EXPERIMENT 17

ELECTRON MOTION IN ELECTRIC AND MAGNETIC FIELDS

PURPOSE

- To study action of magnetic and filed on charged particles
- To establish electron's charge/mass ratio by longitudinal magnetic field method.

APPARATUS

Cathode ray tube with power supply, anode voltage voltmeter, air-core coil with power supply, ammeter.

DESCRIPTION OF THE EXPERIMENT

Electric and magnetic fields affect the motion of charged particles . Characteristic of the motion depends on orientation of the velocity vector in relation to the electric force - **E** and magnetic induction - **B** . The basic particle's parameters i.e. the charge/mass ratio influence the parameters of the motion as well.
Therefore, from observations of electron motion in defined field's geometry it is possible to establish charge/mass ratio of electron.
In the present experiment the so called 'longitudinal magnetic field' method is used .
The cathode-ray tube is placed co-axially inside the air-core coil (Fig. 1.).
Thus, electron beam generated in the tube is affected by the magnetic field of the coil. In result the certain 'trace' is produced on the fluorescent screen of the tube.
The cathode-ray tube is an elongated vacuum tube with a source of high speed electrons (electron gun) at one end and a fluorescent screen at the other. The electron gun furnishes a supply of high speed electrons and by means of electronic lens system brings them into a narrow beam. The anode voltage - U - accelerates them down the axis of the tube and finally, the beam strikes the fluorescent screen producing a spot.
In the present experiment electron moves between the deflecting plates with alternating voltage applied. Due to this transverse electric field electrons gain the component of velocity vector perpendicular to the axis of the tube - V_y - (and magnetic induction vector as well).
Thus, the magnetic field exerts on the electrons a Lorenz's force - Eq. 1.:

$$F = -e \cdot v_y \cdot B \qquad (1)$$

where :

v_y - component of the velocity vector perpendicular to the magnetic field

B - induction of the magnetic field

e - elementary charge

Lorentz' force is normal to the electron velocity vector providing the centripetal force that bends the electron's trajectory to the circular one in the plane normal to the tube axis-- Eq2.:

$$F_d = \frac{m \cdot v_y^2}{r} \quad (2)$$

The radius of its curvature - ***r*** - is given by Eq. 3.:

$$r = \frac{m \cdot v_y}{e \cdot B} \quad (3)$$

The period - ***T*** - of this rotary motion is given by Eq.4.:

$$T = \frac{2 \cdot \pi \cdot r}{v_y} = \frac{2 \cdot \pi \cdot m}{e \cdot B} \quad (4)$$

Thus, the electron's trajectory is helical. It is built up of two different motions. One, rotary motion is in the plane normal to the tube axis with the component of the velocity vector - V_y - .

Second , translatory motion down the axis of the tube with the component of the velocity vector - V_x - .

The translation velocity - V_x - that results from acceleration by the anode voltage - ***U*** - is given by Eq. 5.:

$$\frac{mV_x^2}{2} = eU$$

$$v_x = \sqrt{\frac{2 \cdot e \cdot U}{m}} \quad (5)$$

While reaching the screen, electrons could be at different distance from the X axis but they all are in the same phase of the rotatory motion. Thus the beam's trace on the screen forms a segment.

For certain sets of - ***U*** - and - ***B*** - values the time of translation along the tube length - ***x*** - is equal to the integral number (- ***n*** -) of time periods of the rotary motion - Eq.6.:

$$x = v_x \cdot nT = v_x \cdot n \cdot \frac{2 \cdot \pi \cdot m}{e \cdot B} \quad (6)$$

When this condition is satisfied all electrons strikes at one point on the screen (segment is reduced to a point) and the 'focusing' state of the electron beam is observed on the fluorescent screen as a small spot.

One can evaluate from Eq. 4, 5 and 6 the dependence between ***x*** , ***B*** , ***U*** values that describes the focusing of the electron beam- Eq.7.:

$$\frac{e}{m} = \frac{8 \cdot \pi^2 \cdot n^2 \cdot U}{x^2 \cdot B^2} \quad (7)$$

Thus, on the basis of Eq.7 it is possible to establish electron's charge/mass ratio from cathode-ray tube observations.

