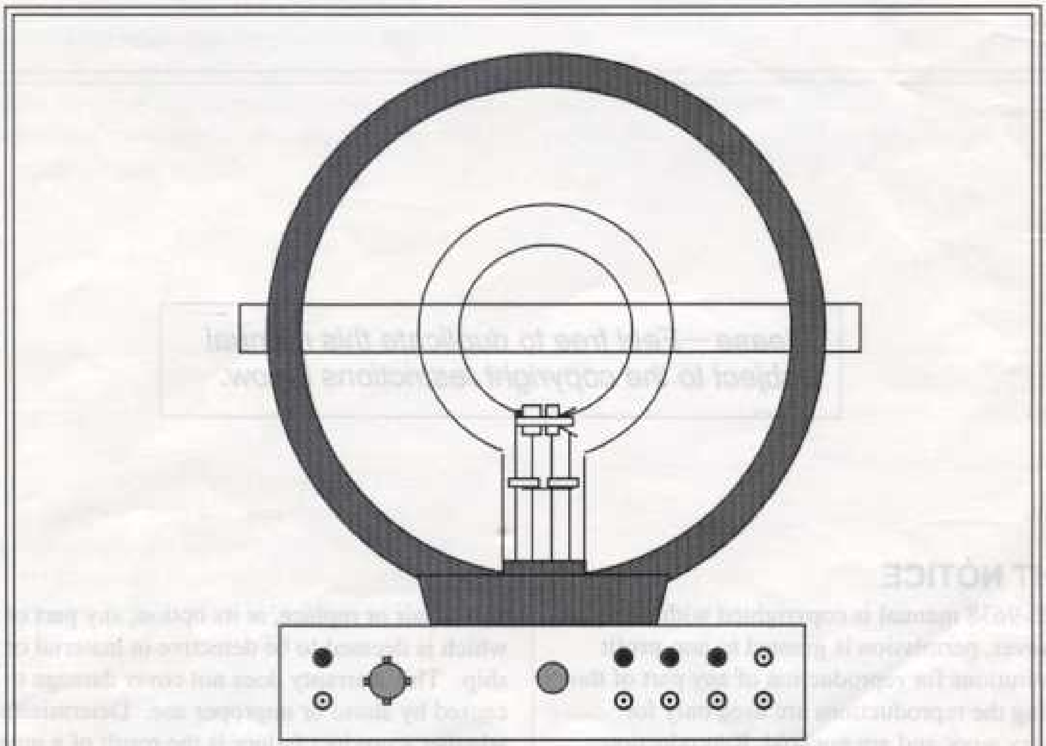
Instruction Manual and Experiment Guide for the PASCO scientific Model SE-9638

012-03471
11/87

e/m
APPARATUS



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INTRODUCTION

The PASCO Model SE-9638 e/m apparatus 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. By measuring the accelerating potential (V), the current to the Helholtz coils (I), and the radius of the circular path of the electron beam (r), e/m is easily calculated: $e/m = 2V/B^2r^2$. (The calculations are explained in the Operation section of this manual.)

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 0-90 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. Other experiments are also possible with the e/m tube. For example, you can use a small permanent magnet instead of the Helmholtz coils to investigate the effect of a magnetic field on the electron beam.

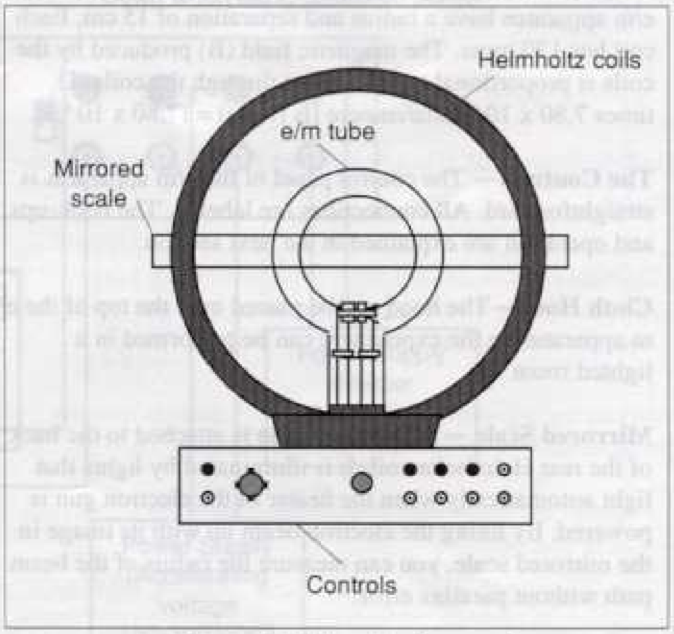


Figure 1 The e/m Apparatus

EQUIPMENT

The e/m Tube —The e/m tube (see Figure 2) is filled with helium at a pressure of 10^{-2} mm Hg, and contains an electron gun and deflection plates. The electron beam leaves a visible trail in the tube, because some of the electrons collide with the helium atoms, which are excited and then radiate visible light.

