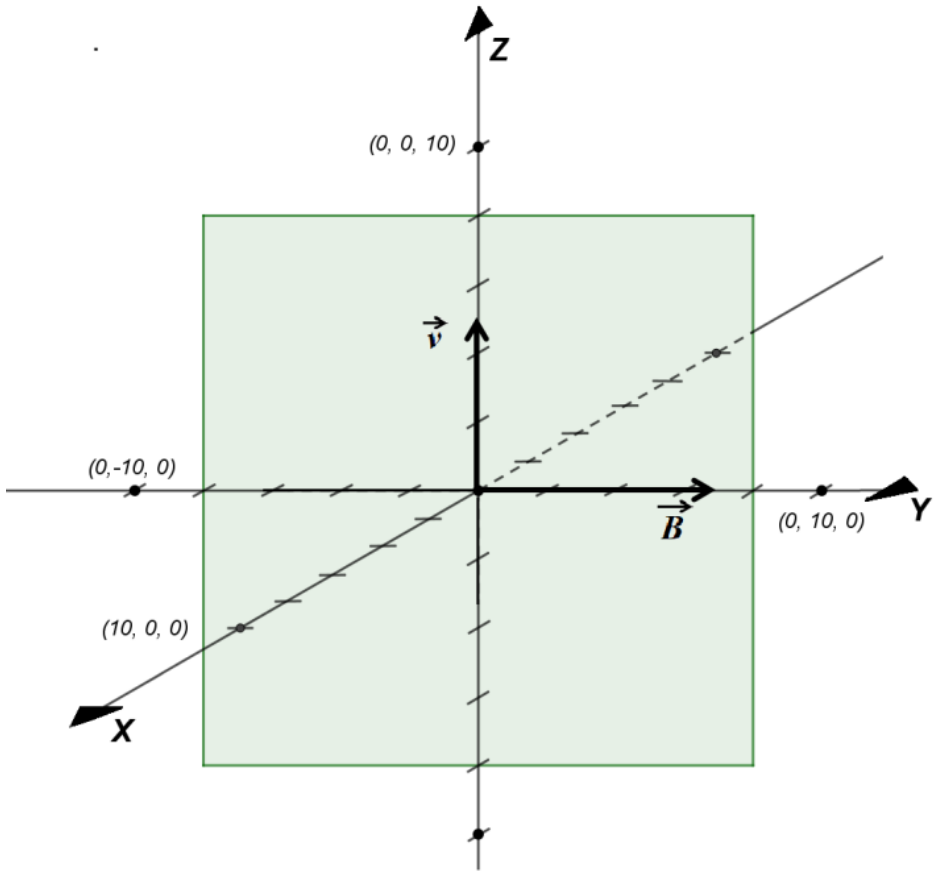
 Name Hayden Fuller Section 6

27A – Magnetic Fields and Forces

1) The force that a magnetic field exerts on a charged particle is given by $\vec{F} = q\vec{v} \times \vec{B}$. For a given charge q = +1.5 nC, velocity 1000 m/s, and field strengths of 0.50 T. The magnetic field vector and velocity vector are $\vec{B}$ and $\vec{v}$, respectively are displayed on the coordinate axis below. The angle between the vectors is 90 degrees. Use unit vector notation when describing the vectors.



a) Expression for magnetic field vector in terms of variables and unit vectors:
B = 0\hat i + 0.5\hat j + 0\hat k

b) Expression for the velocity vector in terms of variables and unit vectors:
v = 0\hat i + 0\hat j + 1000\hat k

c) Find the force on the charge in terms of variables and unit vectors:
qv x B = 750*10^-9 \hat i + 0\hat j + 0\hat k

d) Find the magnitude of the force action on the charge using numbers:
1.5*10^-9C*1000m/s*.5T=750nN

