PHYSICS 571 – Master's of Science Teaching

"Electromagnetism and Light"

Lecture 2 – Magnetic Forces on Charges and Currents

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Magnetism and Electromagnetic Induction

"He who controls magnetism controls the universe."

—Dick Tracy

Outline

Magnetic force on a charge
Magnetic force between two wires
Vector Cross product and right-hand rule
Force on a charge revisited
Magnetic field of a straight wire
Force on a current revisited

Magnetic Force on a charge

If the charge is moving at right angles to the field, then

$F = qvB$

Magnetic Force on a charge

If an electron moves at 200 km/s at right angles to a 3 Tesla magnetic field, what force is exerted on it?

$F = qvB$

Magnetic Force on a charge

A U-235 ion with a charge of +3 is in a centrifuge and is moving at 1000 km/sec. What B-field is needed to keep it moving in a circle of radius 0.5 meters?

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Magnetic Force between two wires

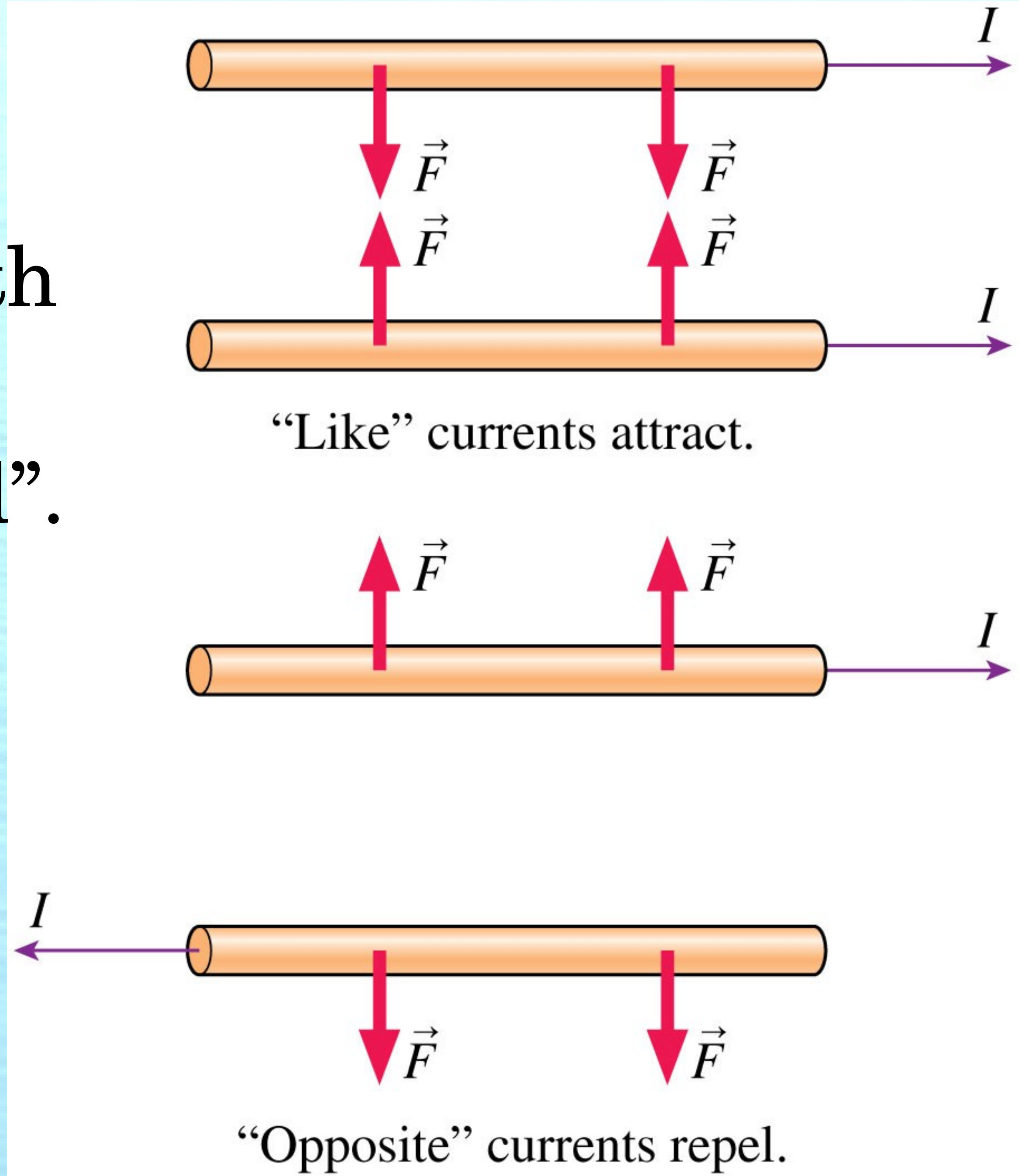
Two wires are 5 meters long and each carry 15 amperes while separated by a millimeter. What is the force between them?

$$F = \mu_0 \frac{I_1 I_2 L}{2\pi d}$$

Magnetic Force between two wires

Wires are assumed
To be of same length
"L". Distance
Between them is "d".

$$F = \mu_0 \frac{I_1 I_2 L}{2 \pi d}$$



Magnetic Force between two wires

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$$F = \mu_0 \frac{I_1 I_2 L}{2 \pi d}$$