The electron gun is shown in Figure 3. The heater heats the cathode, which emits electrons. The electrons are accelerated by a potential applied between the cathode and the anode. The grid is held positive with respect to the cathode and negative with respect to the anode. It helps to focus the electron beam.

> **CAUTION:** The voltage to the heater of the electron gun should NEVER exceed 6.3 volts. Higher voltages will burn out the filament and destroy the e/m tube.

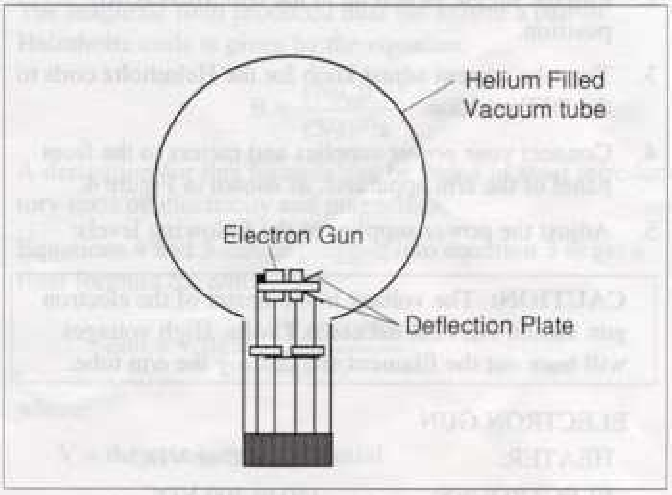


Figure 2 e/m Tube

The Helmholtz Coils—The geometry of Helmholtz coils—the radius of the coils is equal to their separation—provides a highly uniform magnetic field. The Helmholtz coils of the e/m apparatus have a radius and separation of 15 cm. Each coil has 130 turns. The magnetic field (B) produced by the coils is proportional to the current through the coils (I) times 7.80×10^{-4} tesla/ampere [B (tesla) = (7.80×10^{-4})I].

The Controls— The control panel of the e/m apparatus is straightforward. All connections are labeled. The hook-ups and operation are explained in the next section.

Cloth Hood— The hood can be placed over the top of the e/m apparatus so the experiment can be performed in a lighted room.

Mirrored Scale — A mirrored scale is attached to the back of the rear Helmholtz coil. It is illuminated by lights that light automatically when the heater of the electron gun is powered. By lining the electron beam up with its image in the mirrored scale, you can measure the radius of the beam path without parallax error.

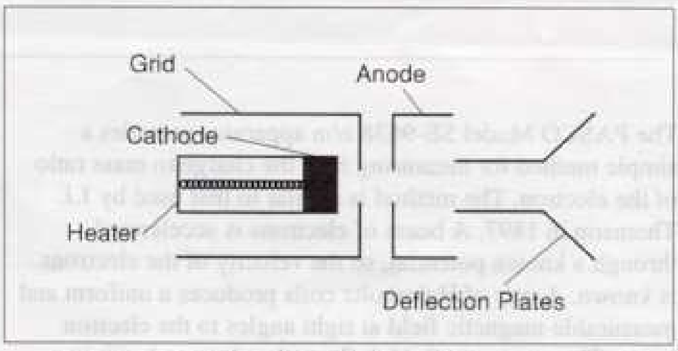


Figure 3 Electron Gun

Additional Equipment Needed —

Power Supplies:

6-9 VDC @ 3 a (ripple < 1%) for Helmholtz coils

(PASCO Model SF-9584 Low Voltage Power Supply)

6.3 VCD or VAC for filament

150-300 VDC accelerating potential (PASCO Model SF-9585 High Voltage Power Supply)

Meters:

Ammeter with 0-2 A range to measure current in Helmholtz coils (PASCO Model SE-9590 or SE-9545 Handheld Multimeter)

Voltmeter with 0-300 V range to measure accelerating potential (PASCO Model SE-9590 or SE-9545 Handheld Multimeter)

OPERATION

Measuring e/m

1. If you will be working in a lighted room, place the hood over the e/m apparatus.
2. Flip the toggle switch up to the e/m MEASURE position.
3. Turn the current adjust knob for the Helmholtz coils to the OFF position.
4. Connect your power supplies and meters to the front panel of the e/m apparatus, as shown in Figure 4.
5. Adjust the power supplies to the following levels:

> **CAUTION:** The voltage to the heater of the electron gun should NEVER exceed 6.3 volts. High voltages will burn out the filament and destroy the e/m tube.