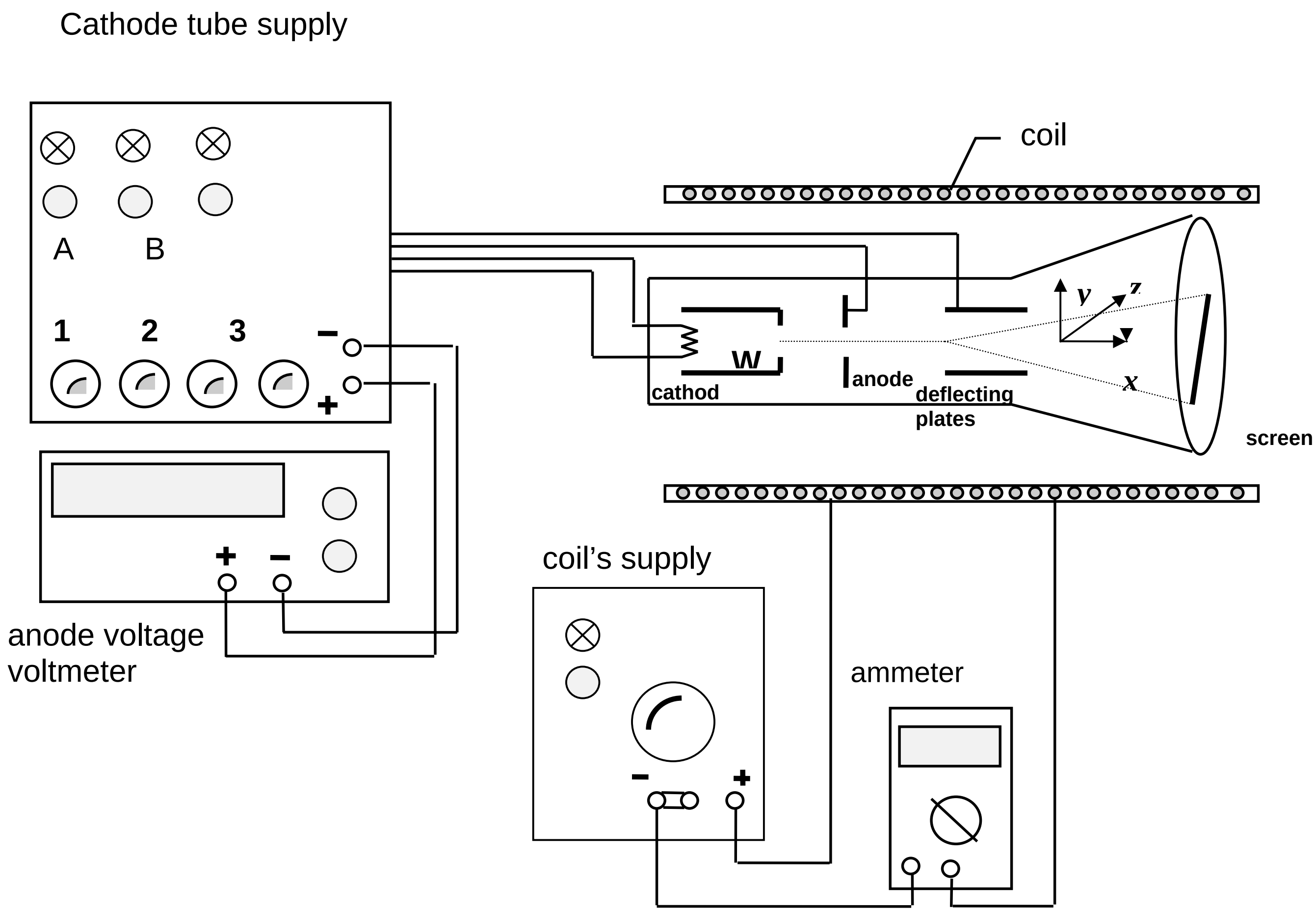

Fig.1. Experimental arrangement

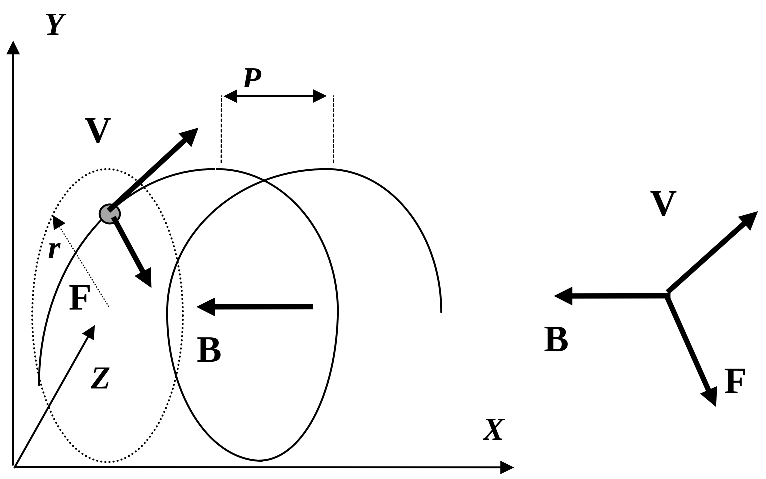

Fig. 2. Electron's motion

MEASUREMENTS

1. Turn on the cathode heater supply - red button on the control panel - and (with 2 min. delay) the anode high voltage supply - yellow button.
2. Adjust with the controls the intensity, sharpness and centring of the spot on the fluorescent screen (Fig.1).
3. Turn on the deflecting voltage - green button - to obtain linear trace on the screen.
4. Turn on the coil power supply.
5. Adjust the accelerating anode voltage value at about 250 Volts (check this on the digital voltmeter).
6. Increase the coil circuit voltage and observe the screen to find the total focusing state. Record the coil current – I_1 - value.
   Keep increasing the voltage to find second and third focusing if it possible.

Repeat procedure of steps 5,6 for at least 10 values of anode voltage .

CALCULATIONS AND PRESENTATION OF RESULTS

1. Calculate from Eq.8. the magnetic induction values ***B*** and ***B²*** for each current value.

$$B = \frac{\mu_0 \cdot \mu \cdot I_1 \cdot N}{2 \cdot \sqrt{\left(r + \frac{h}{2}\right)^2 + \frac{L^2}{4}}} \qquad (8)$$

where:

μ_0 = 4π 10^{-7} [Vs A^{-1} m^{-1}] - magnetic permeability of vacuum
