FRANK Hertz

## INTRODUCTION

From the early spectroscopic work it is clear that atoms emitted radiation at discrete frequencies; from Bohr's model, the frequency of the radiation $\nu$ is related to the change of energy levels through $\Delta E = h\nu$. It is then to be expected that transfer of energy to atomic electrons by any mechanism should always be in discrete amounts. One such mechanism of energy transfer is through inelastic scattering of low-energy electrons.

Frank and Hertz in 1914 set out to verify these considerations.

(i) It is possible to excite atoms by low energy electron bombardment.

(ii) The energy transferred from electrons to the atoms always had discrete values.

(iii) The values so obtained for the energy levels were in agreement with spectroscopic results.

Thus the existence of atomic energy levels put forward by Bohr can be proved directly. It is a very important experiment and can be performed in any college or University level lab.

## OPERATING PRINCIPLE

The Frank-Hertz tube in this instrument is a tetrode filled with the vapour of the experimental substance Fig. 1 indicates the basic scheme of experiment.

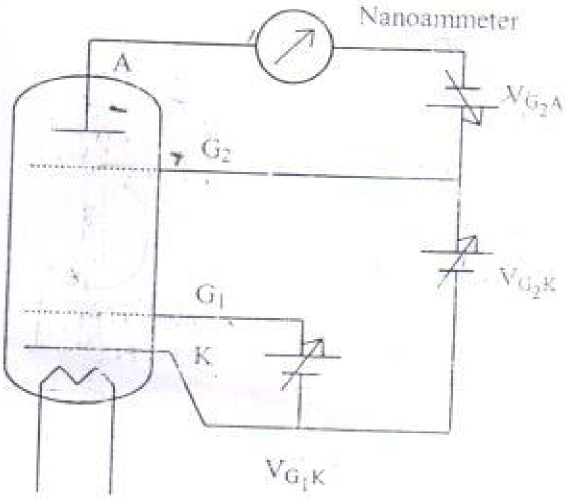


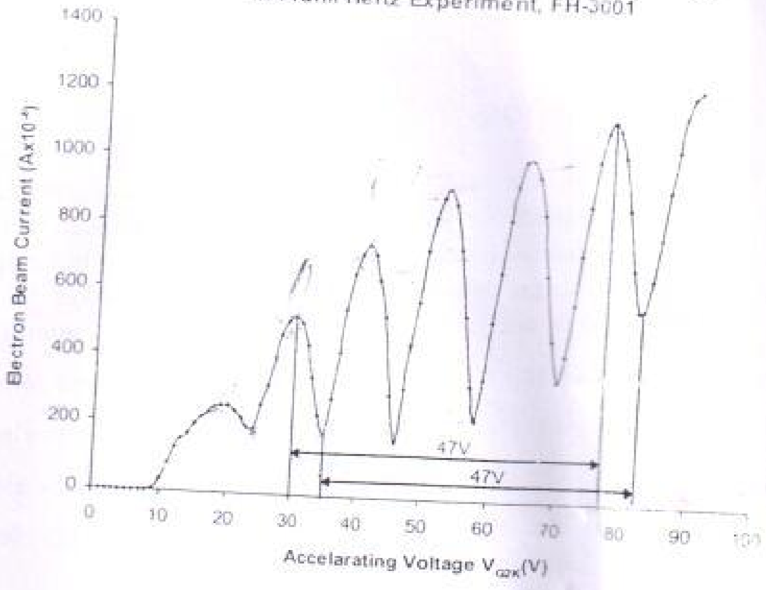

Fig 1

The electrons emitted by filament can be accelerated by the potential $V_{G_2K}$ between the cathode and the grid $G_2$. The grid $G_1$ helps in minimising space charge effects. The grids are wire mesh and allow the electrons to pass through. The plate A is maintained at a potential slightly negative with respect to the grid $G_2$. This helps in making the dips in the plate current more prominent. In this experiment, the electron current is measured as a function of the voltage $V_{G_2K}$. As the voltage increases, the electron energy goes up and so the electron can overcome the retarding potential $V_{G_2A}$ to reach the plate A. This gives rise to a current in the ammeter, which initially increases. As the voltage further increases, the electron energy reaches the threshold value to excite the atom in its first allowed excited state. In doing so, the electrons lose energy and therefore the number of electrons reaching the plate decreases. This decrease is proportional to the number of inelastic collisions that have occurred. When the $V_{G_2K}$ is increased further and reaches a value twice that of the first excitation