ELECTRON GUN

HEATER:	6.3 VAC or VDC
ELECTRODES:	150 to 300 VDC
HELMHOLTZ COILS:	6-9 VDC (ripple should be less than 1%)

6. Slowly turn the current adjust knob for the Helmholtz coils clockwise. Watch the ammeter and take care that the current does not exceed 2 A.
7. Wait several minutes for the cathode to heat up. When it does, you will see the electron beam emerge from the electron gun and it will be curved by the field from the Helmholtz coils. Check that the electron beam is parallel to the Helmholtz coils. If it is not, turn the tube until it is. Don't take it out of its socket. As you rotate the tube, the socket will turn.
8. Carefully read the current to the Helmholtz coils from your ammeter and the accelerating voltage from your voltmeter. Record the values below.

   Current to Helmholtz coils = I = __________

   Accelerating voltage = V = __________

9. Carefully measure the radius of the electron beam. Look through the tube at the electron beam. To avoid parallax errors, move your head to align the electron beam with the reflection of the beam that you can see

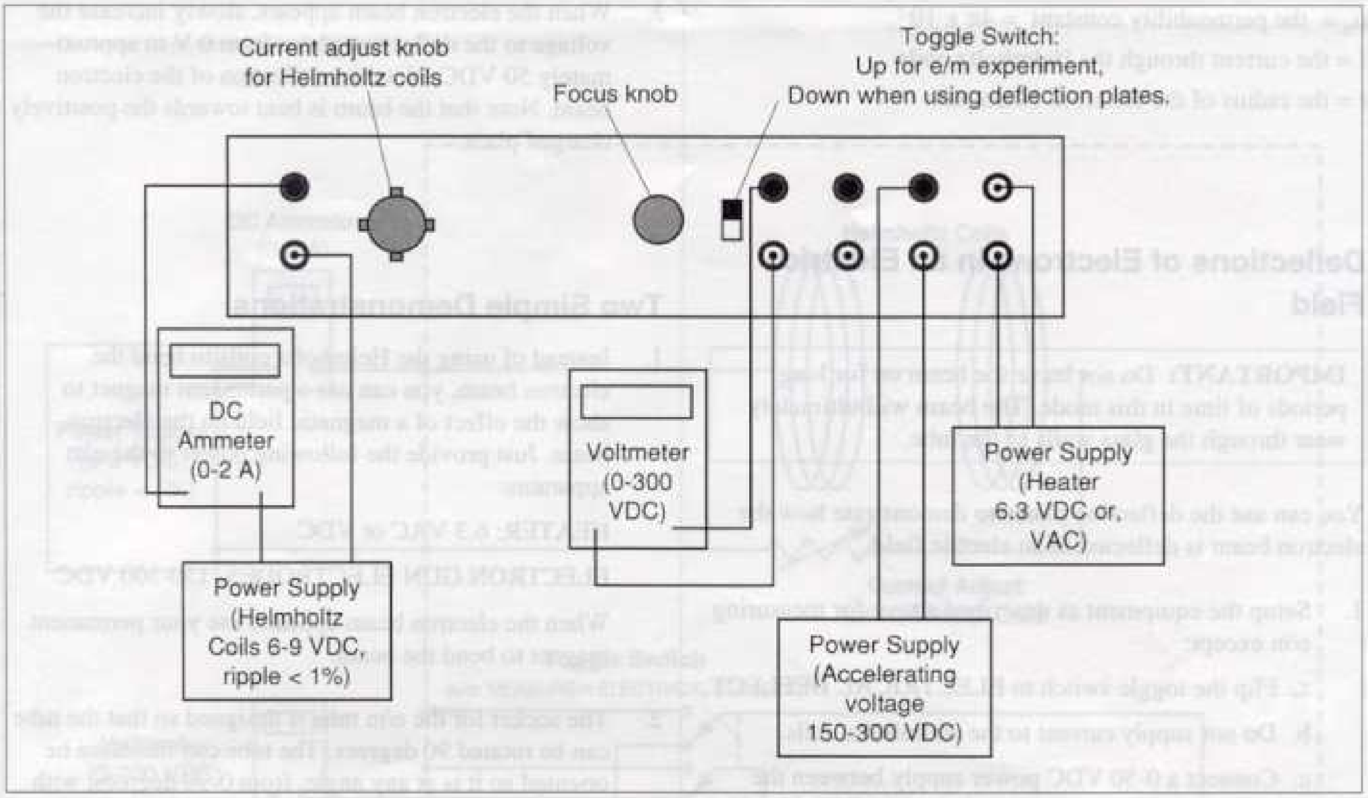


Figure 4 Connections for e/m Experiment

on the mirrored scale. Measure the radius of the beam as you see it on both sides of the scale, then average the results. Record your results below.

Electron Beam Radius = r = ______________________

Analysis of e/m Measurement

The magnetic force (F_m) acting on a charged particle of charge q moving with velocity v in a magnetic field (B) is given by the equation $F_m = qv \times B$, (where F, v, and B are vectors and X is a vector cross product). Since the electron beam in this experiment is perpendicular to the magnetic field, the equation can be written in scalar form as:

$$F_m = evB \quad (1)$$

where e is the charge of the electron.

