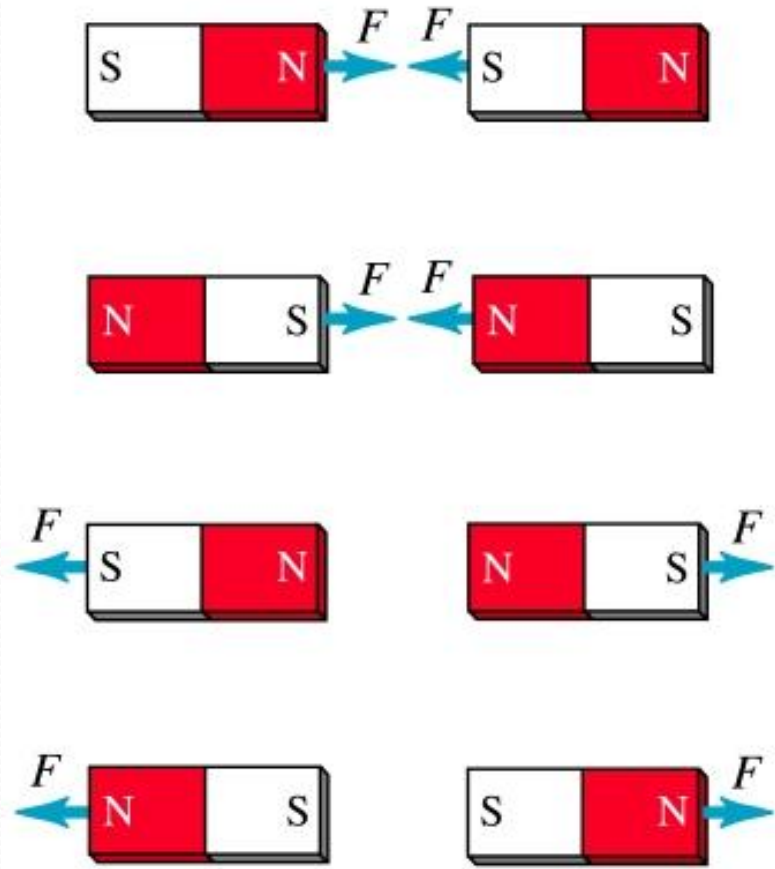


Chapter 20

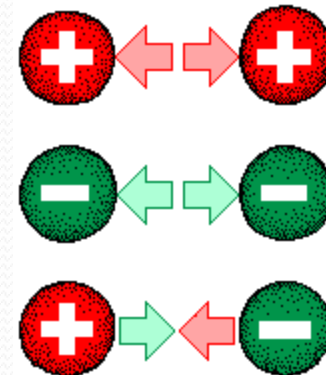
Magnetism

Permanent Magnets

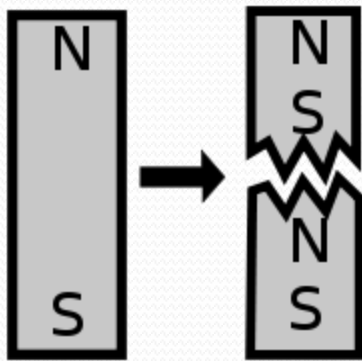


Each magnet has two poles
Unlike poles attract
Like poles repel

Poles behave like
electric charges

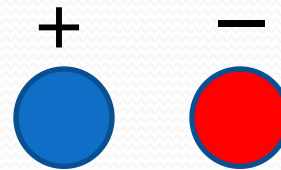


No Monopoles



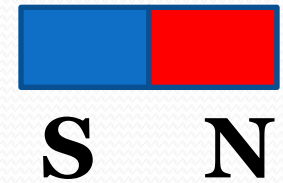
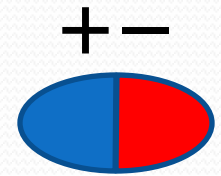
If cut in half, each piece gets two poles

electric charges

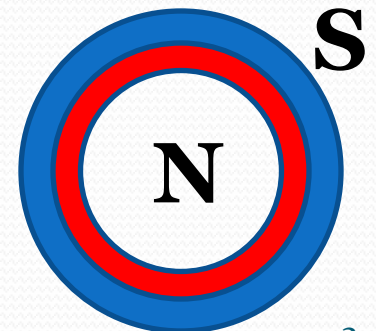
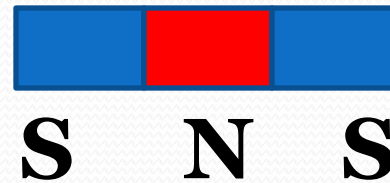


magnet poles

?

