Physics 322
Washington University

Franck-Hertz Experiment: Measuring atomic excitation energies

I. Introduction

A. Experimental Overview

From early spectroscopic work it was observed that atoms emitted radiation at discrete frequencies; from Bohr's atomic model the frequency of the radiation ν is related to the change in energy levels through $\Delta E = h\nu$. Further experiments demonstrated that the absorption of radiation by atomic vapors occurred only for discrete frequencies.

James Franck and Gustav Hertz wondered since the energy of a quantized system could be changed through a collision with a photon (photoelectric effect), could it also be changed with collisions with particles of nonzero rest mass, such as an electron. In 1914 they demonstrated that exciting atoms by particle bombardment is possible, and that the process is also governed by the quantization of energy.

This experiment provides a hands-on demonstration of atomic excitation by electron impact and measurement of atomic excitation energy of mercury and neon. The principle of the Franck-Hertz experiment involves the systematic increase of initial electron energy by increasing the acceleration potential, and measuring the final electron energy after it passes through a gas by means of a retardation potential. When the electron has enough energy to excite an atomic transition, it gives up most of its initial kinetic energy to the atom, with a resulting decrease of its final kinetic energy. Using the apparatus in the lab, excitation energies of the mercury and neon atoms are easily found, providing verification of the quantum-mechanical model of the atom (discrete energy levels). James Franck and Gustav Ludwig Hertz received the Nobel prize for this work in 1925.

B. References

1. Eisberg, R; Resnick, R, *Quantum Mechanics of Atoms, Molecules, Solids, Nuclei and Particles*, 2nd Edition (Wiley & Sons, 1985)
2. Hanne, G.F., *What Really Happens in the Franck-Hertz Experiment?,* American Journal of Physics, Vol. 56, No. 8, 1988
3. Melissinos, A.C., *Experiments in Modern Physics*, (Academic Press, 1966)
4. *ELWE Equipment Manual* (available on class website)
5. *ELWE Experiment Manual* (available on class website)
6. *Franck Nobel Lecture* (available on class website)
7. *Hertz Nobel Lecture* (available on class website)

Class website: http://www.physics.wustl.edu/ClassInfo/322/

II. Theory

In the original Franck-Hertz experiment, electrons were made to collide with mercury atoms in a vapor. The wavelength of radiation corresponding to a transition between the ground state and the first excited state of mercury is 253.6 *nm*; the equivalent photon energy, equal to the excitation energy, is 4.88 *eV*. Franck and Hertz found that electrons of at least that kinetic energy were required to produce an excitation of mercury atoms. This was inferred since the collisions were perfectly elastic when the electron's energy was less than 4.88 *eV* but some inelastic collisions occurred when it was more. At the same time, it was found that mercury atoms emit radiation of 253.6 *nm* if and only if electrons having at least the excitation energy of 4.88 *eV* collide with them.

The Franck-Hertz experiment was significant in showing that atomic systems are quantized, from the evidence not only of photon absorption and emission but also of particle bombardment. In practice, the inelastic collisions of electrons are observed by measuring the electric current arising from electrons in motion through a gas of molecules (see Fig. 1). If the speed of the electrons is reduced drastically by inelastic collisions that result in atomic excitation, then the current registered drops sharply when the kinetic energy of the electrons corresponds to the excitation energy. Indeed, if the electrons are energetic enough, any one of them can make numerous inelastic collisions in passing through the gas, losing an excitation energy in each. Ionization also can result from collisions. If the bombarding particles are electrons, the atoms are ionized by those having a kinetic energy greater than or equal to the atom's ionization energy.

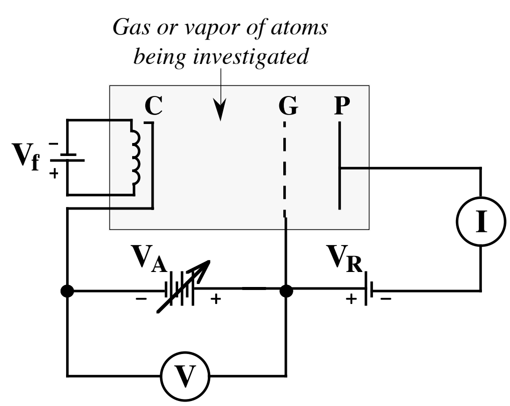

Figure 1: Illustration of the basic Franck-Hertz experimental setup for the mercury tube. V_f denotes filament voltage, V_A accelerating voltage, and V_R retarding voltage.

III. Experiment

A. Equipment

1. ELWE Franck-Hertz mercury tube and oven enclosure (Model 84 82 152)
2. ELWE Franck-Hertz operating unit (Model 84 82 135)
   Provides the required voltages and a DC electrometer amplifier
3. ELWE neon tube assembly (Model 84 82 220)
4. Tektronix TDS3052 digital oscilloscope
5. Keithly 177 microvolt DMM
6. Variac (variable VAC transformer - the ELWE Franck-Hertz mercury tube and oven enclosure is plugged into the variac for precise adjustment of the oven temperature)

Note: The ELWE manuals describe the use of a X-Y plotter. This piece of equipment is to be replaced by the Tektronix TDS3052 digital oscillscope. The scope permits temporal averaging (to increase signal/noise ratio) and can save the acquired waveforms to disk for analysis.

B. Procedure

1. *Initial Setup*
   1. Consult the ELWE Equipment Manual (available on the class website) for electrical connections and equipment specifications. Please read for a basic knowledge on how the equipment operates.
   2. Consult the ELWE Experiment Manual (available on the class website) for a detailed description for performing the experiment.
2. *Methods*

   <u>Mercury Tube</u>

   At room temperature mercury is liquid. The tube will need to heated to create the necessary mercury vapor.
   1. Measurements should be made for three oven temperatures (150°, 175° and 200°C)
   2. For each oven temperature you should investigate how your results vary as a function of filament voltage, accelerating voltage, and retarding voltage.
   3. Determine mercury's excitation energy from your measurements. Why is the energy loss about 4.9eV when the first excited state in mercury corresponds to 4.67eV?

   <u>Neon Tube</u>

   Because neon is in the gas phase at room temperature a heating oven is not necessary. The neon tube assembly employs a tetrode tube which has two grids. Additional wiring is required (see ELWE Experiment Manual available on the class website).
   1. Again you should investigate how your results vary as a function of filament voltage, accelerating voltage, and retarding voltage.
   2. Determine neon's excitation energy from your measurements.

C. Discussions

1. Discuss the physical effect each control (V_f, V_A, V_R and oven temperature for the mercury tube) has on your experiment.
2. From your observations discuss how the Franck-Hertz output current features change as a function of temperature for mercury.
3. Discuss why the collector current dips are not perfectly sharp.
4. Could this experimental approach be effectively used for a molecular gas as opposed to a monatomic gas?