Experiment 4
SPECIFIC CHARGE OF ELECTRON

I. OBJECTIVE

To determine the specific charge (*e/m*) of an electron.

II. PRINCIPLE

Electrons accelerated in an electric field enter a uniform magnetic field ***B*** with a velocity ***v*** directed at right angles to ***B.*** The electrons experience a sideways deflecting force of magnitude *evB* and undergo a uniform circular motion, in a plane perpendicular to the magnetic field. The radius (*r*) of the circular path is related to *v* and *B* by

$$v = \left(\frac{e}{m}\right) B\, r \qquad (1)$$

where, *e* and *m* respectively, represent the charge and rest mass of the electron. If the electron achieves the velocity ***v*** under the influence of an accelerating voltage *V*, then,

$$eV = \left(\frac{mv^2}{2}\right) \qquad (2)$$

Further, if the uniform magnetic field is produced by a pair of Helmholtz coils, each of *N* turns and average radius *R*, carrying a current *I*, the magnitude of ***B*** is given by

$$B = \frac{8}{5\sqrt{5}} \frac{\mu_o NI}{R} \qquad (3)$$

Using *Eqns*. (1), (2) and (3), it can be shown that

$$\left(\frac{e}{m}\right) = 3.9 \frac{V\, R^2}{(\mu_o\, N\, I\, r)^2} \qquad (4)$$

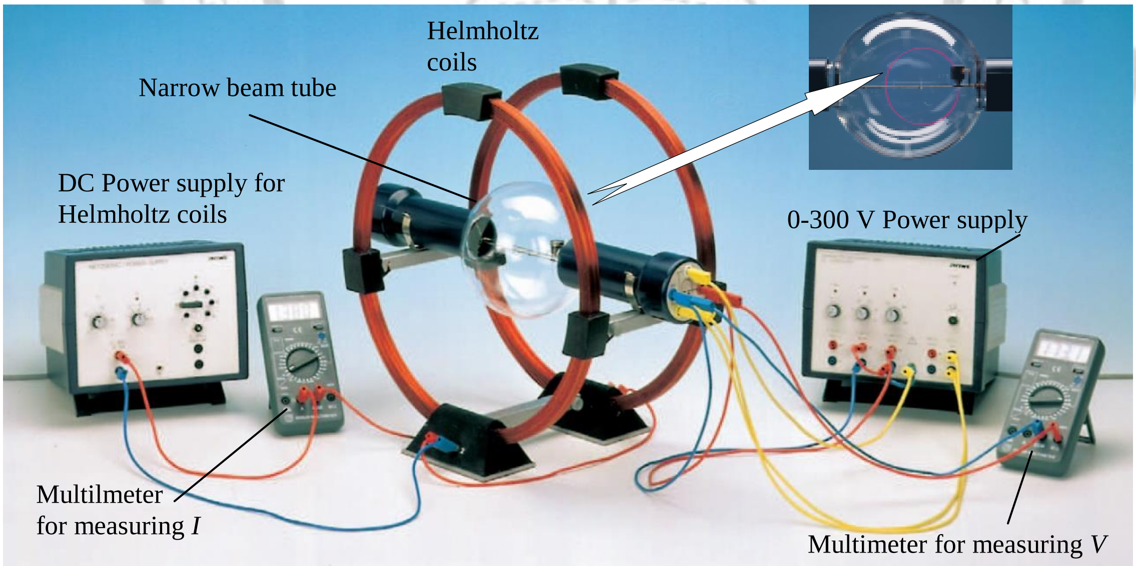

Figure 1 (Source: PHYWE)

III. EXPERIMENTAL SET-UP & APPARATUS DETAILS

The experimental set-up is shown in *Fig.1*. It consists of a pair of Helmholtz coils (*1* and *2*) and a narrow beam tube. The narrow beam tube is placed on metal rods (secured by clips) in such a way that its connections are towards the right of an operator standing on the side of *coil 1*. Two power supplies are used, one for Helmholtz coils and the other for narrow beam tube. A multimeter is used to measure the voltage in the narrow beam tube. The current in the Helmholtz coils is measured by another multimeter or displayed in the ammeter of the DC power supply. Some important parts of the experimental set up are described below.

Helmholtz Coils: For a single coil of radius R and N turns, carrying a current I, the magnetic field at an axial point is given by

$$B = \frac{\mu_o N I R^2}{2\,(R^2 + z^2)^{3/2}} \quad (5)$$

where, z is the distance from the centre of the coil. When two such coils are placed co-axially, then according to the principle of superposition, depending on the relative sense of current flow in the coils, the two fields may either add or subtract to give the resultant magnetic field at any point on the common axis.

