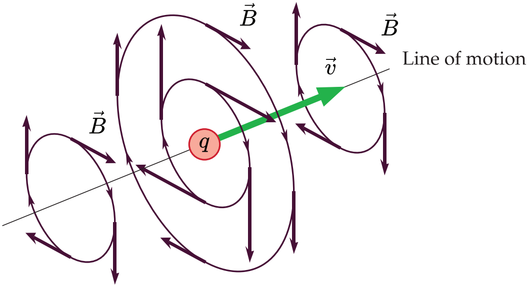
PHY-112
Principles of Physics-II
Akiful Islam (AZW)
Spring-24 | Class-19

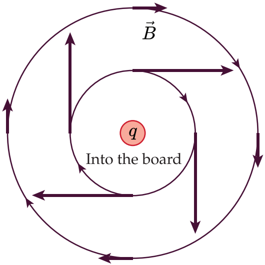
Three Important $\vec{B}$-field Models: Moving Charge, Current, Current Loop

Three Important $\vec{B}$-field Models: Single Moving Charge

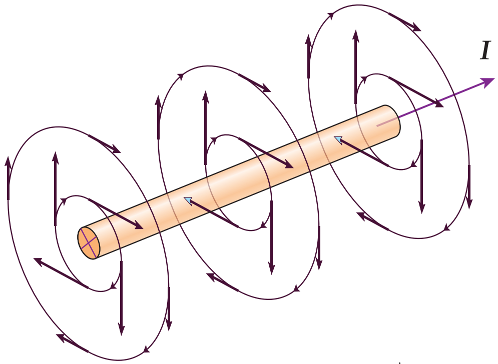
3D view

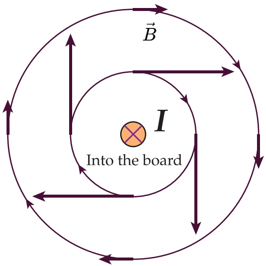


2D view



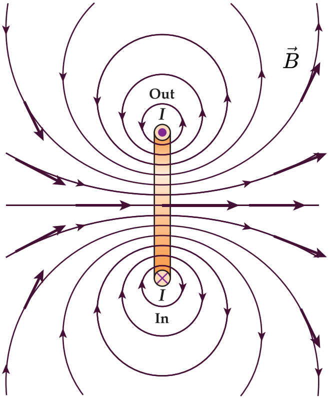
$$|\vec{B}|_{\text{point-charge}} = \frac{\mu_0}{4\pi}\left|\frac{q\vec{v}\times\hat{r}}{r^2}\right| = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$$



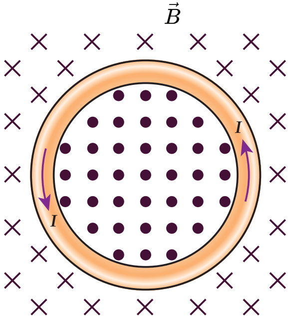


$$|\vec{B}|_{\text{current-segment}} = \frac{\mu_0}{4\pi} \int \left| \frac{I d\vec{s} \times \hat{r}}{r^2} \right| = \frac{\mu_0}{4\pi} \int \frac{I ds \sin\theta}{r^2}$$

3D view (Cross-Section)



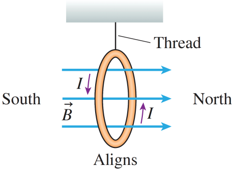
2D view



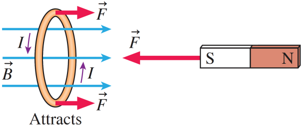
$$|\vec{B}|_{\text{current-loop}} = \frac{\mu_0 I}{2R}$$

$$|\vec{B}|_{\text{current-loop-with-turns}} = \frac{N\mu_0 I}{2R}$$

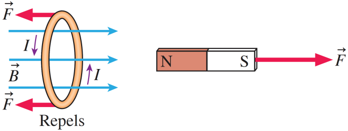
A Current Loop Is a Magnet: Electromagnet



A current loop hung by a thread aligns itself with the magnetic field pointing north.



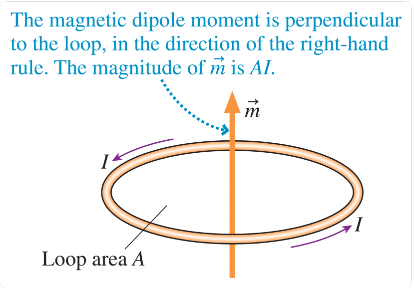
The south pole of a permanent magnet attracts the side of a current loop from which the magnetic field is emerging.



The north pole of a permanent magnet repels the side of a current loop from which the magnetic field is emerging.

