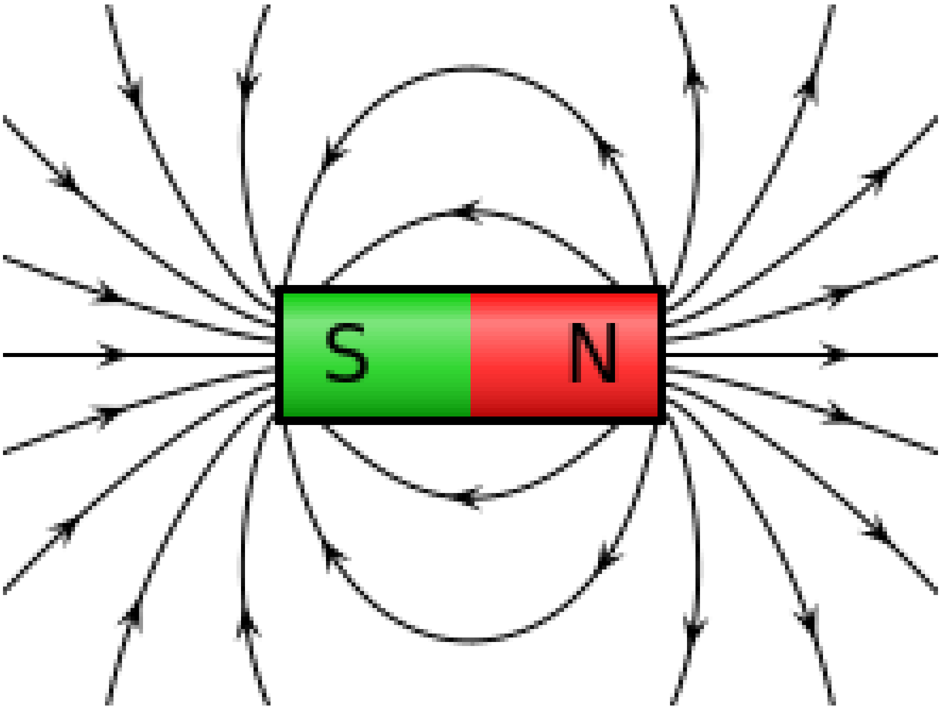
SECTION

Magnetism

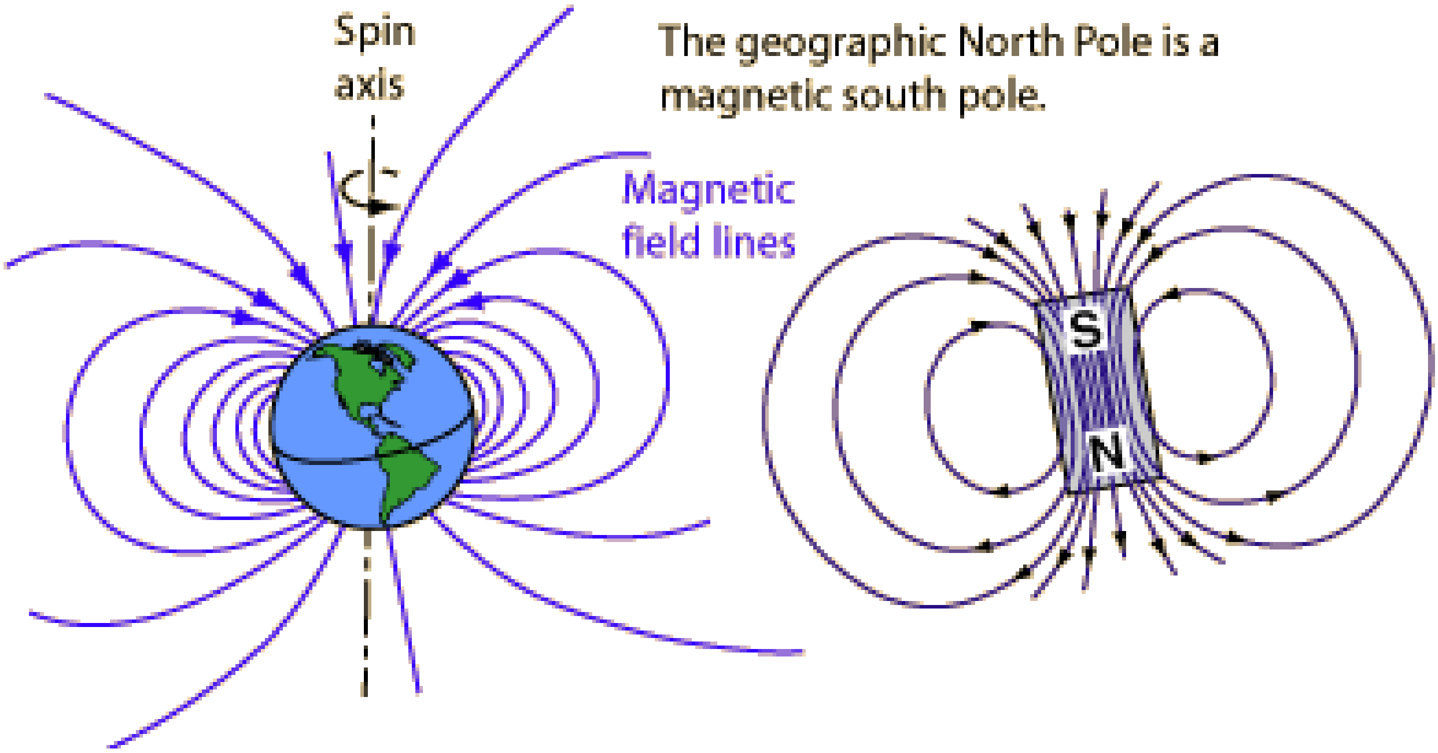
Lecture # 18

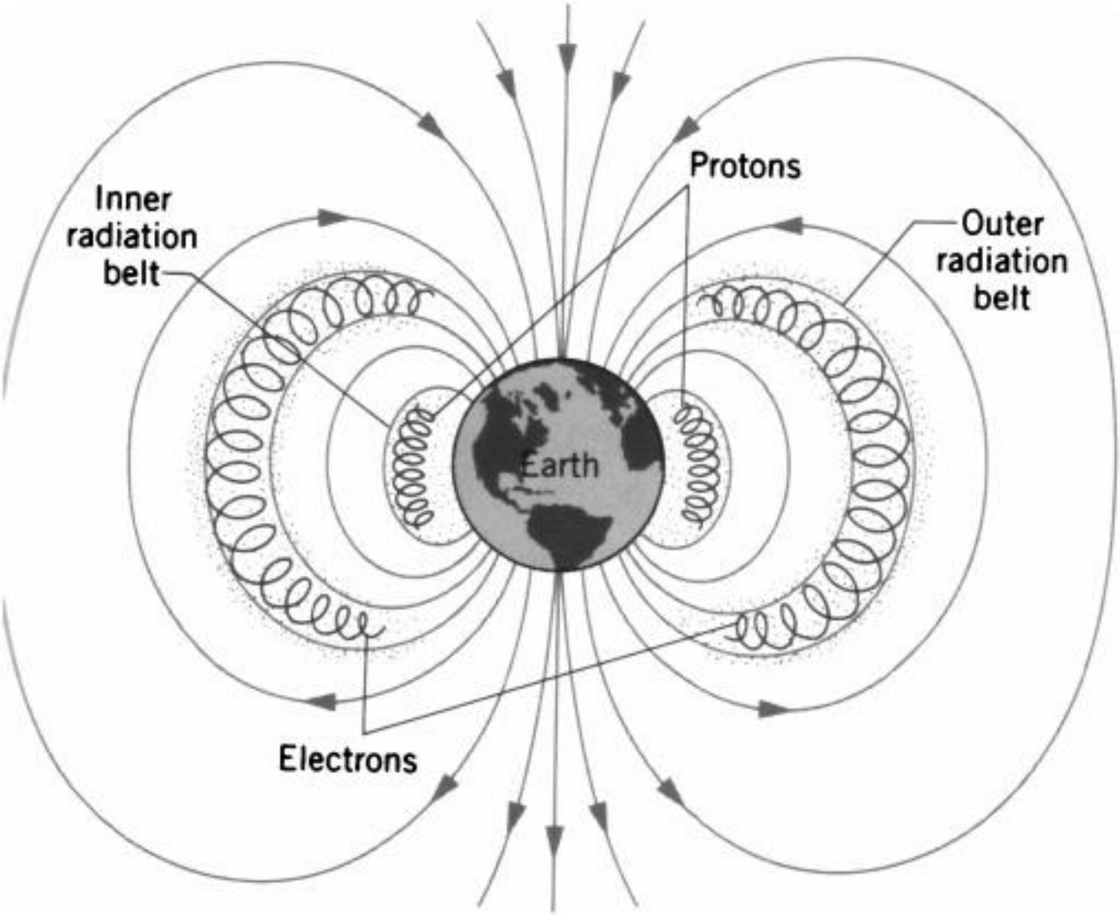
- Magnetism
- Magnetic field
- The magnetic force on a moving charge
- Right hand rule
- The magnetic force on a negative charge

