Scanning Electron Microscopy

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Abstract

The report presents the quantitative and qualitative study of motion of electron beam in a magnetic field. The specific charge of an electron was measured by means of cathode ray tube called teltron tube with present of homogeneous magnetic field due to Helmholtz coil. It was determined to be $(1.66 \pm 0.01) \cdot 10^{11} As/kg$. In second part, Scanning Electron Microscopy (SEM) was operated to record magnified images of different specimen using the electron beam.

1 Introduction and Theory

1.1 Determination of the specific charge of electron

The kinetic energy of the accelerated electrons due to the potential difference U is

$$E_{kin} = \frac{m_e}{2} \cdot v^2 = e \cdot U \tag{1}$$

where e is the electron charge, m_e is the electron mass, and v is the velocity of the electron. The Lorentz force acting on electron moving on homogeneous magnetic field $\vec{B}$ is

$$\vec{F} = e \cdot \vec{v} \times \vec{B}$$

From right hand rule, the force acting on the moving electron is perpendicular to the motion, causing electron to follow a circular path. Thus, the centrifugal force balances the Lorentz force

$$m_e \frac{v^2}{r} = e \cdot v \cdot B \tag{2}$$

where r is the radius of electron orbit. From equations (1) and (2), the specific charge of the electron is given as

$$\frac{e}{m_e} = \frac{2U}{(B \cdot r)^2} \tag{3}$$

The magnetic field due to Helmholtz coil is

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \cdot \mu_0 \cdot n \cdot \frac{I}{R} \tag{4}$$

where I is the current, μ_0 is the vacuum permeability, $n = 154$ is the number of turns of the Helmholtz coil, and $R = (0.2 \pm 0.005)\ m$ is the radius of the Helmholtz coil.

1.2 Physical principle of the Scanning Electron Microscopy

A Scanning Electron Microscopy (SEM) uses a focused beam of electrons to create a magnified image of a sample. The electron beam is scanned in a regular pattern across the surface of the sample and the electrons that are emitted out of the sample are captured and used to create the image.