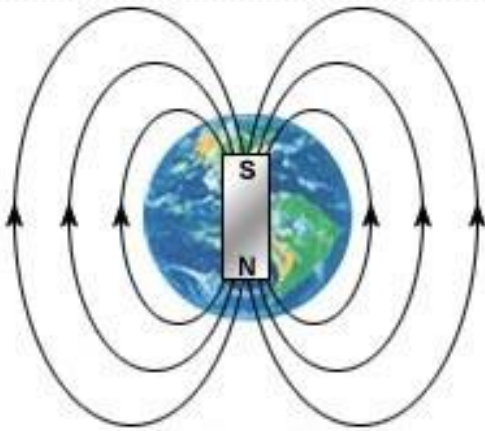


You can try to be creative...



From theoretical point of view, MM are very natural (Maxwell eqs, quantization of charge, GUT...) but the fact is, none have been found ☹

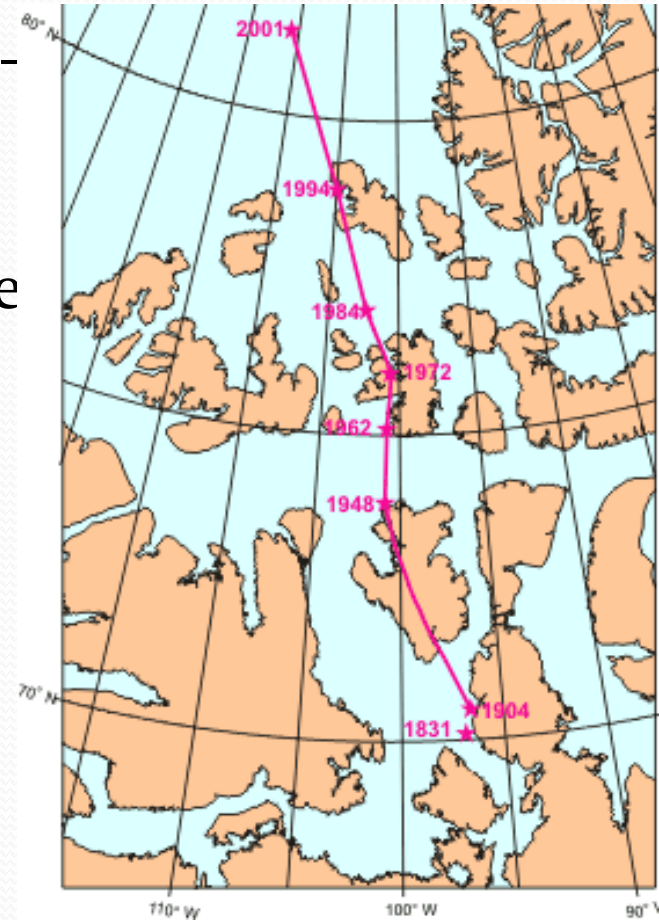
Earth as a Permanent Magnet



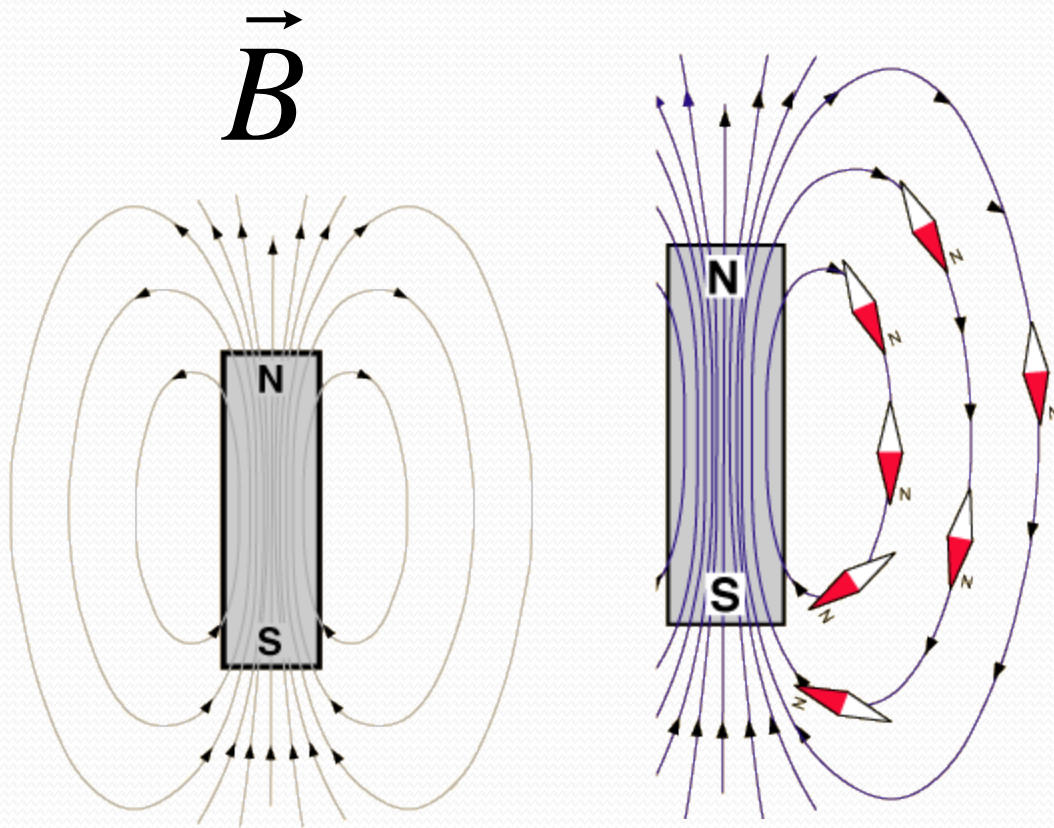
Earth's magnetic field:
similar to that of a bar
magnet



- Earth is a huge magnet - not quite clear why 😊