Helmholtz coils consist of a pair of identical coils (same number of turns and radii) placed co-axially and separated by a distance equal to the radius (R) of the coils. Such a pair produces a nearly uniform magnetic field in the region between the coils, if the sense of currents in the two coils, are such that their magnetic fields add.

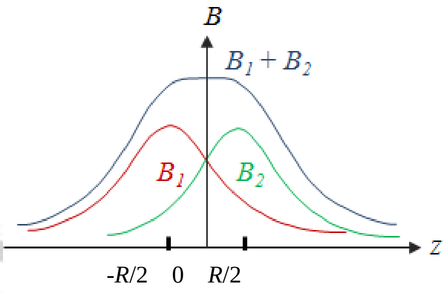

Figure 2

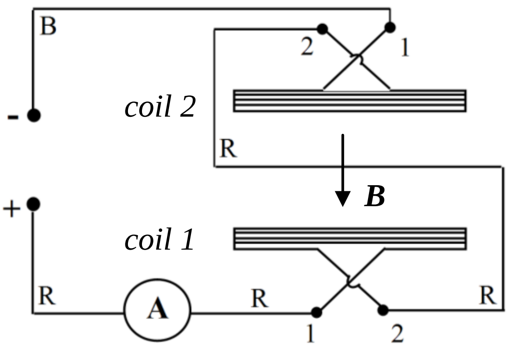

Figure 3

A profile of the axial magnetic field ($B_1 + B_2$) of such a pair of coils is shown in *Fig. 1*, along with the fields due to individual coils. The uniform magnetic field at an axial point (z) between the coils is given by (same as *Eqn. 3.)*

$$B_o = \frac{8\,\mu_o N I}{5\sqrt{5}\,R}$$

In this experiment, the uniform magnetic field is produced by a pair of Helmholtz coils. The arrangement consists of two parallel coils, each of 154 *turns* and average diameter 40 *cm*. The coils are fixed on rigid bases, separated by metal rods, such that the center to centre distance between the coils is 20 *cm*. The Helmholtz coil circuit is shown in *Fig. 3*, in which, a DC power supply is connected in series with the two coils and an ammeter, A (which may be part of the power supply). R and B indicate the red and blue colour cords used for connections. Note that the current entering at *socket 1* flows anticlockwise in the coils, when seen from the socket side. **It is to be noted that the current through the coils must never exceed 3.1*A*.**

Narrow Beam Tube: The narrow beam tube is a glass tube (shown in *Fig. 1*), which after initial evacuation is filled with neon (inert gas) at a pressure of ~ 10^{-1} Pa. It consists of an electron emitting filament or electron gun, a cathode (K), grid (G) and anode (A), shown schematically in *Fig.4*, along with the respective voltages to be applied. The circle and the components shown within it in *Fig. 4*, represent the connections drawing made on the right end panel of the narrow beam tube. The sockets are marked in different colours, corresponding to the respective sockets on the PHYWE (*0…300 V*) power supply, which is separately shown in *Fig. 5*. The colours (Red-R, Blue–B, Yellow-Y and Green-G) of the connecting cords to be used are also indicated in *Fig. 4*. It can be seen from *Fig. 4*, that a fixed filament voltage of 6.3 *V* AC is to be applied to the electron gun. The grid and anode voltages can be varied between -50 *V* to 0 and 0 to +250 (or +300 *V* in some set ups), respectively. The accelerating voltage (*V*) is measured with a multimeter, used in DC voltage mode.

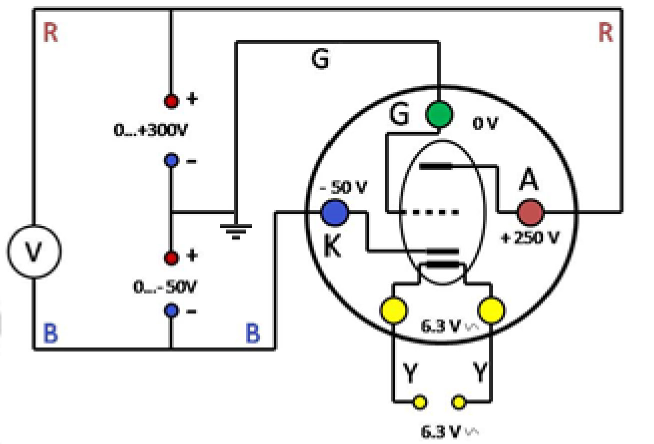

Figure 4 (Source: PHYWE)

