Physics 1B
Electricity & Magnetism

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Outline of today

- Start Chapter 22
  - Magnetic field

Magnetic Fields

The proper way to handle magnetic forces is to concentrate on magnetic fields.

A magnetic field is located in a region of space surrounding a moving charge.

This charge will also have an electric field surrounding it.

A magnetic field is a vector quantity given by:

$$\vec{B}$$

The SI unit of the magnetic field, B is the Tesla.

Earth's magnetic field is: 0.5×10^{-4} Teslas.

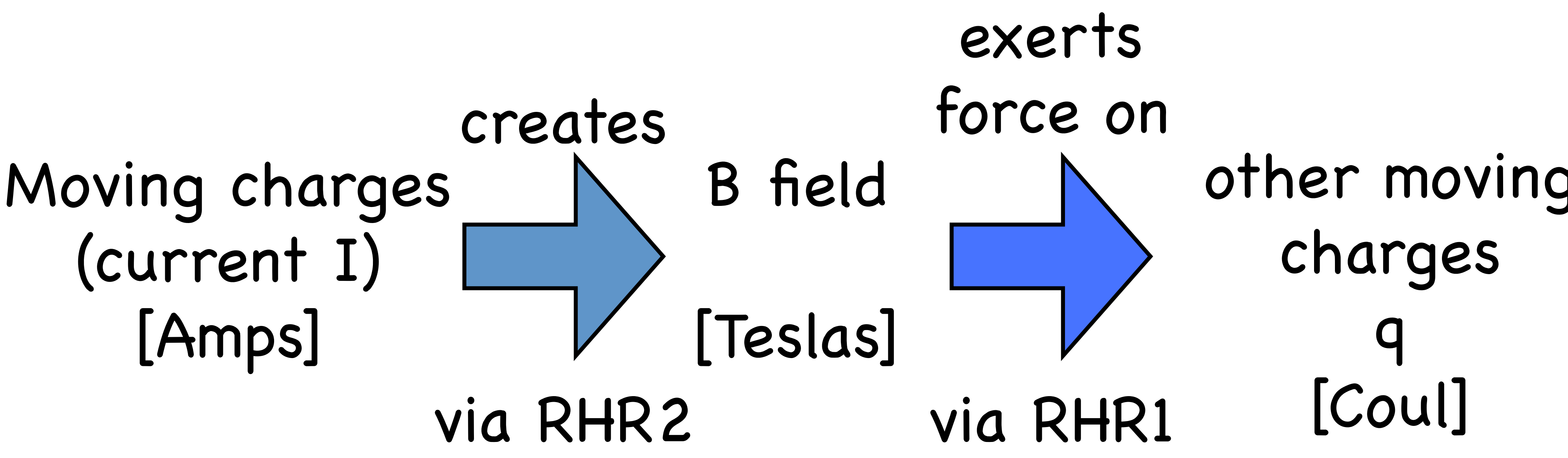
Magnetic Fields

We will treat magnetic forces and fields how we treated electric forces and fields.

We will use a two-step process:

step (i): Moving charges, I, creates a B field.

step (ii): Moving charge, q, experiences magnetic force from the field.



