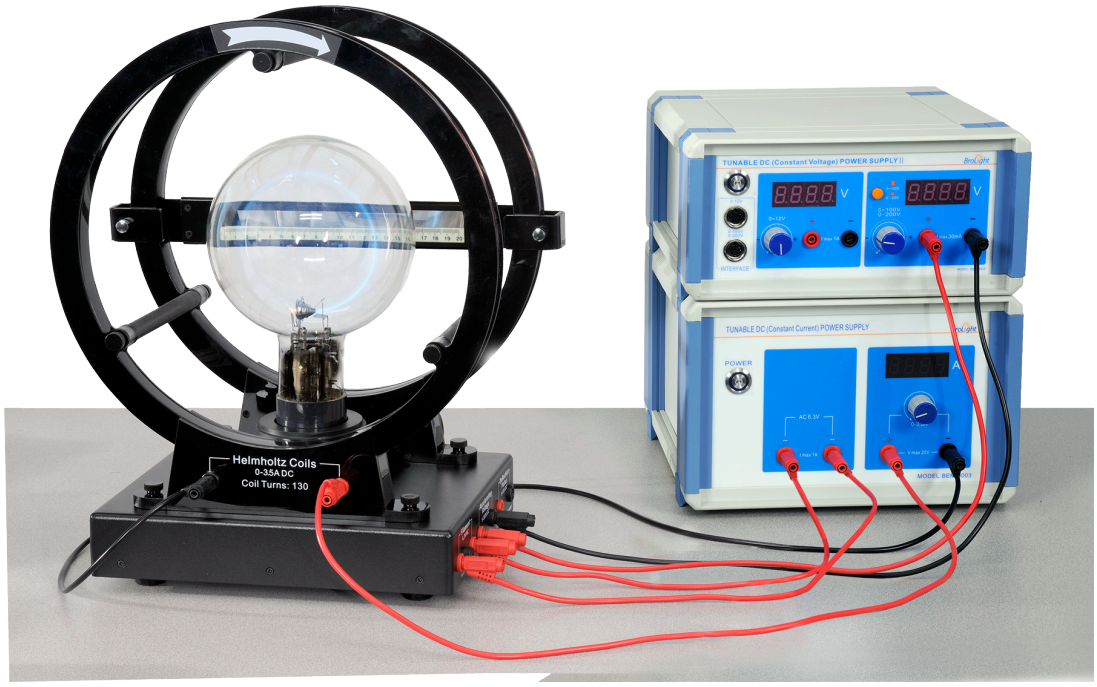
PASCO

Electron Charge-to-Mass Ratio

SE-9629



About the Product

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.

What's Included

- e/m Tube (SE-9651A)
- Helmholtz Coils and Base (SE-9626)
- Tunable DC (Constant Voltage) Power Supply II (SE-9644)
- Tunable DC (Constant Current) Power Supply (SE-9622)

Safety information

⚠ **Warning:** To avoid possible electric shock or personal injury, follow these guidelines.

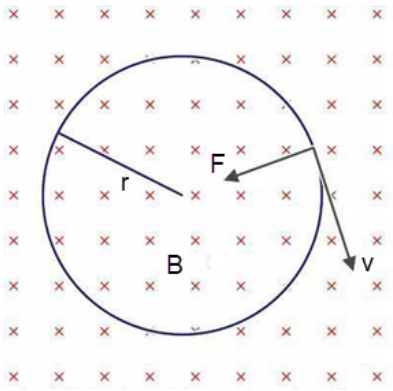
- Clean the equipment only with a soft, dry cloth.
- Before use, verify that the apparatus is not damaged.
- Do not disconnect the power cord safety ground feature.
- Plug into a grounded (earthed) outlet.
- Do not use the product in any manner that is not specified by the manufacturer.
- Do not install 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.

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 *v* in a direction perpendicular to a uniform magnetic field *B* experiences a Lorentz force *F* in a direction perpendicular to both the velocity and the magnetic field:

$$F = evB$$

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

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

and *m* is the mass of an electron. Thus,

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

The velocity *v* depends on the accelerating voltage *U* of the electron gun:

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

Therefore, the specific charge of an electron is given by:

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

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^2r^2 against $2U$ as a straight line through the origin with slope *e*/*m*.

Assembly

Assemble the base

1. 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.
2. Fasten the three support rods from the mounting hardware between the two Helmholtz coils.
3. 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.
4. Holding the e/m tube by its base, align the tab on the tube with the notch in the socket. Turn the tube in the socket until the tab slips into the notch then push the tube into the socket. Make sure that the tube is firmly in place.

> ⚠ **Warning:** Avoid touching the glass bulb of the tube. Do not expose the tube to any mechanical stress or strain. Touch only the plastic part below the glass bulb. Handle with care.

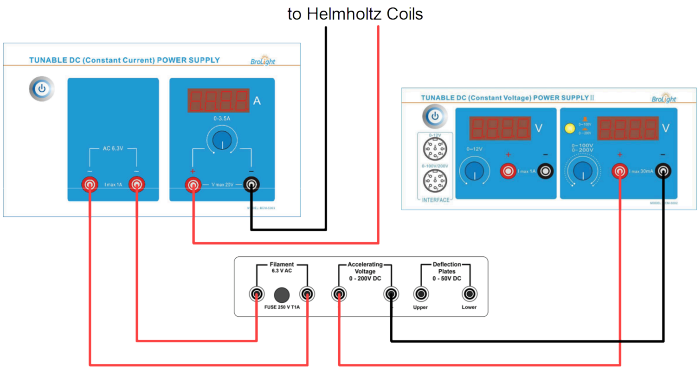
Connect cables and cords

> ⚠ **DANGER:** High Voltage is applied to the e/m Tube. Avoid contact with any part of the body.
>
> - Only use 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.

