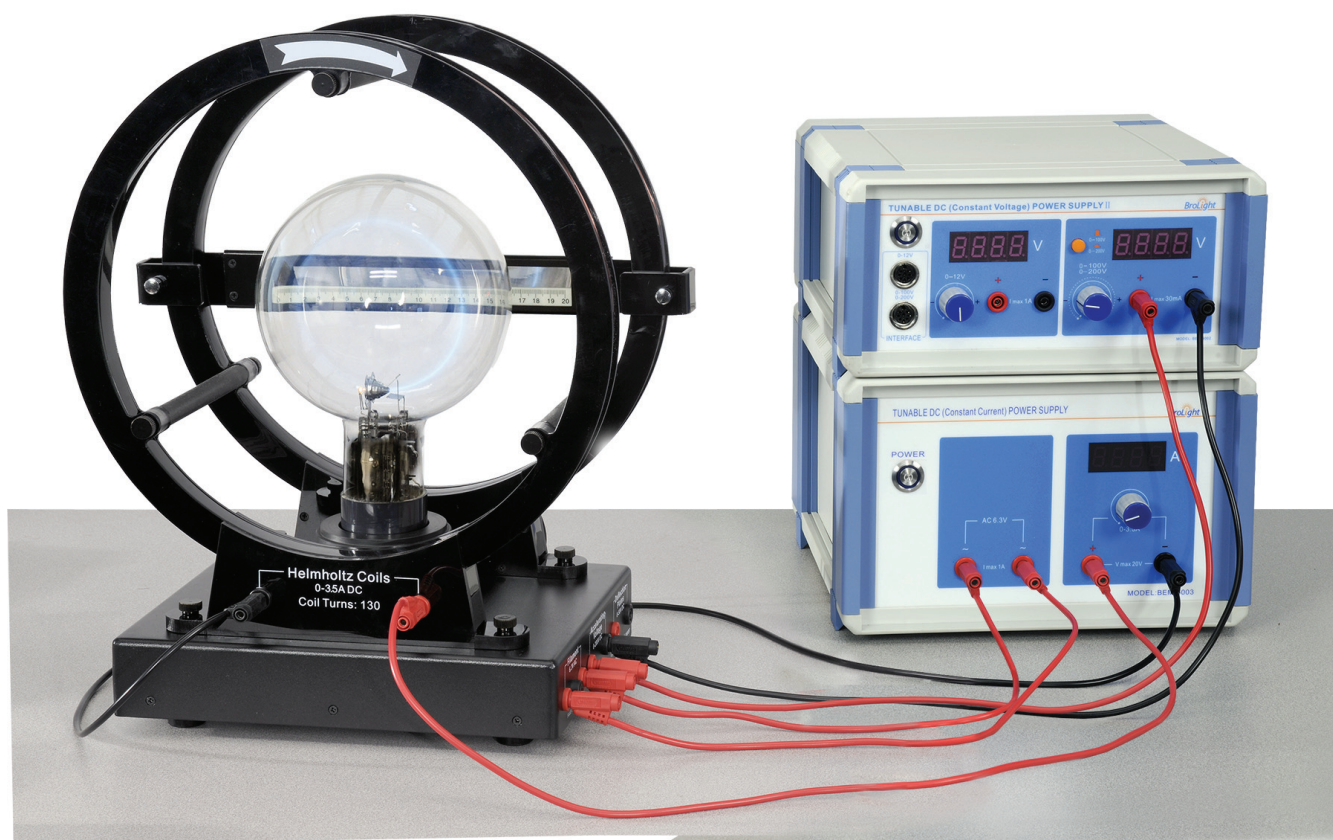


Electron Charge-to-Mass Ratio

Model SE-9629



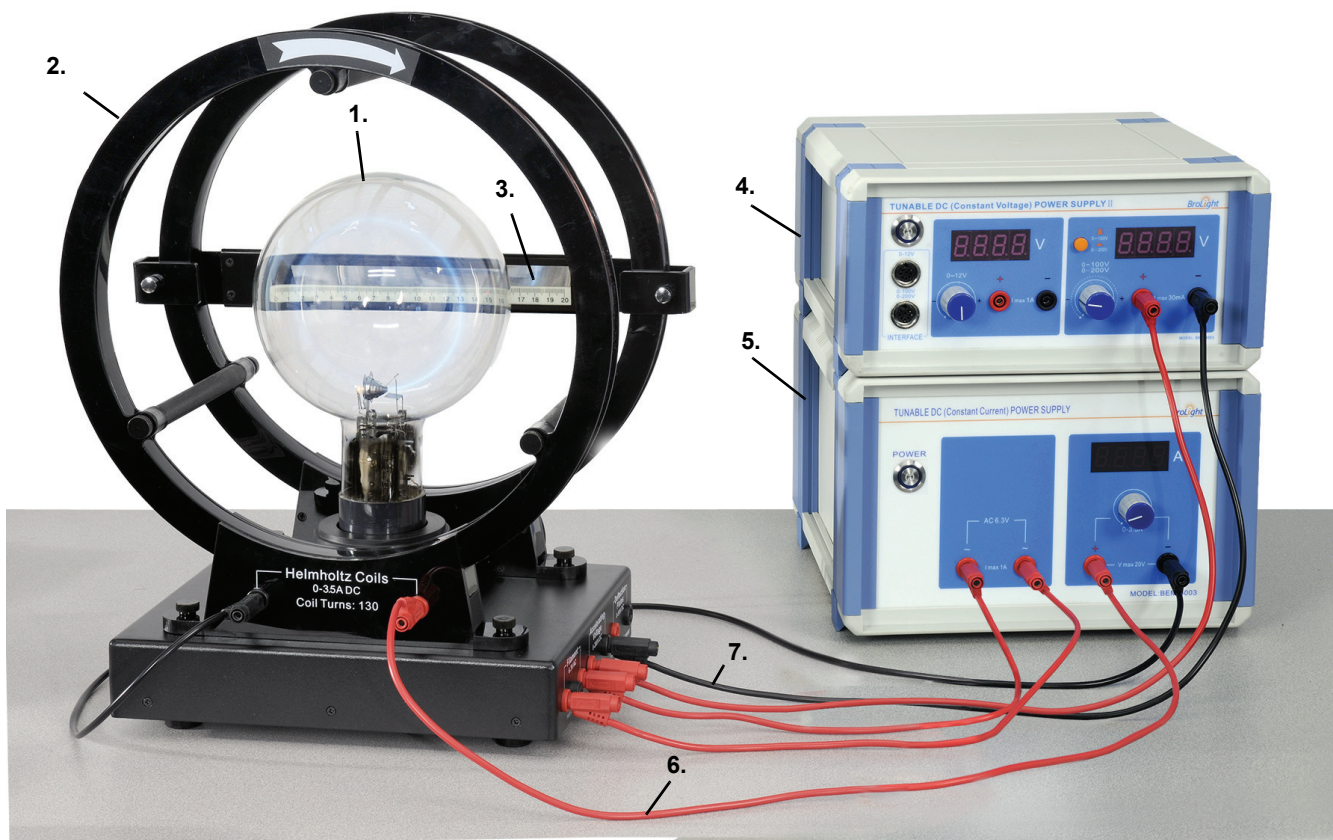
Brolight Technology Co., Ltd

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Electron Charge-to-Mass Ratio

SE-9629



Equipment List

Included Equipment	Model	Quantity
Electron Charge-to-Mass Ratio	SE-9629	1
1.e/m Tube	SE-9651	1
2.Helmholtz Coils and Base	SE-9626	2
3.Mirrored Scale		1
4. Tunable DC (Constant Voltage) Power Supply II, 12 V / 100 V / 200 V	SE-9644	1
5. Tunable DC (Constant Current) Power Supply, 3.5 A / 6.3 V	SE-9622	1
6. Connecting cable, 850 mm, red	EM-9740	Set of 5
7. Connecting cable, 850 mm, black	EM-9745	Set of 5
Connecting Cable for PASCO 850 Universal Interface (not shown)	UI-5218	2
Power Cord (not shown)		2

Recommended Equipment for Alternate Data Recording Method	Model	Quantity
850 Universal Interface	UI-5000	1
PASCO Capstone Software	UI-5400	1
High Current Sensor	PS-2193	1

Limited Warranty and Limitation of Liability

This Brolight product is free from defects in material and workmanship for one year from the date of purchase. This warranty does not cover fuses, or damage from accident, neglect, misuse, alteration, contamination, or abnormal conditions of operation or handling. Resellers are not authorized to extend any other warranty on Brolight's behalf. To obtain service during the warranty period, return the unit to point of purchase with a description of the problem. THIS WARRANTY IS YOUR ONLY REMEDY. NO OTHER WARRANTIES, SUCH AS FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSED OR IMPLIED. BROLIGHT IS NOT LIABLE FOR ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES OR LOSSES, ARISING FROM ANY CAUSE OR THEORY. Since some states or countries do not allow the exclusion or limitation of an implied warranty or of incidental or consequential damages, this limitation of liability may not apply to you.

Safety Information

















WARNING: To avoid possible electric shock or personal injury, follow these guidelines.

- Clean the equipment only with a soft, dry cloth.
- Before use, verify that the apparatus is not damaged.
- Do not defeat the power cord safety ground feature.
- Plug into a grounded (earthed) outlet.
- Do not use the product in any manner that is not specified by the manufacturer.
- Do not install substitute parts or perform any unauthorized modification to the product.
- Line and Current Protection Fuses: For continued protection against fire, replace the line fuse and the current-protection fuse only with fuses of the specified type and rating.
- Main Power and Test Input Disconnect: Unplug instrument from wall outlet, remove power cord, and remove all probes from all terminals before servicing. Only qualified, service-trained personnel should remove the cover from the instrument.
- Do not use the equipment if it is damaged. Before you use the equipment, inspect the case. Pay particular attention to the insulation surrounding the connectors.
- Do not use the equipment if it operates abnormally. Protection may be impaired. When in doubt, have the equipment serviced.
- Do not operate the equipment where explosive gas, vapor, or dust is present. Don't use it under wet conditions.
- Do not apply more than the rated voltage, as marked on the apparatus, between terminals or between any terminal and earth ground.
- When servicing the equipment, use only specified replacement parts.

