Scanning Electron microscopy(SEM)

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Abstract

The main objective of this experiment was to investigate the basic principles of scanning electron microscope (SEM) and also to determine the specific charge of an electron e/m_e . The emission of electron beam by special cathode ray called teltron tube was the phenomenon used for calculation for specific charge of electron. Different samples were investigated using SEM and its different function were utilized for better and detailed image. The specific charge of the electron was found to be $1.792 \pm 0.11 \cdot 10^{11}(0)$As/kg.It lies within the theoretical value of $1.759 \cdot 10^{11}$As/kg.

1 Introduction and Theory

1.1 Determination of the specific charge of electron

If the electron of of charge e and mass m is accelerated with the potential difference of U, it will gain some kinetic energy:

$$E_{kin} = \frac{1}{2} \cdot m_0 \cdot v^2 = e \cdot \ U \tag{1}$$

where v is the velocity of the electron. When magnetic field of strenght B is applied, the lorentz force acting on the electron with velocity is:

$$\vec{F} = e \cdot \vec{v} \times \vec{B} \tag{2}$$

If the velocity v and magnetic field B are perpendicular to each other, the electron will begin to move in circular path due to the centrifugal force which is equal to Lorentz force and it is given by:

$$m_e \cdot \frac{v^2}{r} = e \cdot v \cdot B \tag{3}$$

where r is the radius of electron orbit.from Eqs.1 and 3, the specific charge of electron is given by:

$$\frac{e}{m_e} = \frac{2U}{(B \cdot r)^2} \tag{4}$$

The magnetic field due to the pair of Helmholtz coils can be written as:

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

where I is the current, μ_0 is the vacuum permeability and R is the radius of the Hemholz coils. In this way when electrons are accelerated in an electric field and enter a magnetic field at right angle to the direction of motion, the specific charge of the electron is determined from the acceleration voltage, the magnetic field strength and the radius of the electron orbit.

1.2 Scanning Electron Microscopy (SEM)

It is a type of electron microscope that produces magnified images of a sample by scanning the surface with a focused beam of electrons. Beam of high energy electrons are generated by electrons guns.These focused beam are further processed by magnetic lenses and are focused at the specimen surface.The major component of SEM are the electron gun, the vacuum system, the water chilling system, the column, the speicimen chamber, the detectors and the imaging system.

The electron gun is the top region of SEM that generates the beam of electron by heating the tungsten wire.It consists of three components, a hot wire [- ve] a Wehnelt (grid) cap [-ve], and an anode [+ ve].The wehnelt cylinder focuses the electron throgh the hole in the middle. The anode attrracts the electrons away from the filament .The hole in the anode allows a fraction of the electrons to continue down the column through the lenses to produce a smaller, more cohesive beam.

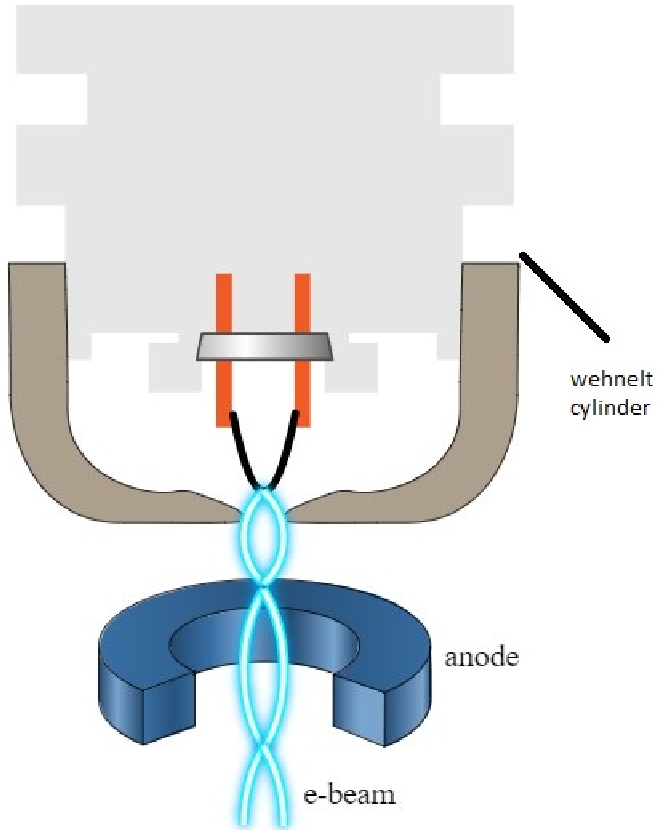

Figure 1: Electron gun

several electromagnetic lenses and apertures ared placed in specific order to reduce the diameter of the electronic beam.The system consists of a condenser lens, objective lens and scanning coils.a. In Electron Microscopes, "electromagnetic lenses" are used.

