IIIT-H

VIRTUAL LABS

Manual for MagnetoStatic Fields

Introduction

We have dealt with electric fields so far. Let us start with the other half of the Electromagnetism.

In the fifth century B.C, the Greeks knew that there are some rocks that attract bits of iron. They are very plentiful in the district of Magnesia, and so that's where the name "magnet" and "magnetism" comes from. The rocks contain iron oxide, which we call magnetite.

In 1100 A.D., the Chinese used these needles of magnetite to make compasses, and in the thirteenth century, it was discovered that magnetites have two places of maximum attraction, which we call poles.

Poles always occur in pairs. Magnetic monopoles do not exist so far. (if you find one you would win a Nobel Prize !!) This is not the case with electricity, we can have electric monopoles.i.e, we can have isolated charges(positive or negative).

We have seen that electric field is the interaction of two or more charges. In the similar way magnetic poles also interact with each other and hence we can figure out magnetic field.

Here we learn how magnetic fields are generated.

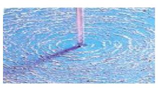
Objectives:

The main objectives of this experiment is to determine magnetic field intensity at various points due to::

1. To calculate the magnetic field at a point in space due to finite line current.
2. To calculate the magnetic field at a point in space due to infinite line current
3. To calculate magnetic field due to a infinite current sheet.
4. To calculate magnetic field due to two parallel infinite current sheets

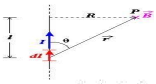
Theory:

Magnetic fields are produced by magnets and moving electric fields. A current through a straight wire produces magnetic field. For example as shown in the figure a straight wire carrying current creates magnetic field which causes the iron fillings to align in circular fashion.



In 1820, Hans Christian Oersted found that a magnetic compass needle deflects when placed near a wire carrying current.

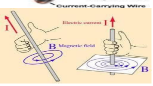
Biot and Savart formulated that the magnetic field dB produced at a point P, as shown in Figure , by the differential current element Idl is proportional to the product Idl and the sine of the angle θ between the element and the line joining P to the element and is inversely proportional to the square of the distance between P and the element.



$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$$

=> $$B = \int \frac{\mu_0}{4\pi}\frac{I d\mathbf{l} \times \hat{\mathbf{r}}}{|r|^2},$$

Direction of the magnetic field is given by right hand rule as shown in the figures below.



Magnetic fields are characterized by H, magnetic field intensity (magnetic field strength) or B, magnetic field (magnetic flux density or magnetic induction). As E and D are related according to D = εE for linear material space, H and B are related according to B = μH, where μ is the permeability of the material and its units are henry per metre (H/m) ($kg.m.s^{-2}.A^{-2}$).

We have seen various charge distributions like line charge, surface and volume charge. In the similar manner we can have current distributions like line current, surface current density characterized by K(in amperes/meter) and volume current density characterized by J(in amperes/meter^2). The three sources are related as follows.

$$I\,d\mathbf{l} \equiv \mathbf{K}\,dS \equiv \mathbf{J}\,dv$$

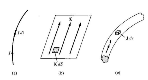


Fig: Various distributions of current: (a) line current (b) surface current (c) volume current

In terms of the distributed current sources, the Biot-Savart law becomes:

$$\mathbf{H} = \int_L \frac{I\,d\mathbf{l} \times \mathbf{a}_R}{4\pi R^2} \quad \text{(line current)}$$

$$\mathbf{H} = \int_S \frac{\mathbf{K}\,dS \times \mathbf{a}_R}{4\pi R^2} \quad \text{(surface current)}$$

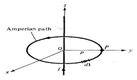
$$\mathbf{H} = \int_v \frac{\mathbf{J}\,dv \times \mathbf{a}_R}{4\pi R^2} \quad \text{(volume current)}$$

Ampere's Law

It is some times difficult to find the magnetic field due to various current distributions. In 1826 Andre-Marie Ampere formulated that the line integral of the tangential component of B around a closed path is the same as the net current I penetrating the closed surface (formed by the closed path) times μ_0 enclosed by the path. To obtain the magnetic field intensity remove the μ_0 from the below expression and replace B by H.

$$\oint_C \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I_{enc}$$

We now apply Ampere's circuit law to determine H(multiply by µ to obtain B) for some symmetrical current distributions as you would have done using Gauss's law for charge distributions. We will consider an infinite line current and an infinite current sheet.