- Use caution when working with voltages above 30 V AC rms, 42 V peak, or 60 V DC. Such voltages pose a shock hazard.
- To avoid electric shock, do not touch any bare conductor with hand or skin.
- Adhere to local and national safety codes. Individual protective equipment must be used to prevent shock and arc blast injury where hazardous live conductors are exposed.
- Special note: If a dangerous voltage is applied to an input terminal, then the same voltage may occur at all other terminals.

Electrical Symbols

	Alternating Current
	Direct Current
	Caution, risk of danger, refer to the operating manual before use.
	Caution, possibility of electric shock
	Earth (ground) Terminal
	Protective Conductor Terminal
	Chassis Ground
	Conforms to European Union directives.
	WEEE, waste electric and electronic equipment
	Fuse
	On (Power)
	Off (Power)
	In position of a bi-stable push control
	Out position of a bi-stable push control

Introduction

The e/m apparatus (Electron Charge-to-Mass Ratio) provides a simple method for measuring e/m, the charge to mass ratio of the electron. The method is similar to that used by J.J. Thomson in 1897. A beam of electrons is accelerated through a known potential, so the velocity of the electrons is known. A pair of Helmholtz coils produces a uniform and measurable magnetic field at right angles to the electron beam. This magnetic field deflects the electron beam in a circular path.

The e/m apparatus also has deflection plates that can be used to demonstrate the effect of an electric field on the electron beam. This can be used as a confirmation of the negative charge of the electron, and also to demonstrate how an oscilloscope works.

A unique feature of the e/m tube is that the socket rotates, allowing the electron beam to be oriented at any angle (from ± 30 degrees) with respect to the magnetic field from the Helmholtz coils. You can therefore rotate the tube and examine the vector nature of the magnetic forces on moving charged particles.

Background Information

In 1887, J. J. Thomson showed that the mysterious cathode rays were actually negatively charged particles — he had discovered the electron. In the same year he measured the specific charge (e/m) of the cathode ray particles, providing the first measurement of one of the fundamental constants of the universe. The specific charge is defined as the charge per unit mass of the particle. Thomson discovered that the value of e/m was independent of the gas used and also independent of the nature of the electrodes.

Principle of the Experiment

In the e/m tube, the electrons move along a circular path in a uniform magnetic field. The tube contains helium gas at a precisely set pressure. The gas atoms are ionized along the length of the circular path due to collisions with electrons. As a result, they are excited and emit light, thereby indirectly making the circular path of the electrons visible. The radius of the path can then be measured directly with a ruler. Since the accelerating voltage U of the electron gun and the magnetic field B are known, it is possible to calculate the specific charge of an electron e/m from the radius of the circular path r .

An electron moving with velocity (\mathbf{v}) in a direction perpendicular to a uniform magnetic field (\mathbf{B}) experiences a Lorentz force (\mathbf{F}) in a direction perpendicular to both the velocity and the magnetic field, $\mathbf{F} = e\mathbf{v}\cdot\mathbf{B}$

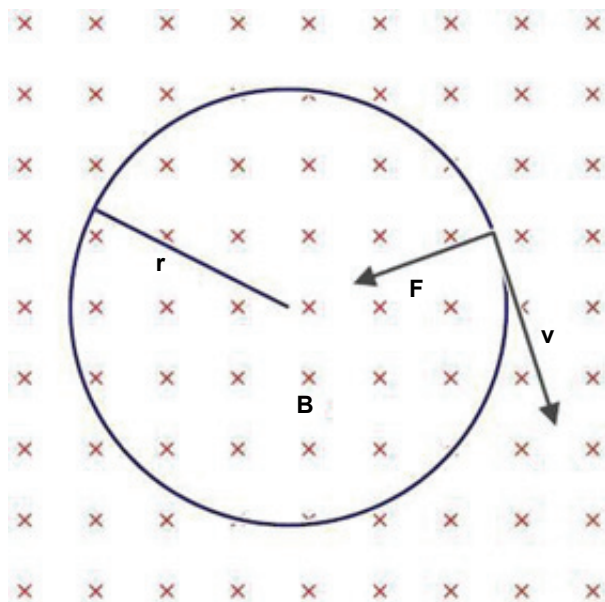
where e is the charge on an electron.

This gives rise to a centripetal force on the electron in a circular path with radius (r), where $\mathbf{F} = m\mathbf{v}^2/r$, and m is the mass of an electron.