$V_{G_2A}$

Fig. 3 Plot of Beam Current Vs. Accelarting Voltage in Frank Hertz Experiment, FH-3001



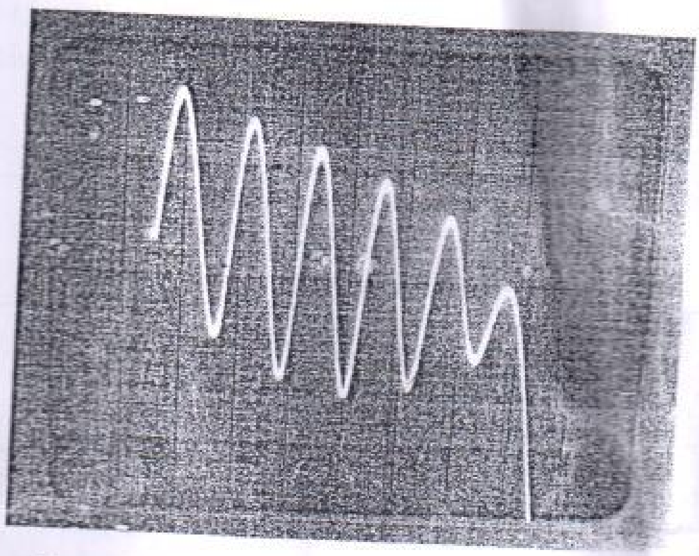



Fig. 4 Oscilloscope display of Frank-Hertz Experiment

potential, it is possible for an electron to excite an atom halfway between the grids, loose all its energy, and then gain anew enough energy to excite a second dip in the current. The advantage of this type of configuration of the potential is that the current dips are much more pronounced, and it is easy to obtain five fold or even larger multiplicity in the excitation of the first level.

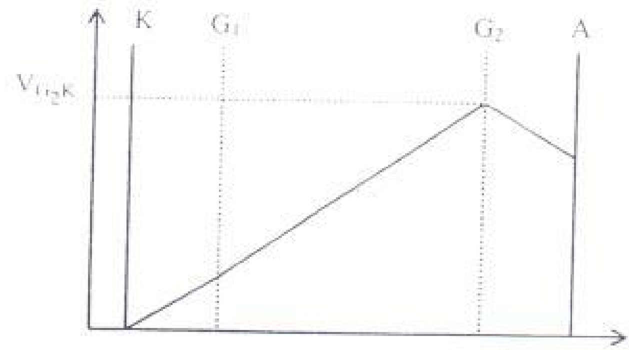



**Fig. 2: Configuration of the Potential in Frank-Hertz Arrangement**

Frank-Hertz Experiment Set-up, Model : FH-3001, consists of the following :

- Argon filled tetrode
- Filament Power Supply : 2.6 - 3.4V continuously variable
- Power Supply for $V_{G_1K}$ : 1.3 - 5V continuously variable
- Power Supply for $V_{G_2A}$ : 1.3 - 12V continuously variable
- Power Supply for $V_{G_2K}$ : 0 - 95V continuously variable
- Saw tooth waveform for CRO display
  *Scanning Voltage : 0 - 95V*
  *Scanning Frequency : 115 ± 20Hz.*
- Multirange Digital Voltmeter
  *Range : 0 - 100V, with 100% over*
  *Display: 3 ½ digit 7-segment LED with auto polarity and decimal indication*
- Multirange Digital Ammeter
  *Range : 0 – 100, 0-10 μA & 0-1μA*
  *Display: 3 ½ digit 7-segment LED with auto polarity*

The instrument can not only lead to a plot of the amplitude spectrum curve by means of point by point measurement, but also directly display the amplitude spectrum curve on the oscilloscope screen. This instrument can thus be used as a classroom experiment as well as for demonstration to a group of students.

