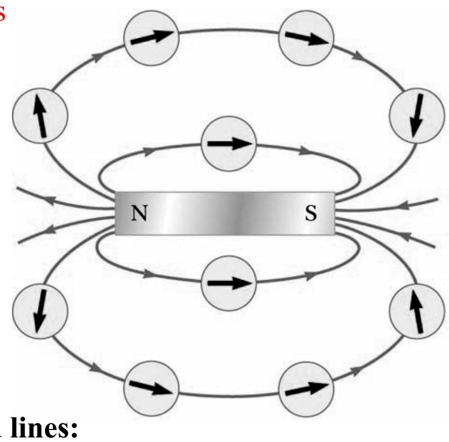
Electromagnetism

Magnetic Fields

What is the cause of magnetic fields?

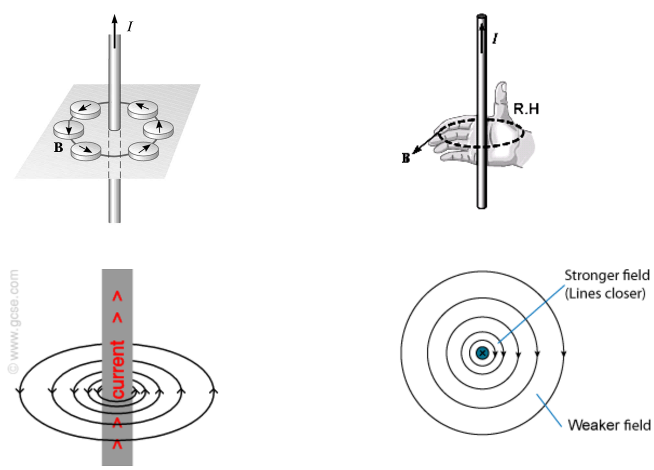
Moving electric charges

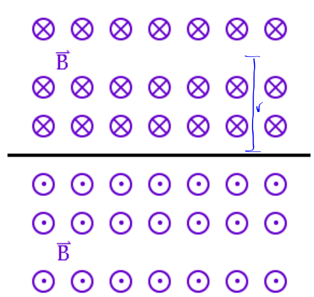
Magnetic Field around a Bar Magnet



Direction of magnetic field lines:
the direction that the North pole of a small test compass would point if placed in the field
- from North to South

Right Hand Rule #1: Magnetic Field around a Current-bearing Wire



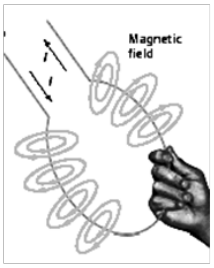


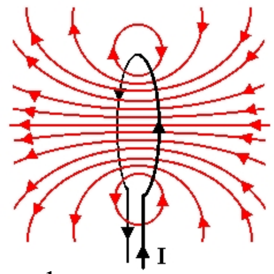
$B = \frac{\mu_0}{2\pi}\frac{I}{r}$

Applications of RHR #1 for the field around a current:

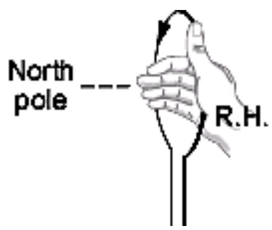
a) Wire Loop: What is the direction of the magnetic field inside the flat wire loops shown below?

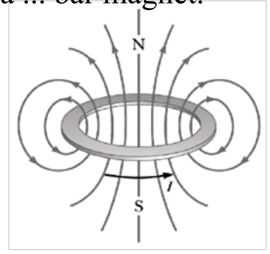
The magnetic field is most intense ... at the center.





Notice that the loop acts like a ... bar magnet.