- North geomagnetic pole \approx south magnetic pole (so that compass' N points to Earth's N)
- There is an offset between magnetic axis and rotation axis



Magnetic Field Lines

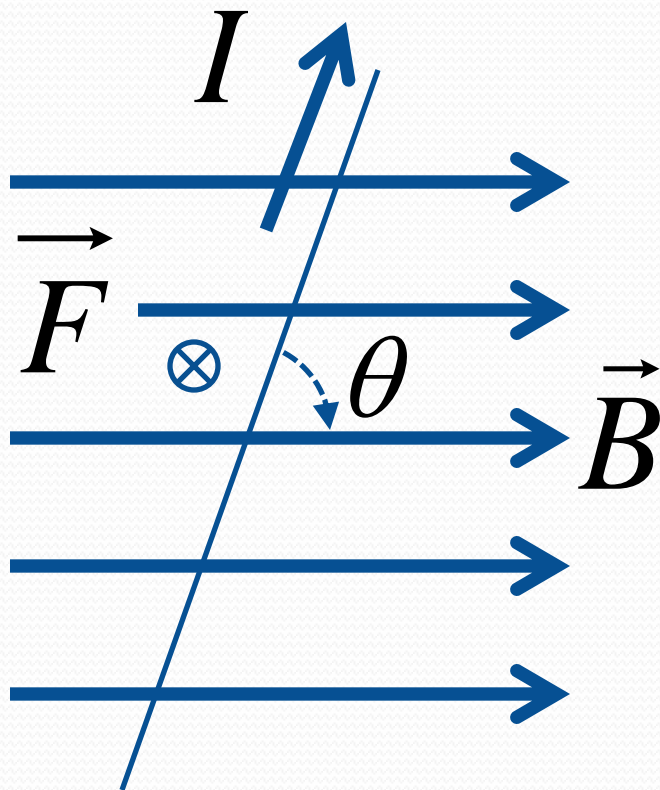


- Direction of lines: tangent to \mathbf{B}
- Density of lines: proportional to $|\mathbf{B}|$
- The N pole of the compass needle points in the direction of \mathbf{B}
- Unlike electric field lines, magnetic field lines do not point in the direction of the force on an electric charge

