Amphere's Law

1

Producing a magnetic field

Electric fields are produced by charges.

Magnetic fields are produced by moving charges.

In practice, we produce magnetic fields from currents. By using Ampere's Law, we can predict the magnetic fields due to several various current configurations. In this course, we will discuss the magnetic field due to a straight current carrying wire, a ring of current, and a solenoid.

2

The magnetic field from a long straight wire

The long straight current-carrying wire, for magnetism, is analogous to the point charge for electric fields.

The magnetic field at a distance *r* from a wire with current I is:

$$B = \frac{\mu_0 I}{2\pi r}$$

μ_0, the permeability of free space, is:

$$\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$$

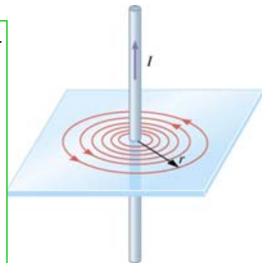


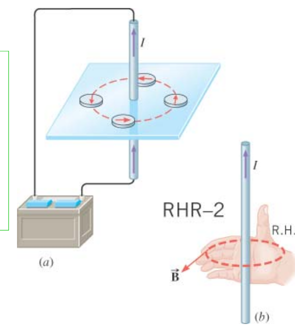
Figure above shows the field lines about a current-carrying straight wire.

3

The magnetic field from a long straight wire

The direction of the field follows another right-hand rule:

Right-Hand Rule No. 2. (RHR-2) Curl the fingers of the right hand into the shape of a half-circle. Point the thumb in the direction of the conventional current, and the tips of the fingers will point in the direction of the magnetic field.



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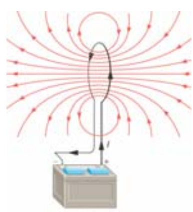
The field from a circular current loop

At the center of the circular loop, the magnetic field is:

$$B = \frac{\mu_o I}{2R}$$

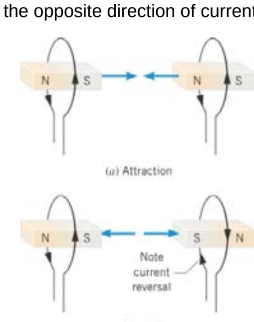
where R is the radius of the loop.



The above shows that the field lines around the loop resemble those from a bar magnet. The direction of the magnetic field can be determined by yet **another RHR** as shown at right.

Forces between two current loops

Again, we have like attract and unlike repel.
Loops with the same direction of current flow attract.
Loops with the opposite direction of current flow repel.



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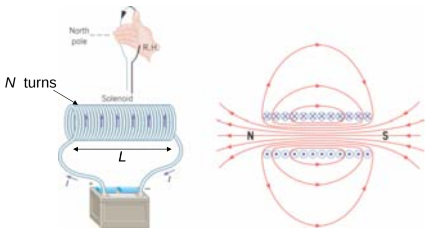
The field from a solenoid



For a solenoid of length L, current I, and total number of turns N, the magnetic field inside the solenoid is given by:

$$\boxed{B = \frac{\mu_0 N I}{L}}$$

The direction of the magnetic field is determined by the same RHR that determines the direction of the magnetic field in a current loop.

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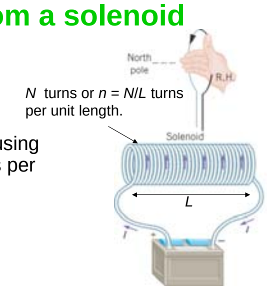
The field from a solenoid

$$B = \frac{\mu_0 N I}{L}$$



We can make this simpler by using $n = N/L$ as the number of turns per unit length, to get:

$$B = \mu_0 n I$$

The magnetic field is almost **uniform** - the solenoid is the magnetic equivalent of the parallel-plate capacitor. If we put a piece of ferromagnetic material (like iron or steel) inside the solenoid, we can modify the magnetic field by a large factor (in here, the field is magnified, and the magnification can be 1000 or so).

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The magnetic field due to a wire

A long-straight wire carries current out of the page. A second wire, to the right of the first, carries current into the page. In which direction is the magnetic field that the second wire feels because of the first wire?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net force is zero

$I_1 \odot$ $\quad$ $I_2 \otimes$

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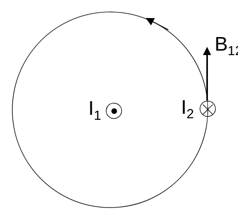
The magnetic field due to a wire

A straight wire produces magnetic fields with field lines forming concentric circles. By using RHR-2, we can figure that the field lines are counter-clockwise. So, at where wire 2 is, the field is pointing up.



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The force between two wires

A long-straight wire carries current out of the page. A second wire, to the right of the first, carries current into the page. In which direction is the force that the second wire feels because of the first wire?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net force is zero

$I_1 \odot$ $\quad$ $I_2 \otimes$

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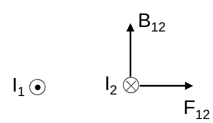
The force between two wires

By RHR-2, we have determined the field is pointing up. Next, use RHR-1, we can determine that the magnetic force is pointing right.



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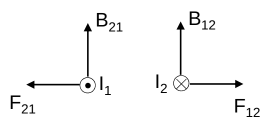
The force between two wires

It is straightforward to show that the force on wire one due to the field, B_{21}, produced by the current in wire 2 causes a magnet force in wire one, F_{21} that has the same magnitude but opposite direction to that of F_{12}.