μ = 1 - relative magnetic permeability of the air
I - current in the coil circuit
N = 2215
r= 0,04[m] – coil's radius
h= 0,009[m] – thickness of coils turns
L=0,3[m] – length of the coil

2. Make a ***U(B²)*** plot .
3. Use the linear regression method to find the linear approximation of the ***U(B²)*** dependence (in a form :***U=a B²*** . Record the ***a*** coefficients' error Δ***a***.

$$U = \frac{x^2}{8\pi^2 n^2}\frac{e}{m}B^2 \qquad (9)$$

take into account the first order – focussing : ***n=1***
x = 0.072 [m] length of the electron's path inside the cathode tube
4. Put the obtained line function on the experimental ***U(B²) plot.***
5. Calculate the electron charge/mass ratio value from the slope ***a*** value – see Eq. 9.
6. Calculate experimental error Δ***(e/m)*** from:

$$\Delta(e/m) = \left(\frac{\Delta x}{x} + \frac{\Delta a}{a}\right) \cdot \frac{e}{m}$$

with $\Delta \boldsymbol{x}$ = 0,004[m]

ANALYSIS AND INTERPRETATION

1. Present the charge /mass ration in a form:

$$e/m = e/m \pm \Delta(e/m)$$

2. Compare obtained result with literature data. Discuss your own results.

DATA TABLE

n (1,2,3)	U [V]	I [A]	B [T]	B^2 [T^2]

REQUIREMENTS

1. Electron motion in magnetic and electric field.
2. Cathode-ray tube. Construction, operation.