The condenser lens control the size of the beam and determines the number of electrons in the beam which hit the sample. Greater lens strength will leads to smaller resulting beam diameter and greater convergence angle. The main role of objective lens is to focus the beam onto the sample.Strength of objective lens changes the position of the point at which the electron are focused on the sample.

Two pairs of scan coils work as scanning system used in order to construct point by point and line by line image. It scan the beam along a line then displace the line position to the next scan so that a rectangular raster is generated both on the specimen and on the viewing screen.

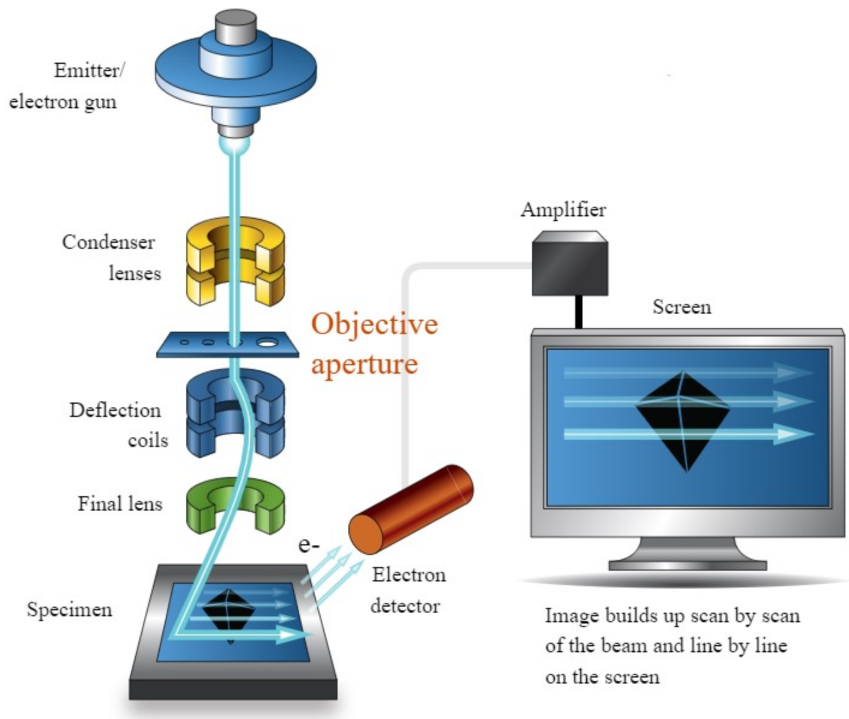

Figure 2: SEM layout and function

Once the beam reach the sample and interact with it, some electrons bounce back out of the sample known as backscattered electrons, other are absorbed by the atoms and displace the other electron known as secondary electrons. The latter one is ideal for recording topographical information.They are ejected only from close to the surface of the sample. When the electron beam hits a sample it interacts with the atoms in that sample.There are a number of outcomes. Some electrons bounce back out of the sample (backscattered electrons), others knock into atoms and displace electrons which in turn, come out of the sample (secondary electrons).

