D.3

Electromagnetic Force

IB PHYSICS | FORCE FIELDS

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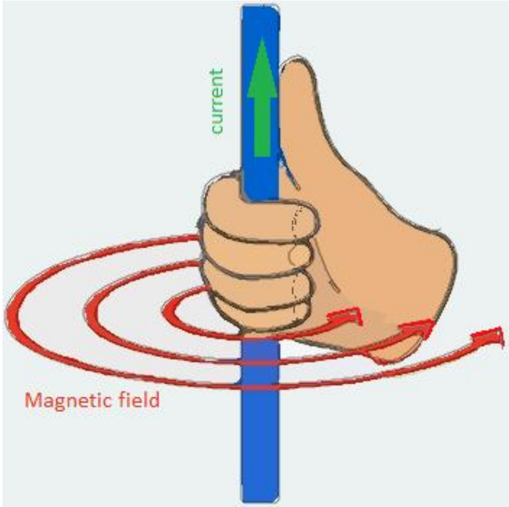
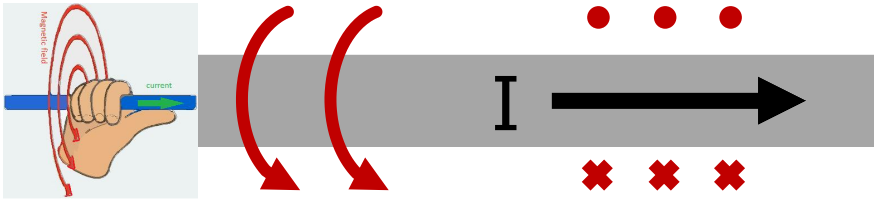
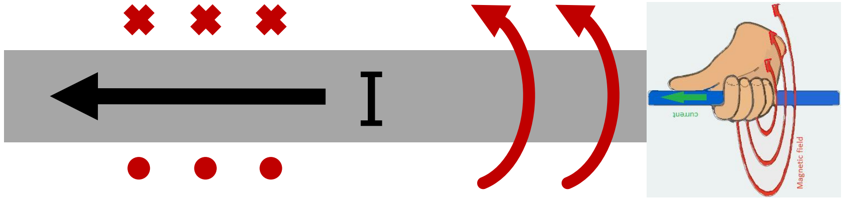
Remember the Right Hand Rule?

Thumb points in direction of the **current**

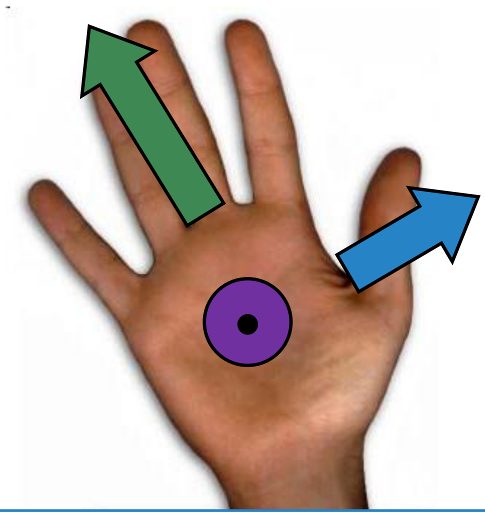
Fingers point in direction of the **field lines**







