed in the tube. By heating the tube the vapor pressure of the mercury rises, and thus the density of mercury atoms with which the electrons can collide increases. At room temperature the effects of the mercury are modest. At higher temperature there is a profound effect of the mercury on the relationship of the current to the voltage applied.

Objectives:

- Learn to operate a picoammeter and a power supply
- Learn to wire and operate a modified vacuum diode incorporating a ”retarding potential.”
- Measure the current-voltage relationship in this diode, and achieve a qualitative understanding of this relationship.
- Measure the effects of a partial pressure of mercury upon the current-voltage relationship of the diode.
- Achieve a qualitative understanding of these effects, including the role of ”quantized excitations” of the mercury atoms.

Suggested Reading: Copies of these are filed in the laboratory

- 1 Theodore Korneff, *Introduction to Electronics* (Academic Press, New York, 1973) pp 111-117. This book contains an introduction to vacuum diodes of which the Franck-Hertz tube is an example.
- 2 Arthur Beiser, *Concepts of Modern Physics* (McGraw-Hill, New York, 1987) pp 151-155.

Suggested Apparatus:

1. Franck-Hertz tube and oven., NEVA Inc. distributed by Klinger.
2. V_{ac} power supply label 6.3 VAC in “Bud box” with blue output connectors. (Plugs in wall socket.)

3. Picoammeter, Keithley Inc. model 410.
4. Retarding Potential supply, 1.5 V dry cell battery.
5. Multimeter
6. D. C. power supply, Lambda LLS3120 0-120 V.
7. Variac supply for heater current.

Safety Considerations: The DC power supply can deliver a high voltage. Adjust it carefully. Make sure that the Franck-Hertz oven is "grounded;" if you do not understand grounding please discuss it with the lab staff. Make sure that the wiring from the DC power supply is done in such a way that you will not accidentally touch anything at high voltage.

Avoiding Damage: The NEVA tube has a filament that must not be overheated, so use the V_{ac} supply that is provided. **Also be careful not to apply more than 70 V between the tube's anode and cathode. If the tube glows blue you are putting on too much voltage.**

Instructions - Operation of a Vacuum Diode

1. To understand the functioning of the Franck-Hertz tube you will need to study the workings of a vacuum diode and the "space charge" effects in them. A descriptive understanding such as in Korneff's book should be sufficient.
2. Make sure you use a voltmeter to measure the voltage between the grid and cathode rather than relying on the power supply meter.
3. The basic instructions for wiring the Franck-Hertz tube are given on the case of the oven and in the NEVA tube manual. To understand this wiring you need to know what an ammeter does. You also need to understand how a power supply with "floating" outputs operates.
4. If time permits, study the effect of the retarding potential on the Franck-Hertz effect for a single elevated temperature.
5. The Frank-Hertz effect is associated with "oscillations" observed in the current-voltage relationship of the diode. At each temperature you may observe several "minima" in the current-voltage relationship. Graph the voltages of these minima versus an "index" (1 for the first voltage minimum, two for the next, et..); include all temperatures for which the Franck-Hertz effect was observed.

Memoranda: Be prepared to discuss the following points; there is no need to prepare written responses.

- What accounts for the shape of the current-voltage curve in the diode at room temperature?
- What does it mean to say that raising the tube's temperature increases the vapor pressure of the mercury? Is this effect related at all to the effect of increasing the cathode's temperature on the diode current?
- Why does higher mercury vapor pressures yield lower anode-cathode currents?
- Does the $\approx 6.3\ V_{ac}$ applied to the filament heater affect the voltage between the anode and cathode?
- Did you see any optical emission from the Franck-Hertz tube? What color of light would you expect from your measurements of the Franck-Hertz oscillations?
- Why was the Franck-Hertz effect considered important enough to award a Nobel prize for its discovery?