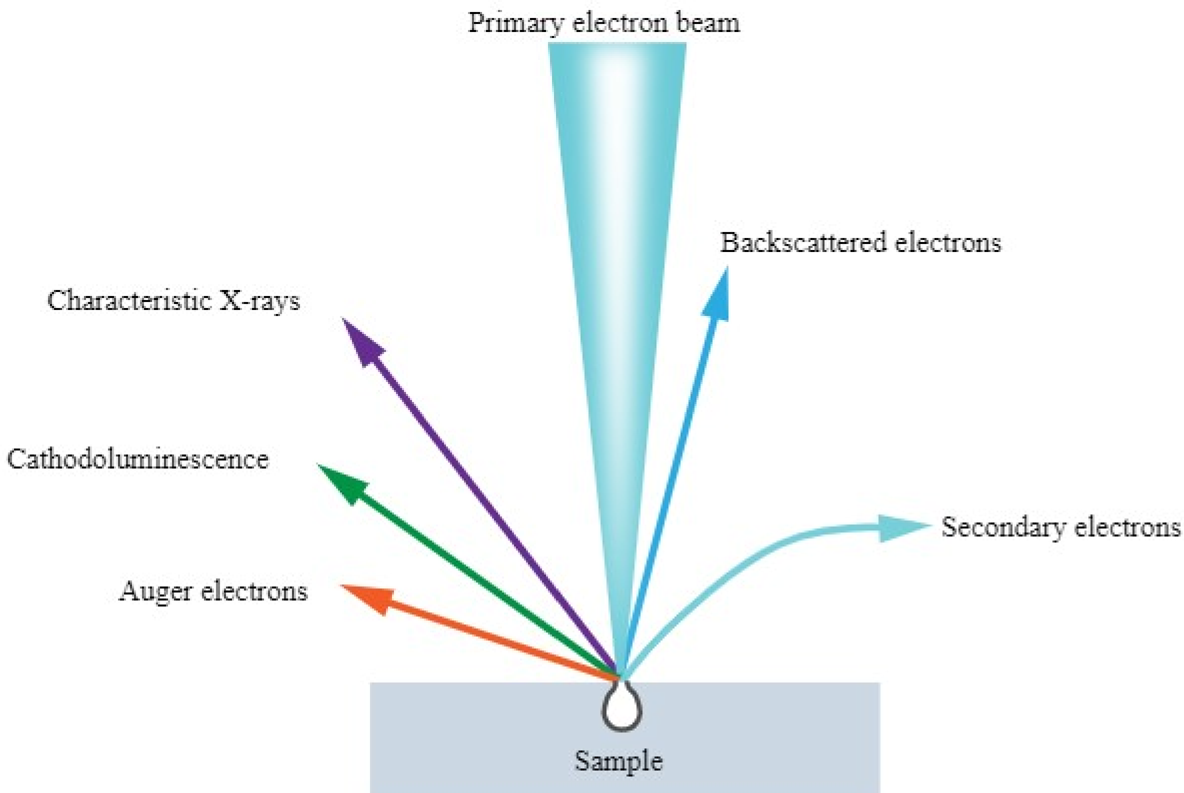

Figure 3: Interaction of electron with sample

Most SEM use at least 2 types of vacuum in order to get consistent electron beam.The first pump in the sequence is rotary pump) is used for rough evacuation and the next level of diffusion pump is used to achieves higher vacuums.

2 Experimental Set-up and Procedure

2.1 Determination of specific charge of electron

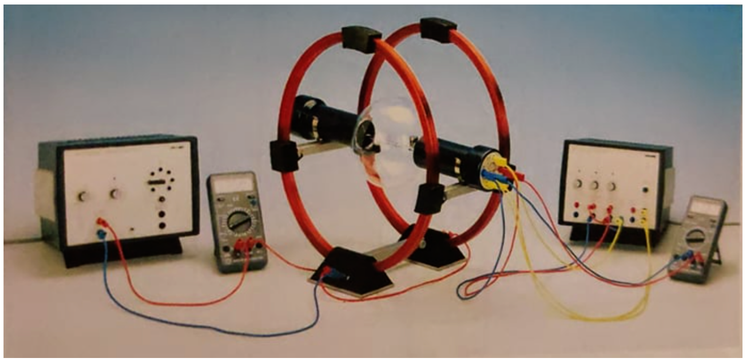

Figure 4: Experiment set-up

A filament was placed inside a glass sphere with inert gas and helmholtz coils were placed– parallel to the table–right outside the perimeters of the sphere. The filament was encased in a long tube with a potential difference between the polar sides. The Helmholtz coils were placed in a serial pattern in order to induce a unidirectional magnetic current. The cathode tube was connected to a voltage supply for creating the potential difference of 250 V. An ammeter was connected to the helmholtz coils and a voltmeter was connected to the tube. Current was supplied from both ends, to the helmholtz coils and the tube. The current and voltage were increased, and a spiral like structure formed, which was aligned by rotating the tube, and the current and voltage were increased to 343 V and 2.28 A for a ring in the 4th mark on the filament. The parameters were further changed and results were tabulated for further circles that were created.Voltage and Current are simultaneously changed to achieve this.