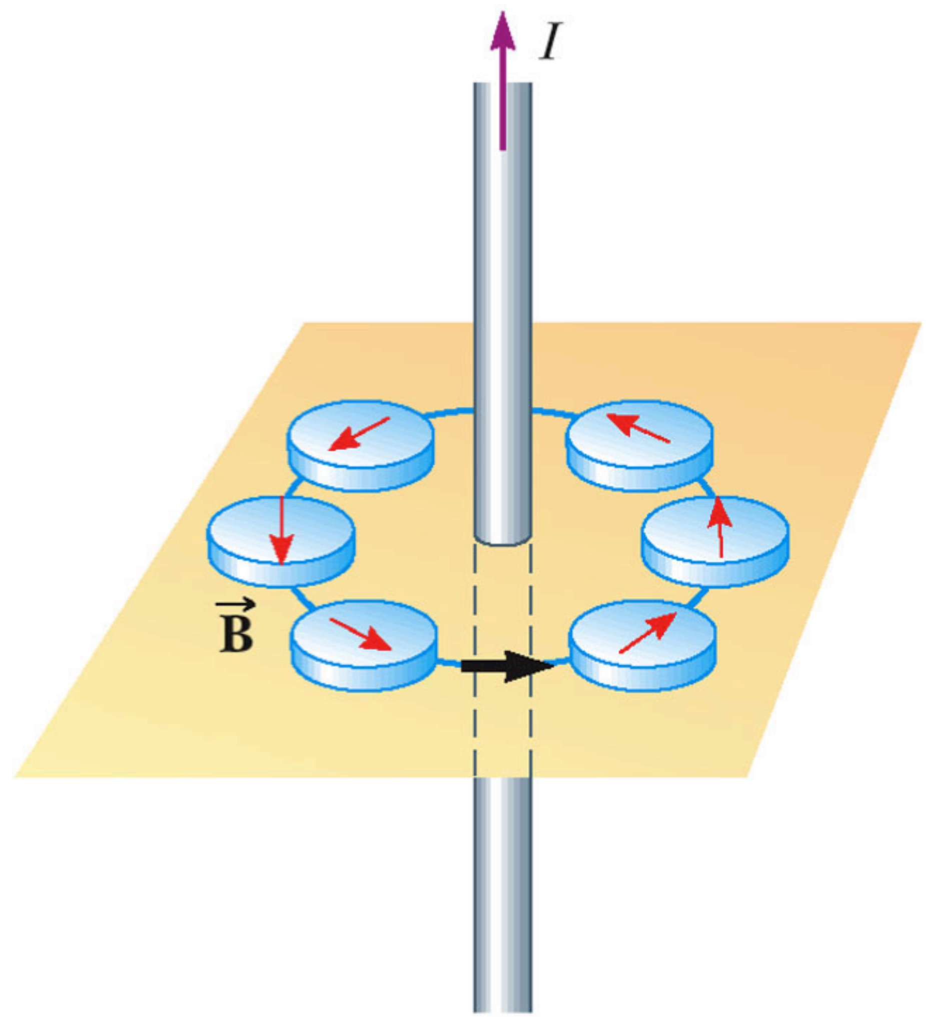
Magnetic Fields

Note that a moving charge will not create a magnetic field, B, that will exert a force on itself.

That violates Newton's Third Law (you need two objects to have a force).

Let's examine the simplest case of a long, straight wire with current I.

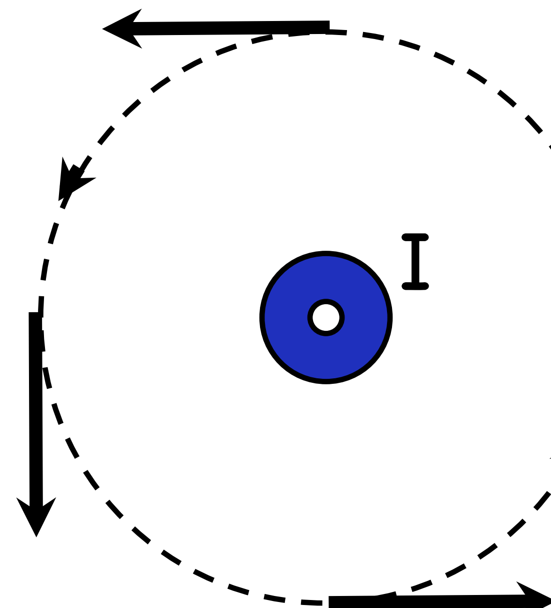
This current will create a magnetic field, B, surrounding it.



Step 1

Many times you will be asked for the magnetic field at a given point.

Here you will just apply RHR2, but take the tangent of the curve at the given point for your answer.