Right Hand Rule #2

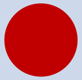


Thumb points in direction of the **current**

Fingers point in direction of the **field lines**

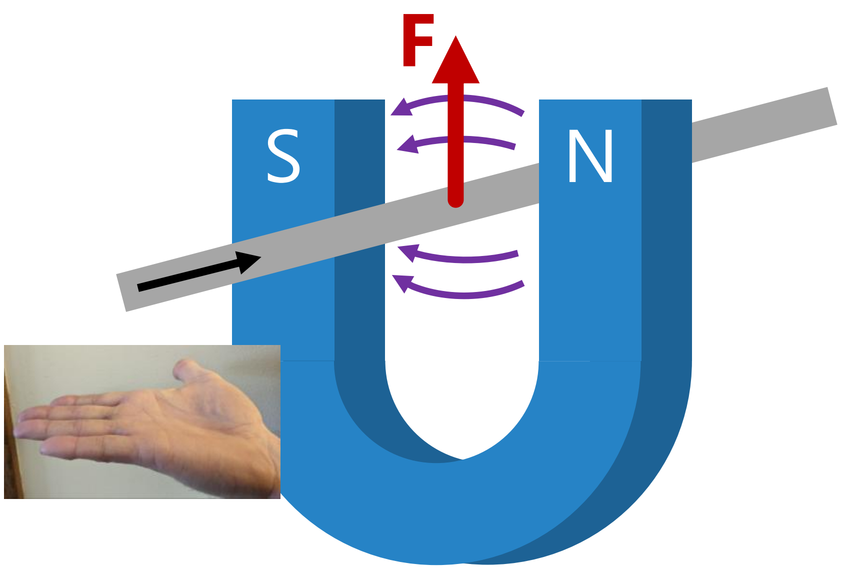
Palm points in direction of the **force**

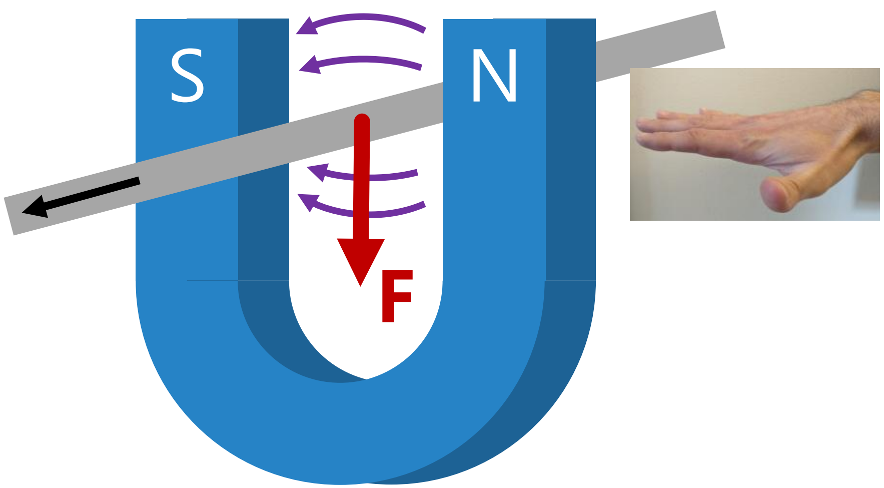
How do you represent a direction that's perpendicular to the paper?

Into the paper		Out of the paper	

Right Hand Rule #2

A current-carrying wire is placed in a magnetic field and the magnetic field exerts a force on the wire





Fields

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Gravitational Field

$$g = \frac{F}{m} = \frac{[\mathrm{N}]}{[\mathrm{kg}]}$$

Magnetic Field

$$B = \frac{F}{I} = \frac{[\mathrm{N}]}{[\mathrm{A}]} = \underset{Tesla}{[\mathrm{T}]}$$