Since the electrons are moving in a circle, they must be experiencing a centripetal force of magnitude

$$F_c = mv^2/r \quad (2)$$

where m is the mass of the electron, v is its velocity, and r is the radius of the circular motion. Since the only force acting on the electrons is that caused by the magnetic field, $F_m = F_c$, so equations 1 and 2 can be combined to give $evB = mv^2/r$ or

$$e/m = v/Br \quad (3)$$

Therefore, in order to determine e/m, it is only necessary to know the velocity of the electrons, the magnetic field produced by the Helmholtz coils, and the radius of the electron beam.

The electrons are accelerated through the accelerating potential V, gaining kinetic energy equal to their charge times the accelerating potential. Therefore $eV = 1/2\ mv^2$. the velocity of the electrons is therefore:

$$v = (2eV/m)^{1/2} \quad (4)$$

The magnetic field produced near the axis of a pair of Helmholtz coils is given by the equation:

$$B = \frac{[N\mu_0]I}{(5/4)^{3/2}a} \quad (5)$$

A derivation for this formula can be found in most introductory texts on electricity and magnetism.

Equations 4 and 5 can be plugged into equation 3 to get a final formula for e/m:

$$e/m = v/Br = \frac{2V\,(5/4)^3 a^2}{(N\mu_0 Ir)^2}$$

where:

V = the accelerating potential

a = the radius of the Helmholtz coils

N = the number of turns on each Helmholtz coil = 130

μ_0 = the permeability constant = $4\pi \times 10^{-7}$

I = the current through the Helmholtz coils

r = the radius of the electrons beam path

Deflections of Electrons in an Electric Field

> **IMPORTANT:** Do not leave the beam on for long periods of time in this mode. The beam will ultimately wear through the glass walls of the 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:
   a. Flip the toggle switch to ELECTRICAL DEFLECT.
   b. Do not supply current to the Helmholtz coils.
   c. Connect a 0-50 VDC power supply between the banana plug connectors labeled DEFLECT PLATES (UPPER and LOWER)
2. Apply the 6.3 VDC or VAC to the HEATER and 150-300 VDC to the ELECTRODES of the ELECTRON GUN (the accelerating potential). Wait several minutes to warm up the cathode.
3. When the electron beam appears, slowly increase the voltage to the deflection plates from 0 V to approximately 50 VDC. Note the deflection of the electron beam. Note that the beam is bent towards the positively charged plate.

Two Simple 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:

   HEATER: 6.3 VAC or VDC

   ELECTRON GUN ELECTRODES: 150-300 VDC

   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 90 degrees. The tube can therefore be oriented so it is at any angle, from 0-90 degrees, 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 it affected.

