Assignment 2 – Charged Particles in magnetic fields

UPPSALA UNIVERSITET

Scientific Programming in Python with Applications in Physics

Learning Outcomes Assessed

1. Write functions describing the motion of a particle.
2. Numerically solve differential equations.
3. Plot results.

Introduction

The general motion of a charged particle in electric $\vec{E}$ and magnetic $\vec{B}$ fields is governed by the Lorentz force

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}),$$

where q and $\vec{v}$ are the charge and velocity of the particle and $\vec{F}$ is the force acting on it. The cross-product operator is available in `numpy` as `numpy.cross`.

In this assignment, we will analyze the motion of a charged particle by numerically solving the corresponding differential equation.

Be careful and *consistent* when choosing your units. SI units as in `scipy.constants` might be a good choice here.

Submission

You need to submit 2 files via studium:

1. Your code as a single .py file. Do not submit code as a PDF, .txt, or anything else.
2. A short report presenting
   (a) the figures requested in the various questions and
   (b) a short explanation of the procedures you used to get them.

(Note the double usage of the word "short" here.) Submit as a PDF. Please do not create a ZIP or other archive.

Alternatively, you may submit a single notebook .ipynb file containing the short explanations about the figures and results in markdown.

Grading

Grade	criteria
3 (pass)	Substantially correct attempt at mandatory parts. Code quality satisfactory. Report including the required figures.
4	As 3, but good attempt, including some extended parts. Code quality good, code commented. Report including the required figures and comments about how you created them.
5	As 4, but excellent attempt, including all extended parts. Code quality excellent, code well commented. Report including the required figures and comments about how you created them and what they show.

We'll make a judgement on the code quality. Good quality code (for this assignment):

- Uses correct naming conventions for variables, functions, constants, etc. (see the course book)
- Sensible names for variables, functions, constants, etc.
- Terse, well-written comments, where appropriate; and to indicate code relating to different sections. Correct spelling.
- Readable; avoids substantial unnecessary complexity and repetition.
- No redundant or unused code.

Mandatory Part

Task 1

Consider a proton moving in x-direction in a homogeneous magnetic field with a field axis in z-direction. The proton has an energy of 1 MeV and the field strength is 3 T. Using an ordinary differential equation solver, follow the motion of this particle for 1 microsecond. Plot and describe the result.

Task 2

Launch the same proton (energy 1 MeV) in the same magnetic field (3 T, parallel to the z-axis), but this time the initial proton velocity has both an x- and a z-component. Follow the motion of this particle for 1 microsecond. Plot and describe the result.

Task 3

Repeat Task 2, but make a 3d plot of your results. Depending on how you do that, you will have to include the line

```
from mpl_toolkits.mplot3d import Axes3D
```

in your import-section.

Extended Part

Task 4

Change the magnetic field so that it is cylindrically symmetric around the z-axis. If r is the distance from the z-axis, in meters, the magnitude of the magnetic field is 9T$/r$. The direction of the B-field at any point should be along a ring around z in the clockwise direction.

Launch a 1 MeV proton at $r = 3$ m straight up (in the z direction) and plot the first microsecond. Describe the result.

It can be noted that the field at $r = 3$ m is very similar to the case in question 1 with a gentle gradient added. The solution should be very similar to that of question 1.

Task 5

Repeat question 4, but make a 3d plot of your results.

Task 6

Evaluate the drift velocity in question 4.