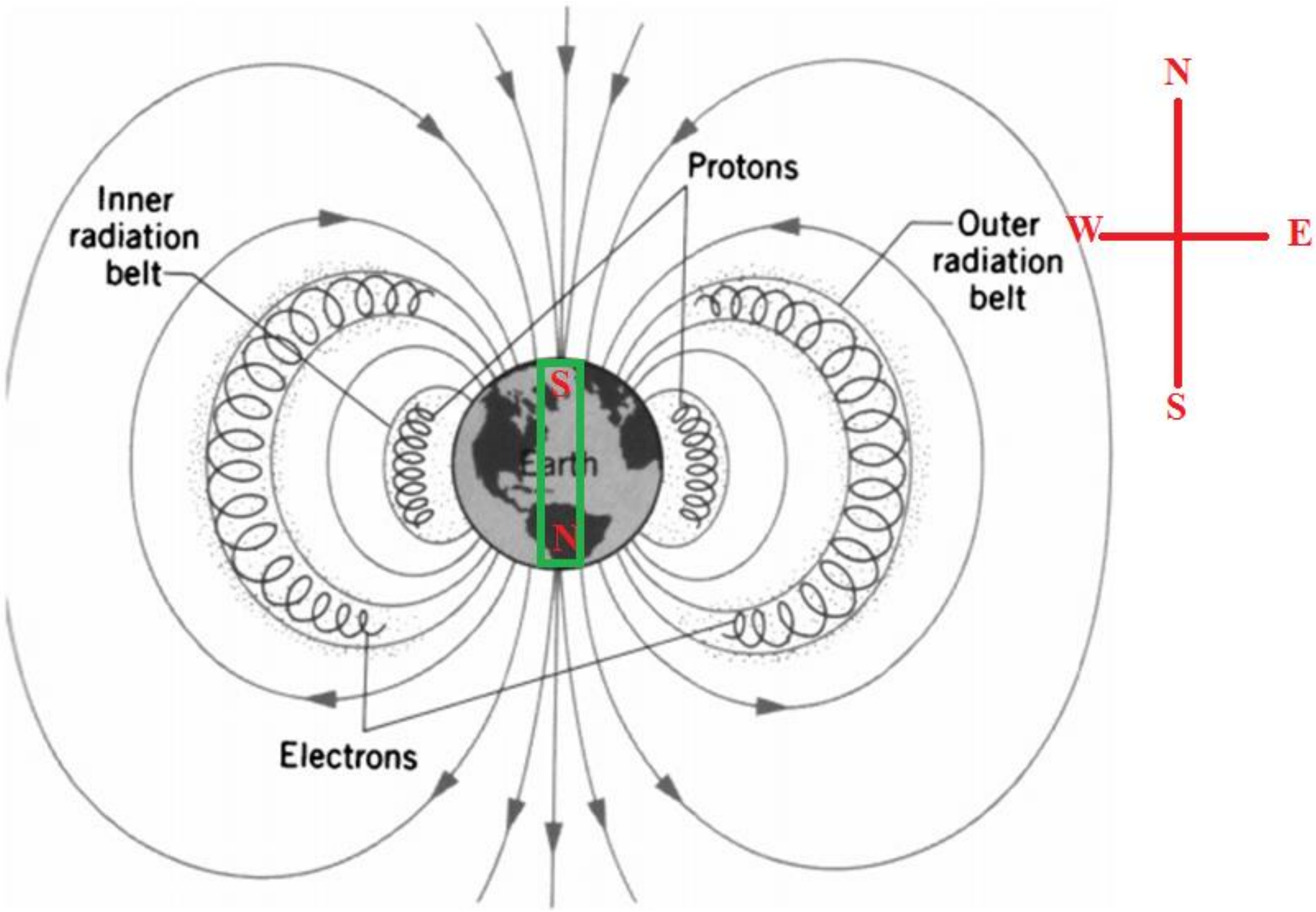
Magnetic field

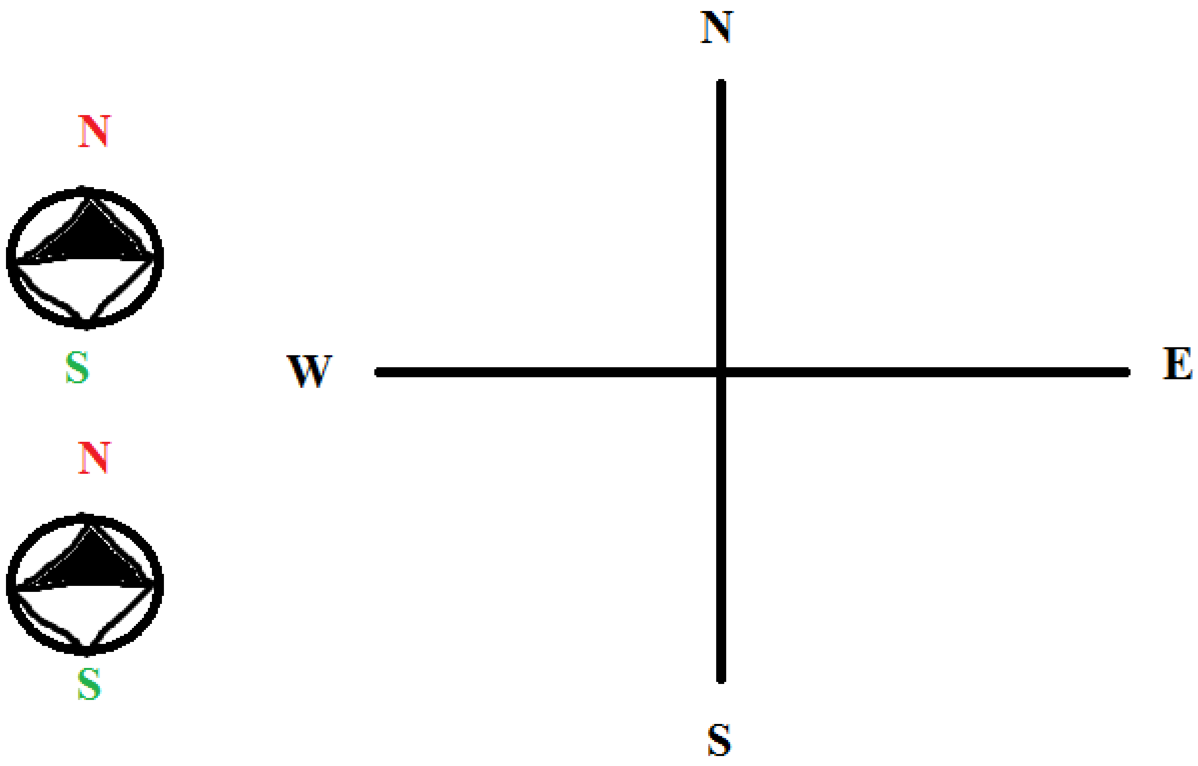


THE MAGNETIC FIELD B




Protons
Inner
radiation
belt
Outer
radiation
belt
Earth
Electrons


Protons
Inner radiation belt
Outer radiation belt
S
Earth
N
Electrons
N
W
E
S


N
S
N
S
N
W
E
S