Magnetic Permeability in air ---> $\mu_0 = 4\pi \times 10^{-7}$

$$F = \mu_0 \frac{I_1 I_2 L}{2\pi d}$$

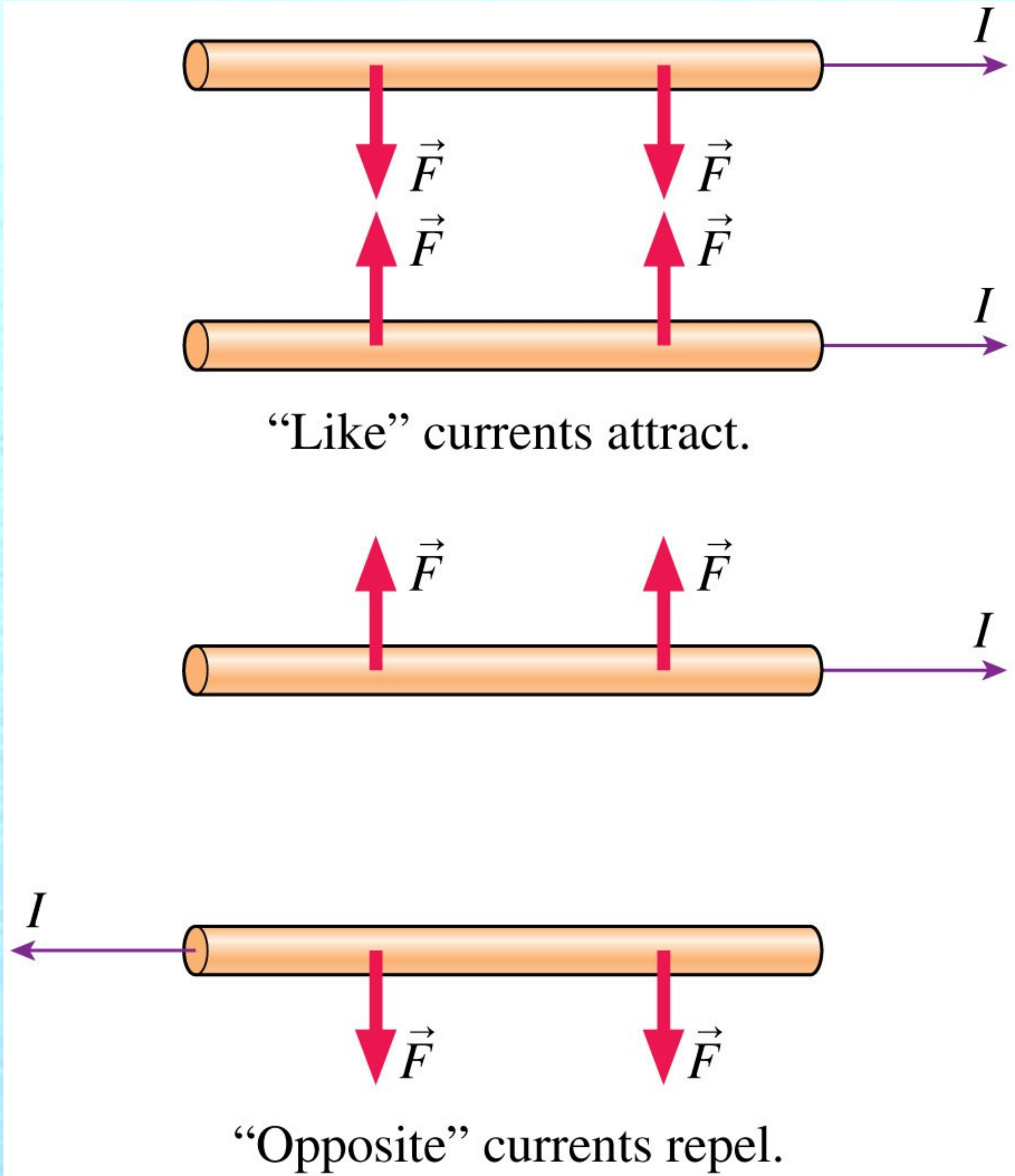
Force between two parallel wires

Electric Permittivity in air ---> $\epsilon_0 = 8.86 \times 10^{-12}$

$$F = \frac{1}{\epsilon_0} \frac{\lambda_1 \lambda_2 L}{2\pi d}$$

Force between two charged wires
Lambda is charge per unit length

DEMO: Force between two wires



Magnetic Poles
CHECK YOURSELF

Wire A having 10 Amps runs current parallel to wire B carrying 20 Amps. Which wire feels the greater attractive force?

A. A
B. B
C. Forces are the same
D. none of the above

Magnetic Poles
CHECK YOURSELF

Wire A having 10 Amps runs current parallel to wire B carrying 20 Amps. Which wire feels the greater attractive force?