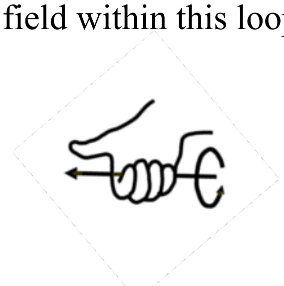


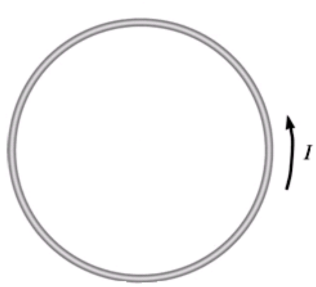
Alternate Version of RHR #1 – use for Loops and Solenoids:

Fingertips: direction of conventional current

Thumb: direction of magnetic field – points north

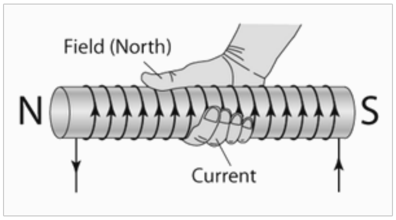
2. Determine the direction of the magnetic field within this loop. (Try both methods.)

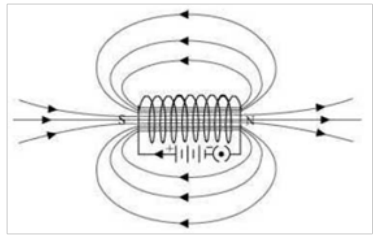




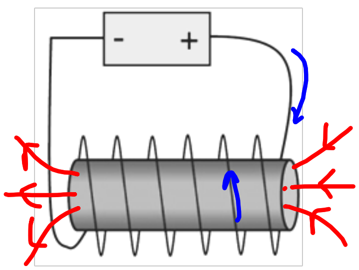
b) <u>Solenoid</u>: What does the magnetic field of a solenoid look like?

Fingertips: direction of current **Thumb:** points North





Your turn



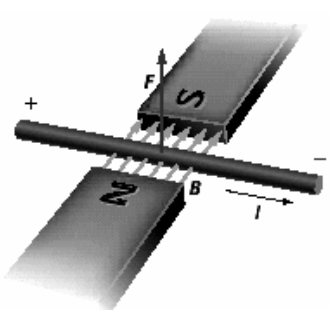
Right Hand Rule #2: Magnetic Force (Flat Hand)

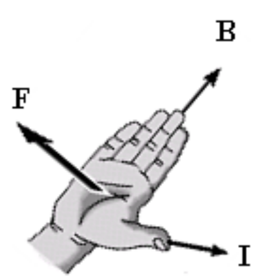
On a Current-bearing Wire

Fingers: external B field – north to south

Thumb: current

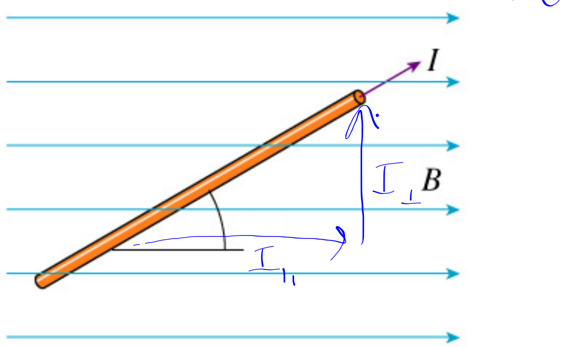
Palm: force – "palm pushes"