> ⓘ **Important:** Make sure that AC voltage switch on the power supplies is set for your AC voltage level.

> **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 **Accelerating Voltage** positive terminal on the platform. Connect the negative terminal of the 200 V DC output of the power supply to the **Accelerating Voltage** negative terminal.
2. On the Tunable DC (Constant Current) Power Supply, connect both terminals of the **AC 6.3 V** output to the **Filament** terminals on the platform.
3. Connect the Helmholtz Coils in series with the Tunable DC (Constant Current) Power Supply:
   a. On the power supply, connect the *positive* terminal of the **3.5 A** output to the *red* terminal on the **front Helmholtz Coil**.
   b. Connect the *black* terminal of the **front Helmholtz Coil** to the *black* terminal of the **back Helmholtz Coil**.
   c. Connect the *red* terminal of the **back Helmholtz Coil** to the *negative* terminal of the **3.5 A** output on the power supply.
4. Connect the power cords to the power supplies and connect the power supplies to an electrical outlet.



Experiment procedure

Adjust voltages and current

Note: Before switching on the power, 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, set the Voltage Range Switch to **0 – 200 V** .
2. For both power supplies, push in the Power Switch to the ON position.
3. Allow the filament to heat up for about 5 minutes.
4. On the Tunable DC (Constant Voltage) Power Supply II, set the Accelerating Voltage to 190 V DC.
5. Connect a wire between the **Accelerating Voltage** *positive* terminal to the **Deflection Plates** *Upper* terminal to make the electron beam appear.
6. On the Tunable DC (Constant Current) Power Supply increase the current to the Helmholtz coils. Watch the electron beam and check that the electron beam curves upward. Continue increasing the current until the electron beam forms a closed circle.
   - If the electron beam does not deflect, reverse the polarity of one of the Helmholtz coils so that current passes through both coils in the same direction.
   - If the electron beam deflects downward, swap the connections on the 3.5 A output terminals on the Power Supply.
   - If the electron beam forms a spiral, rotate the tube on the platform until a closed circle is formed. You may also need to rotate the platform to the right or left to align the magnetic field generated by the Helmholtz coils with the magnetic field of Earth.
7. Disconnect the wire between **Accelerating Voltage** *positive* terminal to the **Deflection Plates** *Upper* terminal.
8. On Power Supply II, adjust the voltage output to the Accelerating Voltage to optimize the focus and brightness of the electron beam.

Record data

1. Read the current display to find the current I_H through the Helmholtz coils. Record the value in Table 1.
2. Read the voltmeter and record the Acceleration Voltage U in Table 1.
3. 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 scale and average the results. Record the average radius in Table 1.
4. Collect additional trials of data using different accelerating voltages and current through the Helmholtz coils.

Note: If you lose the electron beam while adjusting the accelerating voltage, repeat steps 5-7 in the **Adjust voltages and current** procedure.

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.

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

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

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

becomes:

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

R = 158 mm

N = 130 turns per coil

$\mu_o = 4\pi \times 10^{-7}$

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

Table 1. Data

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

Demonstrations

Deflect the beam using an electric field

With no current in the Helmholtz coils, deflect the beam using the deflection plates:

- Connect a wire between the **Accelerating Voltage** *positive* terminal to the **Deflection Plates** *Upper* terminal to make the electron beam deflect upwards.
- Switch the wire to the **Deflection Plates** *Lower* terminal to make the electron beam deflect downwards.

Deflect the beam with a permanent magnet

Hold a permanent bar magnet near the tube to show the effect of a magnetic field on the electron beam. Switch between holding the north end and the south end of the magnet near the beam.

Rotate the tube

Rotate the tube so that it is oriented at an angle with respect to the magnetic field from the Helmholtz coils. As you rotate the tube, observe how the beam deflection is affected.

Deflect the beam using Earth's magnetic field

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?

Sample data

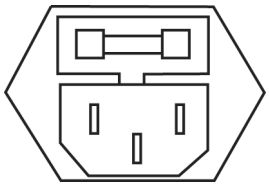
Table 2. Sample Data

TRIAL	U (V)	I_H (A)	R (MM)	E/M (C/KG)	% ERROR
1	100	1.0	45.0	1.80×10^{11}	2.5
2	105	1.1	42.5	1.76×10^{11}	-0.3
3	110	1.2	40.0	1.74×10^{11}	-0.9
4	115	1.3	38.0	1.72×10^{11}	-2.2
5	120	1.4	35.5	1.78×10^{11}	0.9

Fuse replacement

⚠ **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.

1. Disconnect the power cord from the instrument.
2. Open the fuse cover and remove the fuse. The fuse is inside a tray above the AC power cord socket.



3. Use a small screwdriver or other tool to pry the tray open.
4. Replace the fuse with the same type of fuse (250 V T2A). One spare fuse is included inside the tray.
5. Reconnect the power cord and turn on the instrument.

Specifications and accessories

Visit the product page at **pasco.com/product/SE-9629** to view the specifications and explore accessories. Experiment files and support documents can also be found on the product page.

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.

Technical Support

Need more help? Our knowledgeable and friendly Technical Support staff is ready to provide assistance with this or any other PASCO product.

Phone (USA)	1-800-772-8700 (Option 4)
Phone (International)	+1 916 462 8384
Online	**pasco.com/support**

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 or disposal service, or the place where you purchased the product.

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