Thus $e\mathbf{B}\cdot\mathbf{r} = m\mathbf{v}$. The velocity (\mathbf{v}) depends on the accelerating voltage (U) of the electron gun: $\mathbf{v}^2 = 2\mathbf{U}\cdot e/m$. Therefore, the specific charge of an electron is given by:

$$\frac{e}{m} = \frac{2U}{B^2 r^2}$$

If we measure the radius of the circular orbit in each case for different accelerating voltages U and different magnetic fields B , then, according to equation, the measured values can be plotted in a graph of $B^2 r^2$ against $2U$ as a straight line through the origin with slope e/m .



Installation and Maintenance

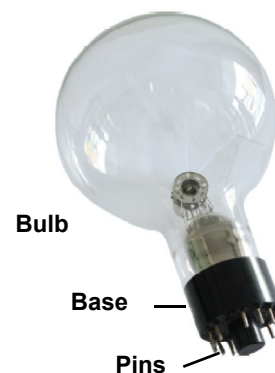


WARNING:

Avoid touching the glass bulb of the e/m Tube. Touch only the plastic part below the glass bulb.

Install the e/m Tube on the Platform

- The e/m tube has a number of pins in its base. The platform has a socket on top that has holes that match the pins on the e/m tube. The number and arrangement of pins and holes means that the e/m tube can fit into the socket in only one way.
- Holding the e/m tube by its base, align the pins on the tube with the holes in the socket and push the e/m tube into the socket. Make sure that the tube is firmly in place.
- Note: The tube is a thin-walled, evacuated glass bulb. Handle with care.
- Do not expose the tube to any mechanical stress or strain.



e/m Tube Specifications	
Filling gas	helium
Pressure:	10^{-1} pascals (Pa)
Filament Voltage	6.3 V AC
Accelerating Voltage	≤ 250 V DC
Deflecting Voltage	≤ 150 V DC

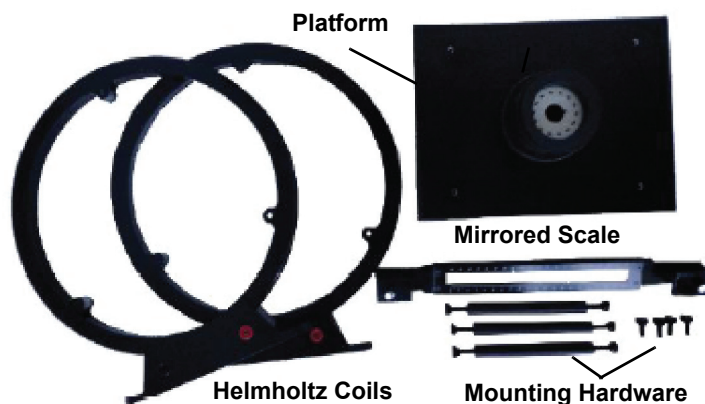
Note: Replace the e/m tube with the same type: Model SE-9651 e/m Tube for SE-9629.

Install the Helmholtz Coils on the Platform

- Use the screws from the mounting hardware to fasten the two Helmholtz coils onto the platform so that the terminals on the coils face toward the outside.
- Fasten the three support rods from the mounting hardware between the two Helmholtz coils.

Install the Mirrored Scale on a Helmholtz Coil

- Loosen *but do not remove* the screws at both ends of the Mirrored Scale.
- Mount the Mirrored Scale on one of the Helmholtz Coils so that the mirror reflects toward the e/m tube coil.
- Tighten the screws on the ends of the Mirrored Scale to hold it in place on the coil.



Connect Cables and Cords

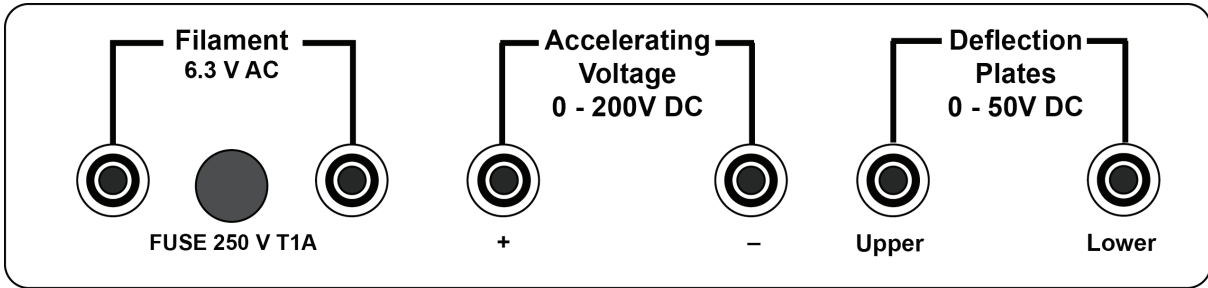
110 - 120 V or 220 - 240 V

Please make sure that you select the right setting according to your AC voltage level.

The product is shipped with the setting on 230 V. Make sure to check the setting.



Note: Before connecting any cords or cables, be sure that all power switches on the Power Supplies are in the OFF position and all voltage controls are turned fully counterclockwise.