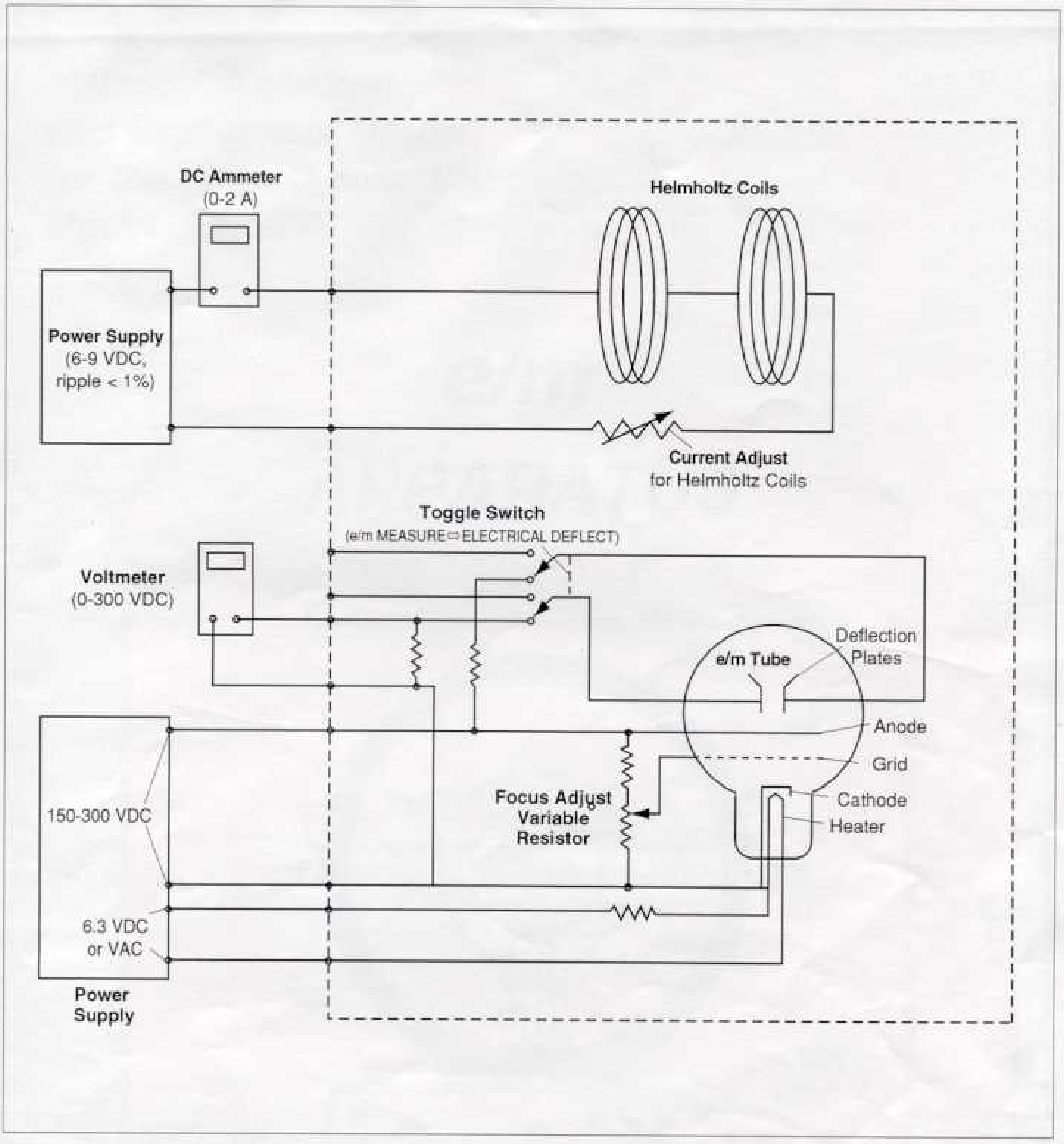


Diagram of Connections for the
SE-9638 e/m Apparatus

RELACIÓN CARGA-MASA DO ELECTRÓN

1. Unha práctica con historia

A práctica que imos realizar hoxe é unha adaptación moderna do histórico experimento levado a cabo por Joseph John Thomson en 1897. Con ela Thomson descubriu o electrón no laboratorio Cavendish da Universidade de Cambridge, Reino Unido. Determinou a relación entre a súa carga e masa, sendo deste xeito artifice da técnica experimental coñecida como **espectrometría de masas**. A día de hoxe, unha placa instalada no edificio do vello laboratorio Cavendish conmemora este feito.

En 1906 recibiría o premio Nobel de Física polos seus traballos sobre a condución da electricidade a través de gases, caracterizando os chamados **raios catódicos**, fluxo de partículas con carga eléctrica (electróns) [1]. Curiosamente sería o seu fillo George Paget Thomson quen recibiría o Nobel de Física en 1937 por demostra-las propiedades ondulatorias do electrón ao estuda-la súa difracción en cristais [2].

O experimento de J. J. Thomson é considerado un dos pioneiros en dar comezo á revolución cuántica. Será por tanto este experimento que veremos na seguinte sección o que vaia a pecha-las Técnicas de Electrodinámica Clásica.

Notas desta sección

> [1] Thomson tamén é recoñecido por propoñer un modelo para a estrutura atómica. Pode que che soe o modelo atómico do *pudin de pasas*. Nel, os electróns son esferas con carga eléctrica negativa incrustados nun átomo esférico de carga positiva.
>
> [2] Recibiu o Nobel xunto ao estadounidense Clinton Joseph Davisson, quen tamén contribuíu a determina-las propiedades ondulatorias do electrón mentres traballaba nos *Telephone Bell Laboratories*.