A. A

B. B

C. Forces are the same ← Newton's third law is true even if you don't know ANYTHING about magnetism...

D. none of the above

$$F = \frac{\mu_0 L}{2\pi d} I_1 I_2$$

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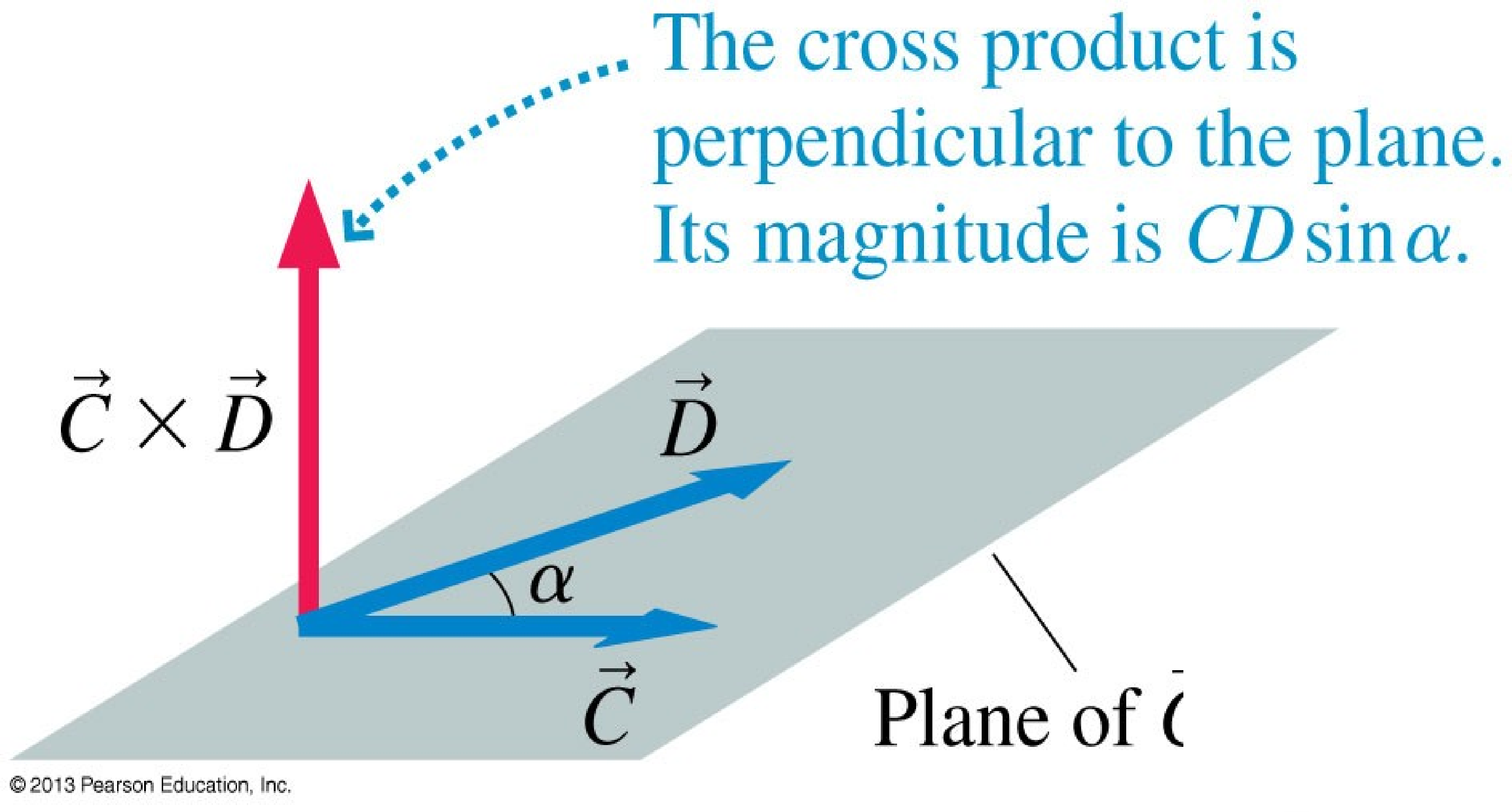
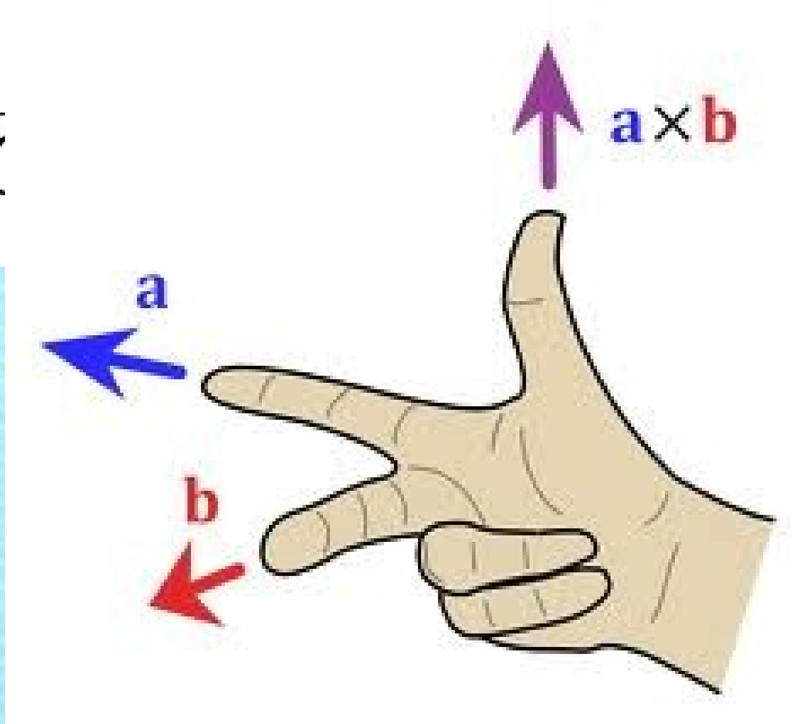
Vector Cross Product





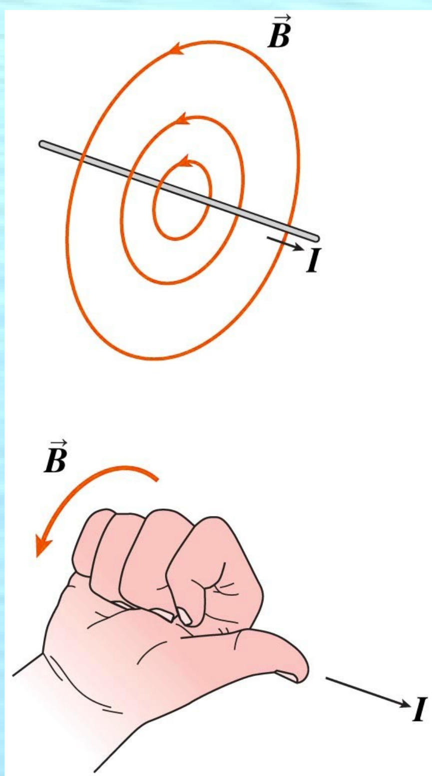
$$\vec{C} \times \vec{D} \neq \vec{D} \times \vec{C}$$

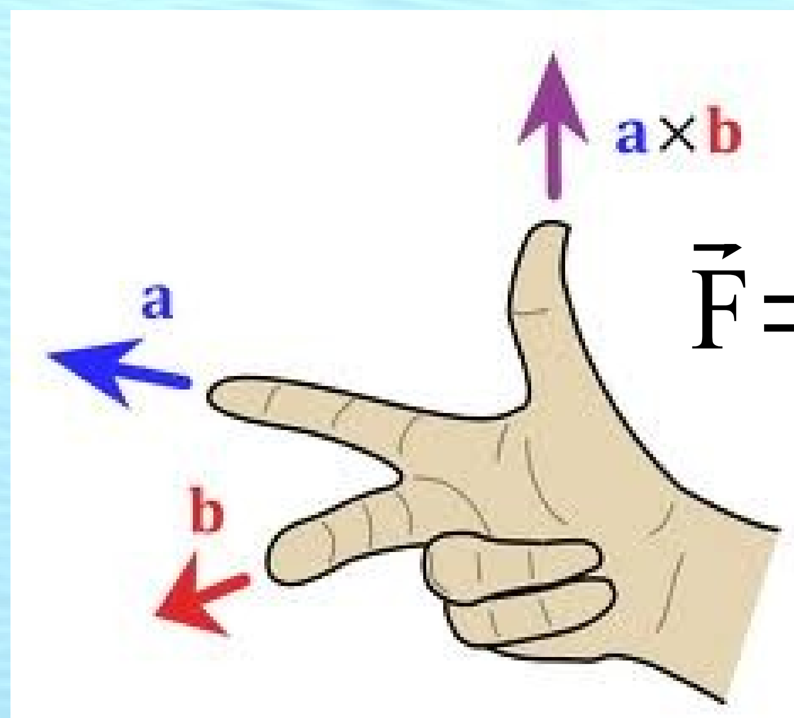
The right-hand rules!