Formula: $\vec{F}_B = \vec{B} \times \vec{I}\,\ell$

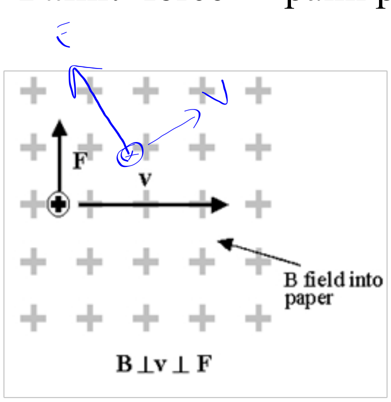
$= B I \ell \sin\theta$

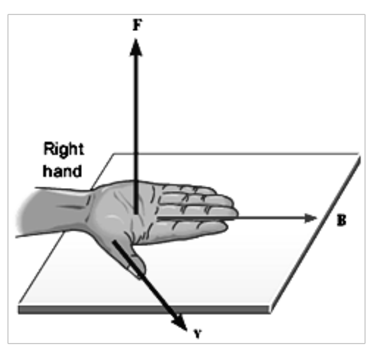


On a Charged Particle

Right Hand: positive charge
Left Hand: negative charge

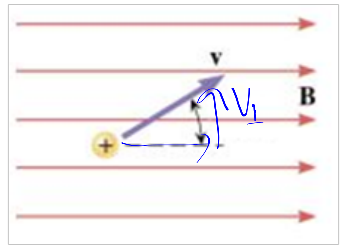
Fingers: external B field – north to south
Thumb: velocity
Palm: force – “palm pushes”





Formula:

$$\vec{F}_B = q\vec{v}\times\vec{B}$$
$$= qvB\sin\theta$$



Maximum force occurs when the current (velocity) is perpendicular to the magnetic field.

No force occurs when the current (velocity) is parallel to the magnetic field.

Magnetic field strength, Magnetic field intensity, Magnetic flux density

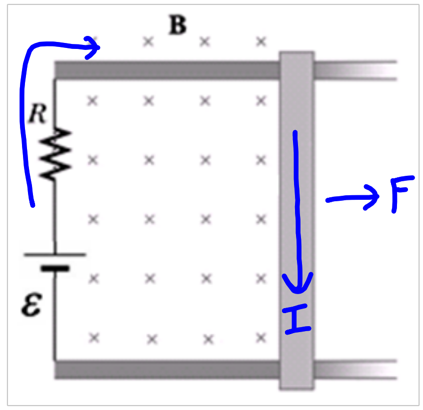
Symbol: B Units: Tesla (T) $\left[\frac{N}{A\cdot m}\right] = \left[\frac{N}{C\cdot \frac{m}{s}}\right]$

3. Rail System: Determine the magnetic force (magnitude and direction) on the rail piece shown.

Magnitude

$F = B(E/R)\ L$

Direction



4. What happens when a charged particle moves in a magnetic field?

a) A charged particle will follow a circular path in a magnetic field since the magnetic force is always perpendicular to the velocity.

b) The magnetic force does no work on the particle since the magnetic force is always perpendicular to the motion.

c) The particle accelerates centripetally but maintains a constant speed since the magnetic force does no work on it.

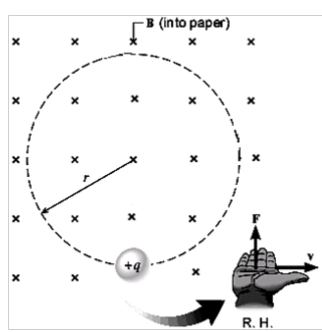
Radius of Circular Path

$\Sigma F = m\, a_c$

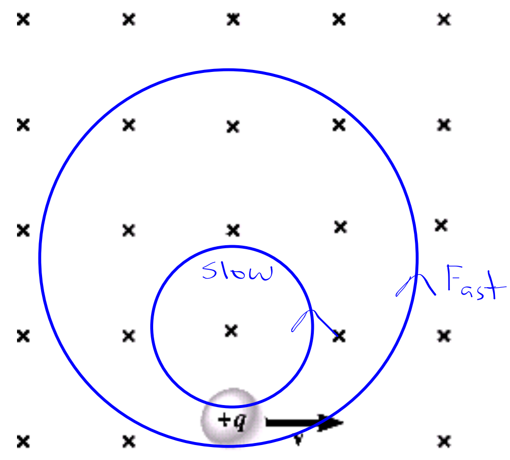
$F_B = m\, v^2 / r$

$q\, v\, B = m\, v^2 / r$

$r = mv / qB$

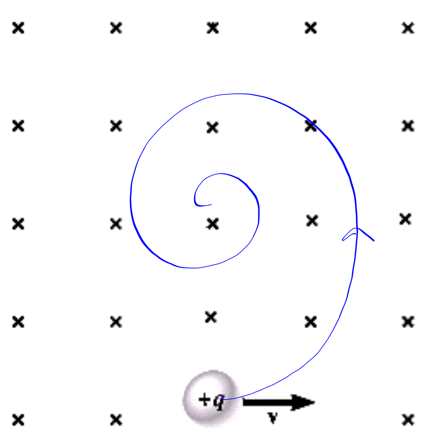


i) Sketch the paths of a slow and a fast proton moving at constant speed.