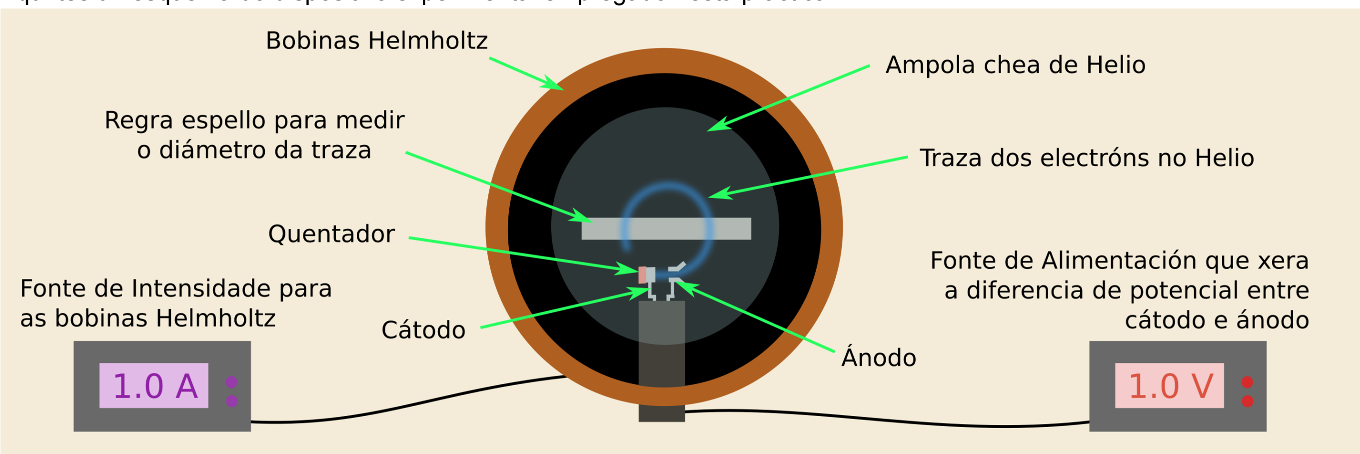
2. Experimento e tarefa a realizar

No seguinte vídeo vén explicado o experimento realizado por Thomson, co que determinarémo-la relación carga-masa do electrón. Máis abaixo tes o desenvolvemento teórico necesario para facelo. Ao visualiza.lo vídeo trata de fixarte nas seguintes cuestións:

- Para que se quece o cátodo?
- Por que podemos visualiza-lo feixe de electróns?
- Que se emprega para xera-la traxectoria circular do feixe de electróns?

(https://youtu.be/BxvTNZ5SiVo)

Aquí tes un esquema do dispositivo experimental empregado nesta práctica:



Como viches no vídeo, e tes detallado na imaxe de arriba, comézase aplicando unha diferenza de potencial V entre o cátodo e o ánodo. O cátodo é quentado (excitado termicamente) para que sexa máis doado arrincarlle electróns. A enerxía cinética que estes electróns adquiren é proporcional a V:

$$\frac{1}{2}mv^2 = eV \ (1)$$

onde m é a masa do electrón, e a súa carga e v a súa velocidade. A diferenza de potencial V arrica o electrón (en realidade, un feixe deles) do cátodo e confirelle unha velocidade v. Debido a que a ampola está chea de Helio, unha fracción de electróns colisiona con estes átomos, excitandoos e deixando a traza da traxectoria seguida polos electróns.

Como sabes, os electróns son partículas con carga eléctrica, polo que se aplicamos un campo magnético B perpendicular á súa velocidade, estes electróns describirán unha traxectoria circular de raio r, sendo a forza de Lorentz igual á forza centrípeta:

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

o xeito de xerar un campo magnético uniforme e perpendicular á velocidade do feixe de electróns é a través das bobinas Helmholtz. Estas xeran o seguinte campo magnético como función da corrente I que circula por elas:

$$B = \frac{N\mu_0 I}{(5/4)^{3/2}a} \; (3)$$

onde $N = 130$ é o número de espiras da bobina Helmholtz, $a = 0.15$ m é o seu raio e μ_0 é a permeabilidade magnética no baleiro.

O primeiro que terás que facer é obter unha expresión para a relación e/m como función de I, V e r considerando as ecuacións anteriores (1-3).

Despois terás que emprega-lo seguinte código de python para simula-lo experimento. Terás que introduci-lo valor para cada intensidade aplicada ás bobinas Helmholtz (I) en Amperios e a diferenza de potencial (V) coa que os electróns son acelerados en Voltios. O programa darache o diámetro que medirías na regra espello. Terás que cubri-la seguinte táboa:

I **(A)**	V **(V)**	d **(m)**
0.5	100.0	
0.5	150.0	
0.5	200.0	
0.5	250.0	
1.0	100.0	
1.0	150.0	
1.0	200.0	
1.0	250.0	
1.5	100.0	
1.5	150.0	
1.5	200.0	
1.5	250.0	
2.0	100.0	
2.0	150.0	
2.0	200.0	
2.0	250.0	

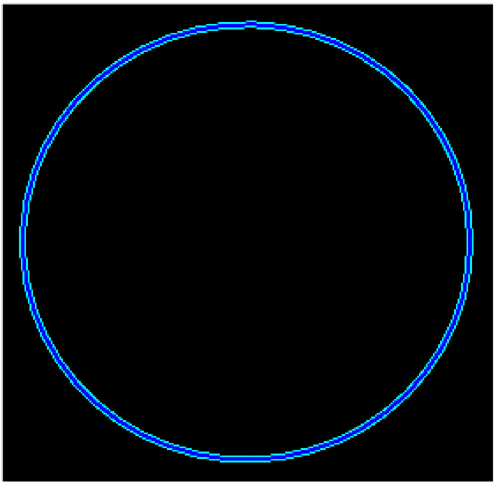
Corre o seguinte código (shift+enter) tantas veces como precises ata ter completada a táboa [1]:

In [2]:
```
%run -i "raicat.py"
```

```
-> Escribe en A a Intensidade (I) que queiras introducir na fonte de alimentaci
ón das bobinas Helmholtz e pulsa ENTER:

-> Escribe en V a Diferencia de Potencial (V) que queiras introducir para arrin
car os electróns e pulsa ENTER:


-> Traza que veriamos no experimento:
```



```
-> Resultado da medida:

     Diámetro d da traza circular (m): 0.045
```

Agora, coa táboa completa, xa podes obter un valor para a relación e/m para cada medida coa expresión que obtiveches. Poderás facer unha media entre tódolos resultados para determina-lo valor de e/m de xeito máis preciso e con iso finalizar esta práctica.

