Protocol

Physikal.-chem. Praktikum 165.008

P3 - Franck-Hertz Experiment

Group F

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1 Objective

In this assignment, the Franck-Hertz experiment is carried out using a Neon- as well as a Mercury-filled tube. While the Neon-tube is run at room temperature, the Mercury tube is run at Temperatures of 150 as well as 180 °C. The available experimental parameters (suction voltage as well as retarding voltage) are tuned in order to attain several clear maxima, before measurements are taken in order to determine the excitation energies of the studied elements.

2 Experiment

In order to start the experiment, the Neon-filled tube was connected to the Franck-Hertz control device. Using its various knobs, the voltages U_1 (suction current between cathode and first grid) and U_3 (retarding current between the anode and second grid) were set to the initial values presented in Table 1. These values were then tuned by setting the control device to quickly sweep the entire available range for U_2 (accelerating voltage between the two grids), in order to get clear and numerous peaks.

Table 1: Initial and tuned operational values of the conducted Franck-Hertz experiments.

	Ne initial	Ne tuned	Hg, 150 °C initial	Hg, 150 °C tuned	Hg, 180 °C initial	Hg, 180 °C tuned
U_1 [V]		0.54	5.00	5.00	5.00	5.31
U_3 [V]	7.00	8.98	1.50	4.08	1.50	0.68

After the ideal parameters were determined, an X/Y-plotter was connected to the control device, with U_2 recorded on the x-axis and the anode current being recorded on the y-axis. Measurements were then plotted to paper using the control device's sweep-function (sweeping over the available range of U_2 values), both in the plotter's CAL-mode, in which one unit on the paper corresponds to a fixed input current, as well as the VAR-mode, in which the was manually scaled to best fit the paper.

Following the experiments using the Neon-tube, the Mercury-tube was connected instead and heated up by setting the desired temperature on the control device. The experimental steps described above were then repeated at tube temperatures of 150 and 180 °C.