1. On the Tunable DC (Constant Voltage) Power Supply II, connect the positive terminal of the **200 V DC** output to the positive terminal (anode) labeled “**Accelerating Voltage**” on the Platform (red sockets) and connect the negative terminal of the **200 V DC** output of the power supply to the negative terminal (cathode) on the platform (black sockets).
 2. On the Tunable DC (Constant Current) Power Supply, **3.5 A / 6.3 V**, connect both terminals of the **6.3 V AC** output to the terminals labeled “**Filament**” on the Platform (red sockets).
 3. Connect the Helmholtz Coils in series with the Tunable DC (Constant Current) Power Supply, **3.5 A / 6.3 V**. On the power supply, connect the positive terminal of the **3.5 A** output to the red terminal on the front Helmholtz Coil. Connect the black terminal of the front Helmholtz Coil to the black terminal of the back Helmholtz Coil. Finally, connect the red terminal of the back Helmholtz Coil to the negative terminal of the **3.5 A** output on the power supply.
- **Note:** Before connecting the power cords, please check that the setting for the input voltage range (110 – 120 V or 220 – 240 V) matches the local AC voltage. For the two power supplies, connect a power cord between the port on the back labeled “**AC POWER CORD**” and an appropriate electrical outlet.

DANGER:

High Voltage is applied to the e/m Tube. Avoid contact with any part of the body.

- Only use safety equipment leads (shrouded patch cords) for connections.
- Make sure that the power supplies are OFF before making the connections.
- Make sure that the power supplies are OFF before installing or replacing the e/m Tube.

Cables and Cords	Specification
Power Cord	Length: 1.5 m, 16 A / 250 V
Connecting Cable, Red (EM-9740)	Length: 0.85 m, 10 A / 300 V
Connecting Cable, Black (EM-9745)	Length: 0.85 m, 10 A / 300 V

Note: Replace the cables and power cords with the same type.

Fuse Replacement

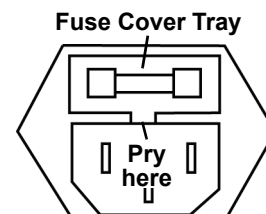
The fuse is inside a tray. Open the cover to remove the fuse.



WARNING

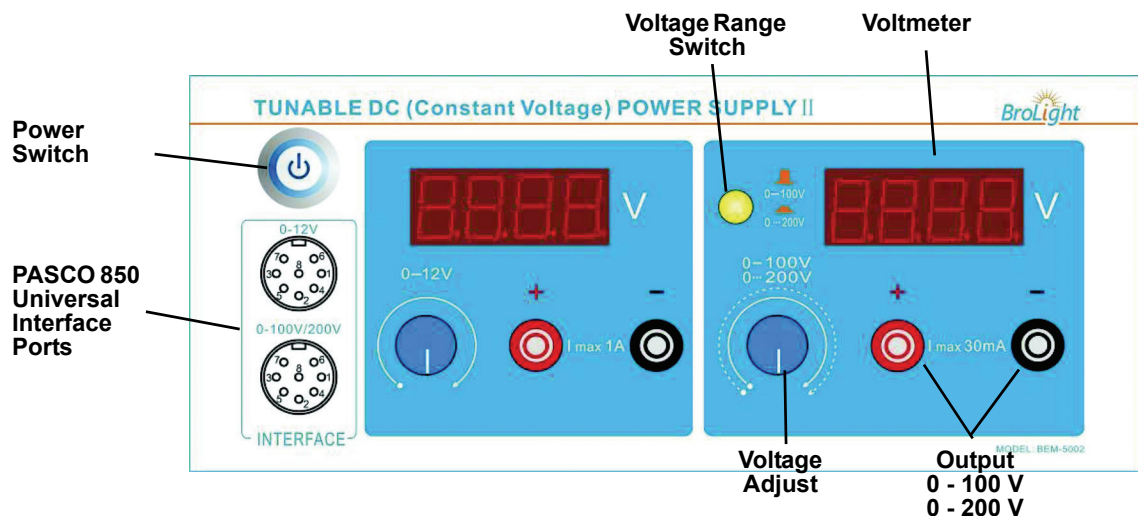
To reduce the risk of electric shock or damage to the instrument, turn the power switch OFF and disconnect the power cord before replacing a fuse.

- Disconnect the power cord from the instrument.
- Open the fuse cover and remove the fuse. (The fuse is inside a tray. Use a small screwdriver or other tool to pry the tray open.)
- Replace the fuse(s). Use the same type of fuse (250 V T2A).
- Reconnect the power cord and turn on the instrument.
- If the problem persists, contact PASCO Technical Support for service.