The accelerated electrons collide with residual gas molecules along their trajectory and ionize them. The corresponding recombination of electrons with neon ions results in a visible luminescence, making the electron trajectory observable in a dark room. With an appropriate adjustment of grid voltage, a focused and bright narrow trajectory of electrons can be seen (see *inset*, *Fig. 1*). The tube is provided with a scale, shaped like a ladder, whose metal rungs are coated with luminous paint. The radius of the electron trajectory is adjusted such that it falls on one of the metal rungs and causes a luminous spot, which enables measurement of the diameter of electron trajectory.

CAUTION: THE INSTRUMENT SUPPLIES VOLTAGES THAT CAN BE DANGEROUS IF CONTACTED PHYSICALLY. HENCE, EXTREME CARE MUST BE TAKEN IN THIS RESPECT AND EXPERIMENT MUST BE PERFORMED UNDER EXPERT SUPERVISION!

IV. PROCEDURE

A. Connecting the Helmholtz coils circuit and setting the current limit

1. Check that DC power supply is switched OFF and voltage knobs are minimized.
2. Connect the output terminals of the power supply in series with the coils, as shown in *Fig. 2*, using appropriately coloured, red and blue cords. Remember that the ammeter may be a part of the power supply and need not be connected externally. Connect the positive (red) terminal of power supply to *socket 1* of *coil 1* with a red cord. The cord connecting the two coils may be red or blue, but it must be across *sockets 2* on both coils. Connect a blue cord between the *socket 1* of *coil 2* and the negative terminal (black) of the power supply. This implies that the current flows anticlockwise in both coils, when seen from *coil 1* side. This ensures that the magnetic fields due to two coils do not cancel each other and add to produce a uniform magnetic field, which is directed from *coil 2* to *coil 1* (as shown in *Fig.2*). Show this circuit to the instructor, before proceeding further.

3. Turn both the current knobs to respective maxima. Then, switch ON the power supply and the multimeter. Increase the output voltage by using voltage control knobs (coarse and fine) such that current in the multimeter increases to 3.1*A*.
4. Turn back the current control knob on power supply slowly to reduce the current limit to zero without changing the voltage. This sets a current limit of 3.1*A*,
5. Set the coil current to the required value for the respective radius of the electron beam.
6. **Reduce the output voltage to zero and switch off Helmholtz coils power supply once all the measurements are over.**

B. Connecting the narrow beam tube circuit

1. Check that the narrow beam tube is symmetrically placed over the two support rods across the Helmholtz coils and the ladder is nearly horizontal. If not, slightly adjust the position and orientation of narrow beam tube. Before connecting PHYWE power supply to narrow beam tube, check that all the voltage control knobs are minimized and note that only sockets 0…50 V, 0…300 V and 6.3 V~ are used in the experiment.
2. Next, connect the power supply to narrow beam tube and the multimeter, using appropriately coloured cords(as shown in *Fig. 4)*, some of which are already connected to the sockets on the right end panel of the narrow beam tube. For multimeter connections, use V/Ω/Hz and COM input jacks and select 1000 *V* range

AT THIS STAGE, REQUEST THE INSTRUCTOR TO CHECK BOTH CIRCUITS, BEFORE YOU SWITCH ON ANY OF THE POWER SUPPLIES!

C. Powering narrow beam tube and Helmholtz coils

1. Check that all the voltage control knobs of PHYWE power supply are minimized. Then, switch ON the power supply by using switch at the rear panel. This will apply 6.3 *V* filament voltage to the narrow beam tube.
2. Wait for 2-3 *min* so that the filament gets heated and starts glowing. Then, increase the grid voltage to50 *V* by using the appropriate voltage control knob and check the corresponding reading in multimeter. Next, using the appropriate voltage control knob, increase accelerating voltage (*V*) till the multimeter shows a reading of 150 *V*.
3. Check that both voltage control knobs of the Helmholtz coils power supply are minimized. Then, switch ON the power supply and increase output voltage by using coarse and fine voltage control knobs. This will result in increase of current in Helmholtz coils, which can be read in the ammeter.
4. As you increase the current in Helmholtz coils to 1-2 *A*, it should be possible to see the complete circular trajectory of the electrons. **If not, then stop increasing the current and consult the instructor. Under no circumstances, the current should be increased beyond the set limit of 3.1 *A*.**
5. Adjust the current in Helmholtz coils such that the electron beam impinges on one of the metal rungs. In such a situation, only a semicircular trajectory can be seen. If required, adjust the grid voltage slightly of PHYWE power supply), to improve the brightness and focusing of the narrow beam. Also adjust the control knob to maintain 150 *V* in the multimeter. Check, that the plane of the circular trajectory is such that it strikes in nearly the middle of all the metal rungs. If not, then very slightly turn the narrow beam tube about the horizontal axis parallel to the coils.
6. Increase the current (*I*) in Helmholtz coils so that the electron beam successively impinges on metal rungs corresponding to trajectory radii (*r*) of 5 *cm*, 4 *cm*, 3 *cm* and 2 *cm*. Note down the values of current (*I*), corresponding to r = 4 *cm* and r = 5 *cm*