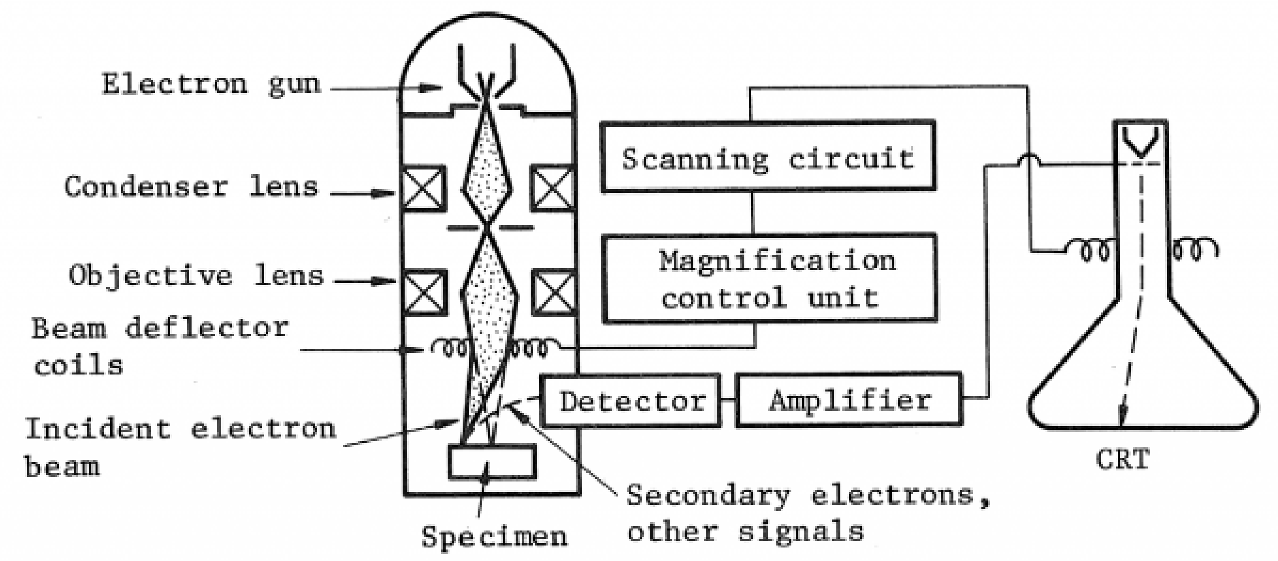


Figure 1: Block diagram showing the working principle of Scanning Electron Microscopes. [3]

The electron beam is produced through Wehnelt cylinder. Inside Wehnelt cylinder a tungsten wire is heated to produce electrons. The electrons are further accelerated through a potential difference to create electron beam, which are then focused to the sample using magnetic lenses in vacuum set up by rotary and diffusion pump. The rotary pump yields course vacuum, while diffusion pump uses heated diffusion pump oil, which sucks out the gas molecules and gets condensed due to water-cooled walls of the cylinder and releases the gases that are then extracted by the rotary pump. As the beam is scanned over the specimen, secondary and back-scattered electrons are produced and detected to form an image of the sample on the screen. In this experiment, samples are gold plated and the secondary electrons emitted due to excitation of atom by electron beams are detected to create a topographic map of the surface of sample.

2 Experimental and Procedure

2.1 Determination of specific charge of electron e/m_e

The experiment is set up as shown in the Fig. (2), with wiring of Helmholtz coils and teltron tube as shown in Figures (3) and (4) respectively.

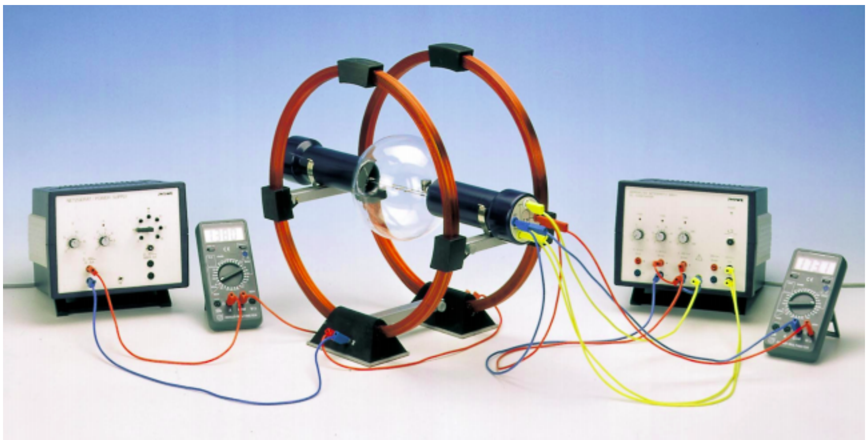


Figure 2: Experimental set-up for determination of the specific charge of the electron. [1]

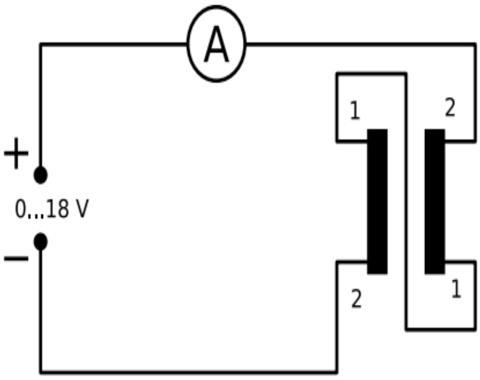


Figure 3: Wiring diagram for Helmholtz coils. [1]