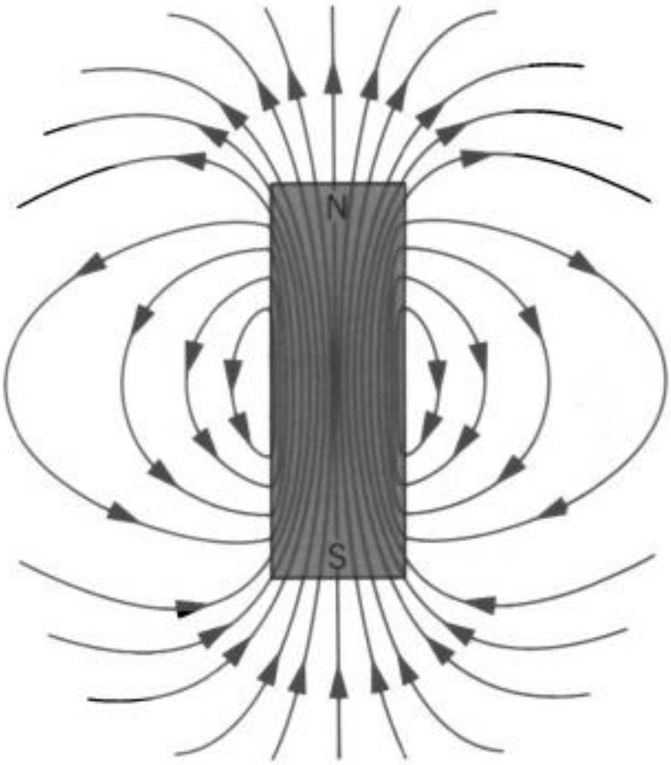


Figure 5 The magnetic field lines for a bar magnet. The lines form closed loops, leaving the magnet at its north pole and entering at its south pole.

magnetic charge $\rightleftarrows$ $\mathbf{B}$ $\rightleftarrows$ magnetic charge.

Wrong Statement