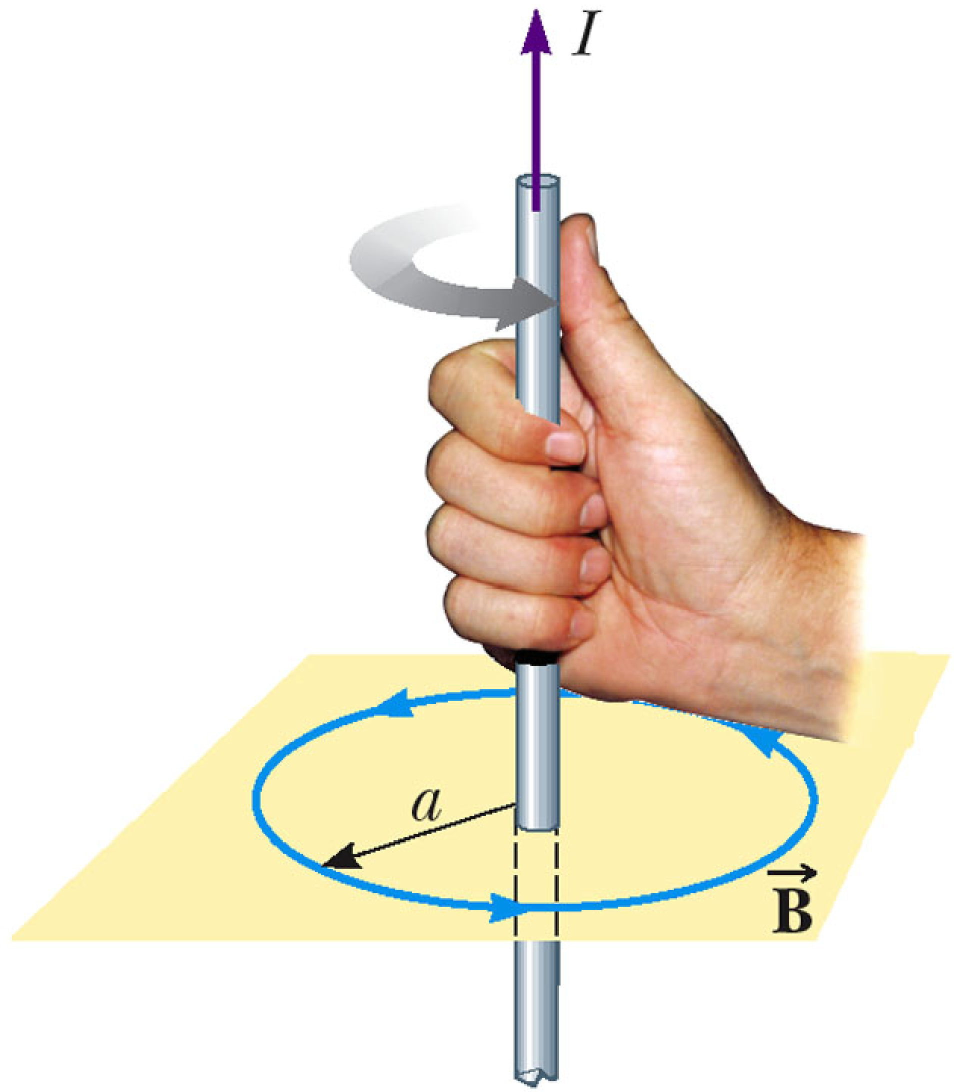
For example, if we were standing below the wire we would observe the magnetic field moving to the right.

But if we were standing above the wire we would observe the magnetic field moving to the left.

Step 1

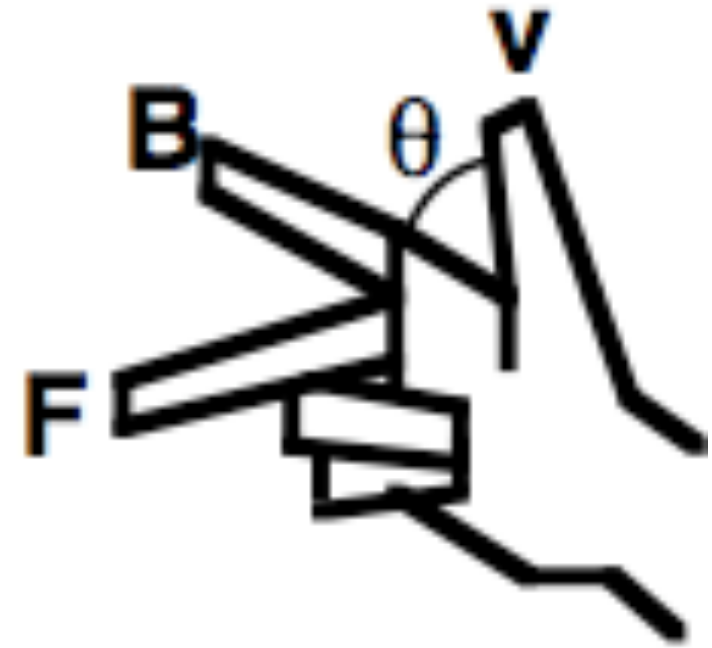
To find the magnitude of the magnetic field from a very long, straight wire use:

$$\left|\vec{B}\right| = \frac{\mu_o I}{2\pi r}$$



Step 2

Then to find the direction of the magnetic force on a moving charge, q, due to magnetic field, B use RHR.