$r = mv/ qB$

ii) Sketch the path of a proton that is slowing down.



$2r = 4m v / 2qB$

iii) How would the radius of the path change if the particle were an alpha particle?

5. A proton is released from rest near the positive plate and leaves through a small hole in the negative plate where it enters a region of constant magnetic field of magnitude 0.10T. The electric potential difference between the plates is 2100 V.

a) Describe the motion of the proton while in the electric field

constant accl in straight line

b) Describe the motion of the proton while in the magnetic field

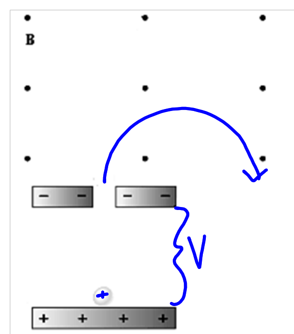
constant accl inward

c) Find the speed of the proton as it enters the magnetic field.

$qV = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2qV}{m}}$

$r = \frac{mv}{qB} = \sqrt{\frac{m2V}{qB^2}}$



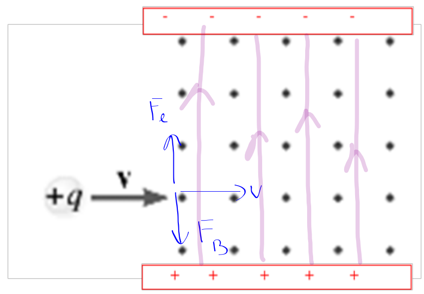
d) Find the radius of the circular path of the proton in the magnetic field.

6. A **Velocity Selector** is a device for measuring the velocity of a charged particle. The device operates by applying electric and magnetic forces to the particle in such a way that these forces balance.

a) Determine the magnitude and direction of an electric field that will apply an electric force to balance the magnetic force on the proton.

$F_e = F_B$

$q\vec{E} = qv\vec{B}$



b) What is the resulting speed and trajectory of the proton?

$v = \vec{E}/\vec{B}$

straight line

c) What would change if the particle were an electron?

Same speed and direction of velocity, forces switch

Electromagnetic Induction

Motional EMF: When a straight conductor is moved in a uniform magnetic field, an emf (potential difference, voltage) is induced between its two ends.

Electrons in the moving conductor experience a downward magnetic force and migrate to the lower end of the conductor, leaving a net positive charge at the upper end. As a result of this charge separation, an electric field is built up in the conductor.

Charge builds up until the downward magnetic force is balanced by the upward electric force due to the electric field. At this point, the charges stop flowing and are in equilibrium. Because of this charge separation, a potential difference is set up across the conductor.

Derivation:

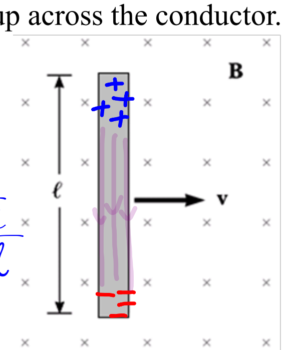
$F_B = F_e$

$\cancel{q} v\vec{B} = \cancel{q}\vec{E}$

$v \cdot B = \frac{\mathcal{E}}{\ell}$

$\vec{\mathcal{E}} = \vec{v}_\perp \times \vec{B}_\perp \cdot \vec{\ell}$

$\vec{E} = \frac{\mathcal{E}}{\ell} = \frac{V}{d}$



For a coil of wire:

$\mathcal{E} = N \cdot B\ell v$

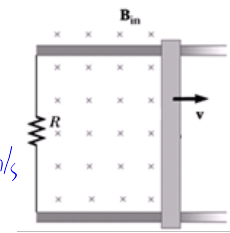
If the conductor is connected to a complete circuit, the induced emf will produce an induced current.