You can get by with two.

1) For magnetic field around a current.

2) For cross-products and everything else!
(result is ALWAYS perpendicular to plane of v and B)





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

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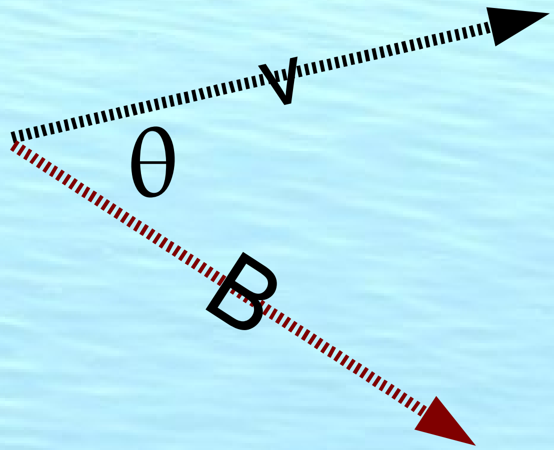
Magnetic field is measured in “Tesla” (T)
Forces are at right angles to fields.
Forces are velocity dependent.

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

$$F = q\,v\,B \sin(\theta)$$

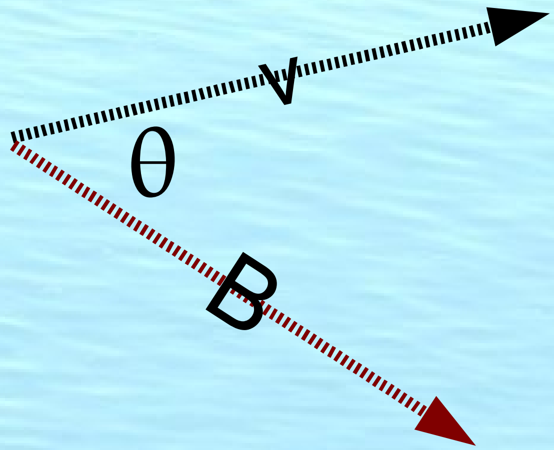


Find the magnitude of the magnetic force on a proton moving at $v = 2.5 \times 10^5$ m/s Perpendicular, at 30 degrees, parallel to a B= 0.5 Tesla magnetic field.

Magnetic force on a charge --->

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

$$F = q\,v\,B \sin(\theta)$$

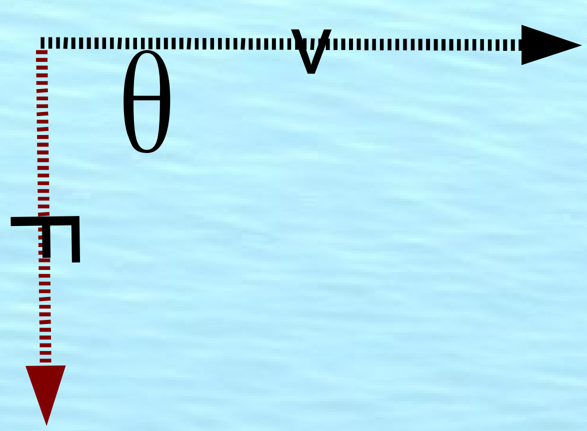


Let's do the force on an electron beam

Electrons move to the right
and you point the north pole of a magnet at them (into the page).

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

The beam moves down!



DEMO – Force on Electron Beam

Magnetic Force on a charge

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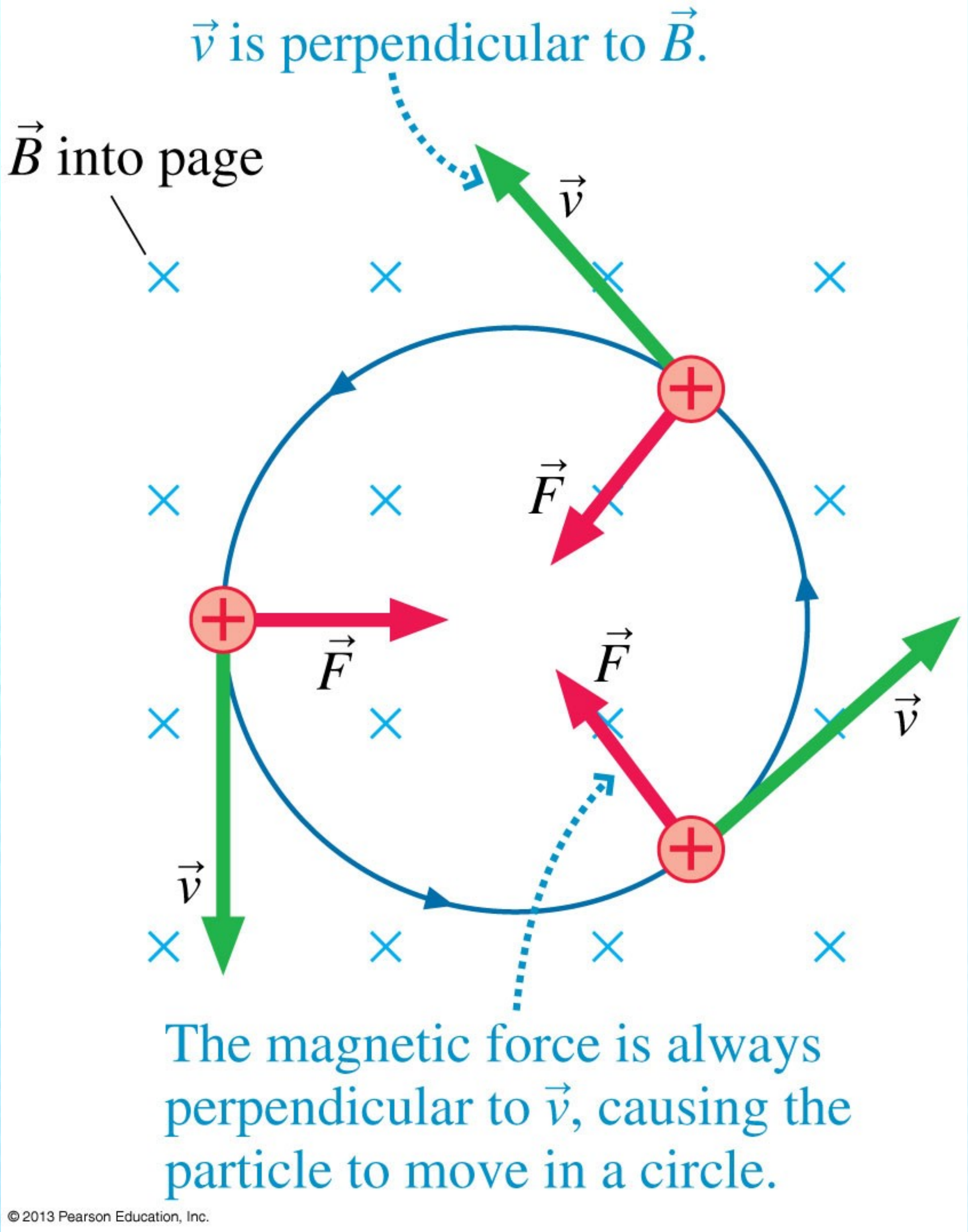