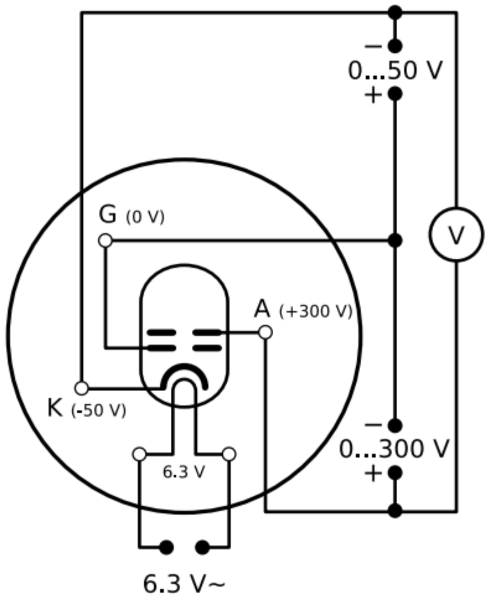


Figure 4: Wiring diagram for the beam tube. [1]

After the setup, when the current was passed through the Helmholtz coil, a curved luminous trajectory was observed. The set of currents and corresponding voltages across the teltron tube were measured for different radii of the electron ray, which were observed when the electron beam struck the luminous bars placed within the tube. The circular path of the electron beam were only considered for the measurements.

2.2 Investigation of samples with SEM

Figure 5: Scanning Electron Microscope (SEM) used for investigation.

The chamber with sample of textile fibres (Sample number 14) was used at the beginning part of the experiment. The water cooling system with rotary pump and diffusion pump were initiated. Once the vacuum was set up, indicated by EMISSION/VACUUM WORKING meter. The OPERATION was started with gradual turning of EMISSION knob. The image was obtained at certain emission rate. The position of sample was adjusted. Adjustments on magnification, X-Y orientation, contrast level, brightness level were carried out to get sharp magnified image of the sample. The sample was replace with other provided lab samples. For replacement, the OPERATION was stopped with EMISSION knob turned completely left. The chamber was opened and the new sample was replaced. The system was left for around 10 minutes to let the system reach vacuum, which was again indicated by EMISSION/VACUUM WORKING meter. The process was repeated again.

3 Result and Data Analysis

3.1 Determination of specific charge of electron

The Helmholtz coil had a radius of $R = (0.200 \pm 0.005)\ m$ and a total of $n = 154$ turns. The instrumental errors in voltage and current measurements were $\Delta V = 1\ V$ and $\Delta I = 0.01\ A$ respectively. Equation 3 was modified as

$$U = \frac{e}{m}\frac{(Br)^2}{2}, \tag{5}$$

where the magnetic field was calculated using equation 4. For different voltages and magnetic fields, the beam was fixed at the same radius and the specific charge of electron was obtained by fitting U as a function of $\frac{(Br)^2}{2}$ using `scipy.stats.linregress` in Python. The error in the specific charge is equal to the error in the slope of the best fit, which was also obtained from the fit. The graph of U as a function of $\frac{(Br)^2}{2}$ for different radii are provided in Fig. 6.