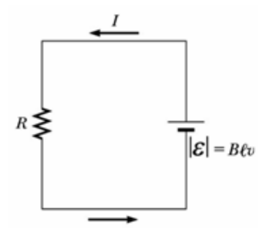
1. a) Determine the magnitude and direction of the current in the rail system shown if a rod of length 1.6 meters is moved at a steady speed of 5.0 m/s through a 0.80 T magnetic field. The rails have negligible resistance but R has a resistance of 96 ohms.

$\mathcal{E} = B\ell v$

$= .8T \cdot 1.6m \; 5m/s$

$= 6.4V$

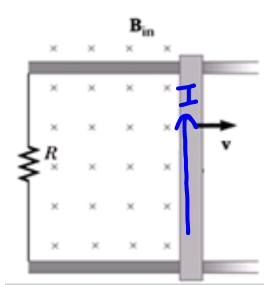


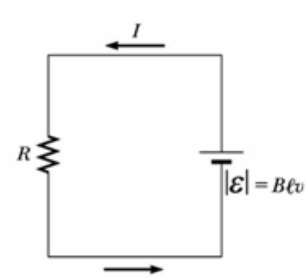


$I = \frac{\mathcal{E}}{R} = \frac{6.4V}{96\Omega} = .067A$

… is equivalent to …

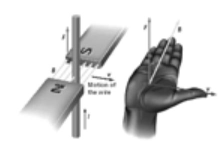
b) Deduce an expression for this current





Direction of Current

The direction of the induced emf and induced current can be found from the right hand rule for forces to find the force on a positive charge in the conductor.



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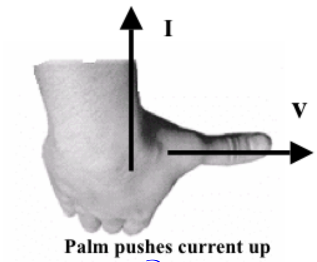
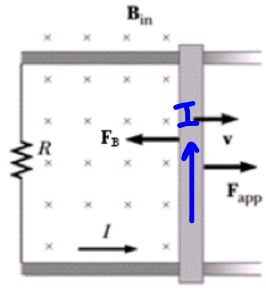
Two Opposing Forces

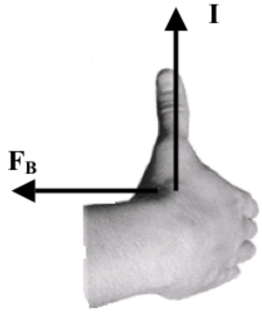


Palm pushes current up

$F = qvB$

An applied force (F_{app}) in the direction of the velocity induces an emf which causes current to be pushed upwards.





Palm pushes bar back

$F = BIl$

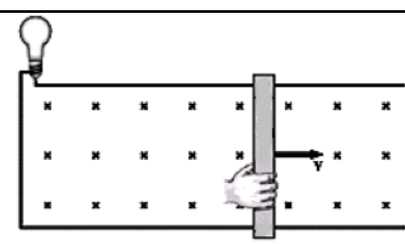
The induced current now generates a magnetic field around the moving bar that causes a magnetic force (F_B) on itself.

The magnetic force acts to oppose the applied force, like drag or friction.

At a constant speed,

$F_A = F_B = BIl$

Suppose a rod is moving at a constant speed of 5.0 m/s in a direction perpendicular to a 0.80-T magnetic field as shown. The rod has a length of 1.6m and negligible electrical resistance. The rails also have negligible resistance. The light bulb, however, has a resistance of 96 Ω. Find:



a) the emf produced by the motion of the rod

6.4v

(b) the magnitude and direction of the induced current in the circuit

.067A
CCW

c) the electrical power delivered to the bulb

$P = I\mathcal{E}$ .43w

d) the energy used by the bulb in 60.0 s.

$E = P \cdot t$ 26J

e) How much external force is applied to keep the rod moving at this constant speed?

$F = BIl$
$= .086N$

f) How much work is done by the applied force in 60.0 seconds?

$P = F \cdot v$

$W = F \cdot d$

5m/s · 60s

g) What happens to this work?