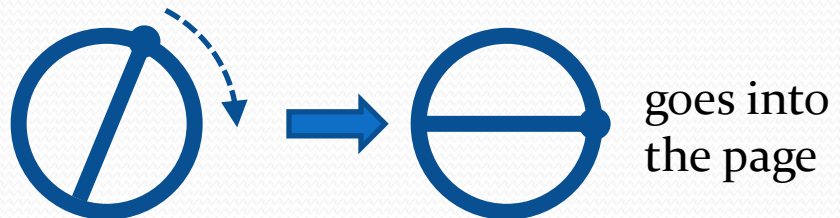
Force on a Current in Magnetic Field

- A magnet exerts a force on a current-carrying wire

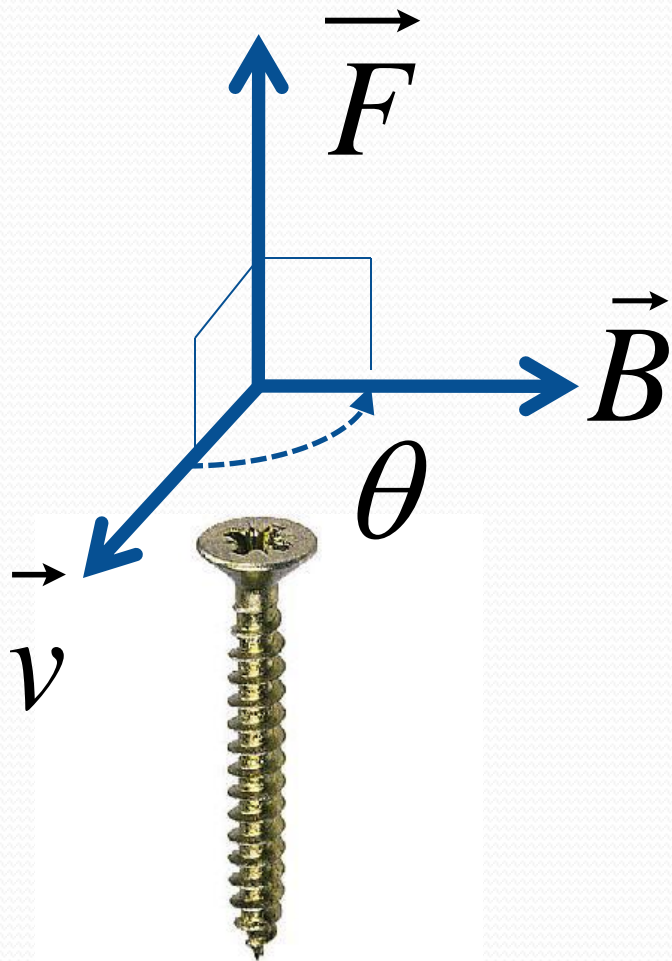
$$F = IlB \sin \theta$$



- Force F is perpendicular to both the current and the field
- The direction of F is the direction in which a right-handed screw would advance in moving from I to B