Magnetic Force on a charge

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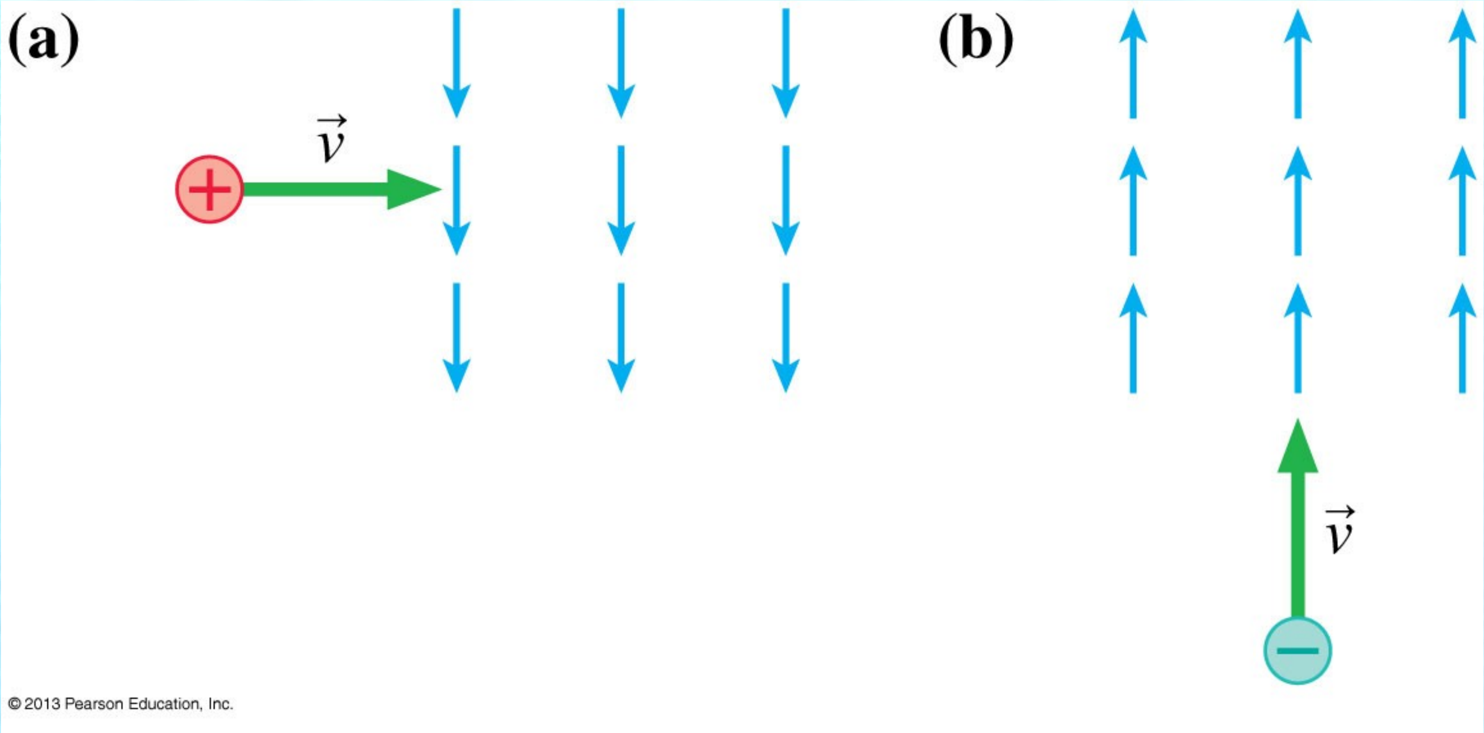
meters?