$$\vec{F} = q\vec{v} \times \vec{B}$$

To find the magnitude of the magnetic force on a moving, v, charge, q, due to magnetic field, B use:

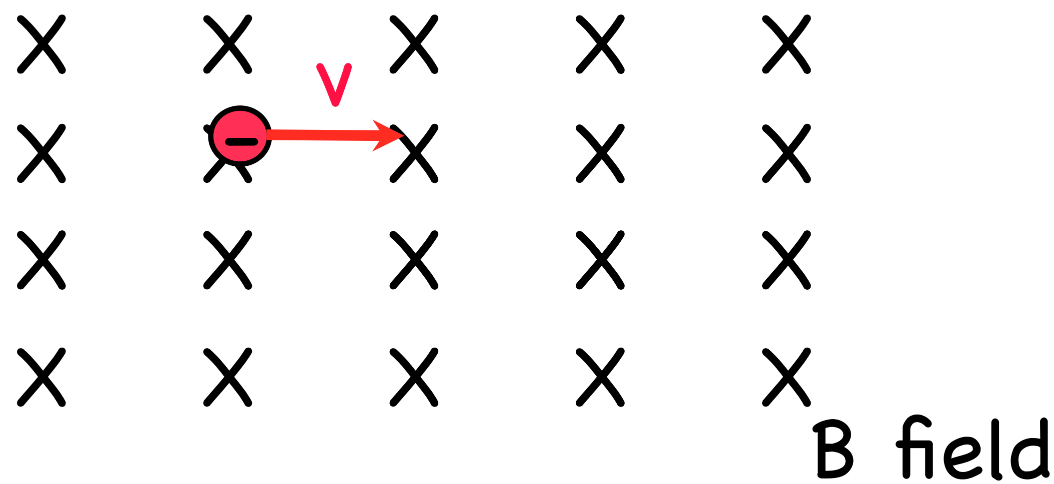
$$F = q|\vec{v}||\vec{B}|\sin\theta$$

where θ is the angle between the velocity and magnetic field vectors.

Step 2

<u>Example</u>

An electron travels at $2.0 x 10^7 m/s$ in a plane perpendicular to a 0.10T large uniform magnetic field as shown below. Describe its resulting path (both magnitude and direction).



<u>Answer</u>

First, you must define a coordinate system.

Let's say the original direction of motion of the electron as the positive x-direction.

Step 2

Answer

Originally, the electron moves to the right and the magnetic field is into the page (board).

Apply RHR1, put your thumb in direction of velocity, your forefinger in the direction of the B-field.

The resulting magnetic force is upward. But you ask yourself one last question, is the electron positively or negatively charged?

It is negatively charged, so you flip the magnetic force vector so that it is downward.

So, the electron will originally feel a downward force due to the external magnetic field.