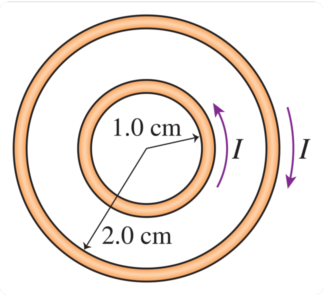
The Magnetic Dipole Moment of a current loop is

$$\vec{m} = I\vec{A} = IA\vec{n}$$



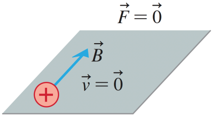
It determines the strength of the electromagnet, and its direction represents the magnet's $\vec{B}$-field direction.

Q: The two loops have equal currents in opposite directions. (i) What current will create a magnetic field strength of $350\,\mathrm{mT}$ at the center?

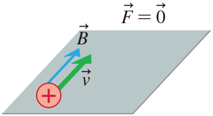


(ii) Find the net Magnetic dipole moment (magnitude and direction) at their common center.

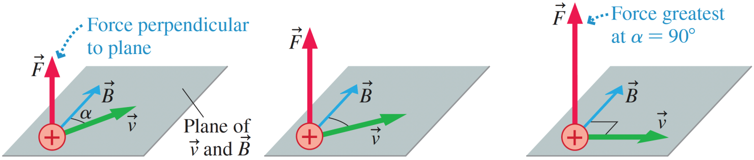
Magnetic Forces on the Three Important $\vec{B}$-field Models



There is no magnetic force on a charged particle at rest.

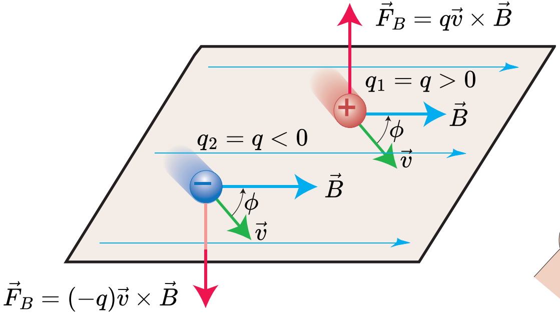


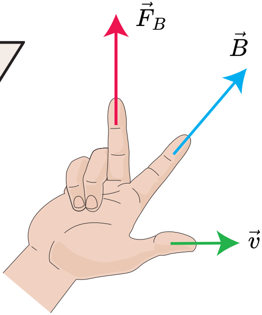
There is no magnetic force on a charged particle moving *parallel* to a magnetic field.



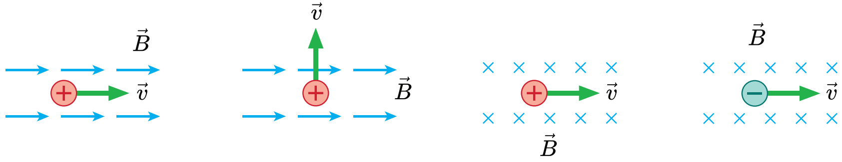
As the angle α between the velocity and the magnetic field increases, the magnetic force also increases. The force is greatest when the angle is 90°. The magnetic force is always perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.

$$\left|\vec{F}_B\right| = \left|q\vec{v} \times \vec{B}\right| = qvB\sin\phi;$$ (direction of Right-Hand Method)

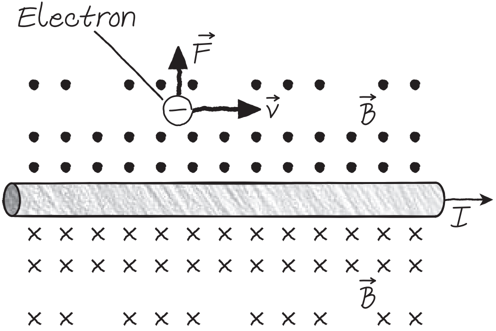




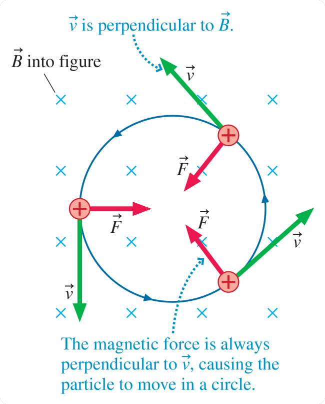
Q: Find the direction and magnitude of $\vec{F}_B$ in all 4 scenarios. Write the directions in vector component form.



Q: A long wire carries a 10 A current from left to right. An electron 1.0 cm above the wire is travelling to the right at a speed of 1.0×10^7 m s^{-1}. What are the magnitude and the direction of the magnetic force on the electron? Take $B = 2.5 \times 10^{-4}$ T.



