Week 6: Using Biot Savart to compute $\overrightarrow{B}$ Fields

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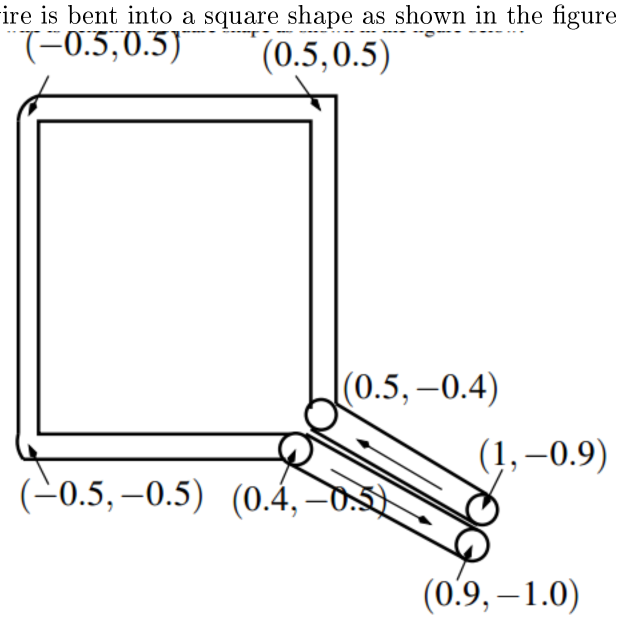
Abstract

In this assignment, we compute the Magnetic Field due to current in a wire. We break up the wire into little pieces, and for each, we use the Biot Savart Law to compute $\overrightarrow{B}$ at different points. We sum up all the contributions to get the $\overrightarrow{B}$ field due to the coil.

Geometry of Problem

A wire is bent into a square shape as shown in the figure below:



The locations are shown in cm. The radius of the wire is 0.05 cm. A current of 1 Amp flows through the wire. The problem is to compute the magnetic field in a cube that goes from $-1 < $ x, y,z < 1.

1. Define the line passing through the centre of the wire where it enters at (1,−0.9) going round the square till it leaves at (0.9,−1). This length is $0.9 + 1 + 1 + 0.9 + 0.5\sqrt{2} + 0.5\sqrt{2}$ cm. Divide the line into pieces of length 0.1 cm. The leads can have lengths slightly longer to make them integer number of pieces.

```
#Defining the wire
x1=np.arange(1,0.5,-0.1/(2**0.5))
y1=np.arange(-0.9,-0.4,0.1/(2**0.5))
y2=np.arange(-0.4+0.1,0.5,0.1)
x2=0.5*np.ones(len(y2))
x3=np.arange(0.5,-0.5,-0.1)
y3=0.5*np.ones(len(x3))
y4=np.arange(0.5,-0.5,-0.1)
x4=-0.5*np.ones(len(y4))
x5=np.arange(-0.5,0.4,0.1)
y5=-0.5*np.ones(len(x5))
x6=np.arange(0.4,0.9+0.1/(2**0.5),0.1/(2**0.5))
y6=np.arange(-0.5,-1-0.1/(2**0.5),-0.1/(2**0.5))
```

2. Create the points corresponding to the ends of the pieces into an array in Python. A single array should go from (1,−0.9) to (0.9,−1).

```
x=np.concatenate((x1,x2,x3,x4,x5,x6),axis=0)
y=np.concatenate((y1,y2,y3,y4,y5,y6),axis=0)
conductor=np.vstack((x,y))#(x,y) of end points
```

3. Locate the centres of the individual pieces.

```
mid=(conductor[:,:-1]+conductor[:,1:])/2 #midpoints
```

4. Pad the centres with a zero column, representing the z coordinate.These are the locations of the centres of the wire pieces.