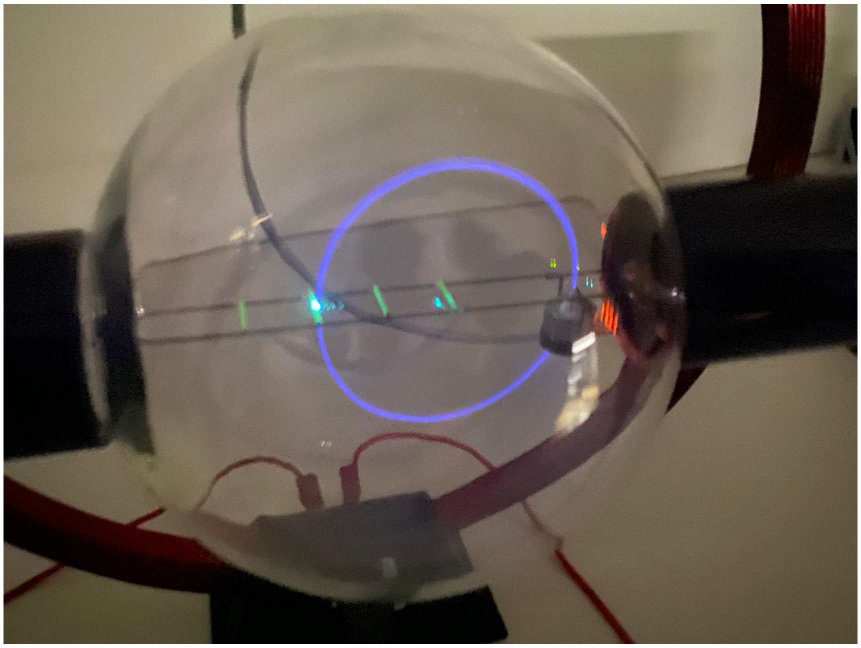

Figure 5: Observed Circular Pathaway of Electrons

Voltage v volts	Current I Ampere	Radius r meter	Magnetic field B tesla	$\frac{e}{m_e}$ As/kg
345	2.28	0.04	1.58×10^{-3}	$(1.7274 \pm 0.09) \times 10^{11}$
343	2.28	0.04	1.58×10^{-3}	$(1.717 \pm 0.09) \times 10^{11}$
189	2.22	0.03	1.54×10^{-3}	$(1.7745 \pm 0.12) \times 10^{11}$
196	2.28	0.03	1.58×10^{-3}	$(1.7446 \pm 0.11) \times 10^{11}$
187	1.58	0.04	1.11×10^{-3}	$(1.9497 \pm 0.12) \times 10^{11}$
268	1.58	0.05	1.09×10^{-3}	$(1.7883 \pm 0.09) \times 10^{11}$
105	2.45	0.02	1.69×10^{-3}	$(1.821 \pm 0.16) \times 10^{11}$
322	1.72	0.05	1.19×10^{-3}	$(1.8131 \pm 0.09) \times 10^{11}$

Figure 6: Experiment results

The value of B is calculated through:

$$B = (\frac{4}{5})^2 \cdot \mu_0 \cdot n\frac{I}{R} \tag{6}$$

The value of e/v is calculated through:

$$\frac{e}{m_e} = \frac{2U}{(B \cdot r)^2} \tag{7}$$

2.2 Scanning Electron Microscope

Figure 7: Scanning Electron Microscope

A sample was placed in the chamber inside the chamber, the x,y position was initialised, the chamber was shut down, and RP, DP(in this order) motors were used to create a vacuum.After the indication from the VL,the operation was started and the display meter was switched to emissions mode.(after checking with the working distance meter, which is needed for thick samples)The image was switched to waveform mode and the character of the waveform in the screen was used to tune the image's properties–brightness and contrast, coarseness and focus, spot focus, and emission current.The screen was switched to video mode and a sharp live image of the sample i.e a shrapnel from a coin was observed. X,y positions and the magnification of the image were altered to study the sample more carefully.The filament got damaged from the usage and had to be replaced. The chambers were shut down and the vacuum was turned off in order to extract the damaged filament. It was removed by unscrewing the upper part of the tubular part of the device, within which it was screwed inside an even smaller holder.The damage to the filament was documented with the usage of an ohmmeter. The operation was closed, the chamber was shut close and vacuums were turned off.(in the opposite order of how they were started: DP,RP) The system was allowed to cool down, then the water coolers were turned off.

Figure 8: Experiment results

3 Error Analysis

The average percentage error of all the data in the table was used to tabulate the error of the experiment. The error for an individual data was formulated by using the error margins of the different input values.

4 Discussion and Conclusion

The main objective of this experiment was to investigate the basic principle of scanning electron microscope (SEM) and to determine the specific charge of electron e/m_0 After conducting the experiment, the specific charge e/m_0 was determined to be $1.792 \pm 0.11 \cdot 10^{11}$As/kg. The experimental value lies within the literature value of $1.759 \cdot 10^{11}$As/kg. After observing the experiment, it was noted that electron imagery is sensitive and prone to more errors while the output is always accurate. The filaments conductivity caused a non-circular pathway to form for some circles in the initial part of the experiment. The electron microscope didn't give optimum output due to operating condition and the usage of used filament lamps was interfering with the results of the experiment.

5 References

- Advance physics Lab Manual C0-486 fall 2020 (Prof.Dr.Arnulf Materny and Dr. Vladislav Jovanov).
- Error analysis booklet for physics teaching lab at Jacobs university
- University Physics by Young and Freedman

- https://myscope.training/index.html/SEMlevel$_{23}$