moving electric charge $\rightleftarrows$ $\mathbf{B}$ $\rightleftarrows$ moving electric charge,

Correct Statement

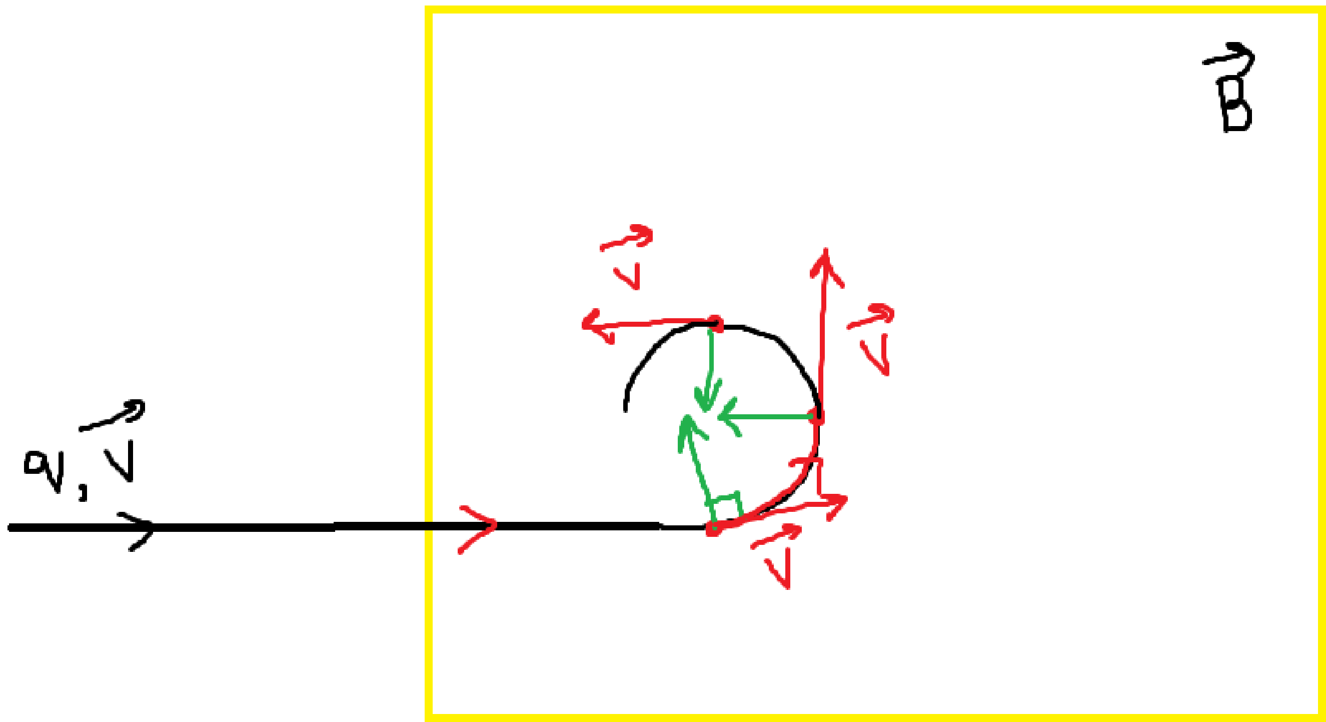
We analyze the magnetic interaction of two currents in a manner similar to that of our analysis of the electric interaction between two charges:

$$\text{charge} \rightleftarrows \mathbf{E} \rightleftarrows \text{charge.}$$

That is, one charge sets up an electric field, and the other charge interacts with the field at its particular location. We use a similar procedure for the magnetic interaction:

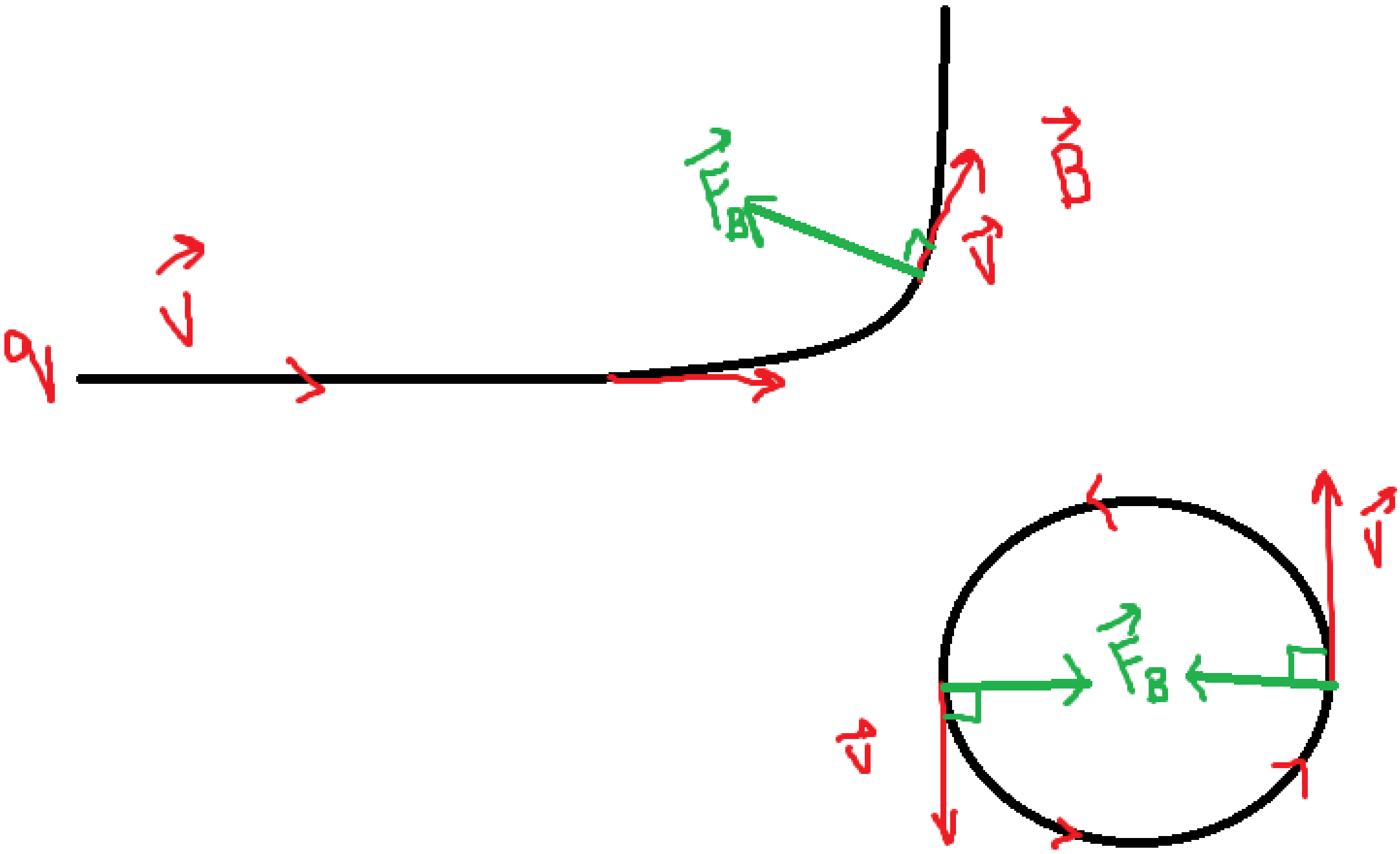
$$\text{current} \rightleftarrows \mathbf{B} \rightleftarrows \text{current.}$$