A particle moving perpendicular to a uniform magnetic field undergoes uniform circular motion at a constant speed, called the **cyclotron motion** of a charged particle in $\vec{B}$-field. **Magnetic Forces do not work!**



Cyclotron Motion: Radius and Frequency

$$F_B = F_{\text{centripetal}}$$

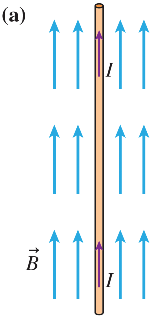
$$qvB = m\frac{v^2}{r_c}$$

Radius of the Cyclotron orbit $r_c = \dfrac{mv}{qB}$

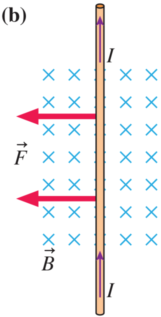
Cyclotron frequency $f_c = \dfrac{v}{2\pi r_c} = \dfrac{qB}{2\pi m}$

Cyclotron is the basis for **Particle Accelerators!**

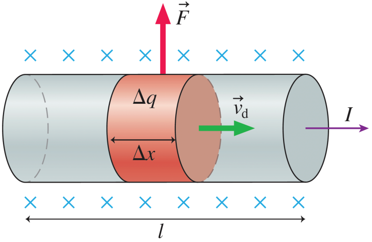
Magnetic Force on Three $\vec{B}$-field Models: Current



There's no force on a current parallel to a magnetic field.

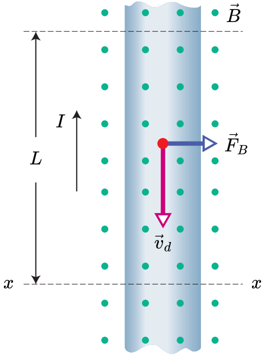


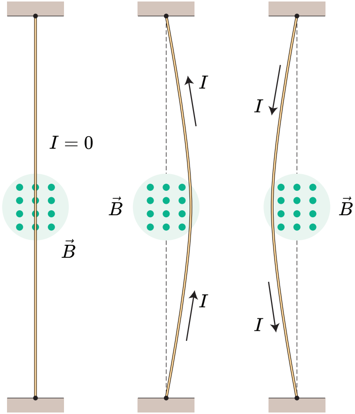
There is a magnetic force in the direction of the right-hand rule.



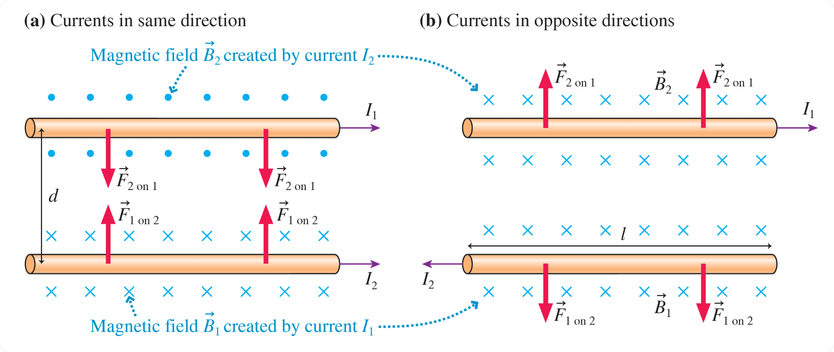
Magnetic Force on Three $\vec{B}$-field Models: Current

$$\left|\vec{F}_B\right| = \left|I\vec{L} \times \vec{B}\right| = ILB\sin\phi;$$ (direction of Right-Hand Method)

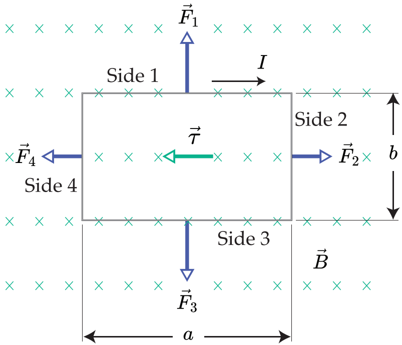




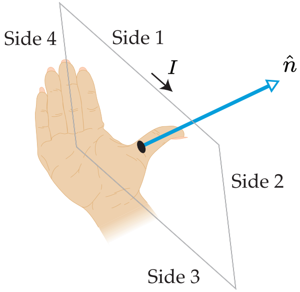
Parallel wires carrying currents in the same direction attract each other; parallel wires carrying currents in opposite directions repel each other.



Magnetic Force on Three $\vec{B}$-field Models: Current Loop



(a)



(b)

Force and Torque on a Current Loop

Magnetic Force on a current loop immersed in **uniform** $\vec{B}$-field is zero. However, there exists a **Magnetic Torque**.

$$\vec{\tau} = \vec{m} \times \vec{B} = (IA)\vec{n} \times \vec{B}$$

The torque is zero when $\vec{m}$ is aligned **parallel** or **antiparallel** to $\vec{B}$ and is maximum when mu is perpendicular to the field.

It is this magnetic torque that causes a compass needle to rotate until it is aligned with the magnetic field.