3 Results

3.1 Determination of Excitation Energy for Neon

Figures 1 and 2 show the recorded Franck-Hertz curves of Neon in the CAL- and VAR-modes of the X/Y-plotter respectively. With the starting point of the plot set as (0,0), the x-values of the peaks and troughs of the curves were measured and recorded in Table 2.
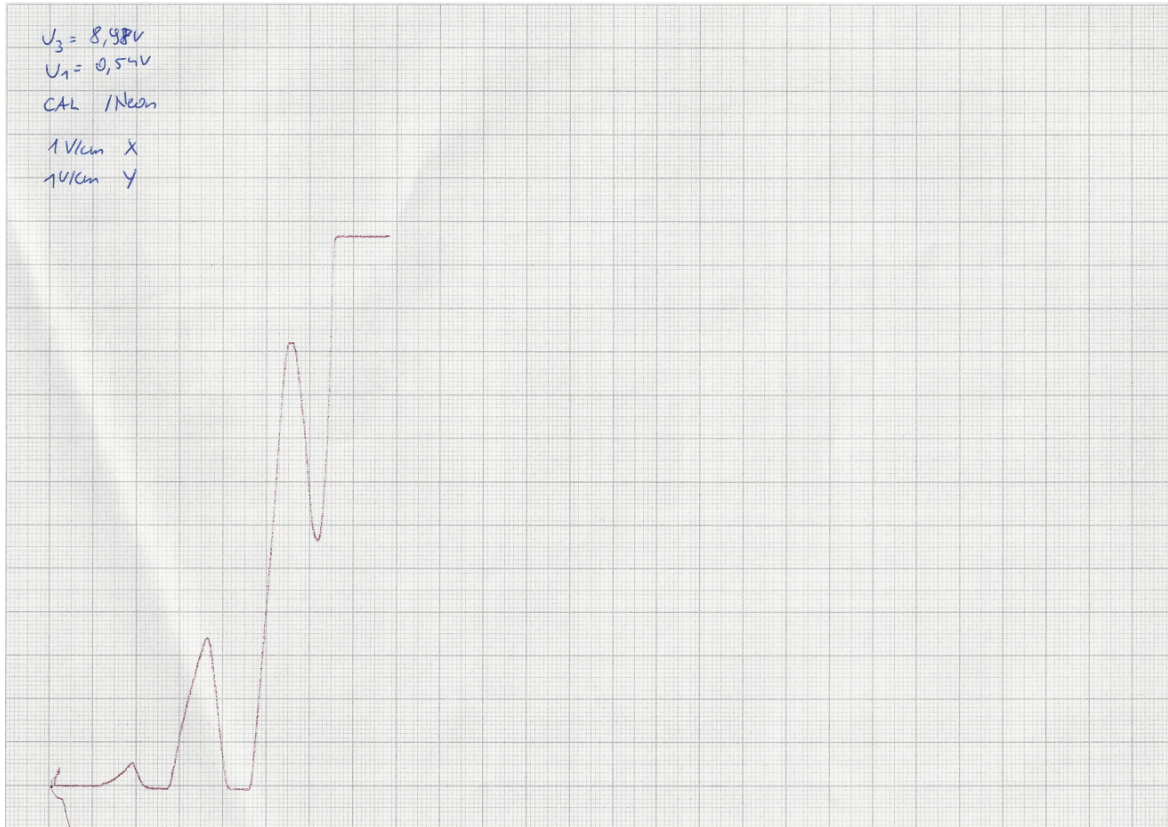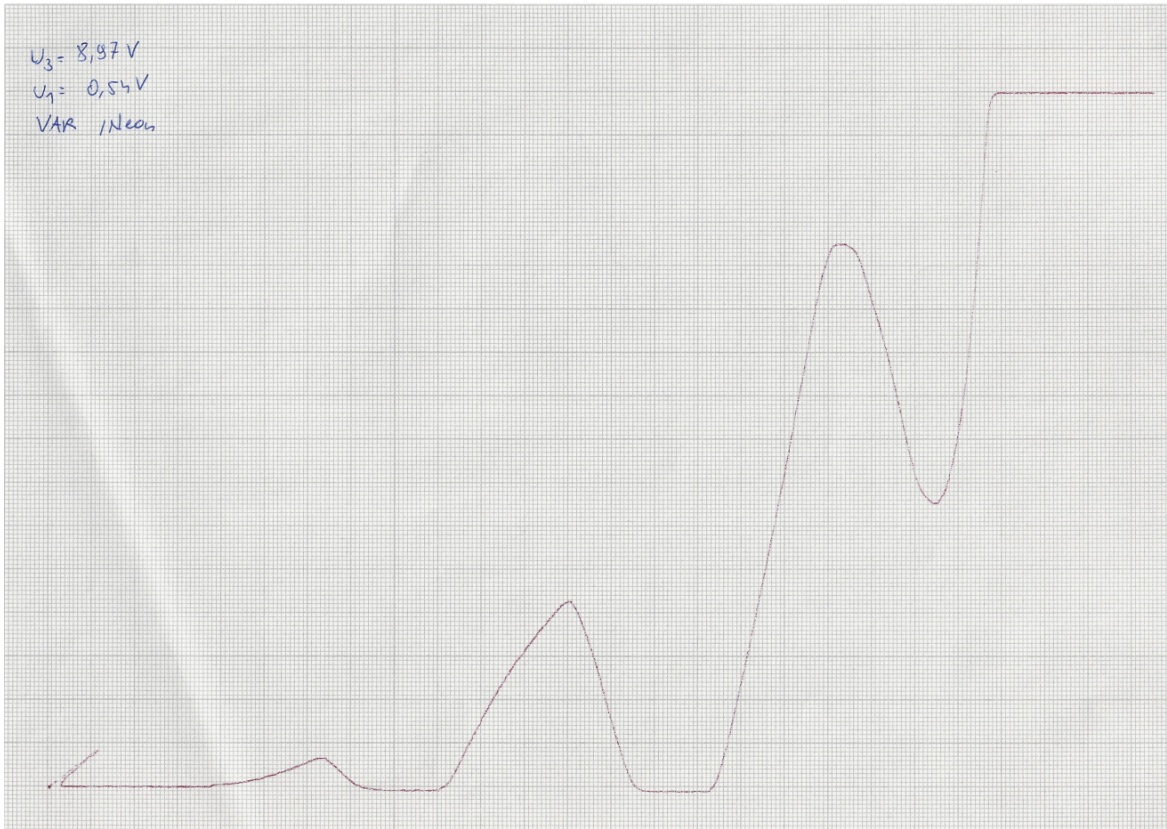