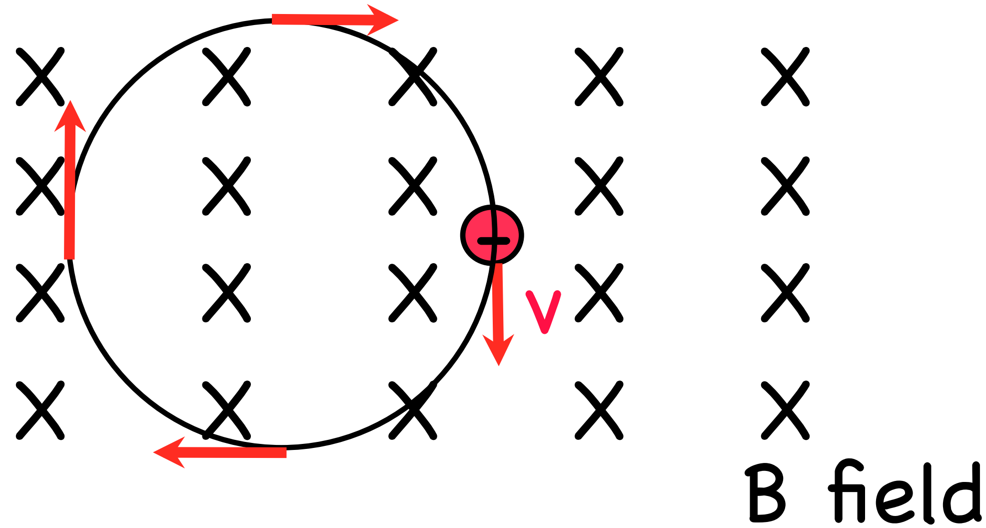
Step 2

Answer

This means that the electron will eventually be moving downward in the magnetic field.

Now, which direction will it feel a force?

Via RHR1, it will feel a force to the left (don't forget to flip the vector at the end).



This will keep on occurring until it completes one circular loop (and then it keeps repeating).

So, the resulting path will be circular (clockwise) as the magnetic force causes centripetal acceleration.

Step 2

v=2.0x10^{7}m/s
B=0.10T

Answer

To find the magnitude, use Newton's 2nd Law with the magnetic field causing a centripetal acceleration.

$$\sum F = ma$$

$$F_B = ma_c$$

$$qvB\sin\theta = m\frac{v^2}{r}$$

$$qB(1) = m\frac{v}{r}$$

$$r = \frac{mv}{qB}$$

We know all of the variables (e and m_e can be looked up).

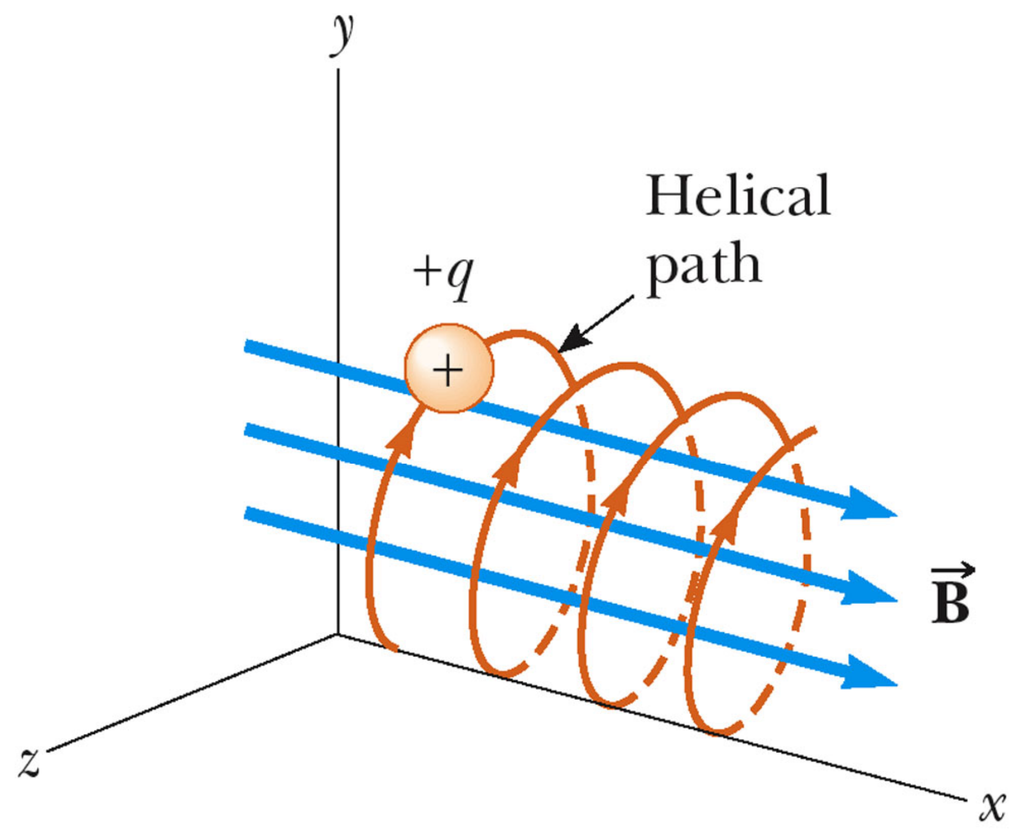
$$r = \frac{(9.11\times10^{-31}\text{kg})(2.0\times10^{7}\ \text{m/s})}{(1.60\times10^{-19}\text{C})(0.10\text{T})} = 1.1\times10^{-3}\text{m}$$

Note that the radius of the path followed depended on the mass and the charge of the object.