Notas desta sección

> [1] O código introduce un pequeno erro de xeito aleatorio en cada unha das medidas do diámetro. Recoméndoche anota-los datos nunha folla de cálculo que che permita analizalos posteriormente con maior facilidade.

Por se quixeres cavilar máis

Noraboa por ter rematado a práctica. Esta foi moi curtiña. Se quedaches con ganas de pensar un pouco máis sobre os raios catódicos, bota unha ollada a esta sección.

(https://www.youtube.com/watch?v=-JetVzgKBb0)

No video musical anterior aparecen Chicho e Cibrán (Boyanka Kostova) xunto a Gatocán e Pemán vendo a tele tirados no sofá. Se te fixaches un pouco, verías que o televisor é un destes antigos, con máis fondo que ancho. A base do funcionamento deste tipo de pantallas de televisión, osciloscopios e monitores é o tubo de raios catódicos (CRT do inglés). Considerando o que vimos no experimento de Thomson, ¿como pensas que se forman as imaxes? Como se pasa dunha tele en branco e negro a unha en cor? Ocorre algo na imaxe se achegas un imán á pantalla? Presentan algún risco para a saúde estes vellos televisores?

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General information

Application

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A mass spectrometer

Mass spectrometry is an analytical technique, which accurately measures the mass of different molecules within a sample. It is normally used to identify samples and determine the purity of samples.

A mass spectrometer generates multiple ions from the sample under investigation, it then separates them according to their specific mass-to-charge ratio, and then records the relative abundance of each ion type. Results are displayed as spectra of the signal intensity of detected ions as a function of the mass-to-charge ratio.

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Other information (1/2)

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Prior knowledge

When electrons are bombarding into a gas sample, the gas break into charged molecules, or ionized. By subjecting them to an electric field and magnetic field, ions of the same mass-to-charge ratio will undergo the same amount of deflection.

Scientific principle

Electrons are accelerated in an electric field and enter a magnetic field at right angles to the direction of motion. The specific charge of the electron is determined from the accelerating voltage, the magnetic field strength and the radius of the electron orbit.

Other information (2/2)

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Learning objective

To learn about the specific charge of the electron, Lorentz force and electron ionization.

Tasks

Determination of the specific charge of the electron (e/m_0) from the path of an electron beam in crossed electric and magnetic fields of variable strength.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

At this experiment dangerous voltages are used. Under no circumstances wires and the plugs must be touched. Only the given at workstation high voltages shall be used. The heater voltages of the tubes to produce the electron beam shall not exceed the given voltages.

Be very careful when handling the structure.

Theory (1/3)

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If an electron of mass m_0 and charge e is accelerated by a potential difference U, it attains the kinetic energy:

$$e.U = \frac{1}{2}.m_0.v^2$$

where v is the velocity of the electron.

In a magnetic field of strength $\vec{B}$, the Lorentz force acting on an electron with velocity $\vec{v}$ is:

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

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Theory (2/3)

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If the magnetic field is uniform, as it is in the Helmholtz arrangement, the electron therefore follows a spiral path along the magnetic lines of force, which becomes a circle of radius r if $\vec{v}$ is perpendicular to $\vec{B}$.

Since the centrigugal force $m_0 . v^2/r$ thus produced is equal to the Lorentz force, we obtain

$$v = \frac{e}{m_0} . B . r$$

where B is the absolute magnitude of $\vec{B}$. From equation (1), it follows that

$$\frac{e}{m_0} = \frac{2U}{(Br)^2} .$$

Theory (3/3)

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To calculate the magnetic field *B*, the first and fourth Maxwell equations are used in the case where no time dependent electric fields exist. We obtain the magnetic field strength B_z on the z-axis of a circular current *I* for a symmetrical arrangements of two coils at a distance *a* from each other:

$$B_z = \mu_0 . I . R^2 + \{(R^2 + (z - \frac{a}{2})^2)^{3/2} + (R^2 + (z + \frac{a}{2})^2)^{3/2}\}$$

with $\mu_0 = 1.257 . 10^{-6} \frac{Vs}{Am}$ and *R* is radius of coil.

