Motion of a Charged Particle in a Magnetic Field

OBJECTIVES

In this lab you will

- Use VPython to simulate the motion of a charged particle in a magnetic field
- See how changing initial conditions changes changes the particle's path
- See how adding an electric field affects the particle's path

The magnetic force on a charged particle is always perpendicular to the particle's velocity vector.

$$\vec{F}_{mag} = q\vec{v} \times \vec{B}$$

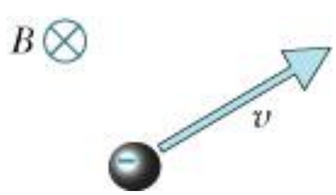
This fact causes particle paths to be curved, and makes their motion somewhat difficult to visualize. The addition of an electric field makes the particle's path more complicated.

$$\vec{F}_{net} = \vec{F}_{mag} + \vec{F}_{el} = q\vec{v} \times \vec{B} + q\vec{E}$$

Using VPython you will be able to manipulate both the magnetic and electric field to produce several particle tracks.

1) Warm Up Problem

<u>Problem 1)</u> At a particular instant, an electron is moving with velocity **v** in the plane of the page, and there is a uniform magnetic field B into the page throughout this region; the magnetic field is produced by some large coils which are not shown. Draw the trajectory of the electron and explain qualitatively.



CHECKPOINT 1: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

2) Particle in Electric and Magnetic Fields

a) Download "Lab 09_student template" from Blackboard.

Your code should look like this:

```
from __future__ import division
from visual import *

# Define Constants
e=1.6e-19
oofpez=9e9

# Initial Values

# Create Objects

# Calculations
```

Do the following in your constants section.

You need both a magnetic field and an electric field. Because each is measured in different units you will also need a separate scale factor for each one.

b) Define a magnetic field "B" as a vector with zero magnitude.

c) Define a magnetic scale factor "Bscalefactor" and set it equal to 1.

d) Define an electric field "E" as a vector with zero magnitude.

e) Define an electric scale factor "Escalefactor" and set it equal to 1.

You will also need a clock in this program.

f) Set the time interval to be 1 x 10^{-11} s.

Do the following in the initial values section.

g) Set your time "t" to be 0.

Do the following in your create objects section.

h) Create a red sphere called "atom". Place it at the origin. Give it a radius of 1 x 10^{-10} m.

i) Assign atom a charge of e and a mass of 7 protons.

```
atom.q=e
atom.m=7*1.7e-27
```

The atom now resembles a lithium ion.

j) Give the atom a velocity ("atom.v") of (1 x 10^{-2}, 0, 0) m/s.

k) Define the atom's momentum ("atom.p") in terms of the atom's velocity and mass.

When the atom moves you will want to be able to see the path it took.

l) Type the following line to make a trail of the atom's path.

```
atomtrail = curve(color=atom.color)
```

This trail is similar to a graph in that the above code simply tells VPython that it will make a trail. The instructions to actually make the trail will be in the loop.

m) Make two different color arrows to represent the magnetic and electric fields. Name them "Earrow" and "Barrow". Place Barrow at (0, 0, -1 x 10^{-9}) m. Place Earrow at (2 x 10^{-10}, 0, -1 x 10^{-9}) m. Remember to include scale factors.

Although you are only going to display the electric and magnetic fields at one location, they are present and constant everywhere in your program.

Turn off autoscaling by typing the following in the end of your create objects section.

n) scene.autoscale = 0

Do the following in your calculations section.

You will now write a loop which will make the atom move and display the effect of the magnetic and electric forces on its motion.

o) Construct a while loop that will run continuously by typing:

```
while 1:
```

All other code will now be in the while loop i.e. indented once.

You will not be updating atom.v in this loop. So instead of using atom.v, use atom.p divided by atom.m.

p) Calculate the net force on the particle "F".

This is given by the Lorentz force.

$$\vec{F}_{net} = \vec{F}_{mag} + \vec{F}_{el} = q\vec{v} \times \vec{B} + q\vec{E}$$

VPython has a simple way to make it calculate a cross product.

$$\vec{A} \times \vec{B} \rightarrow \text{cross}(A,B)$$

q) Update the momentum with the momentum update formula.

r) Update the position with the position update formula.

s) Add to the trail of the atom with the following line of code.

```
atomtrail.append(pos=atom.pos)
```

t) Add one time interval to t.

That is the end of your code.

u) Make the magnetic field (0, 1, 0) T (you will need to change Bscalefactor appropriately).

i. Looking in the direction of the magnetic field, is the atom circling clockwise or counterclockwise?

v) Change the magnetic field to be (0, 5, 0) T.

ii. What happens to the atom's path?

w) Change the magnetic field back to (0, 1, 0) T.

CHECKPOINT 2: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

3) Effect of Initial Velocity and Charge

a) Reverse the direction of the initial velocity.

iii. What happens to the atom's path?

b) Change the velocity back to its original value.

c) Make the charge on the atom negative.

iv. What happens to the atom's path?

d) Change the atom's charge back to a positive charge.

e) Change the atoms velocity to (1 x 10^{-2}, 1 x 10^{-3}, 0) m/s.

v. What happens to the atom's path?

vi. Of the components of velocity, which ones are changing and which ones are constant?

f) Change the velocity back to its original value.

CHECKPOINT 3: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

4) Effect of Electric Field

a) Add an electric field of 0.001 N/C in the positive y direction.

vii. What happens to the atom's path?

b) Does an electric field exist such that the atom will move with constant velocity? If not, explain why such an electric field does not exist. If yes, code it in and verify that your code shows the atom traveling in a straight line.

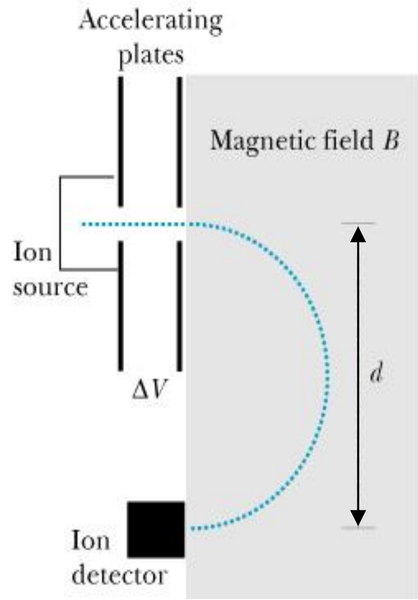
c) Change the electric field to be in the positive x direction, and predict the direction in which the atom will travel.

viii. What happens to the atoms path?

d) Give the atom zero initial velocity and describe its path.

CHECKPOINT 4: Ask an instructor to check your work for credit. You may proceed while you wait to be checked off

5) Final Problem



In the simple mass spectrometer shown, positive ions with net charge +q and mass M are released at very low speed into two "accelerating plates" with potential difference ΔV. In the gray region there is a uniform magnetic field **B**.

- What is the magnetic field that would cause such an ion to take the semicircular path shown?
- What units are tesla? What units does your answer have?

CHECKPOINT 5: Ask an instructor to check your work for credit.