Let us consider a long filamentary current I(by filamentary we mean the radius of is negligible or very thin) which is placed along the z-axis as in Figure. We assume it to be infinitely long. Our aim is to determine the magnetic field intensity H at point P. We have to choose a closed path (when we form a closed surface with this path it must be penetrated by a filamentary current - you will appreciate the significance of the idea of penetration when working with current loop containing several turns) and it must pass through the point P. The path is as shown above and is called as Amperian Path. If you choose a symmetrical path then solving the problem would be easy. Now evaluating the mathematical part of ampere's law would yield:

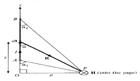
$$I = \int H_\phi \mathbf{a}_\phi \cdot \rho\, d\phi\, \mathbf{a}_\phi = H_\phi \int \rho\, d\phi = H_\phi \cdot 2\pi\rho$$

Which turns out to be:

$$\mathbf{H} = \frac{I}{2\pi\rho}\mathbf{a}_\phi$$

But if we consider a finite line current AB as shown below and magnetic field at a point P, whose distance is comparable to the dimensions of the length then the integral results in

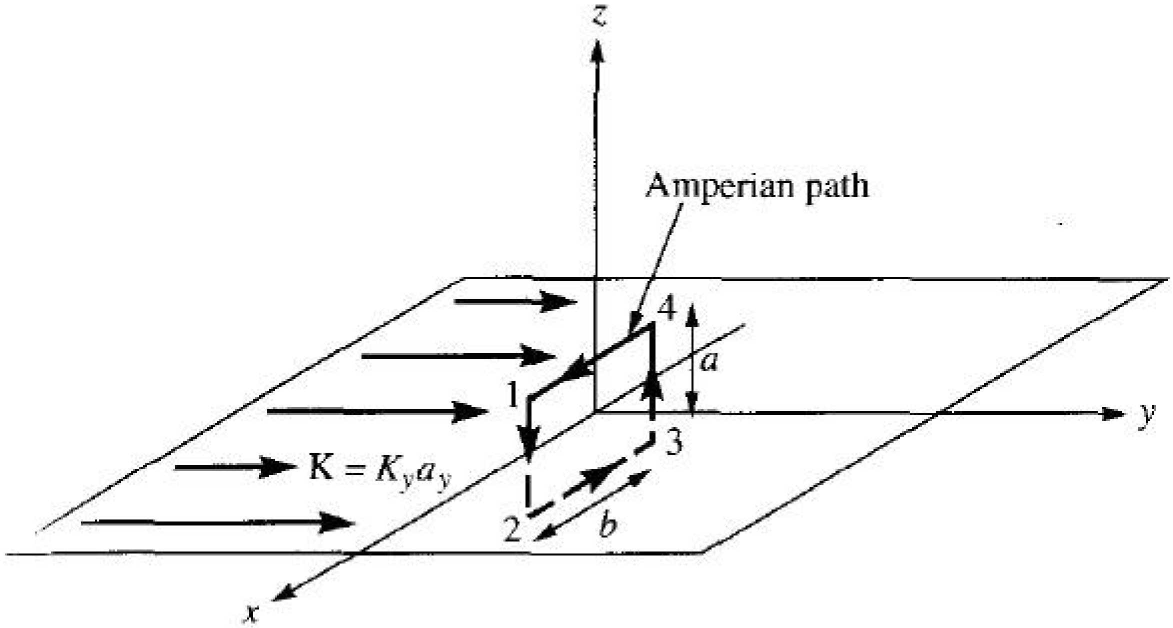
$$\mathbf{H} = \frac{I}{4\pi\rho}(\cos\alpha_2 - \cos\alpha_1)\mathbf{a}_\phi$$



Choosing an Amperian path would be tricky in above case. The Amperian path must contain the point P and the surface formed by the path must be penetrated by the current.