Force on a Charge in Magnetic Field

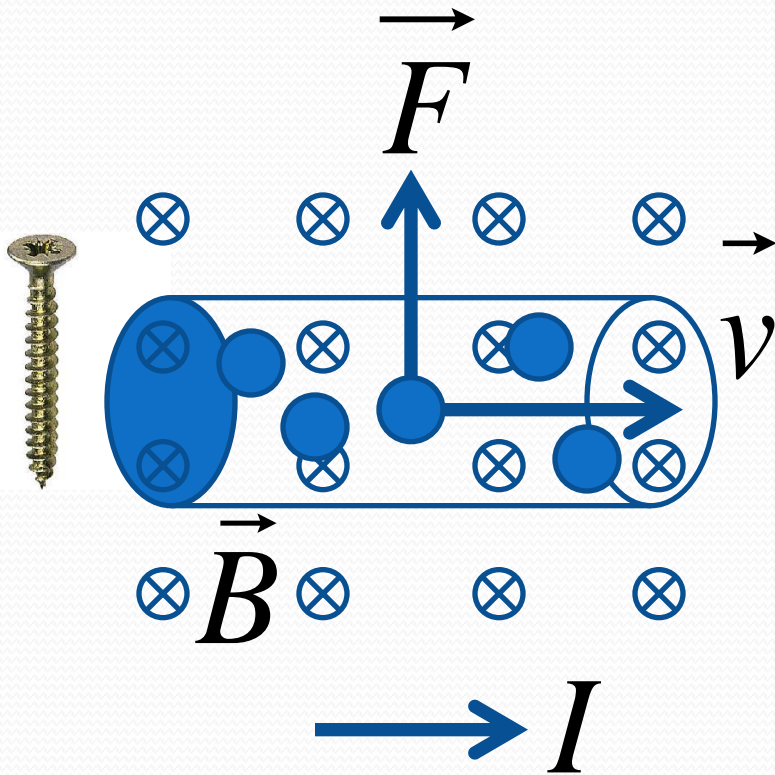


Force exerted on a charge moving in magnetic field:

$$F = qvB \sin \theta$$

- Force F is perpendicular to both the velocity and the field
- The direction of F for a positive charge is the direction in which a right-handed screw would advance in moving from v to B

Force on Current vs Charge



- Current due to a single charge:

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

- Current due to many charges:

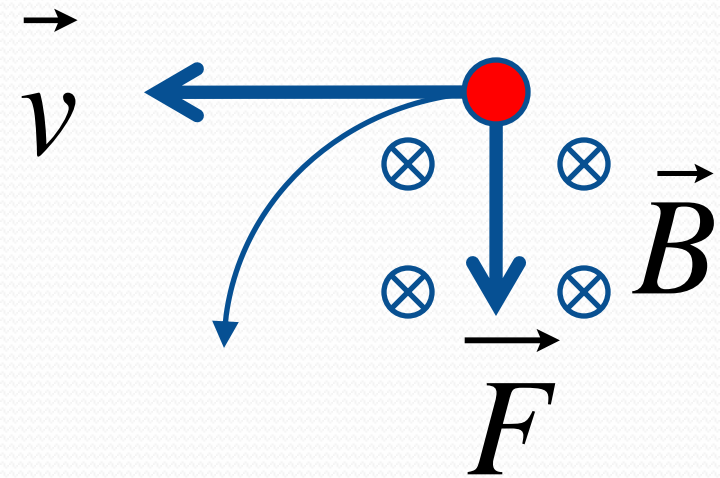
$$I = N \frac{q}{t}$$

- Force on these charges:

$$F = NqvB = Nq \frac{l}{t} B = IlB$$

Magnetic field units: Tesla
 $1 \text{ T} = 1 \text{ N/A}\cdot\text{m}$

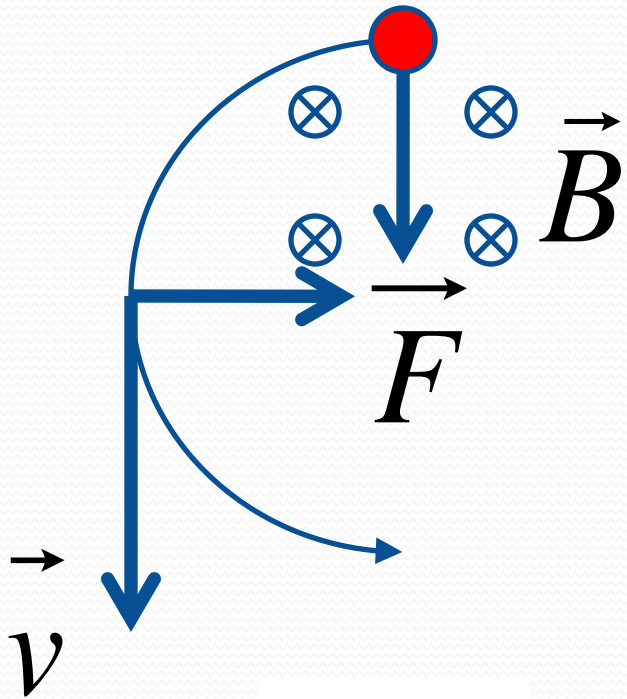
Motion in Magnetic Field



Force perpendicular to direction
→ $|\mathbf{v}|$ does not change



Motion in Magnetic Field



Force perpendicular to direction
 $\rightarrow |\mathbf{v}|$ does not change



Motion in Magnetic Field

Radial acceleration $a = \frac{v^2}{R}$

$F = qvB = m \frac{v^2}{R}$

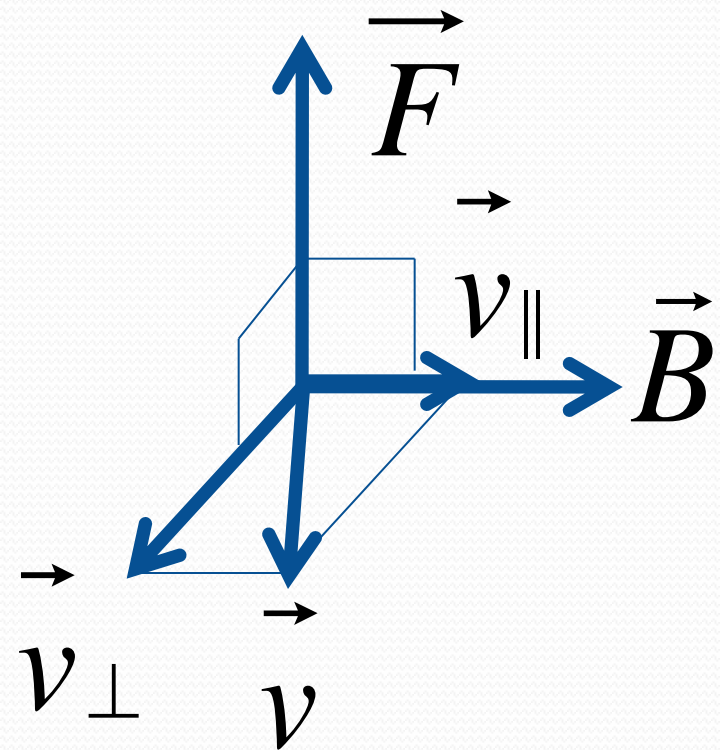
Newton's 2nd law

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

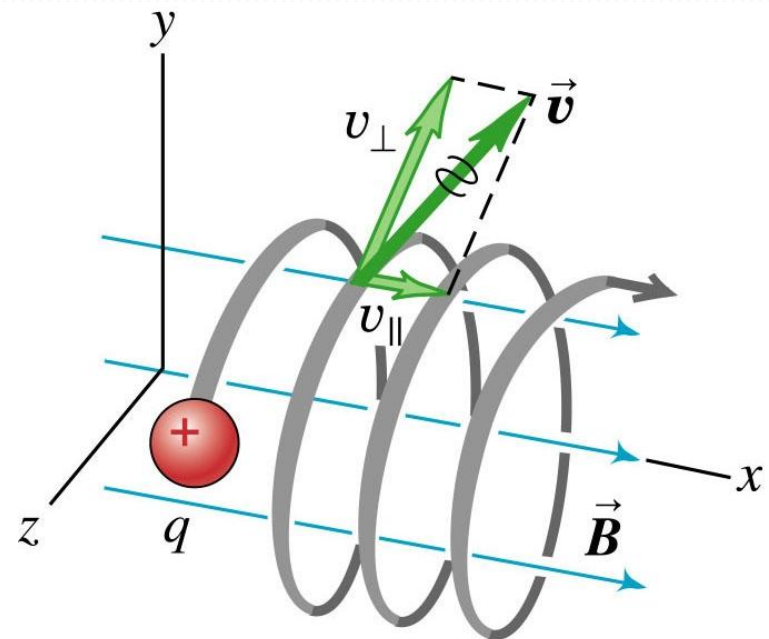
Angular velocity: $\omega = \frac{v}{R} = \frac{qB}{m}$