Electric Field

$$E = \frac{F}{q} = \frac{[\mathrm{N}]}{[\mathrm{C}]}$$

Magnetic Flux

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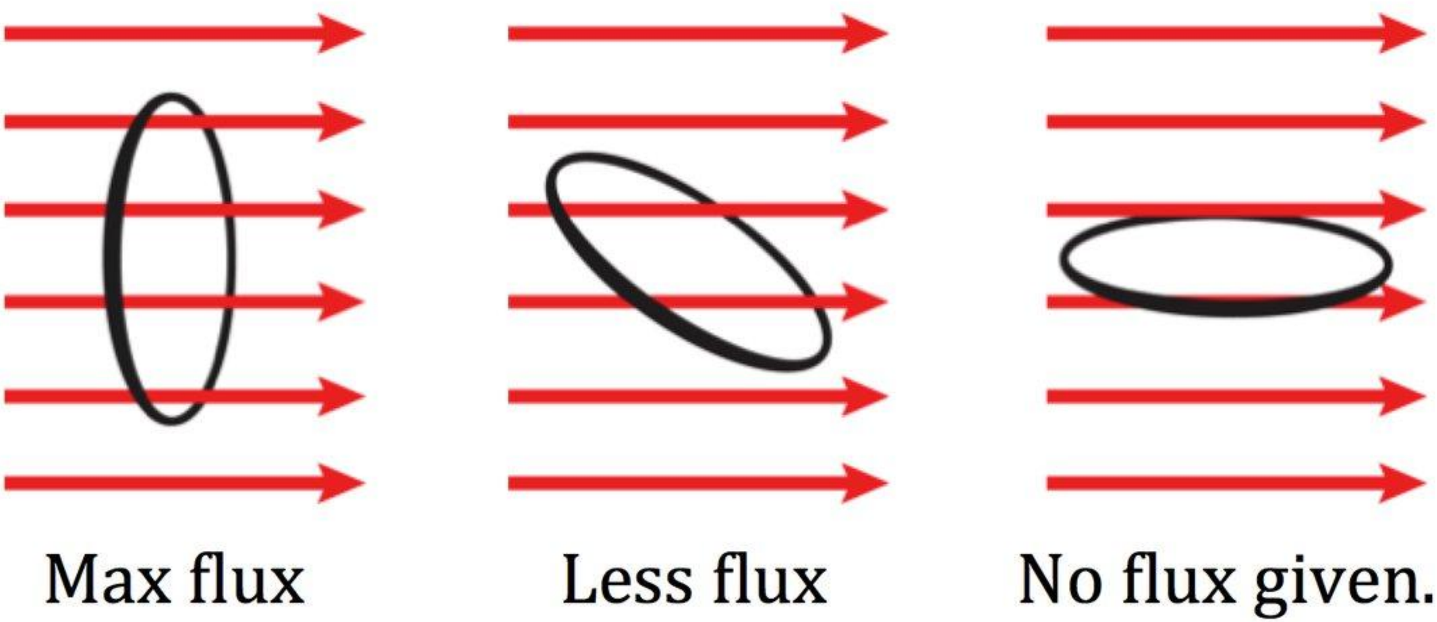
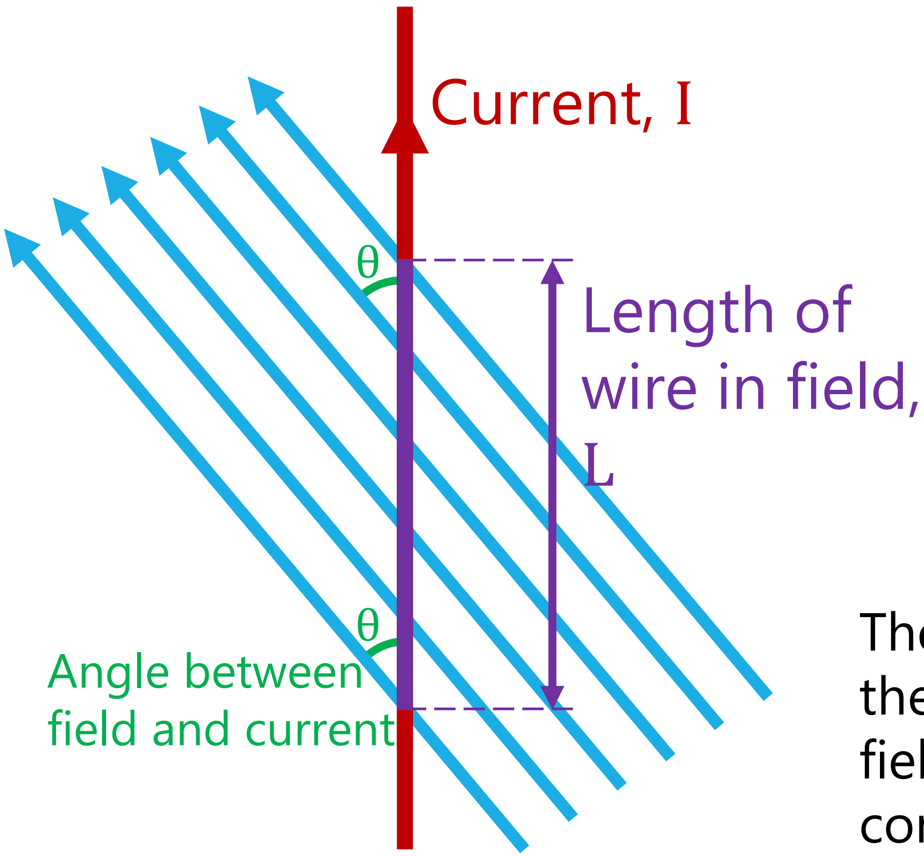
The magnetic field strength is sometimes referred to as magnetic flux and depends on how perpendicular the current is in relation to the field direction