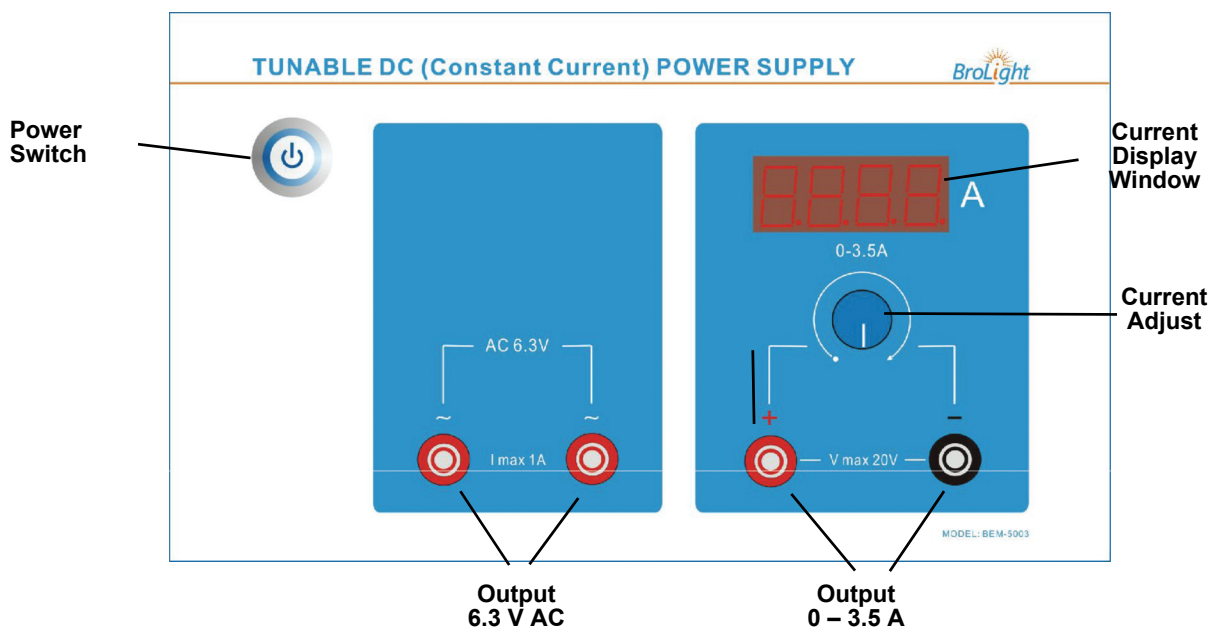
Note: Replace the burned fuses with new fuses of the same type. (One spare fuse is included inside the Fuse Cover Tray.)

Tunable DC (Constant Voltage) Power Supply II



- Voltmeter: Displays the accelerating voltage across the e/m tube.
- Voltage Range Switch: Sets the voltage range as 0 – 100 V (□) or 0 – 200 V (□) for the Accelerating Voltage.
- Power Switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the voltage across the e/m tube for both voltage ranges.
- Output: Output power.
- Data Interface: Connect to the analog channels of the PASCO 850 Universal Interface using the included DIN plug - to - DIN Plug Connecting Cables (UI-5218).

Tunable DC (Constant Current) Power Supply, 3.5 A / 6.3 VI




- Power Switch: Turns the power to the instrument ON or OFF.

- Current Adjust: Sets the current through the Helmholtz coils.
- Output: Output power.
- Current Display Window: Displays the current through the Helmholtz coils.

Experiment Procedure

Adjust Operating Voltages and Current

Note: Before switching on the power, be sure that all voltage and current controls are turned fully counterclockwise.

- To get a clearer view of the electron beam, conduct the experiment in a darkened room.
1. Connect all the cables and cords as described previously.
 2. On the Tunable DC (Constant Voltage) Power Supply II, set the Voltage Range Switch to 0 – 200 V (□).
 3. For both power supplies, push in the Power Switch to the ON position.
 4. On the Tunable DC (Constant Voltage) Power Supply II, set the Accelerating Voltage (anode) to 120 V DC.
 5. Wait several minutes for the filament to heat up*. When it does, you will see the electron beam emerge from the electron “gun”. The electron beam is initially horizontal and is visible as a dim, bluish ray.
 6. On Power Supply II, adjust the voltage output to the Accelerating Voltage to optimize the focus and brightness of the electron beam.
 7. On the Tunable DC (Constant Current) Power Supply, **3.5 A / 6.3 V**, increase the current to the Helmholtz coils. Watch the electron beam and check that the electron beam curves upward.
- 

***NOTE:** It is very important to allow the e/m tube and apparatus to warm up for several minutes prior to making any measurements.
- If the electron beam is not deflected at all, reverse the polarity of one of the Helmholtz coils so that current passes through both coils in the same direction.
 - If the electron beam does not curve upward, swap the connections on the **3.5 A** output terminals on the Power Supply.
8. Continue increasing the current until the electron beam forms a closed circle.
 - If the electron beam does not form a closed circle, slightly rotate the Platform to the right or left to align the magnetic field generated by the Helmholtz coils with the magnetic field of Earth.

Record Data: Standalone

9. Carefully read the Current Display to find the current (I_H) through the Helmholtz coils and record the value in Table 1. Carefully read the Voltmeter and record the Acceleration Voltage (U) in Table 1.
10. Carefully measure the radius, r , of the electron beam. Look through the e/m tube at the Mirrored Scale. To avoid parallax errors, move your head to align the electron beam in the tube with the reflection of the beam as you see it in the Mirrored Scale. Measure the radius of the electron beam as you see it on both sides of the Mirrored Scale, and then average the results. Record the average radius in Table 1.
11. Record other series of measured values for different Accelerating Voltages (U) and current (I_H) through the Helmholtz coils. Record your measurements in Table 1.

