Introduction

The Specific Charge of Electron Apparatus is used in conjunction with the Electron Tube to measure the ratio of electron charge $e$ to electron mass $m$. An electron stream is accelerated through a measured potential difference. The stream is projected through, and perpendicular to, a magnetic field of sufficient strength to cause it to bend in a circular path. The value of $e/m$ can be computed from the relationships that exist among the acceleration potential, the strength of the magnetic field, and the diameter of the circular path that the electron beam describes.

It is suggested that the Specific Charge of Electron Apparatus be used with the Discharge Tube Power Supply (31384-1). The Discharge Tube Power Supply provides all voltages necessary to operate the Electron Beam Tube. If you don’t have the 31384-1 Discharge Tube Power Supply, the following supplementary equipment is needed: an AC ammeter capable of measuring up to 1 amp AC; an adjustable AC power source capable of providing up to 1 amp AC at 6.3 VAC; three adjustable DC power sources — one capable of 0-80 VDC at 10mA, one capable of 0-200 VDC at 10mA, and one capable of 0-20 VDC at 5A; a DC ammeter capable of measuring up to 5A; and a DC voltmeter capable of measuring up to 200V.

Theory

The discovery of the electron as a discrete particle of electricity is generally credited to the British physicist Sir J.J. Thomson (1856-1940). His extensive studies of cathode rays culminated in the quantitative observations of the deflection of these rays in magnetic and electric fields. These researches led to methods for the measurement of the ratio of charge to mass $e/m$ for the electron.

Robert A. Millikan (1868-1953) was able to measure the charge of the electron ($1.60206 \times 10^{-19}$ coulomb) in his famous oil-drop experiments. The currently accepted value for $e/m$ is $1.75890 \times 10^{-11}$ coulombs/kg, and thus the mass of the electron could accurately be determined.

From the definition of the magnetic induction $B$ in a magnetic field, the force $F$ acting upon a charge $e$ that is moving with velocity $v$ perpendicular to the direction of the field is given by

$$ F = Bev $$

Since the direction of this force is always perpendicular to the velocity vector, it follows that the force is a centripetal one. Such a force causes the electron to move in a circular path. Hence,

$$ \frac{mv^2}{r} = Bev $$

where $r$ is the radius of the circular path of the electron.
The kinetic energy acquired by an electron that falls through a potential difference $V$ is given by

$$eV = \frac{m v^2}{2}$$

From equations (2) and (3)

$$\frac{e}{m} = \frac{2V}{(Br)^2}$$

The apparatus used in this experiment makes it possible to measure the values of $V$, $B$, and $r$ and therefore to determine the ratio $e/m$.

The magnetic field that bends the beam is produced by a current in two Helmholtz coils. These coils are mounted vertically and, therefore, produce a field in the horizontal direction. When the distance between the coils is equal to the radius of either coil, a nearly uniform field is produced at the midway point.

This occurs because the field contributed by each coil is diminishing with a constant rate over a short distance. The diminution of the field of one coil is compensated for by the equal increase in the field produced by the other coil.

The electron tube is held in a socket mounted between the coils, and on their common axis. The currents in the coils must be in such a direction that the fields of the coils are in the same direction along their common axis.

The magnitude of the flux density $B$ at the central point is given by

$$B = \frac{8\mu_0 NI}{\sqrt{125R}}$$

Where $N$ is the number of turns per coil, $I$ the current in the coils, $R$ the coil radius, and $\mu_0$ the permeability of free space ($4\pi \times 10^{-7}$ weber/amp-m). The flux density is given in webers/meter$^2$ when $I$ is in amperes and $R$ is in meters.

By combining equations (4) and (5) an expression for $e/m$ can be obtained that includes only constants for a given set of coils and the measurable quantities $V$, $I$, and $r$. When the specified mks units are used, $e/m$ is expressed in coulombs/kilogram.

**Procedure**

The apparatus consists of two major parts: a specially designed CENCO three-element electron tube and a pair of Helmholtz coils. Within the electron tube an "electron gun" is mounted, with its center line coincident with the vertical axis of the tube.

The gun consists of an indirectly heated cathode, which supplies the electrons; a grid, charged to a positive potential with respect to the cathode, which serves to focus the electron beam; and a circular plate, which is held at a high positive potential and thus accelerates the electrons.

