IIA2

Modul Atomic/Nuclear Physics

Franck-Hertz Experiment

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Experiment IIA2 - Franck-Hertz Experiment

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1.1 Preliminary Questions

- Explain the FRANCK-HERTZ experiment in our own words.
- What is the meaning of the unit eV and how is it defined?
- Which experiment can verify the 1. excitation energy as well?
- Why is an anode used in the tube? Why is the current not measured directly at the grid?

1.2 Theory

1.2.1 Light emission and absorption in the atom

There has always been the question of the microscopic nature of matter, which is a key object of physical research. An important experimental approach in the "world of atoms "is the study of light absorption and emission of light from matter, that the accidental investigation of the spectral distribution of light absorbed or emitted by a particular substance. The strange phenomenon was observed (first from FRAUNHOFER with the spectrum of sunlight), and was unexplained until the beginning of this century when it finally appeared:

- If light is a continuous spectrum (for example, incandescent light) through a gas of a particular type of atom, and subsequently , the spectrum is observed, it is found that the light is very special, atom dependent wavelengths have been absorbed by the gas and therefore, the spectrum is absent. These lines are called *absorption lines*.
- Conversely, the same gas radiates when it is heated and only enough light of exactly the same wavelength, which then in a spectroscope appears as luminous *emission lines*.

Systematic studies of KIRCHHOFF, BUNSEN and others showed that each atom has its characteristic emission or absorption spectrum. The spectral analysis was already in chemistry an important tool even before the phenomenon was understood in principle. The solution to this problem succeeded the Danish physicist NIELS BOHR. In his famous BOHR postulates, he transferred the quantum hypothesis, with the first MAX PLANCK of black body radiation to the atom.

1.2.2 the BOHR Postulates

The postulates of NIELS BOHR are:

1. An electron in an atom moves in a circular orbit around the nucleus in COULOMB potential of the core and obeys the laws of classical mechanics.
2. Instead of infinitely many possible orbits according to classical mechanics, an electron moves only on such paths, for the orbital angular momentum L is an integral multiple of PLANCKs constant h.
3. Notwithstanding the fact that an electron undergoes a constant acceleration (circular motion!), it does not emit electromagnetic radiation. The total energy remains constant.
4. An electron emits electromagnetic energy only when his train of energy E_i Egg changes and changes in a web of energy E_f. The frequency ν of the emitted Radiation is then equal to $\nu = {}^{(E_i - E_f)}/_{h}$.

With these demands, the said observations can qualitatively and in the case of the hydrogen atom, are even quantitatively explained. Thus, light emission occurs only in "portions" (quantum) of size $h\nu = E_i - E_f$. Light absorption is exactly the reverse process. In a heavy atom such as mercury (^{202}Hg), which we will use in the FRANCK-HERTZ experiment, most of the electrons are strongly bound by the electrostatic attraction of the nucleus, so it takes a lot of energy to bring them out from these states. However, the outermost electrons are shielded in part by the inner attraction of the core. Their binding energy is therefore much smaller. One lists the corresponding level states at transitions between them because light is emitted or absorbed in or near the visible region at.

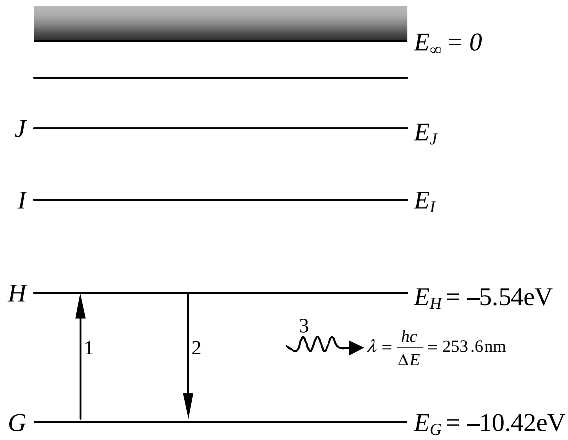

Figure 1.1: Energy levels of Hg

Figure 1.1 shows the most important states of the valence electrons of ^{202}Hg. In the ground level G,the valence electron has the energy $E_G \approx -10.42\,\text{eV}$. The first excited state H has the energy $E_H \approx -5.54\,\text{eV}$. More excited states are $I, J, ...$ The energy used to bring the valence electron from the ground state to the lowest excited state G to H is:

$$\Delta E = E_H - E_G = 4.88\,\text{eV} \tag{1.1}$$

ΔE is the first excitation energy of the Hg-atom. If by any cause, the Hg-atom has been excited in the state H (1), it will return after some time in the ground state (2). It is a quantum of light (photon) energy $\Delta E = 4.88\,\text{eV}$ and the wavelength $\lambda = {}^{hc}/_{\Delta E} = 253.6\,\text{nm}$ is emitted (3).

1.2.3 Scattering of electrons on atoms

The FRANCK-HERTZ tube contains mercury vapor at low pressure. Through this tube, an electron is sent. On their way, the electrons with mercury are interacting with silver atoms. The following can happen:

- As long as the kinetic energy of an electron is less than the first excitation energy of the Hg atom, it comes to an elastic shock and the kinetic energy of two shock partner remains.

$$b + A \longrightarrow b' + A' \tag{1.2}$$

b: slow electron, $E^b_{kin} < 4.88\,\text{eV}$
A: atom at rest
b′: a little more slow electron, $E^{b'}_{kin} = E^b_{kin} - \Delta E_{kin}$

A′: atom with recoil enenrgy

The recoil energy ΔE_{kin} is very small because the electron is much lighter than the atom. Therefore, the electron must collide with many atoms before it comes to a stop. In the diluted gas, there is no significant loss of energy from traveling a great distance.

- However, the kinetic energy is large enough ($E^b_{kin} > 4.88\,\text{eV}$), so an inelastic shock can occur and a portion of the kinetic energy of the electron goes into the atom by the valence electron from the ground state G and is lifeted into the first excited state H. The electron is considerably slower after such a shock.

  In a second process, immediately after the shock ($\Delta t \approx 10^{-8}\,\text{s}$) the atom returns back to the ground state, which sends a light quantum (photon) of energy $E = h\nu = 4.88\,\text{eV}$ and wavelength $\lambda = {}^{h\cdot c}/_{\Delta E} = 253.6\,\text{nm}$. Schematically, the situation is like this:

$$b + A \longrightarrow b' + A^* \tag{1.3}$$

$$A^* \longrightarrow A' + h\nu \tag{1.4}$$

b: fast electron, $E^b_{kin} > 4.88\,\text{eV}$
A: atom at rest in the ground state
b′: slower electron, $E^{b'}_{kin} = E^b_{kin} - 4.88\,\text{eV}$
A*: atom excited with little recoil energy
A′: atom again in the ground state (with some recoil energy)
$h\nu$: photon with energy: $E = h\nu$

- In an electron tube in which the electrons are constantly on their way through the gas and accelerated by an electric field, a third important process can stilltake place, if the field is so strong that an electron gains sufficient energy to its mean free path between two bumps gains to the next shock and ionize a mercury atom, that is, an electron knock out ($E^b_{kin} > 10.42\,\text{eV}$). Two electrons are present, and at the earliest opportunity encounters difficulties for releasing ionization of two more electrons. A chain reaction takes place. The gas intensive lighting emits (photons) because it contains many ionized atoms that capture electrical light. In this process of igniting the electric, the resistance of the tube falls considerably. Using a voltage multiplier, a steady state is achieved.

1.3 Experiment

The experiment of Franck and Hertz from 1914 provided an important confirmation of the then brand new atom model of Niels Bohr. The present setup substantially corresponds to the original apparatus used.
In a heating furnace, the Franck-Hertz tube is heated to a temperature between 150 °C and 200 °C. In the tube, is a little mercury ^{202}Hg. The temperature of the furnace can be controlled and mercury is in the vapor phase. The warmer it is, the more mercury atoms are located between the cathode and grid. From the filament, electrons are emitted thermally (heating voltage $U_H = 6.3\,\text{V}$). With a voltage U_A (variable between 0 and 70 V), these electrons are the anode towards the programmed values. Some of the electrons fly through the holes in the