More practice on direction of magnetic forces

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

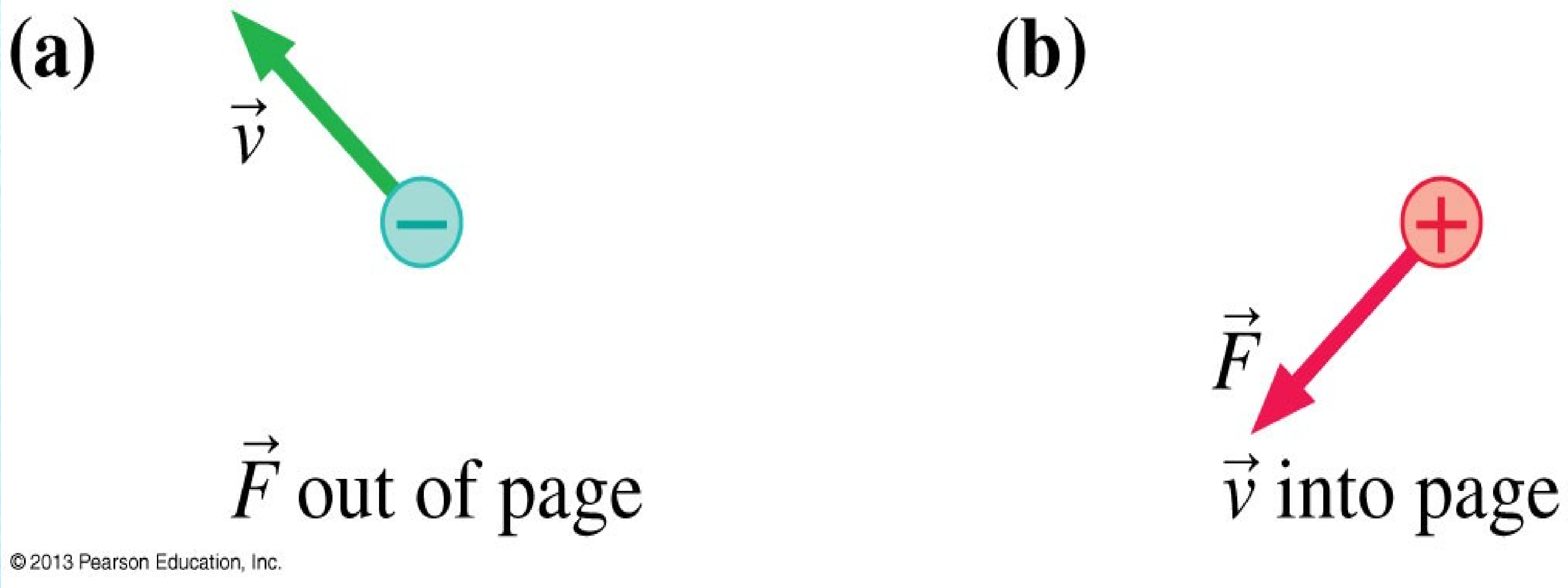
What is direction of initial Force for velocity and B-field given?



More practice on direction of magnetic forces

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

What is direction of B-field to produce the indicated Force for the given velocity?



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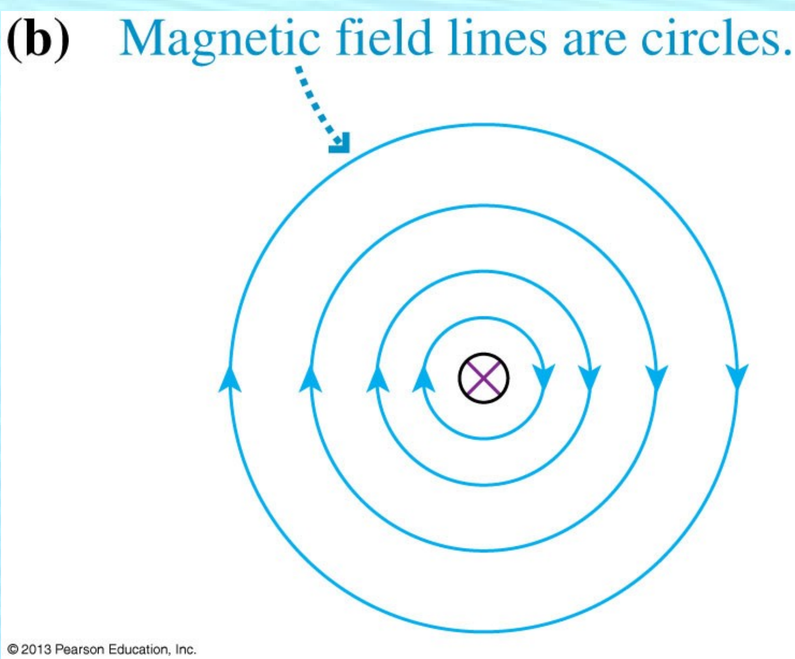
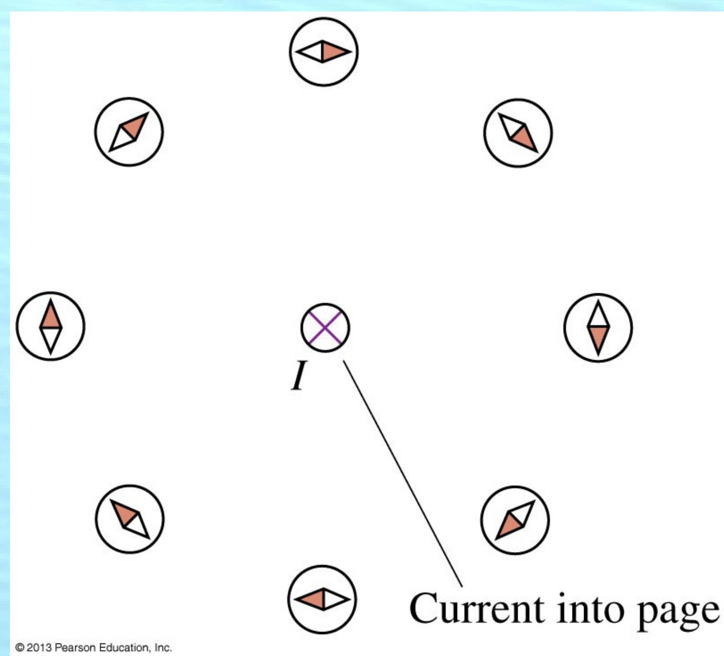
Electric Currents and Magnetic Fields

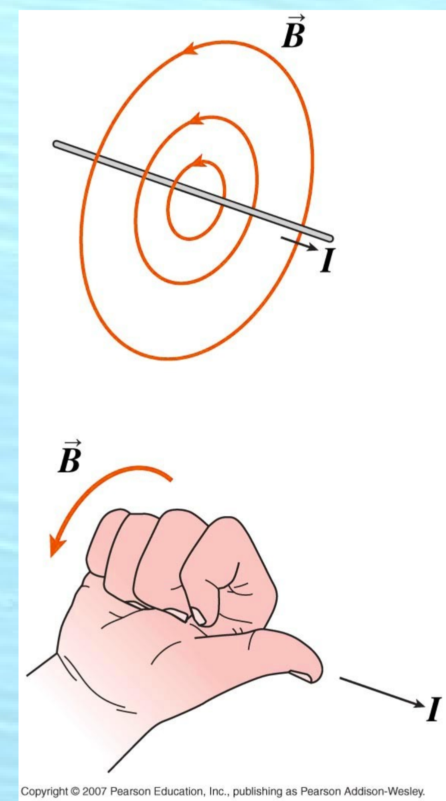
magnetic field forms a pattern of concentric circles around a current-carrying wire

when current reverses direction, the direction of the field lines reverse

The "hitch-hikers right hand rule" relates current direction to B-field.