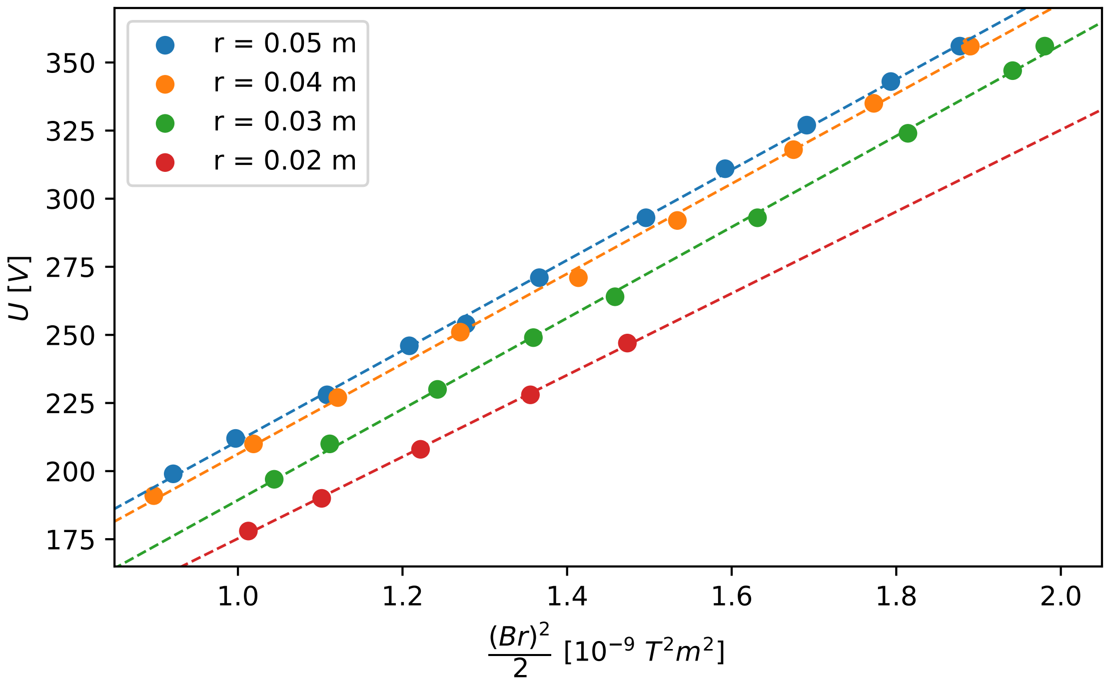


Figure 6: Determination of specific charge of electron for different radii.

radius $[cm]$	5	4	3	2
$\frac{e}{m}$ $[10^{11}\ As/kg]$	1.660 ± 0.014	1.654 ± 0.021	1.671 ± 0.018	1.500 ± 0.023

Table 1: Specific charge of electron for different radii.

The values of specific charge of electron along with the uncertainties are provided in Table 1. As the value of $\frac{e}{m}$ for the radius of 2 cm was significantly less than the theoretical value of $1.759 \cdot 10^{11}\ As/kg$, it was not considered in the calculation of mean value $\frac{e}{m}$. Hence the mean value for radii of 3, 4, and 5