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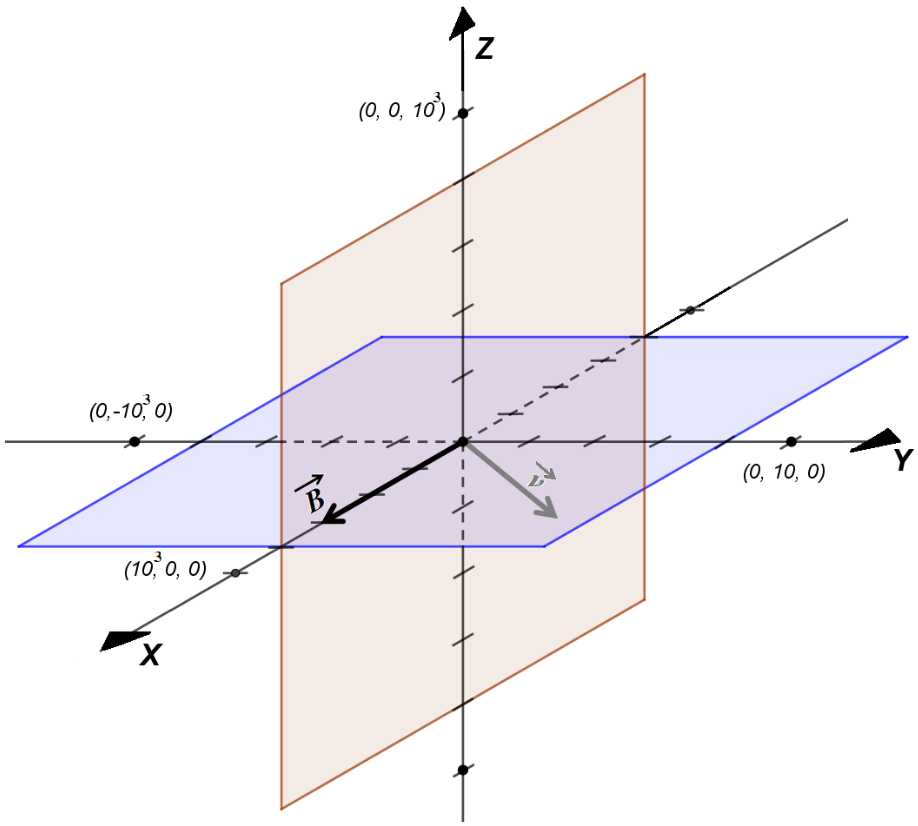
2) The force that a magnetic field exerts on a charged particle is given by $\vec{\boldsymbol{F}} = q\vec{\boldsymbol{v}}\; x\; \vec{\boldsymbol{B}}$. A particle with mass m = 2.0x10^{-8} kg and charge q = +2.5x10^{-8} C has an initial speed of $v = 4\sqrt{2}\; x\; 10^3$ m/s moves in a field of 0.5 T. The magnetic field vector and velocity vector are $\vec{\boldsymbol{B}}$ and $\vec{\boldsymbol{v}}$, respectively are displayed on the coordinate axis below. The velocity vector is in the *x*-*z* plane. The angle between the vectors is 135 degrees. Use unit vector notation when describing the vectors.



a) Expression for magnetic field vector in terms of variables and unit vectors:

B = .5 i + 0 j + 0 k T

b) Expression for the velocity vector in terms of variables and unit vectors:

i	j	k
-1*10^-4	0	-1*10^-4
.5	0	0

v = -4000 i + 0 j -4000 j m/s

c) Find the force on the charge in terms of variables and unit vectors:

F = 0i + -0.5*10^-4 j + 0k N

d) Find the magnitude of the force action on the charge:

|F| = 2.5*10^-8 * 4 sqrt(2) *10^3 * .5 * sin(135) = 5*10^-5 N

e) Find the acceleration vector $\vec{\boldsymbol{a}}$ for the charge:

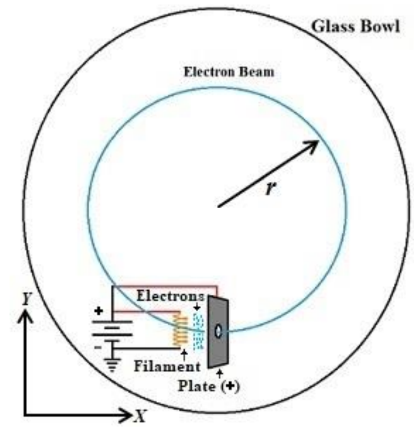
F=m*a
a=F/m=0i + -2.5*10^3 j + 0k m/s^2

27B – Experiment: Magnetic Force on a Moving Charge – q_e/m_e

Objective: In this module you will observe the trajectory of an electron beam in a uniform magnetic field oriented in various ways to the electron velocity. You will then use your observation of the radius of the electron trajectory to measure the charge to mass ratio for an electron.

Equipment:
One *e/m* apparatus (Large mounted glass bulb with Helmholtz coils); one Leybold or PASCO power supply for electron gun heater and accelerating voltage, one 24V/3A dc power supply for magnetic coil current, 8 banana plug leads.