We can use this fact to separate objects with the same charge but with different masses (Mass Spectrometer).

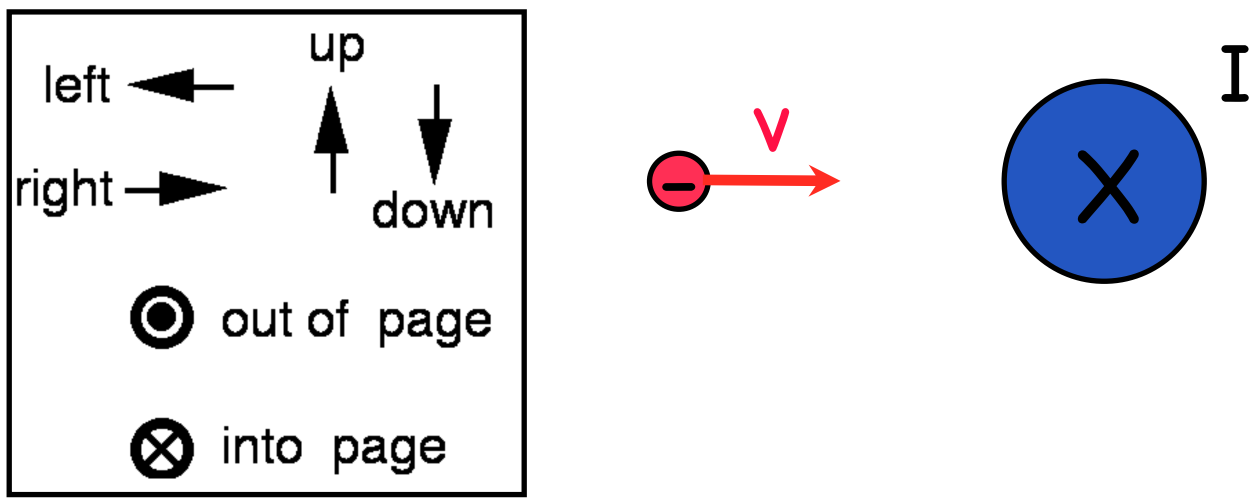
In the previous example, if the electron's original velocity was not perpendicular to the magnetic field, then the resulting path will be a spiral.

This spiral path is called a helix.



Magnetic Forces

- <u>Example</u>
- Consider an electron 1.00cm away from a wire with a current of 0.500A. Calculate the magnitude and describe the direction of the magnetic force exerted on this electron, if it moves at a velocity of 1.00mm/s radially inwards towards the wire.



<u>Answer</u>

First, you must define a coordinate system.

Let's choose the center of the wire as r=0 and have standard directional conventions.

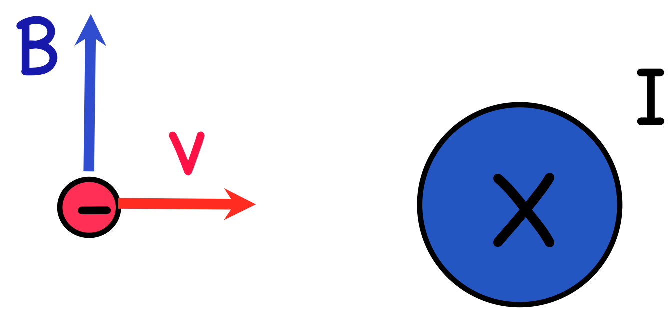
Step 1

<u>Answer</u>

Let's take this step-by-step; first step one: find the magnetic field created by the wire at the location of the electron.

Apply RHR2, and we find that at the location of the electron the magnetic field is upwards.