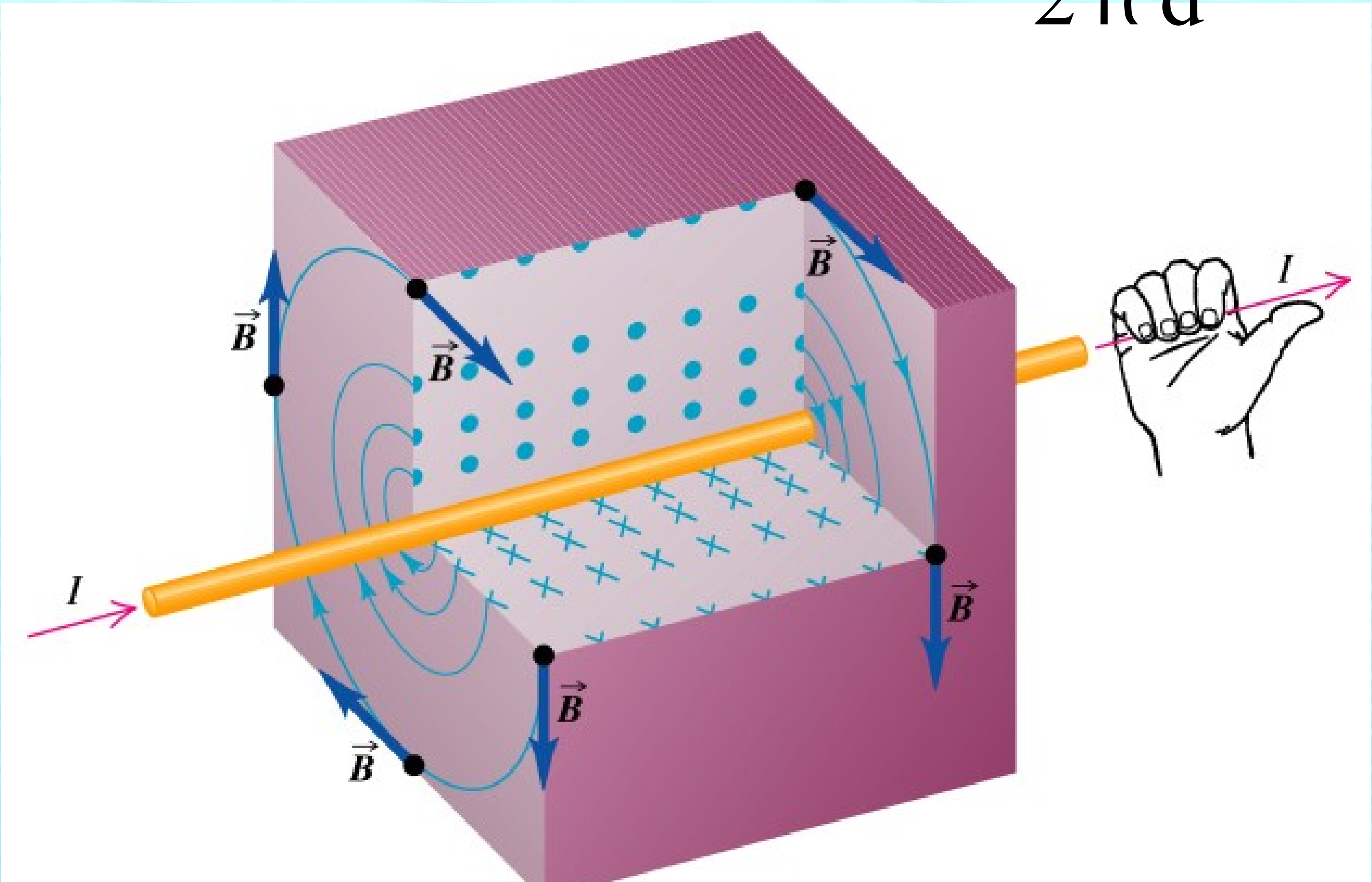






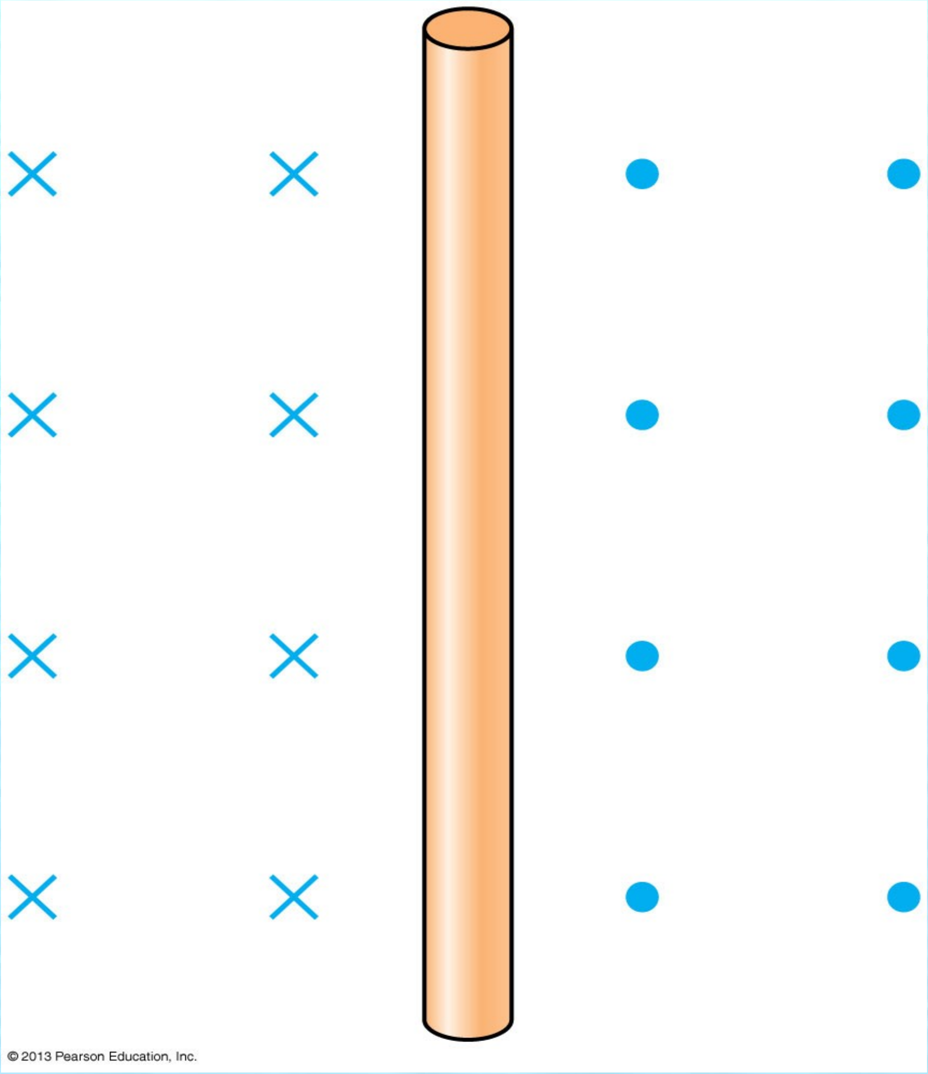
Magnetic field of a wire encircles the current.

For infinitely long wire --> $B = \frac{\mu_0 I}{2\pi d}$



Test yourself

What is the direction of the current in the wire in the sketch below?



What do I need to know?

Magnetic field around a straight wire is circular

Given a magnetic field, what is the force on a current or on a moving charge?

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Ampere's Law ---> $\int \vec{B} \cdot d\vec{r} = \mu_0 I_{encircled}$

Magnetic force on a charge ---> $\vec{F} = q\vec{v} \times \vec{B}$

Magnetic force on a current ---> $\vec{F} = nALq\vec{v}_d \times \vec{B}$

$\vec{F} = I\vec{L} \times \vec{B}$

Time for the T-shirt!

In standard household wiring, parallel wires about 1 mm apart carry currents of about 15 A.
What is the magnetic field at 1 mm?
What is the magnitude of the force per
Unit length between the wires?