Theory:
This section will lead you through the basic theory for this experiment by relating magnetic force to centripetal acceleration for a particle moving at a velocity controlled by an accelerating potential. A schematic of the essential physical elements is shown to the right. This schematic shows electrons being accelerated in a vacuum by a potential difference. An external magnetic field passes through the globe in the ***Z***-direction.



1) First consider the force $\vec{F}$ on a charged particle with charge q and mass m moving at velocity $\vec{v}$ through a magnetic field $\vec{B}$.
   a) Write an expression for the force $\vec{F}$ on a charged particle with charge q and mass m moving at velocity $\vec{v}$ through a magnetic field $\vec{B}$.

      F = qv x B

   b) Assume that the magnetic field $\vec{B}$ is in the +***Z***-direction and the velocity is $\vec{v} = v_x\hat{\imath} + v_y\hat{\jmath}$. Find the vector force $\vec{F}$ in terms of variables and unit vectors. This is the force $\vec{F}$ that causes the circular motion.

$$\begin{array}{ccc} i & j & k \\ qvx & qvy & 0 \\ 0 & 0 & B \end{array}$$

      F=qvyB i -qvxB j

   c) Find the magnitude of the force $|\vec{F}|$ from part (b) above.

      |F|=qv x B

   d) In what plane is the force $\vec{F}$?

      xy

2) Next consider the magnitude of the centripetal force F_c for a particle moving in a circle in terms of the mass *m*, speed *v*, and radius *r* of the particle's trajectory (see Diagram). Write an expression for the magnitude of the centripetal force.

F=mv^2/r

3) Combine your answers to questions 1c and 2 to find an expression for *q/m* in terms of *v*, *B*, and *r*.

F=qvB=mv^2/r q/m=v/(rB)

4) The speed of the charged particle in your apparatus is governed by the accelerating potential between the emitting filament and accelerating plates. Assume the initial velocity is zero and the particle accelerates through a potential difference of *V*. Use the conservation of mechanical energy *E*, which states that the energy $E = K + U$ is constant, solve for the particle speed *v* at the plates in terms of the potential *V*, charge *q* and mass *m*.

V=q/C
U=q*V
K=.5mv^2

E1=0+q*V=E2=.5mv^2+0

q/V=.5mv^2
2q/(Vm)=v^2
v=sqrt(2q/Vm)

5) Combine your relations from questions 3 and 4 to find for charge to mass *q*/*m* in terms of the experimental variables: potential *V*, magnetic field *B*, and radius of beam *r*.

q/m=sqrt(2q)/sqrt(Vm)rB

Eq. (27a)

The diameter and spacing of the coils for your experiment, (named for Helmholtz) produces a nearly uniform field in the region inside the coils. For the Helmholtz coils, the magnetic field is given by $B = I(\mathrm{A}) \times \kappa \ \ (\mathrm{T/A})$, where *I*(A) is the coil current in amperes and κ is a constant. The value for κ will be given to you in the lab. Now we can set or measure all the parameters on the right of equation (27a) that you wrote above.

Procedure:

There are three separate power supplies for the system. Each is mentioned below.

1st) Current must be supplied to the large Helmholtz coils to create the magnetic field. This is supplied with an HP or Agilent dc 24/3A power supply. <u>Set it to about 7 V with a limit of 2 A.</u>

2nd) Power must be supplied to the electron gun cathode to heat the cathode, emitting electrons by thermionic emission. Use the heater side of the Leybold or PASCO power supply. It should be set for you. Do not change it without discussing with a class facilitator.

3rd) Accelerating voltage must be supplied to the electron gun to give the emitted electrons significant kinetic energy. Use the high voltage side of the Leybold or PASCO power supply. Set it initially to 250 V.

Darken the room and use the shroud to better view the glow from the electron beam path through the gas. The trajectory can be tuned slightly using the "Focus" knob on the *e/m* apparatus.

- Start by setting the accelerating voltage to about 250V and then varying the magnet current.

1) Write down your <u>qualitative observations</u> on changes in the beam appearance as you increase magnet current.

radius is inversely proportional to current

2) Set the magnet current to about 1.5A and then vary the accelerating voltage from about 200 V to 300 V. Write down your <u>qualitative observations</u>.

increased voltage is increased beam size

Choose at least four combinations of accelerating voltage and magnet current and record current, voltage, and trajectory radius to calculate e/m. Have at least two members of your group measure the trajectory radius for a given set of conditions. (Note that there is a mirror at the back of the chamber. Parallax error in measurement of *r* can be decreased by moving your eye to match the beam with its reflection.)

