Phys 132 2022

Lecture 23

Weds: Discussion / quiz

Thurs: Warm Up 9

Field produced by a loop along loop axis

The Biot-Savart Law can be used to find the magnetic field produced by any stationary current.

$$\vec{B}_{segment} = \frac{\mu_0}{4\pi} \frac{I \Delta\vec{s} \times \hat{r}}{r^2}$$

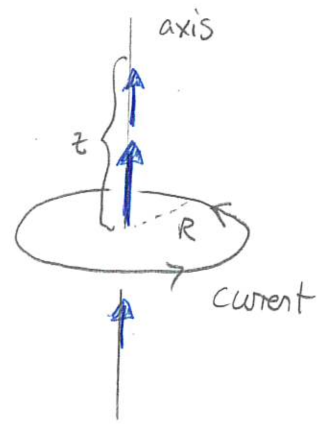
In general the calculations that result are apparently insurmountable. However, it can be used to find the magnetic field anywhere along the axis of a circular loop of current. It gives:

1) field magnitude at location height z above the plane of the loop

$$B = \frac{\mu_0}{2} \frac{I R^2}{(z^2+R^2)^{3/2}}$$

2) field direction given by r.h. rule

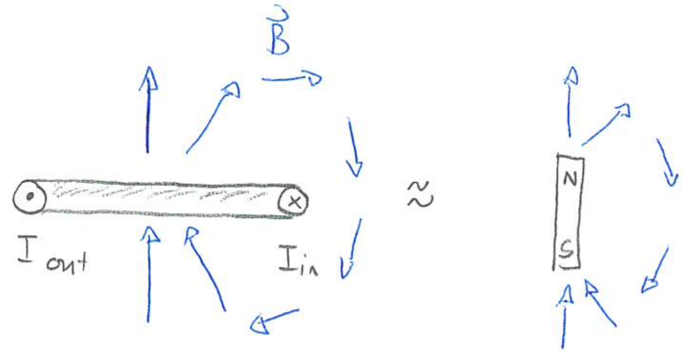
- orient r.h. so fingers curl in current sense → thumb points field direction.



Demo: Current board with loop - place compass at various locations

Demo: PSU-S $\vec{B}$ field for a single loop.

This field resembles the field produced by a bar magnet. Since a bar magnet has two poles we will call the current loop a magnetic dipole.



We can assess the interactions between such loops or dipoles by translating each to a bar magnet and using those to model the interaction.

Quiz 1 ~ 50% - 80%

Loops of current, particularly with small spatial dimensions, are important in the study of magnetism:

1) the magnetic dipole approximation allows one to approximate the field well at distances far from the current loop.

2) such loops provide models of permanent magnets. Here a permanent magnet is simply a collection of aligned loops.

3) magnetic dipoles provide a model of how broad classes of materials respond to external magnetic fields.

4) loops of currents provide controllable magnetic fields - such magnetic fields are used in NMR, MRI, ...

In general the magnetic dipole approximation results in a measure of the magnet's dipole properties:

The magnetic dipole moment for any current loop is a vector $\vec{m}$:

1) magnitude

$$m = IA$$

2) direction via the r.h. rule.

Units Am^2

The classical theory of electromagnetism describes how to determine the magnetic dipole moment for any current distribution. However, the idea extends to subatomic particles (electron, proton, ...) and some of these have non-zero dipole moments even though no charge can conceivably be moving to produce a current loop. Such particles enable the technology of NMR, MRI, ...

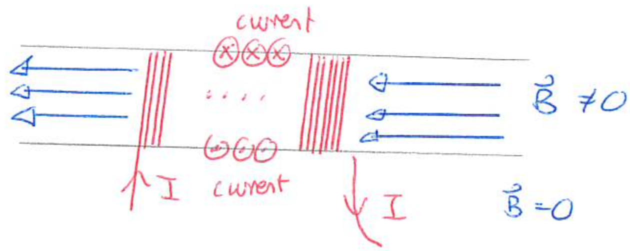
Demo: PhET MRI - show simplified NMR

Solenoids.

A solenoid is a collection of stacked loops that can carry current.

Demo: * Actual solenoid

* Solenoid tube



In order to analyze this we note the current sense and use a version of the r.h. rule to determine the field direction. A reworking of the Biot-Savart law results in Ampère's Law which allows exact calculation of the magnetic field produced by an infinitely long solenoid

The magnetic field due to an infinitely long solenoid is:

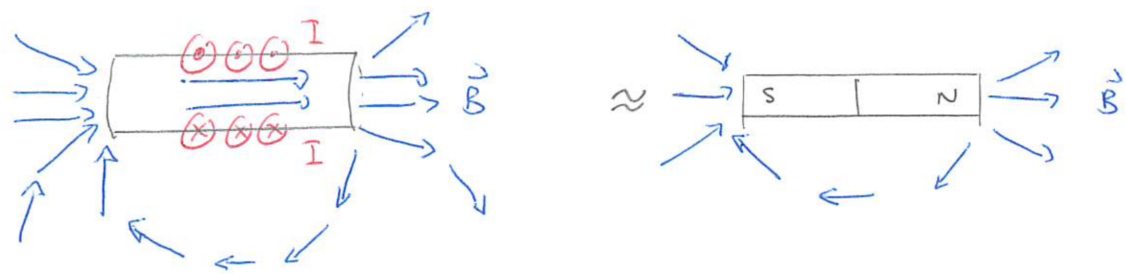
1) zero outside the solenoid
2) uniform inside " " with magnitude

$$B = \mu_0 I n$$

where n is the number of coils per meter. The r.h. rule gives the direction.

Quiz 2 ~ 30% - 60%

A finite length solenoid behaves like a bar magnet

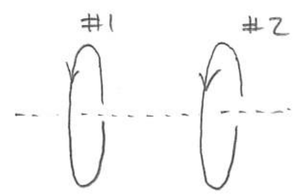


Quiz 3 ~70% ~90%

Demo: Current board/solenoid

Forces exerted by magnetic fields

Consider two current-carrying loops in each other's vicinity. Since each acts as a bar magnet, we expect that loop #1 will exert a force on loop #2. We can restate this as:



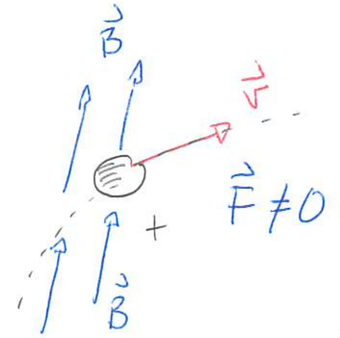
(loop 1 produces a field $\vec{B}_1$) → (The field $\vec{B}_1$ exerts a force on the current in loop 2)

We can raise the question - will a magnetic field exert a force on a moving charge.

Demo: Crooke's tube + magnet

In general:

(A magnetic field will exert a force on any moving charged particle)



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