Record Data: Alternate Method

- Alternatively, the PASCO 850 Universal Interface (UI-5000) can be used with the High Current Sensor (PS-2193) and the PASCO Capstone Software (UI-5400) to measure and record the voltage and current.

Table 1.1: Data

Trial	U (V)	I_H (A)	r (mm)	e/m (C/kg)	Percent Error
1					
2					
3					
4					
5					

Analysis of e/m Measurements

The magnetic field, \mathbf{B} , generated in a pair of Helmholtz coils is proportional to the current, \mathbf{I}_H , passing through a single coil. The constant of proportionality, k , can be determined from the coil radius, \mathbf{R} , and the number of turns, \mathbf{N} , on the coil.

$$\mathbf{B} = \frac{\left(\frac{4}{5}\right)^{\frac{3}{2}} \mu_0 \mathbf{N} \mathbf{I}_H}{\mathbf{R}}$$

With this expression for \mathbf{B} , the initial formula for e/m,

$$\frac{e}{m} = \frac{2U}{\mathbf{B}^2 \mathbf{r}^2}$$

becomes:

$$\frac{e}{m} = 2U \frac{\left(\frac{5}{4}\right)^3 \mathbf{R}^2}{(\mathbf{N} \mu_0 \mathbf{I}_H \mathbf{r})^2}$$

\mathbf{R} = 158 mm and \mathbf{N} = 130 turns per coil

\mathbf{U} = Acceleration Voltage

\mathbf{R} = Radius of the Helmholtz coils

\mathbf{N} = Number of turns on each coil

μ_0 = Permeability constant ($4\pi \times 10^{-7}$)

\mathbf{I}_H = Current through the Helmholtz coils

\mathbf{r} = Radius of the electron beam (closed circle)

- Accepted value of the charge-to-mass ratio, e/m, is 1.76×10^{11} C/kg

Deflections of Electrons in an Electric Field**IMPORTANT:**

Do not leave the electron beam on for long periods of time in this mode. The beam will eventually wear through the glass bulb of the e/m Tube.

You can use the deflection plates to demonstrate how the electron beam is deflected in an electric field.

1. Setup the equipment as described above for measuring e/m except do not supply current to the Helmholtz coils.
2. Apply 6.3 V AC to the “Filament” terminals and 120-200 V DC to the terminals of the “Accelerating Voltage”. Wait several minutes to warm up the cathode.
3. When the electron beam appears, connect a 0-100 V DC power supply to the terminals labeled “Deflection Plates (Upper and Lower)”. Slowly increase the voltage to the deflection plates from 0 V to approximately 100 V DC.

Note the deflection of the electron beam. Note the beam direction.

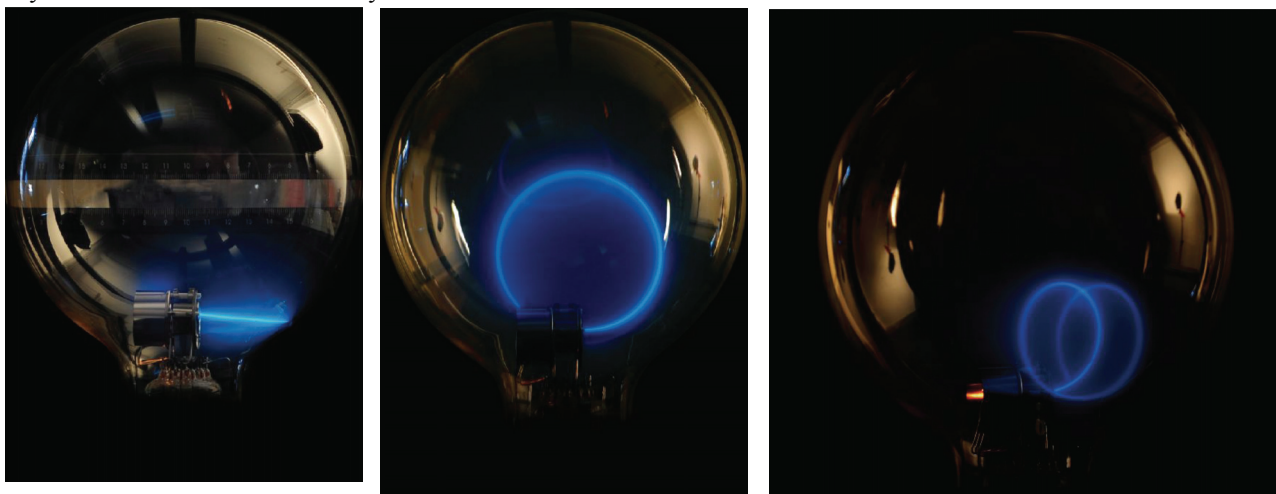
Demonstrations

1. Instead of using the Helmholtz coils to bend the electron beam, you can use a permanent magnet to show the effect of a magnetic field on the electron beam. Just provide the following power to the e/m apparatus:

Filament: 6.3 V AC

Accelerating Voltage: 120 - 200 V DC

- When the electron beam appears, use your permanent magnet to bend the beam.
2. The socket for the e/m tube is designed so that the tube can be rotated. The tube can therefore be oriented so it is at a certain angle, with respect to the magnetic field from the Helmholtz coils. By setting up the equipment as for measuring e/m , you can rotate the tube and study how the beam deflection is affected.