Accelerating potential(V)	Coil Current (A)	Calculated *B* (T)	Beam radius (m)	*q/m* (C/kg)
200	2	14.78*10^-4	.0325	4.16*10^6
250	1.5	11.085*10^-4	.055	4.10*10^6
300	1	7.39*10^-4	.075	5.41*10^6
350	1.2	8.868*10^-4	.0751	5.25*10^6

B=7.39*10^-4*I T/A

3) Calculate the average and standard deviation of your *q/m* measurements and report them below.

average = 4.73*10^6 Standard deviation = 0.697*10^6

C/kg

4) It is not too difficult, using chemical techniques or the Millikan Oil Drop experiment to measure the charge on an electron, but it is difficult to directly measure the mass of an electron.
   a) Take the literature value of the charge of the electron $q_e = 1.60\times10^{-19}$ C and compute the mass of the electron m_e from your measured q/m_e ratio.

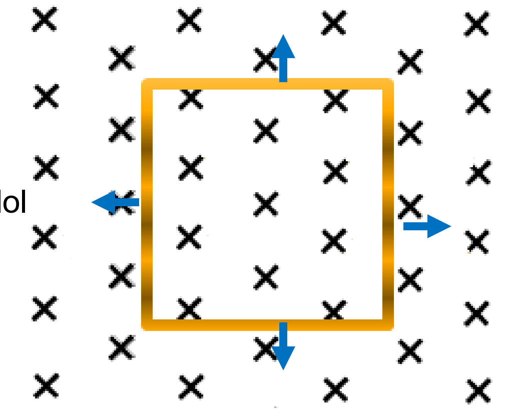
m_e = 3.38*10^-26 kg

   b) How well does your measurement agree with the literature value of the electron mass $m_e = 9.11 \times 10^{-31}$ kg? What is the major source of uncertainty?

not very close, off by 5 orders of magnitude, likely due to measurement error

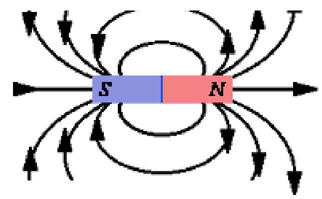
27C – Magnetic Force on a Current Loop

Calculating the force on a current loop in a magnetic field is more subtle than on a single straight wire.



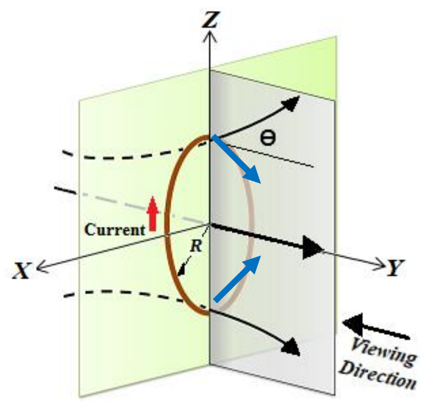
1) The net force on a current loop in a uniform magnetic field is zero. Argue why this is so using the rectangular loop in the field shown to the right. Assume that the current flows clockwise around the loop. Show forces on the diagram. done lol (Hint: Consider the magnitude and direction of the force on each side of the loop.)

   All sides of the loop have equal and opposite forces acting on them, leading to zero net force



The net force on a loop is not necessarily zero if the magnetic field is not uniform. In this section you will calculate the net force on current in a circular loop in a diverging magnetic field. Recall for a bar magnet, that the magnetic fields at each end of the magnet are diverging as illustrated in the sketch.

Consider a circular loop of radius *R*, carrying current *I* in a magnetic field pointing to the right. At the loop, the top magnetic field vector *B* is 10 degrees above horizontal and the bottom magnetic field vector *B* is 10 degrees below horizontal. The observer on the right sees the current going in the clockwise direction.



2) Sketch a force vector at the top and bottom of the circular loop. done lol
3) What is the magnitude of the horizontal component of the force on a small length of wire *ds* at the top of the loop? (Note that the vertical components of force should have canceled with each other in your sketch.)

   $F=qVB\sin(0)=0$

4) Integrate over the length of the loop to find the net force on the loop.

   $\int B*I*\sin\theta \, ds$

5) Does the force increase or decrease as the coil is moved to the right? Explain your response.

   decreases because the magnitude of the field is decreasing with greater distance

Note: This is the principle that is involved in the well-known jumping ring demonstration. A great demo by an excellent lecturer can be found here. https://www.youtube.com/watch?v=6OI_vsaF8q8.