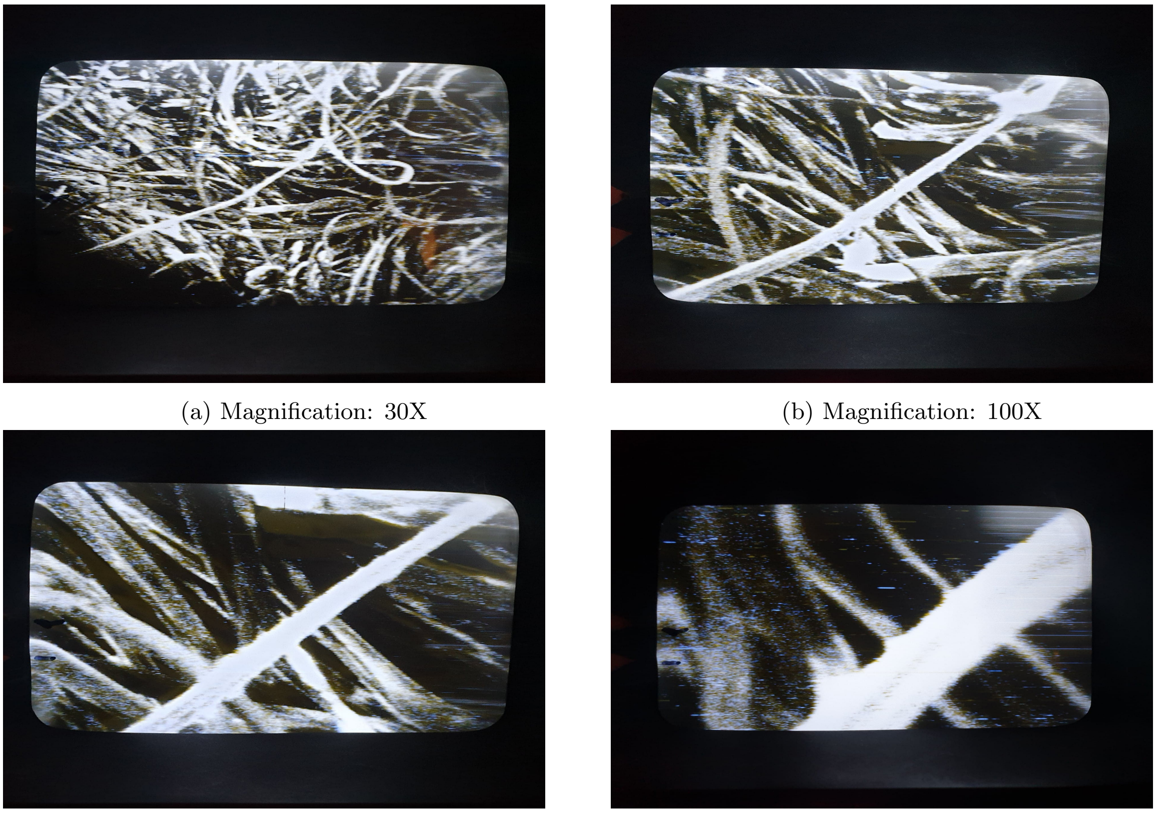
cm is

$$\frac{e}{m} = (1.66 \pm 0.01) \cdot 10^{11}\ As/kg,$$

where the error is taken to be the propagated error from each radius since the standard error of the mean was smaller.

3.2 Investigation of samples with SEM

A sample made up of textile plated with a thin layer of gold was taken and it was investigated under Scanning Electron Microscope for different magnification. The emission current, working distance, and stigmator along with brightness and contrast were adjusted to focus the sample and to obtain the image with high resolution. The different parts of sample were observed by moving it in X-Y direction. The samples were investigated for magnification of until 2000X. Clear images for magnification of 30, 100, 300, and 1000 were obtained as follows. For further magnification, the images could not be sufficiently resolved.



(a) Magnification: 30X

(b) Magnification: 100X

(c) Magnification: 300X

(d) Magnification: 1000X

Figure 7: Sample with various magnification seen through SEM.

4 Discussion and Conclusion

The specific charge of electron e/m was determined using the teltron tube and Helmholtz coil to be $(1.66 \pm 0.01) \cdot 10^{11}\ As/kg$, which is less than the theoretical value of $1.759 \cdot 10^{11}\ As/kg$ [1]. The main source of error is speculated to be the error in determining exactly when the beam is hitting the rod perpendicularly at the assumed radius. Our calculation further assumes the case of a single charge with only magnetic field, which might be different from the actual case with many electrons which exert electric and magnetic forces, which are both outward along the radius and hence the actual radius of the beam is higher, which would result in lower value of specific charge.

Scanning Electron Microscope (SEM) was used to investigate different samples during the later half of experiment. The working of the SEM was examined and several samples were investigated under SEM with varying magnification. The SEM used in this experiment was able to resolve clear images until 1000X magnification while for further magnification, the images were blurry. The higher magnifying power of Scanning Electron Microscope compared to Optical Microscope is due to the smaller wavelength of electrons compared to visible light due to which clear images could be resolved in SEM for much smaller region without the effect of diffraction and interference.

References

[1] Prof. Dr. Arnulf Materny, Dr. Vladislav Jovanov *Advanced Physics Lab I CO-486-A Fall 2020*.

[2] Scanning Electron Microscopy Working Principle, `https://myscope.training/index.html/SEMlevel_3_1`

[3] `https://richardandersson.net/?p=69`