For the Helmholtz arrangement of two coils (*a* = *R*) with number of turns *n* in the centre between the coils one obtains

$$B = (\frac{4}{5})^{3/2} . \mu_0 . n \frac{I}{R} .$$

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Setup and procedure

Setup (1/2)

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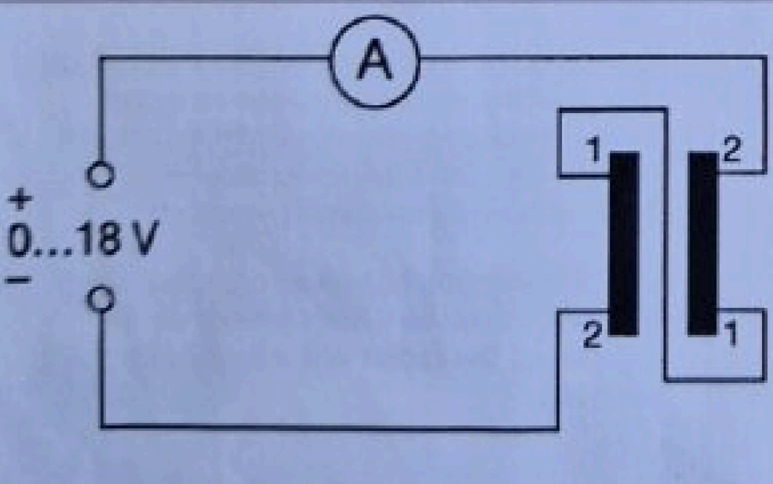

Wiring diagram for Helmholtz coils

The two coils are turned towards each other in the Helmholtz arrangement. Since the current must be the same in both coils, connection in series is preferable to connection in parallel.

The maximum permissible continuous current of 5A should not be exceeded.

If the polarity of the magnetic field is correct, a curved luminous trajectory is visible in the darkened room.

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Setup (2/2)

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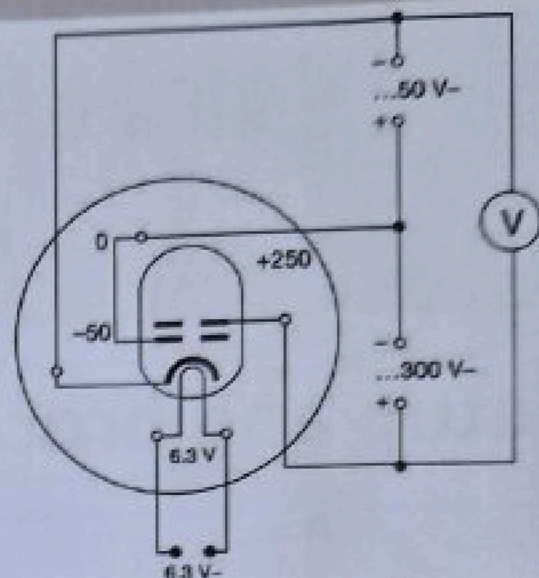
If the trace has the form of a helix this must be eliminated by rotating the narrow beam tube around its longitudinal axis.

For detailed description of the narrow beam tube, please refer to the operating instructions.



Wiring diagram for Narrow beam tube

Procedure

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Experimental setup

By varying the magnetic field (current) and the velocity of the electrons (acceleration and focussing voltage), the radius of the orbit can be adjusted, such that it coincides with the radius defined by the luminous traces.

When the electron beam coincides with the luminous traces, only half of the circle is observable. The radius of the circle is then 2, 3, 4 or 5 cm.

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Evaluation (1/2)

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For the coils

$R = 0.15\ m$
$n = 124$

$R = 0.2\,m$ and $n = 154$

current I and specific charge of the electron e/m_0 are determined for various voltages U and various radii r of the electron trajectories.

Compare the mean value of the measured specific charge of the electron and the literature value:

$e/m = 1.759.10^{11}\,As/kg$

	$r = 0.02m$		$r = 0.03m$		$r = 0.04m$		$r = 0.05m$	
$\frac{U}{V}$	I	$\frac{e/m_0}{10^{11}\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\frac{As}{kg}}$	I	$\frac{e/m_0}{10^{11}\frac{As}{kg}}$
100	2.5	1.7	1.6	1.8	1.1	2.2	0.91	2.0
120	2.6	1.9	1.7	1.9	1.3	1.9	1.0	2.0
140	2.8	1.9	1.9	1.8	1.4	1.9	1.1	1.9
160	-	-	2.0	1.9	1.5	1.9	1.2	1.9

$\overline{e/m_0} = (1.84 \pm 0.02).10^{11}\,As/kg$

Current I and specific charge of the electron e/m_0

Evaluation (2/2)

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How does Lorentz force acts on the electron?

- ○ It causes the electron to move in a circular motion
- ○ It influences the speed of the electron

Check

What might be the most remarkable error in the measurements?

- ○ Radius of the coils
- ○ Electric current
- ○ Radius of the circle

Check

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