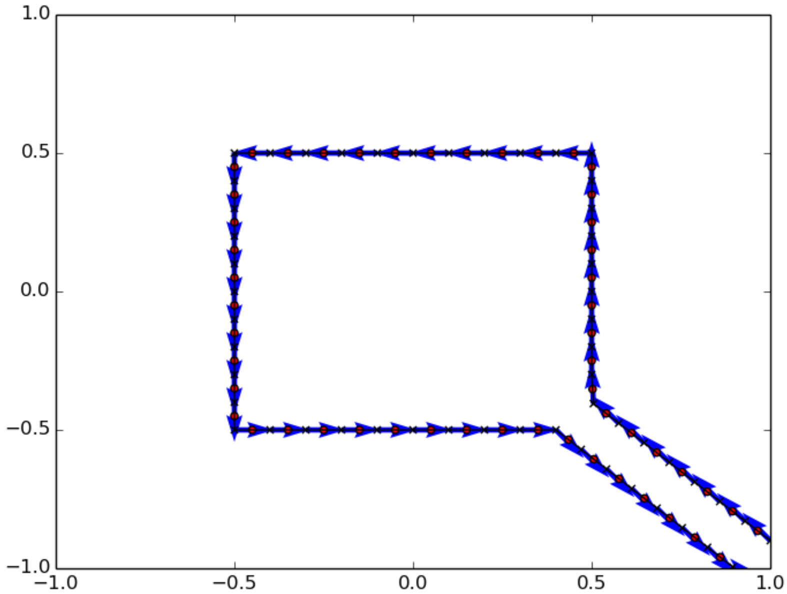
```
mid=np.vstack((mid[0,:],mid[1,:],np.zeros(len(mid[0,:]))))
```

5.Create a vector of current directions (the amplitude is unity).

```
dr_x = np.diff(x)          #dx
dr_y = np.diff(y)          #dy
dr_x=np.divide(dr_x,(dr_x**2 + dr_y**2)**0.5)
dr_y=np.divide(dr_y,(dr_x**2 + dr_y**2)**0.5)
dl=np.vstack((dr_x,dr_y))          #vector dl
```

6. You should plot the end locations (with crosses), the centres with red dots and the current arrows in blue (use quiver, right over the plot)

```
mp.figure(1)
mp.plot(x,y,'k')
mp.quiver(x,y,dr_x,dr_y,color='b')
mp.scatter(mid[0,:],mid[1,:],c='r')
mp.scatter(conductor[0,:],conductor[1,:],c='k',marker='x')
mp.axis([-1.0,1.0,-1.0,1.0])
mp.savefig('Fig1.png')
```



7. Now create an array of points in (x, y,z) that are 0.1 spaced. this will be a 3 − D array for each of x, y and z, and each array will have 213points. To do this, create each as a 1-Dimensional vector and use meshgrid.

```
c=np.arange(-1,1.1,0.1)
Y,X,Z=np.meshgrid(c,c,c)
```

8. Create arrays to hold B at these points. (Dimension will be 21×21×21×3)

```
B=np.zeros((21,21,21,3))
```

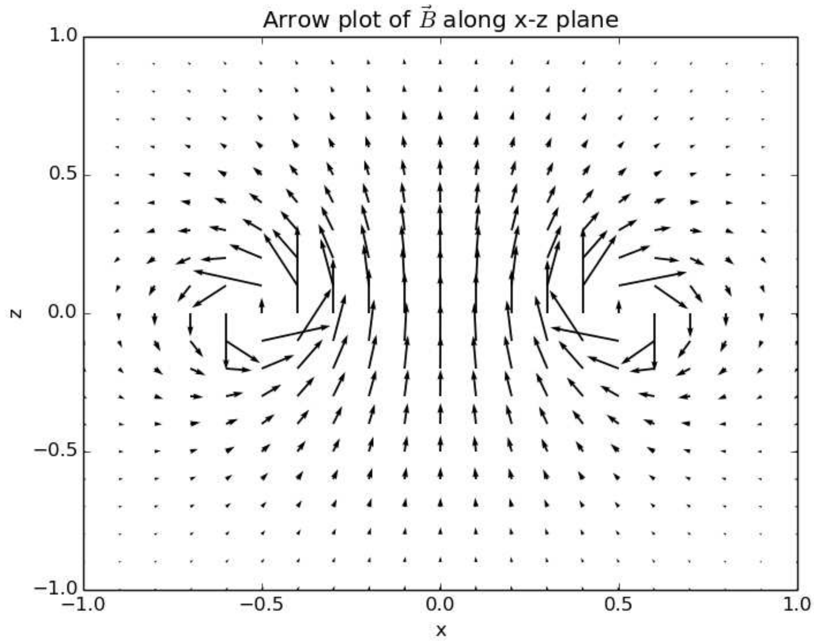
9. Now implement the Biot Savart Law at each point (x_i , y_j ,z_k), due to the m^{th} wire element.