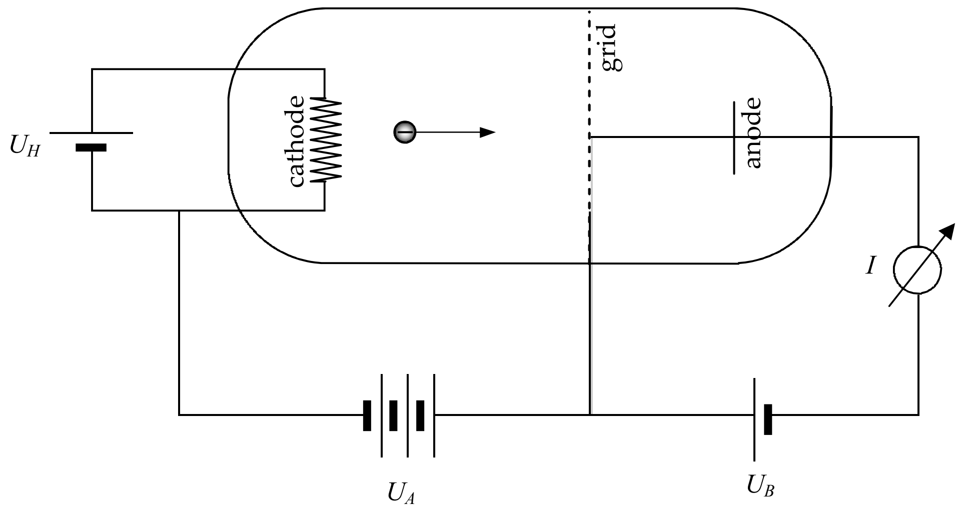

Figure 1.2: Schematic setup of FRANCK-HERTZ tube

anode to the collecting electrode. The prerequisite is that they are fast enough to overcome a stopping voltage (= Offset voltage) of $U_B = 1.5\,\mathrm{V}$. The experiment consists of the fact that the current I to be measured in the collecting electrode as a function of the anode voltage U_A is recorded on a diagram. The result can be not be explained from the basis of classical physics; however, the BOHR atomic model provides a satisfactory interpretation.

1.3.1 Accesories

Components	Number
FRANCK-HERTZ tube	1
Combined current and voltage meter	1
Power suppl unit (type Variac)	1
Thermometer	1
Protective Eyewear	2

1.3.2 Versuchsaufbau und Justage

Voltage [V]	Temperature [°C]
150	155
170	170
190	200

Table 1.1: Correlation between temperature and heating voltage

- The tube emits UV light. Therefore, the protective eyewear must be worn.
- Temperature setting: the temperature is measured with a Variac transformer and controlled in the circuit electric heater. Heating floor initially with full scale (220 V) to about 10°C below the desired temperature. Then adjust the Variac to the guideline of the adjusted desired temperature and wait until a steady state has been reached (about 15

minutes). Table 1.1 shows an approximate relationship between the temperature in the furnace and the voltage on the Variac.

- The Picoammeters has three areas. The 10^{-8} A, 10^{-9} A, 10^{-10} A are valid for a full scale.
- The accelerating voltage is read on a liquid crystal display.

1.3.3 Implementation

- Choose a temperature between 150°C and 200°C and wait until it has set itself.
- Increase the voltage slowly til a plasma in the tube ignites.
- Write down continuously, the current-value pairs.
- The power will have maxima and minima. Make sure that you have not "missed" any plotted points not "missed".
- Observe the luminous phenomena below the lattice. It can form "even light".
- Repeat the experiment with the two other temperatures.

1.3.4 Tasks for Evaluation

- Make a plot of the measured current vs. voltage curves.
- Qualitatively describe the characteristics of the current as a function of the acceleration voltage.
- Explain the minimas of this function?
- Qualitatively describe how and why those curves change with temperature.
- Determine the voltage differences between the minimas. What is your observation?
- Average over all voltage differences of all measured curves and calculate the standard deviation.
- Compare your obtained values with a literature value.
- Is there a correlation between the "glowing levels" and the minimas? Justify our answer.

1.4 Literature

- Wolfgang Demtröder, *Experimentalphysik 3 - Atome, Moleküle und Festkörper*, Springer Verlag