Magnetic field Strength



$$B = \frac{F}{ILsin\theta}$$

The force on the wire is proportional to the charge moving perpendicular to the field. Because of these the perpendicular component must be used in the calculation

Fields

$$B = \frac{F}{IL\,sin\theta}$$

$$F = BIL\,sin\theta$$

F	Magnetic force *Newtons [N]*
B	Magnetic field strength *Tesla [T]*
I	Current *Amperes [A]*

L	Length of conductor in uniform magnetic field
θ	Angle between magnetic field and current

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D. Fields

Standard level and higher level	
D.1 Gravitational fields	$F = G\frac{m_1 m_2}{r^2}$ $g = \frac{F}{m} = G\frac{M}{r^2}$
D.2 Electric and magnetic fields	$F = k\frac{q_1 q_2}{r^2}$ where $k = \frac{1}{4\pi\varepsilon_0}$ $E = \frac{F}{q}$ $E = \frac{V}{d}$
D.3 Motion in electromagnetic fields	$F = qvB\sin\theta$ $F = BIL\sin\theta$ $\frac{F}{L} = \mu_0\frac{I_1 I_2}{2\pi r}$

Try This…

A current of 3.8 A in a long wire experiences a force of 5.7×10^{-3} N when it flows through a magnetic field of strength 25 mT. If the length of wire in the field is 10 cm, what is the angle between the field and current?

$$F = BIL\,sin\theta$$

$$\theta = sin^{-1}\left(\frac{F}{BIL}\right) = sin^{-1}\left(\frac{(5.7 \times 10^{-3})}{(25 \times 10^{-3})(3.8)(0.1)}\right)$$

$F = 5.7 \times 10^{-3}\ \mathrm{N}$

$B = 25\ \mathrm{mT} = 25 \times 10^{-3}\ \mathrm{T}$

$I = 3.8\ \mathrm{A}$

$L = 10\ \mathrm{cm} = 0.1\ \mathrm{m}$

$$\theta = 36.87°$$

Strength of Field around Wire

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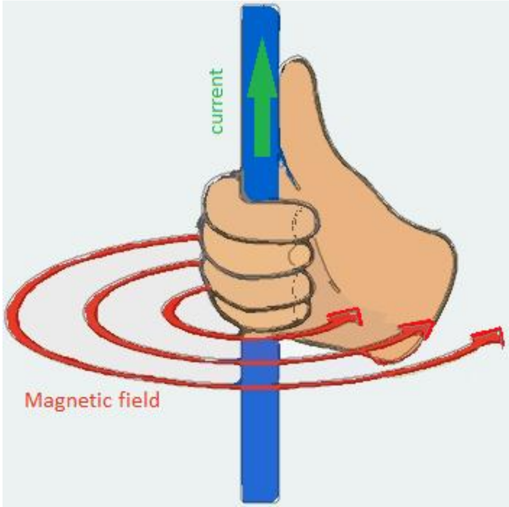
$$B = \frac{\mu_0 I}{2\pi r}$$