## ANALYSIS OF THE DATA

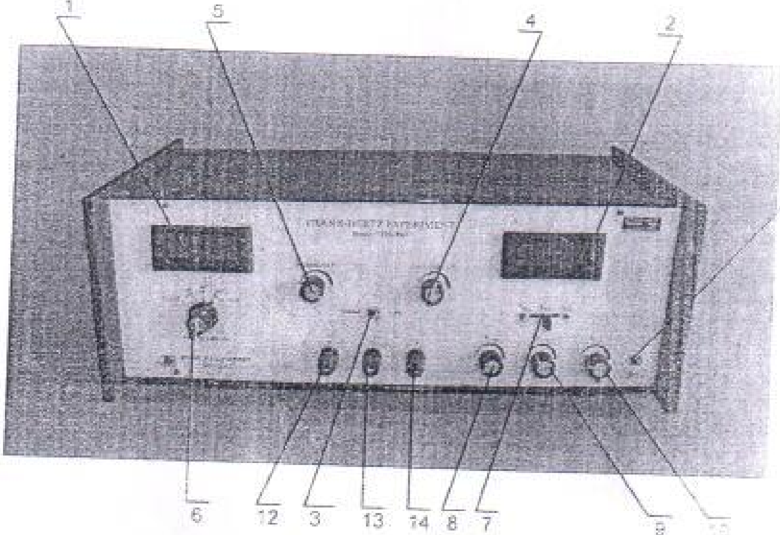
Data obtained for the excitation potential point by point are shown in Fig. 3. The reading are taken for 1V changes on grid 2 ($V_{G_2K}$). A significant decrease in electron (collector) current is noticed every time the potential on grid 2 is increased by approximately 12V, thereby indicating that energy is transferred from the beam in (bundles) quanta of 12 eV only. Indeed, a prominent line in the spectrum of argon exists at 1045 Å corresponding to eV=11.83.

The location of the peaks is indicated in Fig. 3. Average value of spacing between peaks is 11.75 eV compared with the accepted value of 11.83V.

## UNPACKING

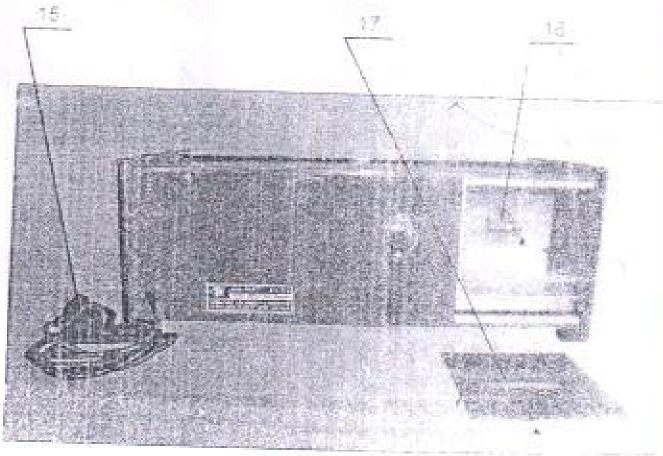
Unpack the instrument carefully and check the accessories with the packing list. The instrument is checked thoroughly before dispatch, damage/shortage, if any should be reported immediately.

Take out the Frank-Hertz Tube from its window-marked 'Frank-Hertz Tube Window' by removing its cover.




## PANEL CONTROLS AND THEIR FUNCTIONS

1) Ammeter
2) Voltmeter
3) Manual - Auto Switch
4) Scanning Voltage Knob
5) Filament Voltage Knob
6) Current Multiplier Knob
7) Voltage Display Selector: $V_{G_1K}$, $V_{G_2A}$ or $V_{G_2K}$
8) $V_{G_1K}$ Adjust knob : 1.3 - 5V
9) $V_{G_2A}$ Adjust Knob : 1.3 - 15 V
10) $V_{G_2K}$ Adjust knob : 0 - 80V
11) Power Switch
12) Y-Output Terminal
13) Ground Terminal
14) X-output Terminal
15) Power Lead
16) Frank Hertz Tube
17) Frank-Hertz Tube Window



## INSTALLATION

Before the Frank-Hertz tube is put in its socket, make sure the power supplies- $V_{G_1K}$, $V_{G_2A}$ & $V_{G_2K}$ are working properly. For this proceed as follows.