Figure 1

$U_3 = 8,97 V$
$U_1 = 0,54 V$
VAR / Neon

Figure 2

Table 2: X-values of measured peaks and throughs in the CAL- and VAR-mode Ne-plots

	X-value CAL [mm]	X-value VAR [mm]
Peak 1	19	63
Peak 2	36	120
Peak 3	56	183
Trough 1	27	88
Trough 2	46	152
Trough 3	62	205

In order to be able to use the more precise VAR-values for further calculations, the reduction factor of the VAR-scaling has to be calculated. This is done by dividing a specific distance in CAL-mode from the equivalent distance in VAR-mode. For the purposes of this experiment, the distance in X-direction between the first and last peak is used.

$$R = \frac{X_{cal,2} - X_{cal,1}}{X_{var,2} - X_{var,1}} \tag{1}$$

where: R = Reduction factor
$X_{cal,1}, X_{cal,2}$ = X-coordinates of specified points on the CAL-plot
$X_{var,1}, X_{var,2}$ = X-coordinates of specified points on the VAR-plot

Using the values of Peaks 1 and 3 in Table 2, a reduction factor of 0.3083 is determined. Since, during the CAL-measurement, the X/Y-plotter was set to record one volt of input voltage as one millimeter on the paper, the distance of two neighboring peaks or troughs on the VAR-graph only needs to be multiplied with the reduction factor in order to calculate the excitation energy of the studied element in electron-volts (eV):

$$\Delta E = (X_{var,n} - X_{var,n-1}) \cdot R \tag{2}$$

where: $X_{cal,n-1}, X_{cal,n}$ = X-coordinates of neighboring peaks or troughs in the VAR-Plot

This calculation was done using all peak and trough pairs and its results are shown in Table 3.

Table 3: Calculated excitation energies of Neon from all measured peak and trough pairs.

	Δ**E [eV]**
Peaks 1,2	17.58
Peaks 2,3	19.43
Troughs 1,2	19.73
Troughs 2,3	16.34

Using Equation 3, the arithmetic mean of these values is calculated. The result of this is the determined activation energy.

$$\overline{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \tag{3}$$

where: $\overline{x}$ = Arithmetic mean of taken measurements
n = Number of measurements
x_i = Value of measurement i

In order to calculate the total error of this result, two different error sources need to be evaluated.

Firstly, the uncertainty in voltage readings, resulting from the limited resolution of the used plot paper, needs to be taken into account. This is simply double the lowest measurable voltage (double since the voltage difference is calculated from two single measurements). This in turn is equal to the resolution of the paper (1 mm) multiplied by the reduction factor R.

$$u_{res} = 2 \cdot R \cdot r \tag{4}$$

where: u_{res} = Uncertainty resulting from measurement resolution
R = Reduction factor
r = Resolution of the paper

Secondly, the random uncertainty of the taken measurements can be calculated as the standard error of the mean:

$$u_{sem} = \frac{1}{\sqrt{n}} \cdot \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (x_i - \overline{x})^2} \tag{5}$$

where: u_{sem} = Standard error of the mean
n = Number of measurements
x_i = Value of measurement i
$\overline{x}$ = Arithmetic mean of measurements

From these two values, the total uncertainty can then be calculated:

$$u = \sqrt{u_{res}^2 + u_{sem}^2} \tag{6}$$

where: u = Total uncertainty

Using the equations above, the excitation energy of Neon ΔE_{Ne} is determined as **(18.26 $\pm$ 1.01) eV**.