only. Remember that due to current limitations, it may not be possible to make the electron beam impinge on some of the metal rungs at certain voltages.

7. Decrease the current in Helmholtz coils to zero and repeat *step 6*for a total of 10 values of accelerating voltages in steps of 10 V voltages, up to a maximum of 240 V. In all cases, note down the values of current (*I*), corresponding to *r = 4 cm* and *r =5 cm only*.**The accelerating voltage should never be increased beyond 250 V.**

D. Closing the experiment

Reduceto zero the anode voltage and then the grid voltage control knobs and switch OFF PHYWE power supply. Next, reduce voltage output of Helmholtz coils power supply to zero and switch it OFF. Reduce the current knob also to minimum. Switch OFF the multimeter. Disconnect and remove all the connecting cords of Helmholtz coil circuit. **For the narrow beam tube, remove the connections only at power supply and multimeter ends and NOT on the narrow beam tube panel.** Switch OFF the mains for both power supplies.

V. RESULTS AND CALCULATIONS

1. For each of the two trajectories corresponding to *r= 4 cm* and *r = 5 cm*, tabulate the accelerating voltages, *V* and the corresponding values of current, *I*andI^2. You may use an appropriately designed Table or use two separate Tables for two values of *r*.
2. Apply the method of '*least squares fitting of a straight line passing through origin*' to obtain the slope *'S'* and its uncertainty 'ΔS' corresponding to the linear relationship ($I^2 = S.V$) treating (*V* as *x*)and (I^2 as *y*).For this, use *Eqns. (10)* and*(11)* of the *S*ection on *'Analysis of Experimental Data'*. You must have additional columns in the measurement tables for all the quantities, required for the calculation of *'S'* and 'ΔS'. Write down all the column sums (Σx_i^2, Σd_i^2 and $\Sigma y_i.x_i$) used in the calculations.
3. Using *Eqn. (4)*, Calculate for both sets of data, the average values of (*e/m*)**,** given by

$\left(\frac{e}{m}\right) = \left(\frac{3.9}{S}\right)\left[\frac{R}{\mu N r}\right]^2$ and its standard deviation, $\Delta\left(\frac{e}{m}\right) = \left(\frac{\Delta S}{S}\right)\left(\frac{e}{m}\right)$

4. Calculate the error weighted average $\bar{z}$of ($z = e/m$) and its final error Δz, given by (*see the reference (p.41) in the Section on Analysis of Experimental Data*)

$$\bar{z} = \frac{\sum\left(\frac{1}{\Delta z_i}\right)^2 z_i}{\sum\left(\frac{1}{\Delta z_i}\right)^2} \quad \text{and} \quad \Delta z = \frac{1}{\sqrt{\sum\left(\frac{1}{\Delta z_i}\right)^2}}$$

and write the final result for the measured value of (e/m) along with its uncertainty.

VI. PRECAUTIONS

1. **The instrument supplies voltages that can be dangerous if contacted physically. Extreme care must be taken in this respect and the experiment must be carried out under expert supervision. Therefore, the power supplies should NOT be switched ON, until the circuit is checked by the instructor/supervisor.**
2. **Do not touch or disturb the connections on the side panel of narrow beam tube.**
3. **The multimeter used in the narrow beam tube circuit must be in DC voltage mode (1000 *V* range) the connections must be made to the proper sockets.**

4. All voltage control knobs must be minimized before switching ON any power supply and power supplies must be switched OFF, before making any changes in circuit or
5. The current limit of 3.1*A* must be set in DC (Helmholtz) power supply and the accelerating voltage in the narrow beam tube must never exceed 250 *V*.

SUGGESTED READING: *Physics, Vols. 2*, D. Halliday, R. Resnik and K. S. Krane