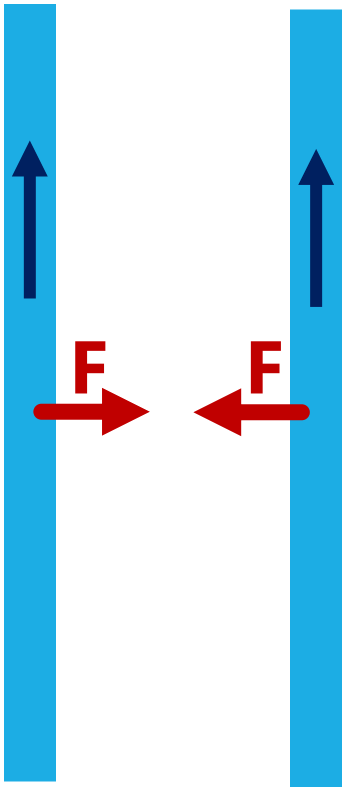
The strength of the magnetic field around a current carrying wire depends on the current, distance from the wire, and the permeability of free space



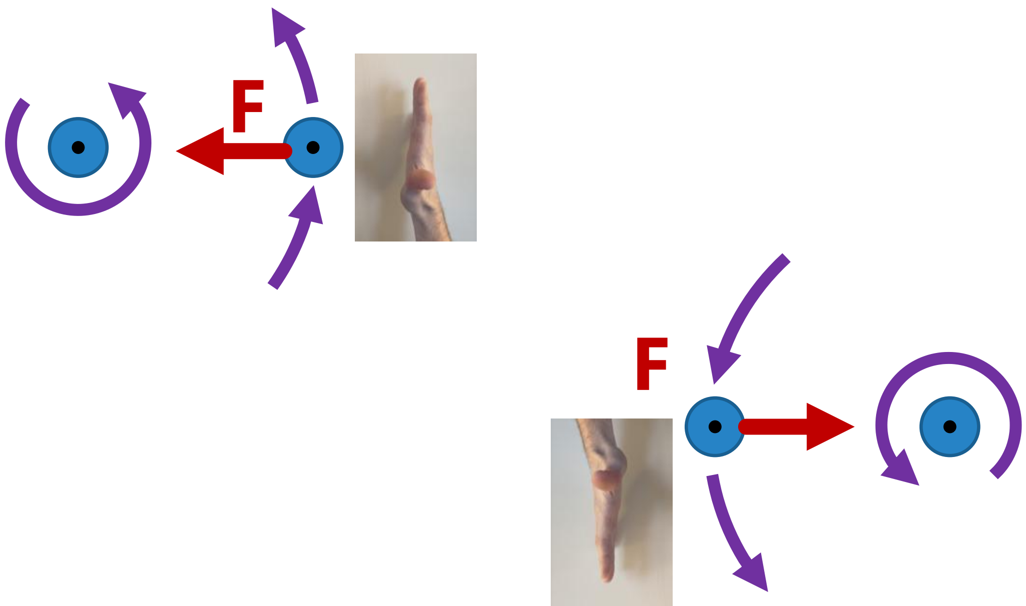
Fundamental constants

Quantity	Symbol	Approximate value
Acceleration of free fall	g	$9.8\,\text{m s}^{-2}$ (Earth's surface)
Gravitational constant	G	$6.67 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
Avogadro constant	N_A	$6.02 \times 10^{23}\,\text{mol}^{-1}$
Permittivity of free space	ε_0	$8.85 \times 10^{-12}\,\text{C}^2\,\text{N}^{-1}\,\text{m}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\,\text{T m A}^{-1}$

Definition of the Ampere



Consider two parallel wires, with current in the same direction. Do they attract or repel??