1. Put all the control knobs (Scanning Voltage $V_{G_1K}$, Filament Voltage $V_{G_2A}$ & Accelerating Voltage $V_{G_2K}$ Knobs) to their minimum position by rotating anticlockwise.
2. Turn the Manual-Auto switch to Manual
3. Turn Voltage Display Selector to $V_{G_1K}$ and rotate the $V_{G_1K}$ knob clockwise to see if the power supply is working properly. Similarly turn the Voltage Display Selector to $V_{G_2A}$ and $V_{G_2K}$ and check if these power supplies are also O.K..
4. Switch 'OFF' the power and put Frank-Hertz tube in the socket. **As the tube is delicate and very expensive this operation must be handled very carefully and by a technical hand only.**

***The instrument is now ready for operation***

## OPERATING INSTRUCTIONS

1) Before the power is switched 'ON' make sure all the control knobs are at their minimum position and Current Multiplier knob at $10^{-7}$ position.
2) Switch 'ON' the power.
3) Turn the Manual-Auto Switch to Manual, and check that the Scanning Voltage Knob is at its minimum position.
4) Turn Voltage Display Selector to $V_{G_1K}$ and adjust the $V_{G_1K}$ knob until voltmeter reads 1.5V. → 1.89 V display [illegible]
5) Turn Voltage Display Selector to $V_{G_2A}$ and adjust the $V_{G_2A}$ knob until the voltmeter read 7.5. → [illegible]

When you have finished step 1-5, you are ready to do the experiment with following parameters.

| | |
|---|---|
| *Filament Voltage* | *: 2.6 V (minimum position)* |
| $V_{G_1K}$ | *: 1.5 V* |
| $V_{G_2A}$ | *: 7.5 V* |
| $V_{G_2K}$ | *: 0 V* |
| *Current Multiplier* | *: $10^{-7}A$* |

These are suggested values for the experiment. The experiment can be done with other values also.

6) Rotate $V_{G_2K}$ knob and observe the variation of plate current with the increase of $V_{G_2K}$. The current reading would show maxima and minima periodically. The magnitude of maxima could be adjusted suitably by adjusting the filament voltage and the value of Current Multiplier. Now take the systematic readings, $V_{G_2K}$ vs. plate current. For better resolution, the reading may be taken at a interval of 1V

Plot the graph with output current on Y-axis and accelerating voltage $V_{G_2K}$ at X-axis.

7) Turn the Manual-Auto switch to 'Auto', connect the instruments Y, G, X sockets to Y, G X of oscilloscope. Put the Scanning Range switch of oscilloscope to X-Y mode/external 'X'. Switch on the power of oscilloscope, adjust the Y and X shift to make the scan base line on the bottom of screen. Rotate the 'Scanning Knob' of the instrument and observe the wave-form on the oscilloscope screen. Adjust the 'Y-gain' and 'X-gain' of oscilloscope to make wave-form clear and Y amplitude moderate. Rotate the scanning potentiometer clockwise to end. Then the maximum scan voltage is 85V. Measure the horizontal distance between the peaks. The distance of two consecutive peaks (count the grids) and multiply it by V/grid factor (X-gain) of oscilloscope. This would give the value of argon atom's first excitation potential in eV.

## PRECAUTION

1) Before taking the systematic readings, gradually increase the value of $V_{G2k}$ to a maximum. Adjust the filament voltage if required such that max. readings is about 1000 on $X10^{-8}$ range. This will insure that all the readings could be taken in the same range.
2) During the experiment (manual), when the voltage is over 60V, please pay attention to the output current indicator, If the ammeter reading increases suddenly, decrease the voltage at once to avoid the damage of the tube.
3) Whenever the Filament Voltage is changed, please allow 2/3 minutes for its stabilisation.
4) **When the Frank-Hertz Tube is already in the socket, please make sure the following before the power is switched 'ON' or 'OFF', to avoid damage to the tube.**
   a) Manual - Auto switch is on Manual and Scanning and Filament Voltage knob at its minimum position (rotate it anticlockwise) and Current Multiplier knob at $10^{-7}$.
   b) $V_{G_1K}$, $V_{G_2A}$, and $V_{G_2K}$ all the three knobs are at their minimum position.