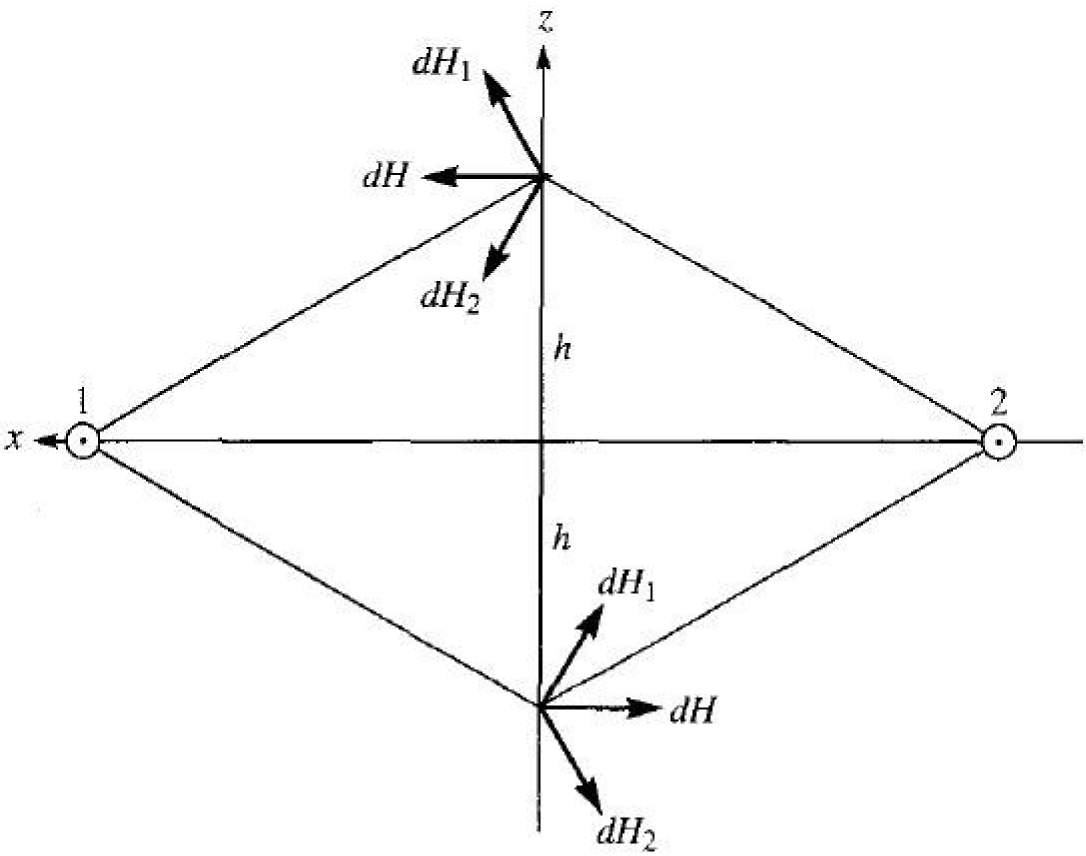
Now let us consider an infinite plane sheet containing an electric current which is in the same direction everywhere. The strength of the current would be described by current per unit length (with the 'length' drawn at right angles to the direction of the current). So the units of 'surface current density' would be amps/metre.

To find the H at a distance a/2 from the sheet whose surface current density is $K_y a_y$ A/m we first need to have an idea of what H is like. To achieve this, we regard the infinite sheet as comprising of filaments; dH above or below the sheet due to a pair of filamentary currents located at 1 and 2 is shown below.



The Bio-Savart law shows that the contributions to H_z produced by a symmetrically located pair of filaments cancel. Thus, H_z is zero and only H_x component is present. It is evident from the figure below that no current filament can produce H_y .

Therefore to apply ampere's law we can choose the amperian path as 1-2-3-4.



Applying Ampere's law we have

$$\mathbf{H} = \begin{cases} H_o \mathbf{a}_x & z > 0 \\ -H_o \mathbf{a}_x & z < 0 \end{cases}$$

where

$$H_o = \frac{1}{2} K_y$$

Thus we can find magnetic field (or its intensity) due to various current distributions applying Ampere's Law and we need to have prior knowledge of how magnetic field would be like, to choose the appropriate Amperian Path.

Procedure:

This experiment consists of four stages and each stage will teach you a new concept.

The experiment was designed in a way, so that you can quickly change the parameters and observe the results. This makes you to have a more clear picture of the concepts.
Start the experiment by pressing *start* button

- **STAGE 1**:
    1. In stage 1, we will see that magnetic field is generated from the moving electric charges.
    2. Here you can change the parameters current density, coordinate of the point where magnetic field has to be measured, and the length of the wire (remember it is a finite wire) using the sliders provided at the bottom of the window.
    3. After setting parameters, click the button "Run Simulation". You can see the animation of process of calculating magnetic field intensity at a point.
    4. In the experiment only x-coordinate of a point can be changed. Calculate the magnetic field intensity at various paoints(refer the theory section !!!)
    5. Observe the graphs on the right hand side of window. Analyze them and try to make a report of your understanding of the graph. (ofcourse, you can always refer to theory section)
    6. To move on to next stage press next button on the top of window.

- **<u>STAGE 2</u>**:

  Now, we show the above process for a infinite current carrying wire.

  1. Changing parameters is similar to above (Make a note of about alpha, beta values).
  2. To move on to next stage press next button on the top of window.

- **<u>STAGE 3</u>**:

  1. Now, we move on to experiment on infinite current sheet. vary the current density by using the sliders provided at the bottom of the window.
  2. Click on the screen to know direction and magnitude of magnetic field intensity at a particular point (observe the arrows on the gaussian surface (cube like surface)).
  3. Analyze the graphs based on the formula shown in the window.

- **<u>STAGE 4</u>**:

  Now, we show the process of stage 3 for a infinite current charge (Tired ?? last stage !!!)

  1. Here, you can better understand the magnetic field intensity. Using mouse, click on the screen and make a report on the following:
  2. By clicking between the infinite current sheets
  3. By clicking outside the infinite current sheets
  4. How would the graph of H vs r look like.