Helical Motion

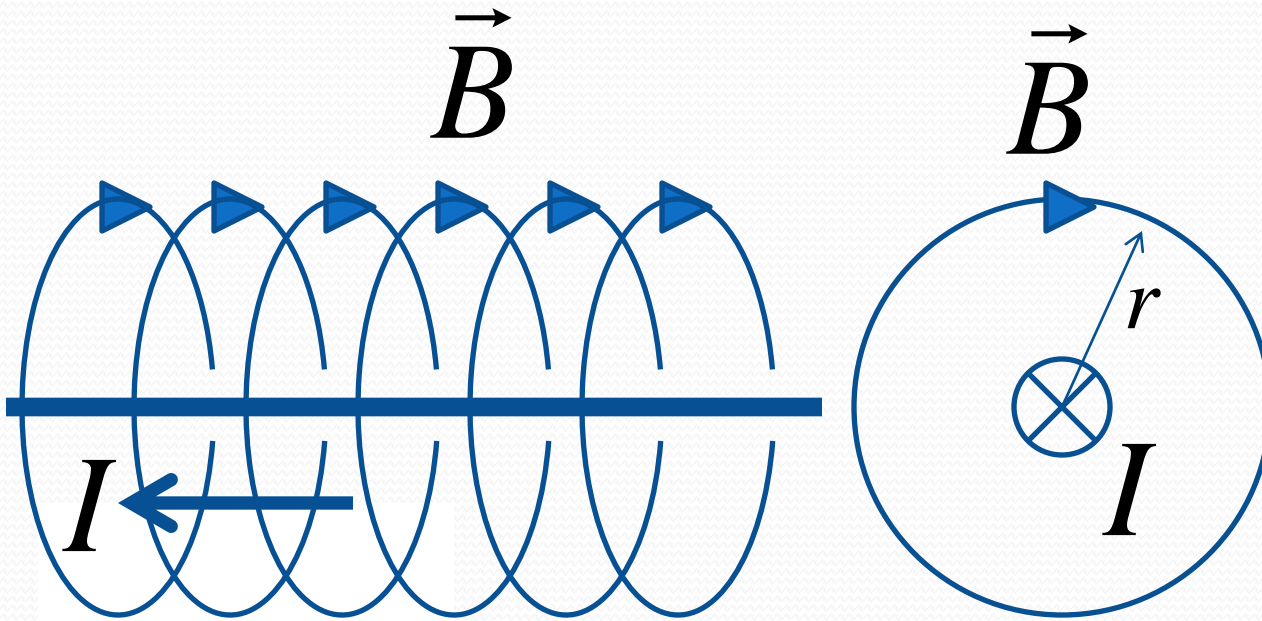
- occurs in 3D when direction of initial velocity is not perpendicular to the field