## PACKING LIST

1) Frank-Hertz Main Unit
2) Frank-Hertz Tube
3) Set of wires for connecting Frank-Hertz Main Unit to Oscilloscope
4) Operating Instruction Manual

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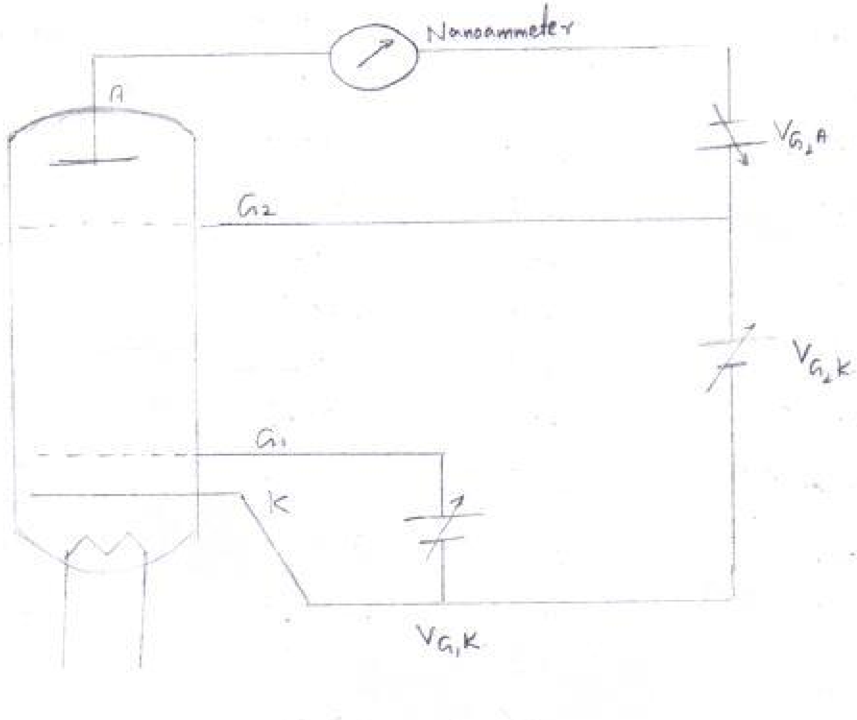
# Frank-Hertz Experiment



IM: To demonstrate the existence of discrete energy levels in argon and determine minimum exitation level of argon.

ATERIALS REQUIRED: 1) Oscilloscope
2) Multimeter
3) Frank-Hertz Tube
(in a circuit)

PERIMENTAL SETUP:




$246 \times 10^{-7}$

$= 24.6 \times 10^{-6}$

190 OBSERVATION:

Least count of the ammeter = 0.01 ~~x10~~$^{-9}$ A

Multiplier = $10^{-9}$

Least count of the voltmeter = 0.1 V

Initial Voltages

$V_{a1K}$ = 1.5V

$V_{a_2A}$ = 7.5V

| $V_{a2K}$ (in 10V) | Current (in A) | $V_{a2K}$ (in V) | I (in A) | $V_{a2K}$ (in 10V) | I (in A) |
|---|---|---|---|---|---|
| 0.08 | 0.01 | 1.80 | 7.30 | 3.9 | 19.69 |
| 0.10 | 0.01 | 1.90 | 7.28 | 4.0 | 2.20 x $10^{-9}$ |
| 0.20 | 0.02 | 2.00 | 7.02 | 4.1 | 2.36 |
| 0.30 | 0.02 | 2.10 | 6.45 | 4.2 | 2.32 |
| 0.40 | 0.02 | 2.20 | 5.89 | 4.3 | 2.01 |
| 0.50 | 0.02 | 2.3 | 4.96 | 4.4 | 1.42 |
| 0.60 | 0.02 | 2.4 | 4.56 | 4.5 | 0.80 |
| 0.70 | 0.03 | 2.5 | 5.21 | 4.6 | 0.49 |
| 0.80 | 0.16 | 2.6 | 7.96 | 4.7 | 0.87 |
| 0.90 | 0.55 | 2.7 | 10.89 | 4.8 | 1.56 |
| 1.00 | 1.28 | 2.8 | 13.77 | 4.9 | 2.28 |
| 1.10 | 1.65 ~~2.1~~ | 2.9 | 14.47 | 5.0 | 2.91 |
| 1.20 | 1.91 | 3.0 | 14.72 | 5.1 | 3.41 |
| 1.30 | 3.60 | 3.1 | 13.52 | 5.2 | 3.62 |
| 1.40 | 5.21 | 3.2 | 11.02 | 5.3 | 3.65 |
| 1.51 | 6.17 | 3.3 | 8.00 | 5.4 | 3.39 |
| 1.6 | 6.75 | 3.4 | 5.23 | 5.5 | 2.80 |
| 1.7 | 7.35 | 3.5 | 3.68 | 5.6 | 1.96 |
| | | 3.6 | 6.33 | 5.7 | 1.16 |
| | | 3.7 | 11.52 | 5.8 | 0.94 |
| | | 3.8 | 16.43 | 5.9 | 1.72 |
| | | | | 6.0 | 2.64. |

| | | | |
|---|---|---|---|
| 6.1 | 3.72 | 7.6 | 6.46 |
| 6.2 | 4.24 | 7.7 | 6.57 |
| 6.3 | 4.73 | 7.8 | 6.36 |
| 6.4 | 5.04 | 7.9 | 5.80 |
| 6.5 | 5.04 | 8.0 | 4.95 |
| 6.6 | 4.74 | 8.1 | 4.07 |
| 6.7 | 4.03 | 8.2 | 3.69 |
| 6.81 | 3.01 | 8.3 | 4.15 |
| 6.9 | 2.20 | 8.4 | 4.92 |
| 7 | 2.04 | 8.5 | 5.~~78~~8 |
| 7.1 | 2.95 | 8.6 | 6.65 |
| 7.2 | 3.84 | 8.7 | 7.37 |
| 7.3 | 4.73 | 8.8 | 7.85 |
| 7.4 | 5.50 | 8.9 | 8.18 |
| 7.5 | 6.14 | 9.0 | 8.20 |
| | | ~~9.1~~ | |
| | | 9.2 | |