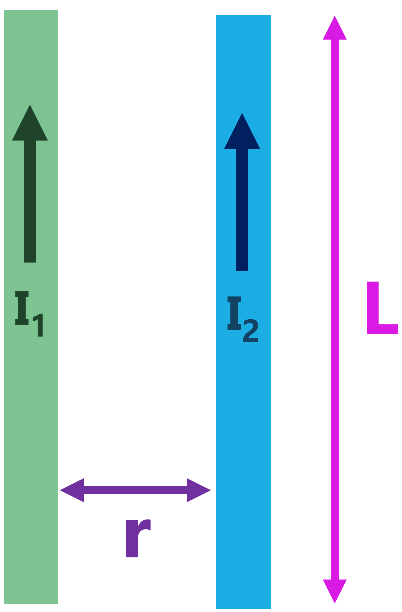


***One ampere is defined as the current that would cause a force of 2×10^{-7} N per meter between two long parallel conductors separated by 1 m in a vacuum*

Definition of the Ampere

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

$$F = BIL\,\cancel{\sin\theta}$$



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

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

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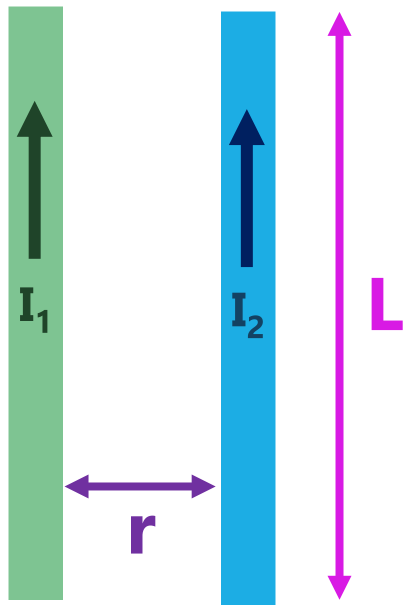
Try This