The magnitude of the magnetic field will be given by:



$$\left|\vec{B}\right| = \frac{\mu_o I}{2\pi r}$$

$$B = \frac{\left(1.26\times10^{-6}\ \mathrm{T\cdot m}/\mathrm{A}\right)\left(0.5\mathrm{A}\right)}{2\pi\left(0.01\mathrm{m}\right)} = 1.00\times10^{-5}\,\mathrm{T}$$

Step 2

Answer

Now, for step two: find the magnetic force caused by the magnetic field.

Apply RHR1, put your thumb in direction of velocity, your forefinger in the direction of the B-field.

The resulting magnetic force is out of the page. But you ask yourself one last question, is the electron positively or negatively charged?

It is negatively charged, so you flip the magnetic force vector so that it is into the page.

So, the magnetic force on the electron is parallel to the direction of the current.

Step 2

Answer

Next, to calculate the magnitude use the magnetic force equation:

$$F = q\left|\vec{v}\right|\left|\vec{B}\right|\sin\theta$$

$$F = \left(1.60\times10^{-19}\,\mathrm{C}\right)\left(1.0\times10^{-3}\,\mathrm{m/s}\right)\left(1.0\times10^{-5}\,\mathrm{T}\right)\sin 90^\circ$$

$$F = 1.60\times10^{-27}\,\mathrm{N}$$

The electron will be deflected toward the direction of the current flow.

If we reversed the direction of the current, then the force on the electron would have reversed as well.

Concept Question

- Two current-carrying wires are exactly parallel to one another and both carry 1 Amp of current. The current in wire 1 moves up while the current in wire 2 moves down. What is the direction of the magnetic field caused by wire 1 at the location of wire 2?

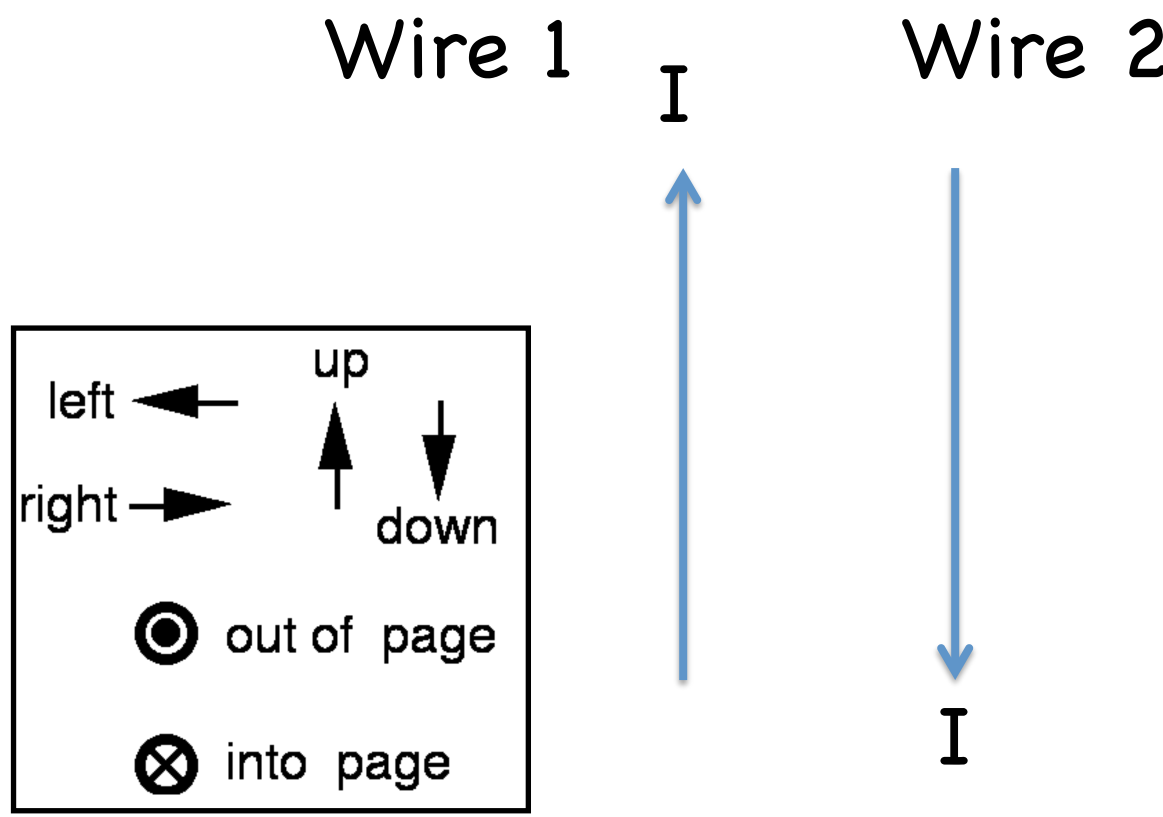
A) Into the page.