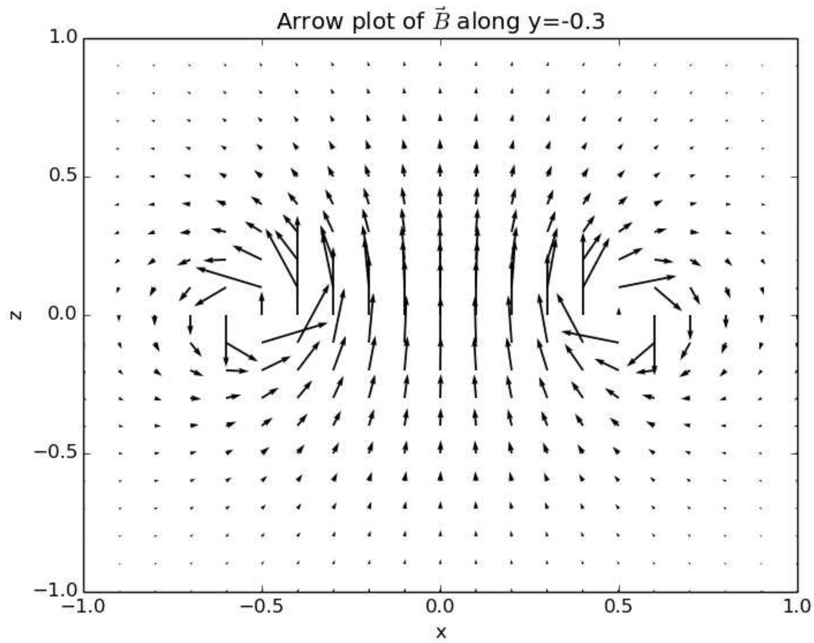
```
for i in range(len(dr_x)) :
```

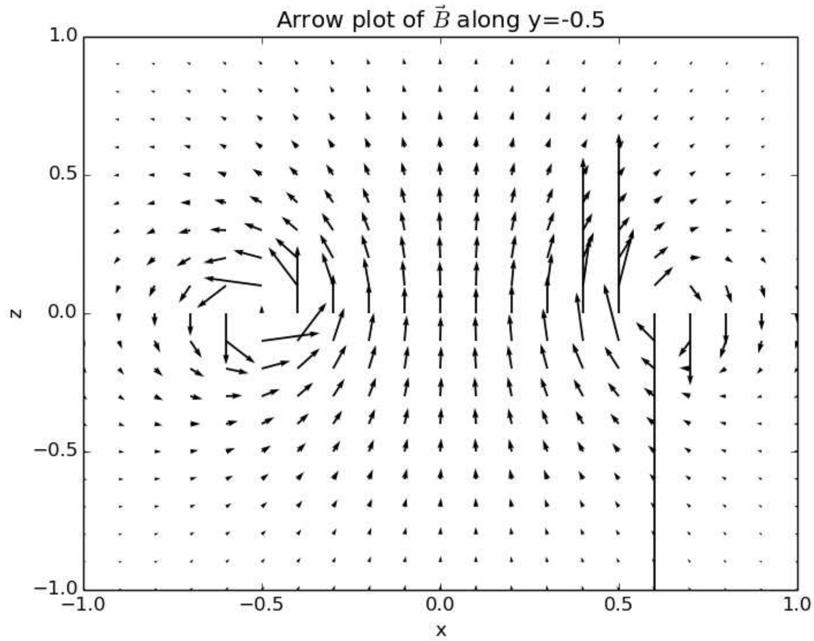
```
        Rx=X-mid[0][i]
        Ry=Y-mid[1][i]
        Rz=Z-mid[2][i]
        R=(Rx**2 + Ry**2 +Rz**2)**1.5
        B[:,:,:,0]+=dr_y[i]*Rz/(R)
        B[:,:,:,1]+=(-dr_x[i]*Rz)/(R)
        B[:,:,:,2]+=(dr_x[i]*Ry - dr_y[i]*Rx)/(R)
```