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

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\ m\ A^{-1}}$$

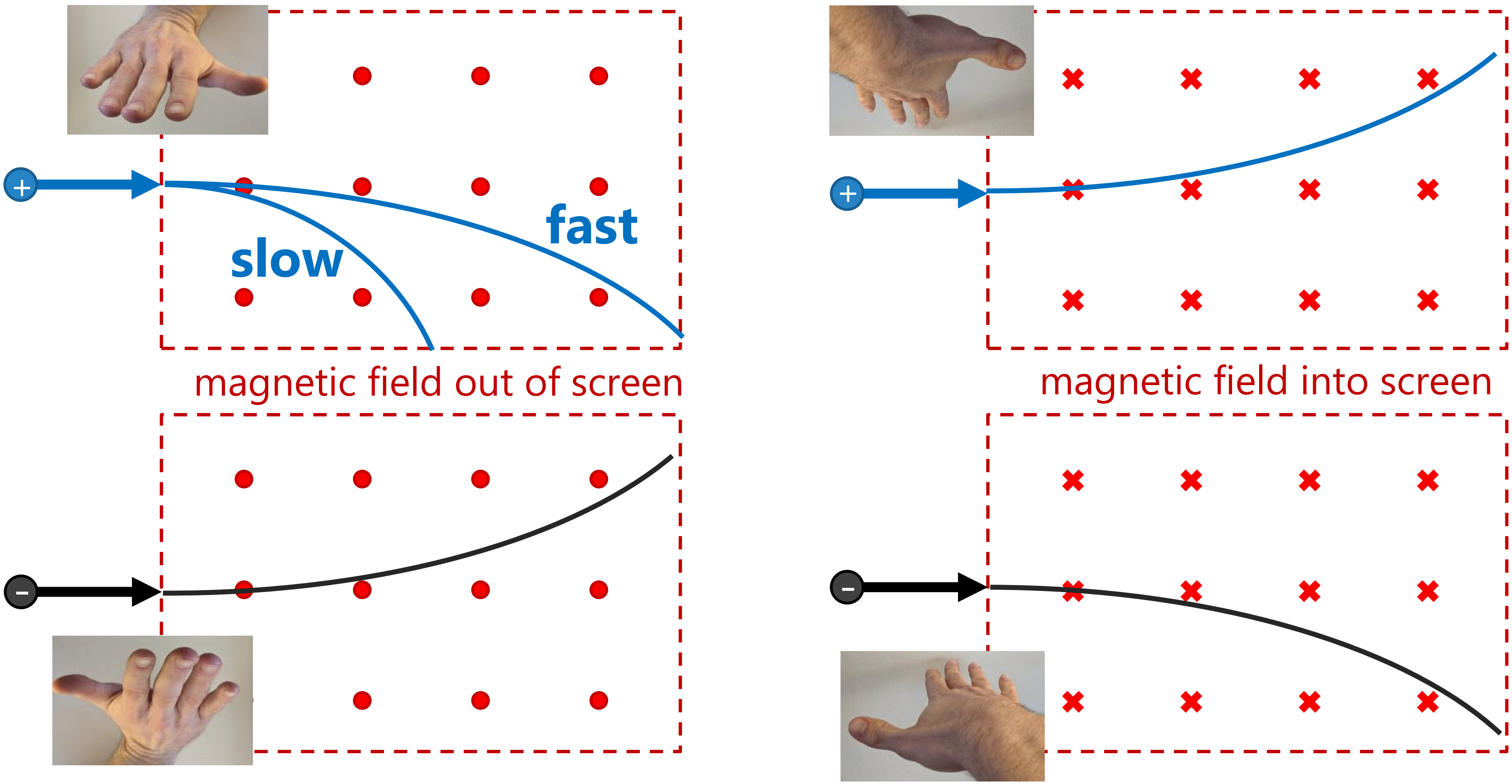


Two parallel wires have currents of 8.0 A and 3.0 A respectively. What is the separation distance if the 0.2-meter-long wires are experiencing an inward force of attraction of 1.5×10^{-5} N?

$$\frac{1.5 \times 10^{-5}}{0.2} = \frac{(4\pi \times 10^{-7})(8.0)(3.0)}{2\pi r}$$

$$r = 0.064\ \mathrm{m} = 6.4\ \mathrm{cm}$$

Particles Moving Across Fields



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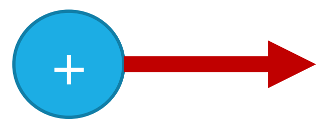
Force on a Charged Particle

When there is a magnetic force on a current carrying wire, the force is really on the moving charges inside of the conductor.

Single charged particles can also experience a magnetic force when moving through a magnetic field…



$$v = \frac{L}{t}$$

$$L = vt$$

$$I = \frac{q}{t}$$

$$F = BIL\,sin\theta$$

$$F = B\left(\frac{q}{\cancel{t}}\right)(v\cancel{t})\,sin\theta$$

$$F = Bqv\,sin\theta$$

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Try This…

What is the magnetic force acting on a proton (+1.6 × 10^{-19} C) moving at an angle of 32° across a magnetic field of 5.3 × 10^{-3} T at a speed of 3.4 × 10^{5} m s^{-1}?

$$F = qvB\ sin\theta$$

$$F = (1.6 \times 10^{-19})(3.4 \times 10^{5})(5.3 \times 10^{-3}) sin 32°$$

$$q = 1.6 \times 10^{-19}\ \mathrm{C}$$
$$v = 3.4 \times 10^{5}\ \mathrm{m\ s^{-1}}$$
$$B = 5.3 \times 10^{-3}\ \mathrm{T}$$
$$\theta = 32°$$

$$F = 1.5 \times 10^{-16}\ \mathrm{N}$$

Lesson Takeaways

D.3

- ❑ I can calculate electromagnetic force on a current carrying wire in a magnetic field
- ❑ I can describe and calculate the force between two parallel current carrying wires
- ❑ I can calculate the force on a charged particle in a magnetic field