The electron stream is projected vertically through a small hole at the center of a disk, which is mounted horizontally on the upper end of the electron gun. Four circles, with centers coincident with the hole and of radii 0.50, 1.0, 1.5, and 2.0 cm, are marked on the upper face of the disk.

The bulb and disk are coated with a material that fluoresces when struck by electrons. The tube contains a trace of an inert gas that aids in focusing the electron beam as well as causing the beam, to make a visible trace.

The Helmholtz coils of the CENCO apparatus are wound on non-magnetic aluminum rings, with 119 turns of wire on each coil. The rings have their rims milled away at one end to facilitate the measurement of the mean diameter. With a current of about 4 amps, a flux density of approximately $2 \times 10^4$ weber/m$^2$ is produced.

The strength of the magnetic field can be adjusted by changing the current in the coils. Variation of either the accelerating potential difference in the tube or the strength of the magnetic field causes the radius of the circle described by the electron beam to vary.

If the beam is made to describe a semicircle above the disk and, on returning to the disk, strike one of the four circles marked on its face, the diameter of the beam's semicircle is equal to the radius of the circle on the disk.

The electron-tube filament current should be operated at 5.0-7.0 volts AC.

**Note:** The rated value of the tube filament is 6.3 volts and 0.6 amps. The life of the expensive tube is limited. To ensure maximum life, the filament voltage should always be kept at the lowest value that produces a well-focused, visible beam. A thermal overload switch is designed into the Helmholtz coil base to protect the tube filament. If the overload switch opens during operation, check the electrical circuit to determine the source of the problem and reset the overload switch by pushing the button in. A plate potential of 80-200 volts gives the best operating range.
It is also very important that the DC power source be well filtered to minimize ripple; otherwise, the beam cannot be finely focused.

The cathode "gun" is located about 0.254cm below the anode plate opening. This causes the center of curvature of the emerging beam to lie just below the anode plate.

When conditions are adjusted so that the beam strikes a circle on the anode disk, the true diameter of the beam circle is larger than the recorded value. This results in a recorded value of e/m that is larger than the actual value. To account for the displacement of the cathode below the anode plate, equation (4) becomes:

\[
\frac{e}{m} = \frac{2V}{B^2 r_0^2 + (0.254 \times 10^2)^2}
\]

If the plate or grid current is more than a few milliamperes, the filament voltage is higher than necessary. The grid potential should be positive, less than that of the plate, and adjusted to give the beam a sharp focus. The focusing of the electron beam is accomplished by varying the grid voltage and also by ionization of the gas in the tube.

The filament current and the plate potential should be kept as low as possible to still give a well-focused, visible beam. Voltage should be applied only when observations are being made, in order to prolong the tube life.

Precautions must be taken to see that no significant stray magnetic fields affect the apparatus. The effects of the earth's magnetic field are not large in comparison with the effect of the coils, but a correction can be made for this if desired. In addition to the usual instrumental errors, it is instructive to consider some other sources that may limit the precision of the results of this experiment.

Inability to judge accurately when the electron beam is exactly on the circle is one source of error. Since the opening in the plate through which the electrons emerge is of a finite diameter, electrons will emerge at a variety of angles from the vertical.

Though these angles are small (due to the small size of the aperture) the electrons emitted at the largest angle will require the most focusing and will therefore lose more of their kinetic energy in their semicircular transit through the tube. It is therefore best to measure the outermost edge of the beam as it strikes any of the concentric circles on the plate. Errors may be minimized by taking the average of a number of readings.

1. Explore the area around the Helmholtz coils to see that there is no serious interference from stray magnetic fields. This can be done with a compass or a gaussmeter.

2. Connect the apparatus as shown in Figure 1. Check that the anodes of the grid and plate are referenced to the cathode of filament. The electrical connections to the electron tube are shown in figure 2.

Caution! Be sure to have the instructor check the wiring before the power sources are energized to prevent damage to the tube and power supply.

3. Adjust the filament current to about 0.9 amps. The e/m base is designed such that 0.9 amperes supplied to the base yields 0.6 amps to the tube filament. After allowing the cathode to heat for about 1 minute, apply the plate potential and grid potential and notice the blue stream of electrons that rises from the hole in the center of the disk. Then reduce the filament current to the minimum level that still yields a visible beam. Adjust the plate potential to 80-200 volts and vary the grid potential to bring the beam into a sharp focus. The electron stream should have a diameter of about 2mm or less.

