Experiment: Electron Charge-to-Mass Ratio System

Purpose

1. Magnetic forces on moving electrons.
2. Observe the trajectory of electron motion in three-dimensional s pace.
3. Determination of the electron charge and mass ratio.

Theory

Lorentz tube, also known as Wehnelt tube, the tube with a large vacuum glass bulb of 160 mm diameter, filled with a certain pressure mixture of inert gases. The interior is equipped with an electron gun, a hot cathode, a modulation board, an accelerating pole and a pair of deflection plates. When the electrode of electron gun is exerted by the appropriate operating voltage, it emits a beam of electrons. Then, electronics and molecules of inert gases collide, so the inert gases light up. It is able to see the light trace on where electrons pass through.

Helmholtz coils are a pair of diameter of 280 mm, each circular coil of 140 turns, coaxial parallel spacing of 140mm, two coils connected in series. When the current flows through the coils, the magnetic field is approximately uniform in between the coil pair. The magnetic field strength can be calculated as follows:

$$B = 9\times10^{-7}(NI)/R = 9\times10^{-4}I(tesla) \qquad (1)$$

N：Coil turns
I：Amps
R：Coil radius (meter)

Fix a pair of Helmholtz coils L1, L2 in the device, and then set the electronic beam tube V1 in the middle of the coils. When the electrode of electron gun is exerted by the appropriate operating voltage, it emits a beam of electrons. It is able to see the light trace on where electrons pass through. At this time, connect the Helmholtz coils to the power supply, the vector expression of the electron force in a magnetic field is

$$\vec{F} = e\vec{V} \times \vec{B} \qquad (2)$$

$\vec{F}$: Electromagnetic forces

$\vec{V}$: Speed of the electron beam

$\vec{B}$: Magnetic fields

We determine the direction of the magnetic force by the left-hand rule, and the magnitude is:

$$F \times -eVBSin\alpha \qquad (3)$$

e: Electron charge

α : Angle between the direction of electron motion and the magnetic field

Turn the electron beam bulb, when the direction of electron motion is consistent with the direction of the magnetic field $\alpha = 0$ or $\alpha = 180°$, the electronic will not be unaffected by magnetic fields, the trajectory of the electron beam is straight. When the direction of electron motion is perpendicular to the direction of the magnetic field, the electrons are exerted by the magnetic force, which is perpendicular to the direction of electron motion $F = eVB$

Since the velocity of electrons is constant, the uniform magnetic field B and the magnetic force are constant, too. The centripetal force of the constant direction acts on the electrons in motion, and the electron motion becomes a circular motion with a uniform speed, its electronic trajectory is circular. When Helmholtz current increases, the magnetic field strength gets greater; when the magnetic filed strength gets greater, the diameter of the circle is smaller.

When the direction of electron movement and the magnetic field are random, the direction of election will be decomposed into parallel and perpendicular components. The parallel component isn't being acted by the force of the magnetic field, so the trajectory of the electron movement is in linear motion. On the other hand, the perpendicular component is being acted by the force of the magnetic field, so the trajectory of electron movement is helical.

When an electron is in uniform circular motion, the formula of centripetal force is $\frac{mV^2}{r}$, this is the force of the magnetic field which acts on the electrons in a uniform magnetic field, so we know

$$\frac{mV^2}{r} = eVB \qquad (4)$$

r: Radius of the trajectory of electron movement
m: Electron mass

We can obtain the charge-to-mass ratio of an electron:

$$\frac{e}{m} = \frac{V}{rB} \qquad (5)$$

The kinetic energy of the electrons in the accelerating electric field is equal to the work done by the electric field, so:

$$1/2V^2 = eVa \qquad (6)$$

Va : Accelerating electrode voltage

Speed of the electron motion can be obtained from formula (6)

$$V = \sqrt{\frac{2eVa}{m}} \qquad (7)$$

Substitute formula (1), (7) into formula (5), we obtain the electronic charge to mass ratio:

$$\frac{e}{m} = \frac{2.47 \times 10^{6} Va}{R^{2} I^{2}} \text{Coulomb / kg} \qquad (8)$$

According to the accelerating electrode voltage *Va*, the Helmholtz coil current *I* and the radius of electron trajectory *r* to calculate the electron charge-mass ratio. Turn off the power, and then exert voltage on the deflection plates to observe the deflection of the electrons under the electric field. When a positive voltage exerts on the upper deflection plate, the electron trajectory moves upward by the force of the electric field, so the deflection angle ϕ is

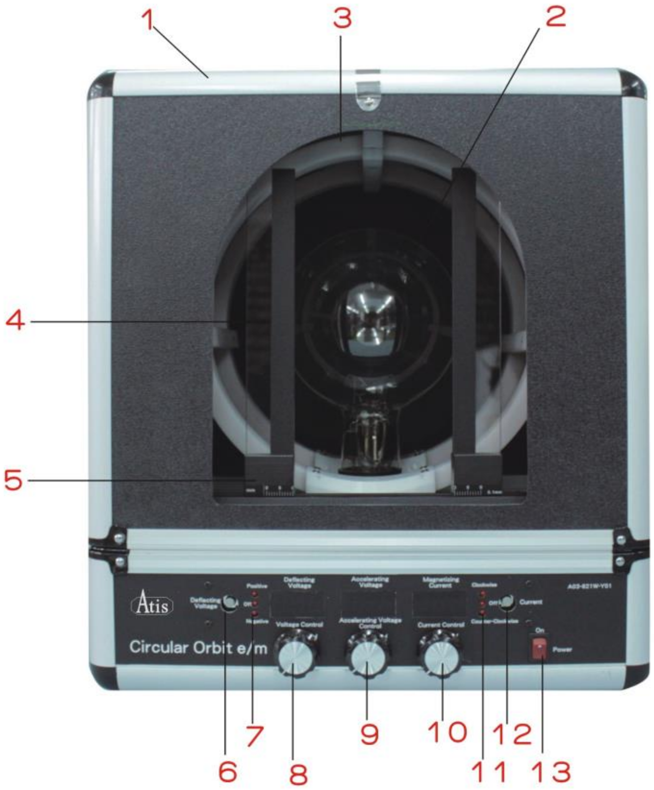
$$tg\phi = (eV_d)/(mdV^2) \qquad (9)$$

V_d: Voltage of the deflection pole
I : Length of deflection plates
d : Distance between the deflection plates
V : Electronic velocity

The voltage of deflection angle is proportional to the voltage of the deflection plates, but the deflection Angles inversely proportional to the velocity of electron, which means it is also inversely proportional to the accelerating electrode voltage. When a positive voltage exerts on the under deflection plate, the electron trajectory moves downward.

To enhance the observed effect, the entire instrument is mounted in a wooden box, which is internally coated with mat-black paint and exterior wood varnish.

Instrument



NO	Accessory	NO	Accessory
1	Helmholtz coil	2	Electron-beam bulb
3	Outer box	4	Gauge
5	Scale	6	Deflecting voltage switch
7	Deflecting voltage Indicator	8	Voltage control
9	Accelerating voltage control	10	Current control
11	Current indicator	12	Current switch
13	Power switch		

Procedure

A. Set up

1. Open the front lid, and then carefully remove the packing carton and take out the electron-beam tube and put it on the base tightly. Be careful not to hold the bulb too tight in case the base loosens. Loosen one of the screws and check if the rotation is flexible. Rotate the base by hands, do not rotate the bulb.

2. Check the control knobs, which should be as follow:

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