Field can't change v_{\parallel} ,
so it remains constant



Magnetic Field of a Wire

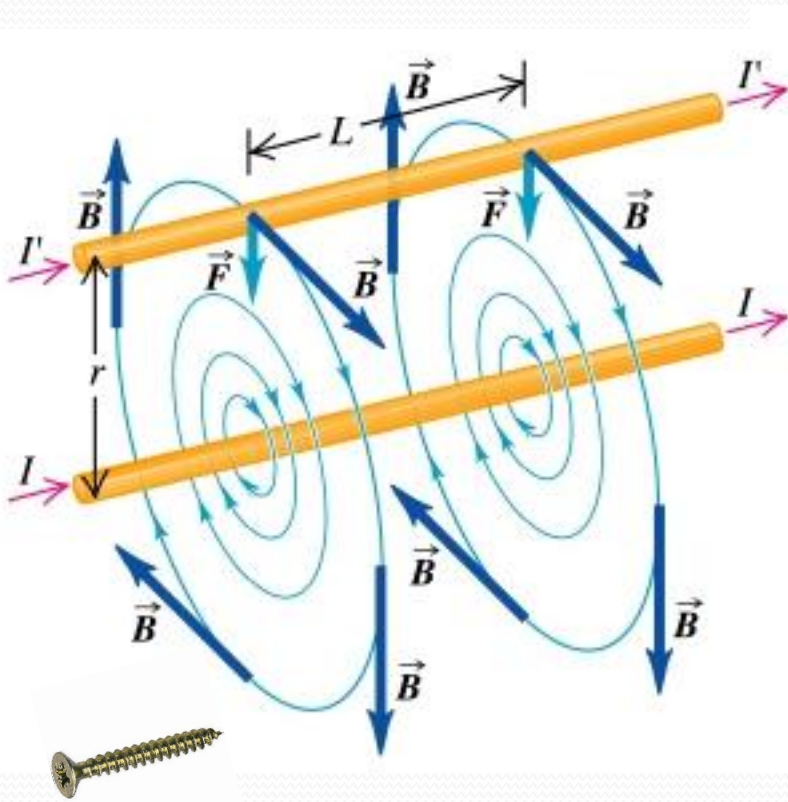


$$B = \frac{\mu_0 I}{2\pi r}$$



$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$
permeability of free space

Force between Parallel Wires

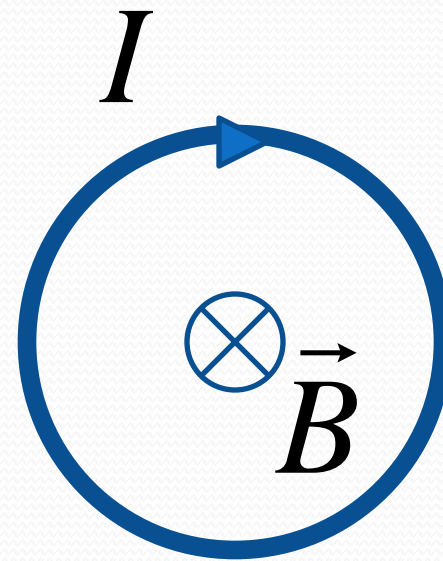
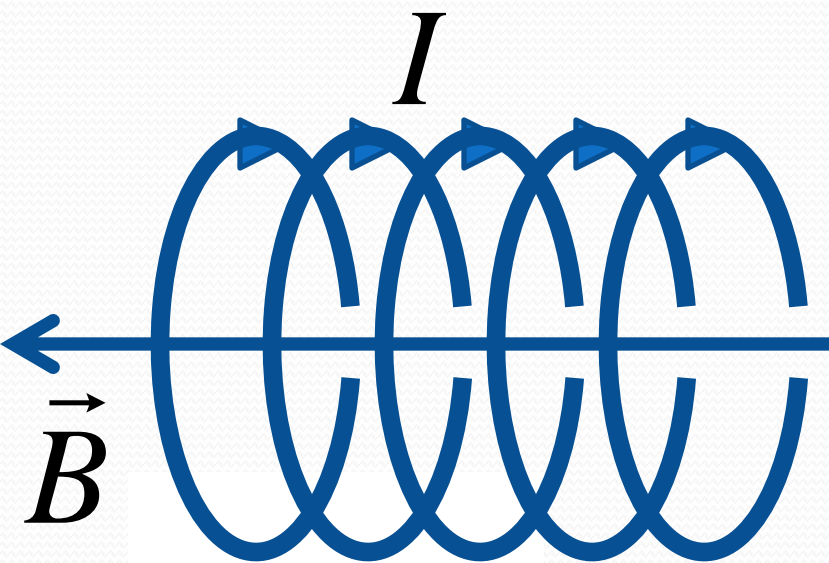


$$B = \frac{\mu_0 I}{2\pi r} \quad \frac{F}{L} = \frac{\mu_0 I I'}{2\pi r}$$

$$F = I' B l$$

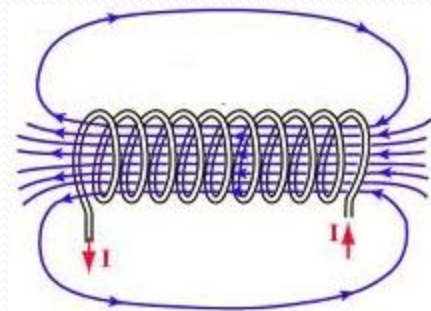
same I direction: wires attract
 opposite I direction: wires repel

Magnetic Field of a Solenoid



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

in the center of the solenoid, assuming $l \gg R$



right or left coil – it doesn't matter