B) Out of the page.

C) Up.

D) To the left.

E) To the right.



Concept Question

- Two current-carrying wires are exactly parallel to one another and both carry 1 Amp of current. The current in wire 1 moves up while the current in wire 2 moves down. What is the direction of the magnetic force caused by wire 1 on wire 2?

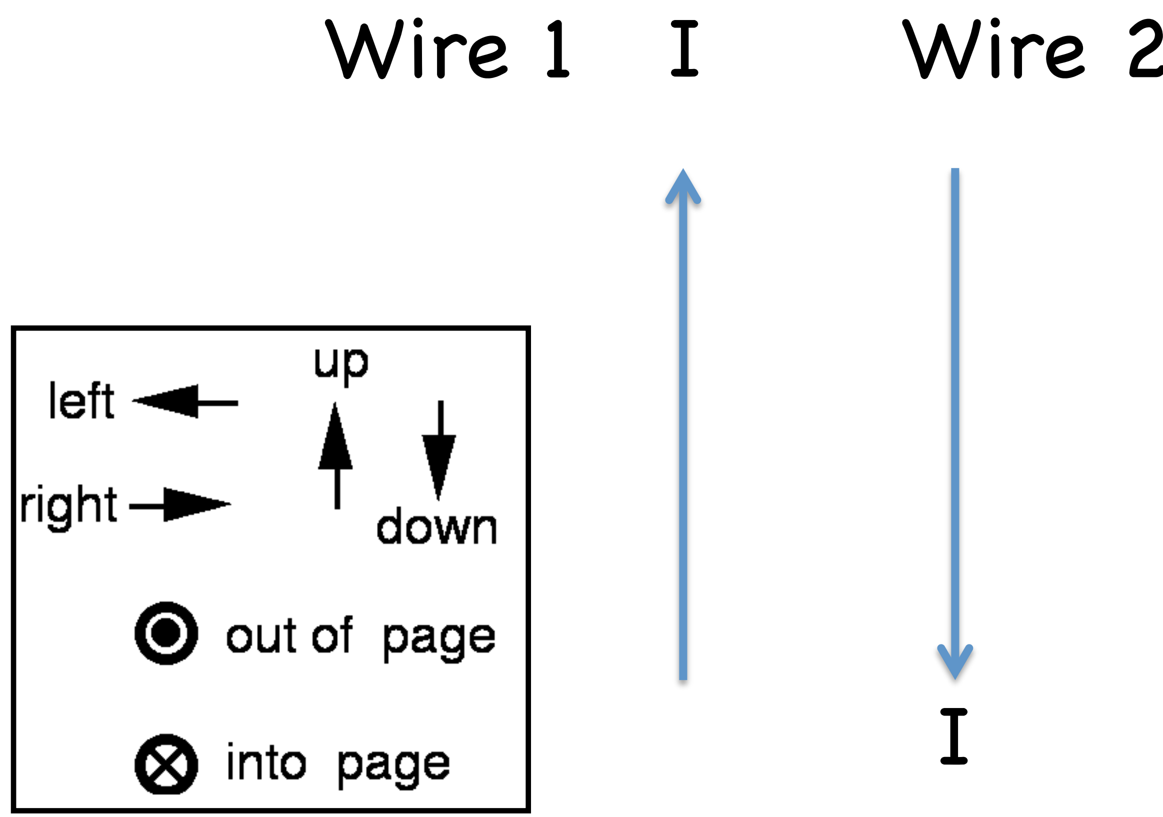
A) Into the page.

B) Out of the page.

C) Up.

D) To the left.

E) To the right.



For Next Time (FNT)

Keep reading Chapter 21

Start working on the homework for Chapter 21