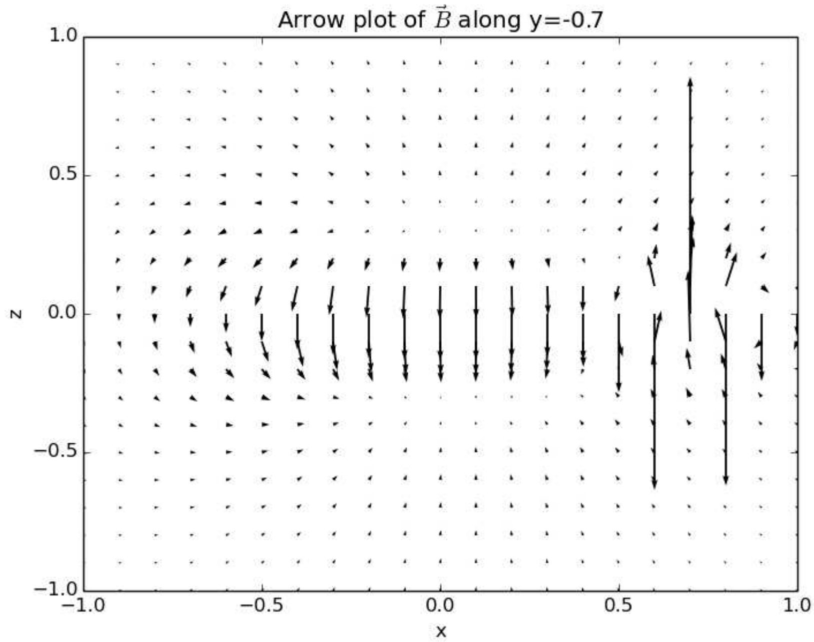
10. Do an arrow plot of the field in the $x - z$ plane, and in vertical planes corresponding to $y = -0.3$, $y = -0.5$ and $y = -0.7$.

```
mp.figure(2)
mp.quiver(np.arange(-1,1.1,0.1),np.arange(-1,1.1,0.1),B[:,10,:,0].T,B[:,10,:,
mp.title(r'Arrow plot of $\vec{B}$ along x-z plane')
mp.xlabel('x')
mp.ylabel('z')
mp.savefig('Fig2.png')

mp.figure(3)
mp.quiver(np.arange(-1,1.1,0.1),np.arange(-1,1.1,0.1),B[:,7,:,0].T,B[:,7,:,2]
mp.title(r'Arrow plot of $\vec{B}$ along y=-0.3')
mp.xlabel('x')
mp.ylabel('z')
mp.savefig('Fig3.png')

mp.figure(4)
mp.quiver(np.arange(-1,1.1,0.1),np.arange(-1,1.1,0.1),B[:,5,:,0].T,B[:,5,:,2]
mp.title(r'Arrow plot of $\vec{B}$ along y=-0.5')
mp.xlabel('x')
mp.ylabel('z')
mp.savefig('Fig4.png')

mp.figure(5)
mp.quiver(np.arange(-1,1.1,0.1),np.arange(-1,1.1,0.1),B[:,3,:,0].T,B[:,3,:,2]
mp.title(r'Arrow plot of $\vec{B}$ along y=-0.7')
mp.xlabel('x')
mp.ylabel('z')
mp.savefig('Fig5.png')

mp.show()
```


Arrow plot of $\vec{B}$ along x-z plane
1.0
0.5
0.0
−0.5
−1.0
z
−1.0
−0.5
0.0
0.5
1.0
x


Arrow plot of $\vec{B}$ along y=-0.3
1.0
0.5
0.0
−0.5
−1.0
z
−1.0
−0.5
0.0
0.5
1.0
x


Arrow plot of $\vec{B}$ along y=-0.5
1.0
0.5
0.0
−0.5
−1.0
z
−1.0
−0.5
0.0
0.5
1.0
x


Arrow plot of $\vec{B}$ along y=-0.7
1.0
0.5
0.0
−0.5
−1.0
z
−1.0
−0.5
0.0
0.5
1.0
x