- Figure 1: The electron beam is horizontal, dim, and bluish.
 - Figure 2: As current through the coils increases, the electron beam curves to form a closed circle.
 - Figure 3: Turning the e/m tube and platform can cause the electron beam to form a spiral path.
3. With no magnet and no current in the Helmholtz coils, rotate the tube or the entire apparatus to see the deflection of the beam due to the Earth’s magnetic field. Is the direction of the deflection of the beam as you expect?

Appendix A: General Specifications

Item	Description
Supply voltage:	110 – 120 V or 220 – 240 V
Supply voltage fluctuations:	±10%
Fuse protection for inputs:	250 V T 315 mA / 2A
Display:	3-1/2 digit display
Using site:	Indoor use
Temperature:	Operating: 0°C to 40°C, Storage: -20°C to 50°C
Operating Altitude:	0 to 2000 meters
Relative humidity:	Noncondensing < 10°C, 90% from 10°C to 30°C, 75% from 30°C to 40°C
Pollution degree:	2
Certifications	CE
Safety compliance:	IEC/EN 61010-1
Overvoltage category:	II
Degree of protections:	IP20
Normal energy protection:	5 J

Item	Description
Tunable DC (Constant Current) Power Supply, 3.5 A / 6.3 V	0~3.5 A DC, $V \leq 24$ V (ripple < 1%) for Helmholtz coils; 3.5 Digit Display; 6.3 V AC, $I \leq 1$ A, 50 / 60 Hz, for Filament, 3.5 Digit Display
Tunable DC (Constant Voltage) Power Supply II	0~12 V DC, $I \leq 1$ A (ripple < 1%), 3.5 Digit Display; 0~100 V DC / 0~200 V DC (ripple < 1%) (Two ranges), $I \leq 30$ mA, 3.5 Digit Display
e/m Tube	Filling gas: helium Pressure: 10-1 Pa Filament Voltage: ≤ 250 V DC Deflecting Voltage: ≤ 150 V DC
Helmholtz Coils	Effective Radius: 158 mm Number of Turns: 130 Input Current: ≤ 3.5 A DC

Appendix B: Teacher's Notes

Sample Data

Manual Measurements

Table 1: Measuring and Calculating e/m

Item	U (V)	I _H (A)	r (mm)	e/m (C/kg)	Percent Error
1	100	1.0	45.0	1.80	2.5
2	105	1.1	42.5	1.76	-0.3
3	110	1.2	40.0	1.74	-0.9
4	115	1.3	38.0	1.72	-2.2
5	120	1.4	35.5	1.78	0.9

Analysis of e/m Measurements

The magnetic field, **B**, generated in a pair of Helmholtz coils is proportional to the current, **I_H**, passing through a single coil. The constant of proportionality, **k**, can be determined from the coil radius, **R**, and the number of turns, **N**, on the coil.

$$B = \frac{\left(\frac{4}{5}\right)^{\frac{3}{2}} \mu_0 N I_H}{R}$$

With this expression for **B**, the initial formula for e/m,

$$\frac{e}{m} = \frac{2U}{B^2 r^2}$$

becomes:

$$\frac{e}{m} = 2U \frac{\left(\frac{5}{4}\right)^3 R^2}{(N \mu_0 I_H r)^2}$$

R = 158 mm and N = 130 turns per coil

U = Acceleration Voltage

R = Radius of the Helmholtz coils

N = Number of turns on each coil

μ_0 = Permeability constant ($4\pi \times 10^{-7}$)

I_H = Current through the Helmholtz coils

r = Radius of the electron beam (closed circle)

- Accepted value of the charge-to-mass ratio, e/m, is 1.76×10^{11} C/kg

Appendix C: Technical Support, Copyright, Warranty

For assistance with the equipment or any other PASCO products, contact PASCO as follows:

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100

Phone: +1 916 462 8384 (worldwide)
877-373-0300 (U.S.)

Web: www.pasco.com

Email: support@pasco.com

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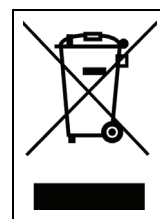
Warranty

For a description of the product warranty, see the PASCO catalog.

Appendix D: Product End of Life Disposal Instructions

Product End of Life Disposal Instructions:

This electronic product is subject to disposal and recycling regulations that vary by country and region. It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment. To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle/disposal service, or the place where you purchased the product.



The European Union WEEE (Waste Electronic and Electrical Equipment) symbol (above) and on the product or on its packaging indicates that this product must not be disposed of in a standard waste container.