3.2   Determination of Excitation Energy for Mercury

Figures **??** through **??** show the recorded Franck-Hertz curves of Mercury in the CAL- and VAR-modes of the X/Y-plotter respectively. With the starting point of the plot set as (0,0), the x-values of the peaks and troughs of the curves were measured and recorded in Table 4.

Table 4: X-values of measured peaks and throughs in the CAL- and VAR-mode Hg-plots at both 150 °C and 180 °C

	X-value CAL 150 °C [mm]	X-value VAR 150 °C [mm]	X-value CAL 180 °C [mm]	X-value VAR 180 °C [mm]
Peak 1	4	22	6	48
Peak 2	8	59	11	86
Peak 3	13	100	16	125
Peak 4	19	141	21	163
Peak 5	24	184	27	204
Peak 6	30	233	32	243
Trough 1	6	46	8	61
Trough 2	11	84	13	101
Trough 3	16	123	18	141
Trough 4	21	163	23	181
Trough 5	26	204	28	221

Using Equation 1, reduction factors for both temperatures were calculated using the first and last peaks. For 150 and 180 °C, these are 0.1232 and 0.1333, respectively. Just like in the Neon experiments, a scale of one volt per millimeter was used and as such the reduced VAR-values can be directly read as Voltages.

Using Equation 2, the excitation energies of each peak and trough pair was calculated and recorded in Table 5

Table 5: Calculated excitation energies of Mercury from all measured peak and trough pairs.

		ΔE [eV]
150 °C	**Peaks 1,2**	4.56
	Peaks 2,3	5.05
	Peaks 3,4	5.05
	Peaks 4,5	5.30
	Peaks 5,6	6.04
	Troughs 1,2	4.68
	Troughs 2,3	4.81
	Troughs 3,4	4.93
	Troughs 4,5	5.05
180 °C	**Peaks 1,2**	5.07
	Peaks 2,3	5.20
	Peaks 3,4	5.07
	Peaks 4,5	5.47
	Peaks 5,6	5.20
	Troughs 1,2	5.33
	Troughs 2,3	5.33
	Troughs 3,4	5.33
	Troughs 4,5	5.33

Using Equations 3–6, the arithmetic means as well as the uncertainties of the excitation energies at 150 and 180 °C are calculated.

The thusly calculated excitation energies are determined as **(5.05 ± 0.29) eV** at 150 °C and **(5.26 ± 0.27) eV** at 180 °C.

4 Disucssion

The determined excitation energy of Neon at (18.26 ± 1.01) eV differs significantly from the literature value for the lowest excitation of Neon at 16.62 eV.[3] This is due to the fact that, after acceleration of an electron to a kinetic energy high enough to inelastically collide and cause an excitation, the electron continues to travel for the length of its mean free path, before doing so. During this time, it is further accelerated by the applied electric field and, upon eventual collision, causes an excitation to a higher energy state than the cited value[1]

By instead comparing to the energy of higher excitation states, one can see that the excitation energy of an electron from a 2p to a 3p orbital lies well within the range of uncertainty of the determined energy value.[3]

Looking at the determined excitation energies for mercury of (5.05 ± 0.29) eV at 150 °C and (5.26 ± 0.27) eV at 180 °C, one can similarly see that these are higher than the lowest excitation of Hg at 4.67 eV, while more closely matching the higher excitation levels at 4.89 and 5.46 eV.[2] The three discussed values for mercury all represent an excitation from a 6s to a 6p orbital - they differ however in spin and angular momentum quantum numbers.

5 Conclusion

References

(1)   Rapior, G.; Sengstock, K.; Baev, V. *American Journal of Physics* **2006**, *74*, 423–428.

(2)   NIST Energy Levels of Neutral Mercury (Hg I).

(3)   NIST Energy Levels of Neutral Neon (Ne I).