Figure 1. Arrangement of apparatus for measurement of e/m
4. Energize the circuit to the field coils and then increase the current until the beam bends into a complete semicircle. Adjust the plate voltage to vary the accelerating potential and change the field current until the beam falls on one of the marked circles. (The grid potential may need to be adjusted when the plate potential is changed in order to keep the beam in focus.) Record the plate potential, the field current, and the radius of the described circle. Measure the mean radius of the Helmholtz coils and record the number of turns per coil (119).

5. Repeat the observations by switching the field current polarity to obtain several sets of data for each of the circles on the disk. Depending on the anode plate voltage applied, it may be impossible to focus the beam on the innermost circle.

**Computation and Analysis**

Using the data recorded from the experiment and the working equation, calculate the values of $e/m$ obtained from the sets of observations. Record the percentage difference between the standard value of $e/m$ and the mean of the values calculated from the observations. Do there seem to be sources of systematic error? Try to identify some of the sources of error.
**Maintenance**

**Troubleshooting:** If you are having problems getting satisfactory results with the apparatus, here are some suggestions:

1. **If you cannot see any visible beam:**
   - Let the tube warm up for about 2 minutes with just the filament voltage of 6.3 VAC applied.
   - Check to make sure the filament is receiving ~ 0.9 amps AC current (you should see a yellow glow under the plate).
   - Ensure that both grid and plate voltages are referenced to the filament (cathode side), and that voltages in the range of 0-80 VDC for the grid and 80-200 VDC for the plate are applied.

If you have checked all these points and you still cannot see any visible beam, call Central Scientific Company and ask for technical assistance.

2. **If a visible beam exists, but is spread out in the radial direction when bent over to the plate:**
   - Check that both the grid and plate potentials are referenced to the cathode side of the filament. Otherwise, a relatively small AC voltage from the filament will be superimposed on the DC accelerating voltage, causing the beam to spread in the radial direction.

3. **If the visible beam is too diffuse in the tangential direction:**
   - Adjust the grid voltage to generate the sharpest beam for the given plate voltage. Vary the plate voltage between about 80-200 VDC to achieve the sharpest beam possible. Apply a field current to bend the beam to the plate. Vary the grid voltage to get the sharpest beam. A beam diameter of 2mm or less should be achievable.

4. **If a beam “reflection” occurs off the top of the tube:**
   - The e/m tube glass envelope is treated internally to prevent static charge build-up on the glass. At lower anode plate voltages, a “reflection” of the beam may occur off the top of the tube. This effect does not prevent accurate data-taking, and can be reduced or eliminated by raising the anode voltage or by bending the beam with field current.

**Rejuvenation of Electron Tube:** After several hundred hours of operation, the beam produced by the electron tube may deteriorate when normal operating voltages are applied. In some instances the tube can be rejuvenated with a suitable “flashing” procedure.

During this procedure no grid or anode voltage should be applied. Apply 6V to the filament (heater) for 1 minute. Then apply 12V for 60 seconds. Then drop the filament voltage to 10V and hold it for 15 minutes. Allow the tube to cool for at least one hour before using it again for experimental purposes. Only do this after several hundred hours or when the beam deteriorates, as there are a limited number of reactivations.

**General:** If the apparatus is operated according to instructions and given reasonable care, it should provide years of satisfactory service. The only maintenance required is the periodic changing of the electron tube. The expected life of the tube can be considerably lengthened if the operating precautions described in these instructions are followed.

If servicing other than tube replacement is required, contact Central Scientific Company's Customer Service Department. So we can serve you better, please do not return any equipment until we have sent you a written authorization.

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**Replacement Parts and Accessories**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cat. No.</th>
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<td>Repl. Electron Beam Tube for 71267</td>
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<tr>
<td>Caliper Jaws to fit Meter Sticks</td>
<td>72695</td>
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<tr>
<td>Digital Multimeter</td>
<td>31884</td>
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<tr>
<td>Digital Discharge Tube Power Supply</td>
<td>31384-1</td>
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<td>Economy 0-5 A DC Ammeter</td>
<td>82412-07</td>
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<td>Economy 0-1A AC Ammeter</td>
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<td>Plain 0.5m Meter Stick</td>
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