✓

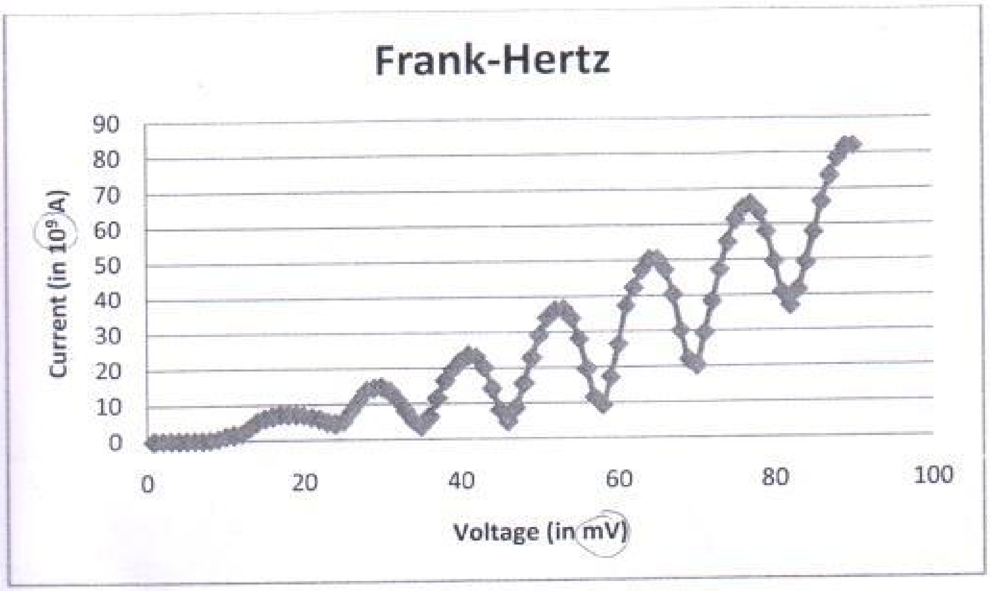
9/10 15/03/12

THEORY: The Frank-Hertz tube in this experiment is filled with argon gas. It is an evacuated glass cylinder with four electrodes. A voltage of about 1.5V is added between the first grid ($G_1$) and the cathode (K) to dismiss the effect of space charge on cathode scattering electrons. When the filament is heated, the electrons transmitted by the cathode oxide are accelerated in the electric field between the 2nd grid ($G_2$) and the cathode, obtaining more and more energy. But at the beginning of because of low voltage between the 2nd grid &

the cathode, the electron energy is low. Thus, the energy exchanged is little even if the electrons collide with the atom. So, the plate current $I_A$ formed by electrons penetrating the second grid will increase $V_{G_2K}$. When $V_{G2K}$ reaches the 1st excitation potential of the argon atom, electrons collide with argon atoms near the second grid (it is non-elastic collision) and transfer total energy obtained in the accelerating field to argon atoms; exciting them from the ground state to the 1st state. But electrons themselves transfer all energy to argon atoms and cannot overcome the reverse field. They are drawn back to the second grid even if some of them penetrated the second grid. So, the plate current $I_A$ is decreased. Then with the increase of $V_{G2K}$, the electron energy increased too. There will be enough energy left after collision with argon atom. Thus, they can overcome the reverse field and reach plate A. And at this time current $I_A$ begins to increase again until $V_{G_2K}$ is 2 times the voltage of argon atoms' 1st excitation potential, when electrons between $G_2$ & K lost energy again because the 2nd non-elastic collision causes the 2nd decrease of acceleration voltage $V_{G2K}$

Let $V_{G2K}$ be the horizontal ordinate and $I_A$ the vertical axis. We can plot the spectrum amplitude curve. The voltage difference between the 2 consequitive peak points is the 1st excitation potential of the argon atom. This expt. illustrates the fact that slow electrons in rank-Hertz tube collide with argon atoms from low to igh level. By measuring the argons 1st excitation level (13.1) we can verify that energy absorbed & transmitted is distcrete and not continuous.






LCULATION:

From the graph, the peak points were noted down. They are.

15) (28, 13.77), (40,22), (52,36.2), (64,50.4), (76,64.6)

Average of the difference of voltage between the peaks

$$= \frac{11+12+12+12+12}{5} = \cancel{12V}\ 11.8\ V$$

RROR ANALYSIS:

Expected Value = 11.83 V

Experimental Value : 1~~1~~8V.

$$\therefore \%\ error = \cancel{\frac{|11.83-12|}{11.83} \times 100 = 1.69\%}$$

$$= \frac{|11.83 - 11.8|}{11.83} \times 100 = 0.25\%$$

Standard deviation

$$\sqrt{\frac{\Sigma(x_i - \bar{x}_i)^2}{n-1}} = \sqrt{\frac{|11.8-11|^2 + |11.8-12|^2 + |11.8-12|^2 + |11.8-12|^2 + |11.8-12|^2}{5-1}}$$

$$= \sqrt{\frac{0.8}{4}} = 0.4472.$$

$$\therefore \text{Standard error} = \frac{0.4472}{\sqrt{5}} = 0.2$$

RESULT: The minimum excitation energy of argon was found out to be $\underline{11.8 \pm 0.2}$ V

Therefore, we can conclude that the ~~ther~~ structure of atomic model put forward by Bohr is correct i.e the energy required for excitation is equal to the energy difference between the 2 levels. The energy levels are quantised.

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References:
IISER lab manual.
instructor.physics.lsa.umich.edu/adv.../Franck_Hertz/.pdf

$\frac{15}{20}$

Bharath C.V.
11-4-2012

Rohit.