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

$$\vec{F} = I\,\vec{L} \times \vec{B}$$

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$$\vec{F} = I \vec{L} \times \vec{B}$$

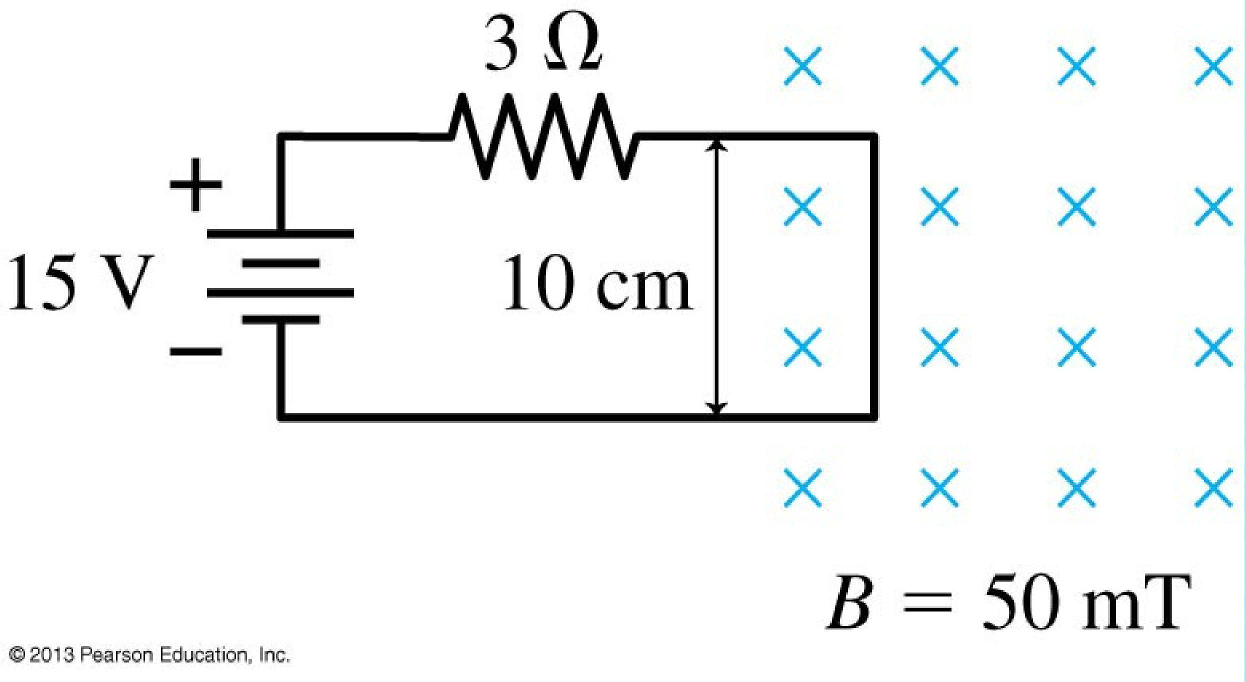
$$F = \mu_0 \frac{I_1 I_2 L}{2 \pi d}$$

The element niobium, which is a metal, is a superconductor (i.e., no electrical resistance) at temperatures below 9 Kelvin. However, the superconductivity is destroyed if the magnetic field at the surface of the wire reaches 0.10 T. What is the maximum current in a straight 3.0—mm diameter superconducting niobium wire?

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

What is the net force on the wire in the circuit below?

$$\vec{F} = I\vec{L} \times \vec{B}$$



What have we learned?

Magnetic field around a straight wire is circular and we can calculate its magnitude

Given a magnetic field, what is the force and direction on a current or on a moving charge?