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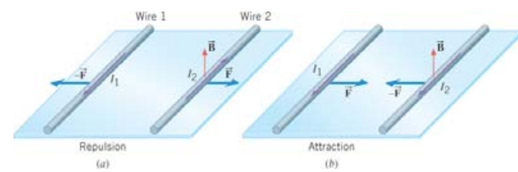
The force between two wires

In this situation, opposites repel and likes attract!
Parallel currents going the same direction attract.
If they are in opposite directions they repel.



Make sure that you can see why B is pointing up at where wire 2 is!

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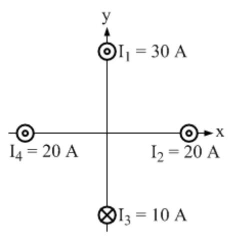
The net magnetic field

In which direction is the net magnetic field at the origin in the situation shown below? All the wires are the same distance from the origin.

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net field is zero



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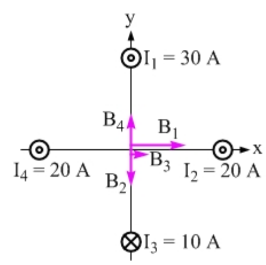
The net magnetic field

We add the individual fields to find the net field, which is directed right.



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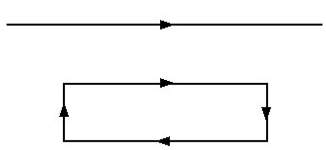
A loop and a wire

A loop with a clockwise current is placed below a long straight wire carrying a current to the right. In which direction is the net force exerted by the wire on the loop?

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net force is zero



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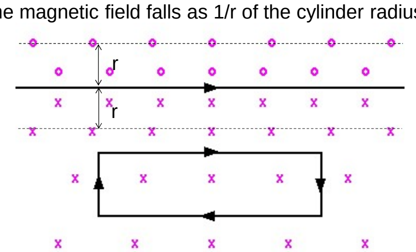
A loop and a wire

The long straight wire creates a non-uniform magnetic field, pictured below. Recall: $B = \mu_0 I/(2\pi r)$. So any point lying on a cylinder with radius r about the wire has the same magnetic field. The magnetic field falls as 1/r of the cylinder radius.



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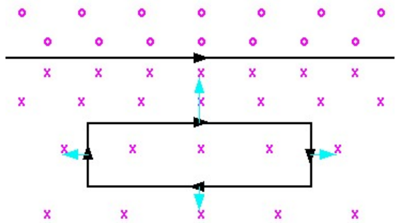
A loop and a wire

The forces on the left and right sides cancel, but the forces on the top and bottom only partly cancel – the net force is directed up, toward the long straight wire.



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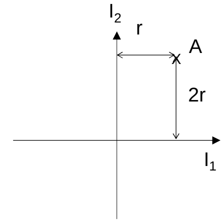
Magnetic field due to two wires

Two long, insulated, current carrying wires are perpendicular to each other. Suppose the magnitude of I_1 is thrice that of I_2 and their directions are as indicated in the figure. What is the direction of the magnetic field at the point A?



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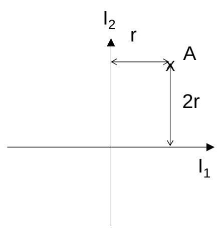
Magnetic field due to two wires

Solution:

I_1 will produce a field B_1 at A with magnitude $\mu_0 I_1/(4\pi r)$ and directed out of screen by RHR-2. At the same time I_2 will produce a field B_2 at A with magnitude $\mu_0 I_2/(2\pi r)$ and directed into the screen. Since $I_1 = 3I_2$, $|\mathbf{B_1}| = 3/2|\mathbf{B_2}|$, the net field should be dominated by $\mathbf{B_1}$ and points out of screen.



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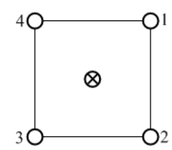
Example: Five wires

Four long parallel wires carrying equal currents perpendicular to your page pass through the corners of a square drawn on the page, with one wire passing through each corner. You get to decide whether the current in each wire is directed into the page or out of the page.

First we'll have a fifth parallel wire, carrying current into the page, that passes through the center of the square. Can you choose current directions for the other four wires so that the fifth wire experiences a net force directed toward the top right corner of the square?



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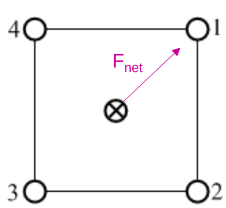
How many ways?

You can choose the direction of the currents at each corner. How many configurations give a net force on the center wire that is directed toward the top-right corner?

1. 1
2. 2
3. 3
4. 4
5. 0 or more than 4



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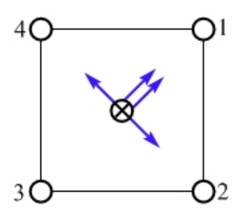
How many ways?

First, think about the four forces we need to add to get a net force toward the top right. How many ways can we create this set of four forces?



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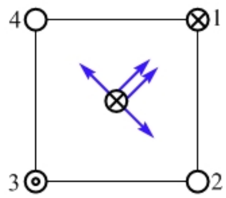
How many ways?

How many ways can we create this set of four forces?

Recall: Currents going the same way attract; opposite currents repel.

Two. Wires 1 and 3 have to have the currents shown. Wires 2 and 4 have to match, so they either both attract or both repel.



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