Here a current sets up a magnetic field, and the other current then interacts with that field.

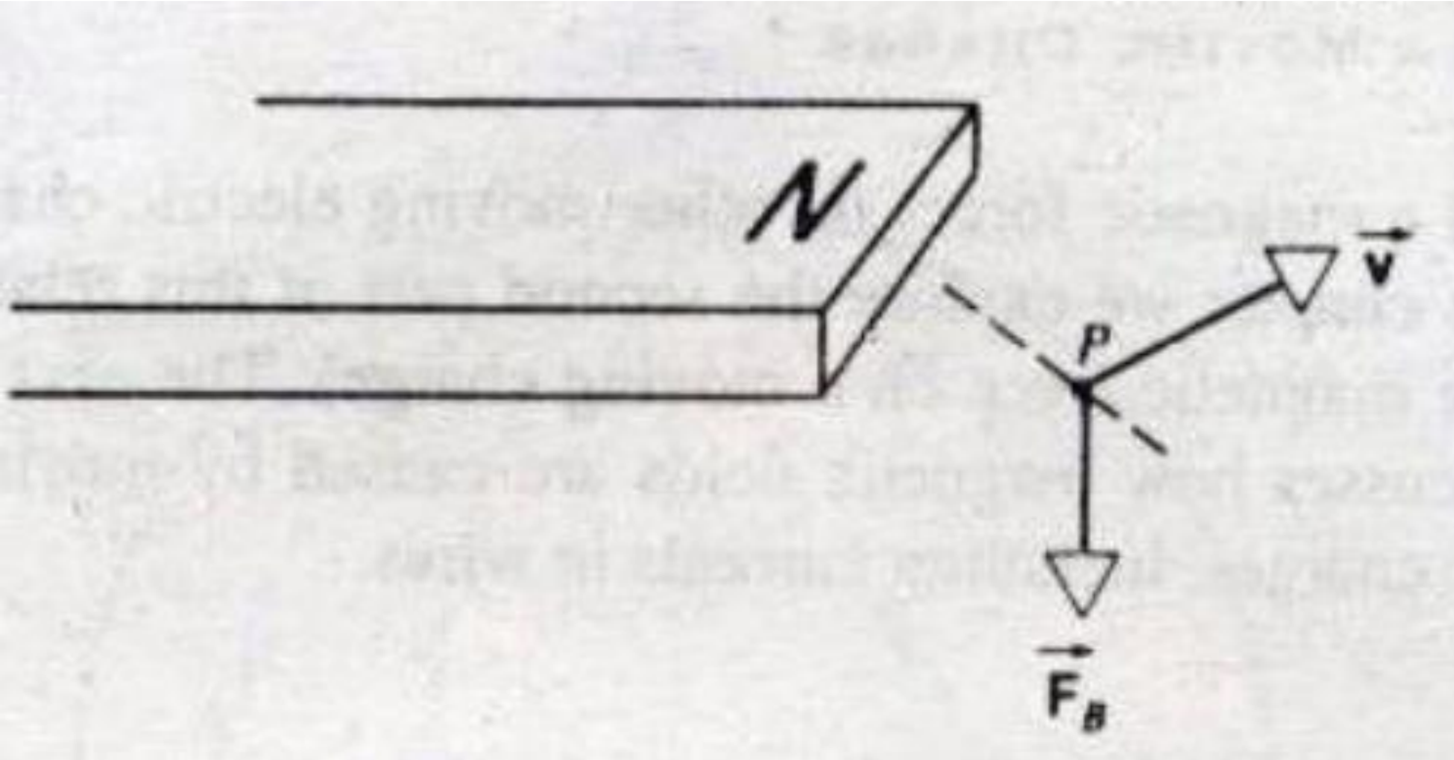


$q, \vec{v}$
$\vec{B}$
$\vec{v}$
$\vec{v}$
$\vec{v}$

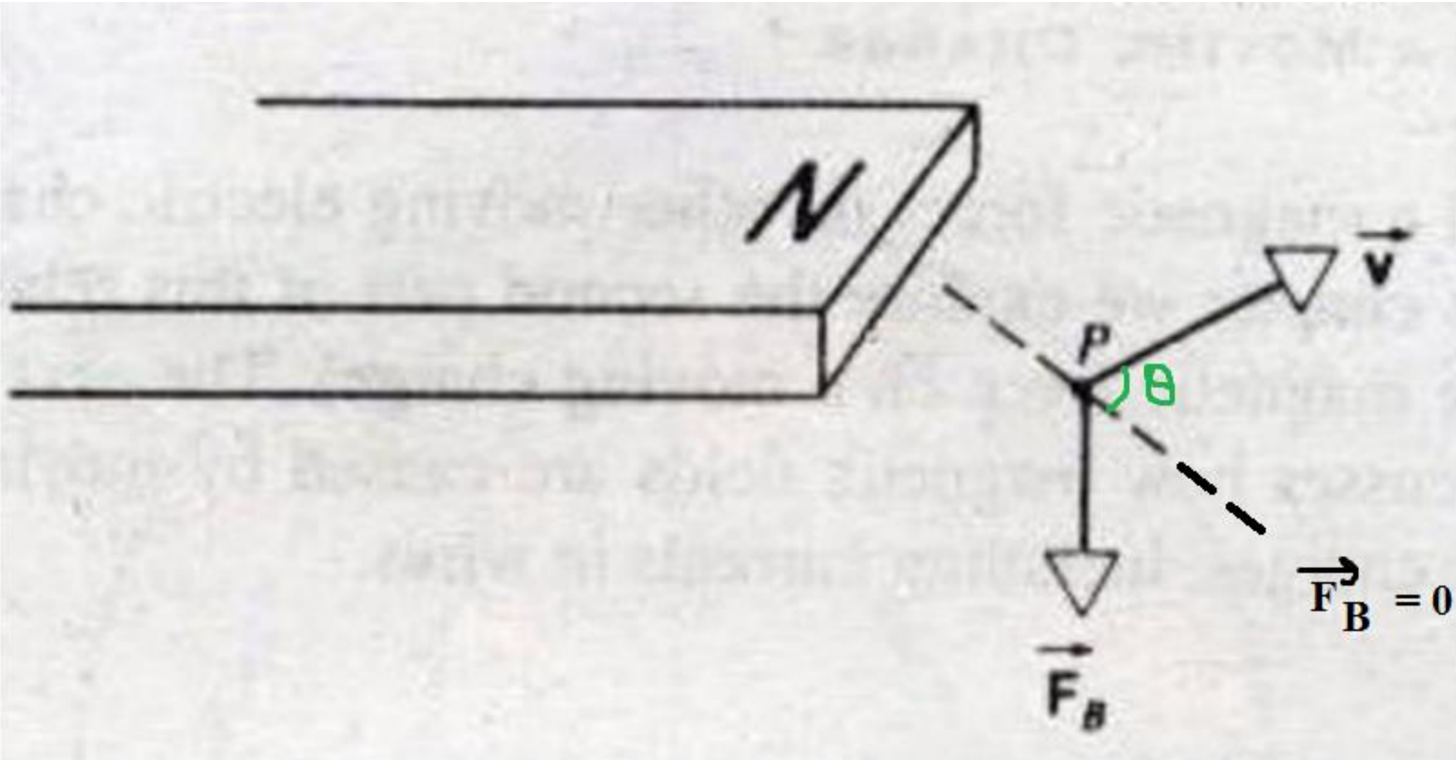
Magnetic force is a deflecting force



The magnetic force on a single moving charge


N
P
v
F_B

1. We first test for the presence of an *electric* force by placing a small test charge at rest at various locations. Later we can subtract the electric force (if any) from the total force, which presumably leaves only the magnetic force. We assume this has been done, so that from now on we can ignore any electric force that acts on the charge.

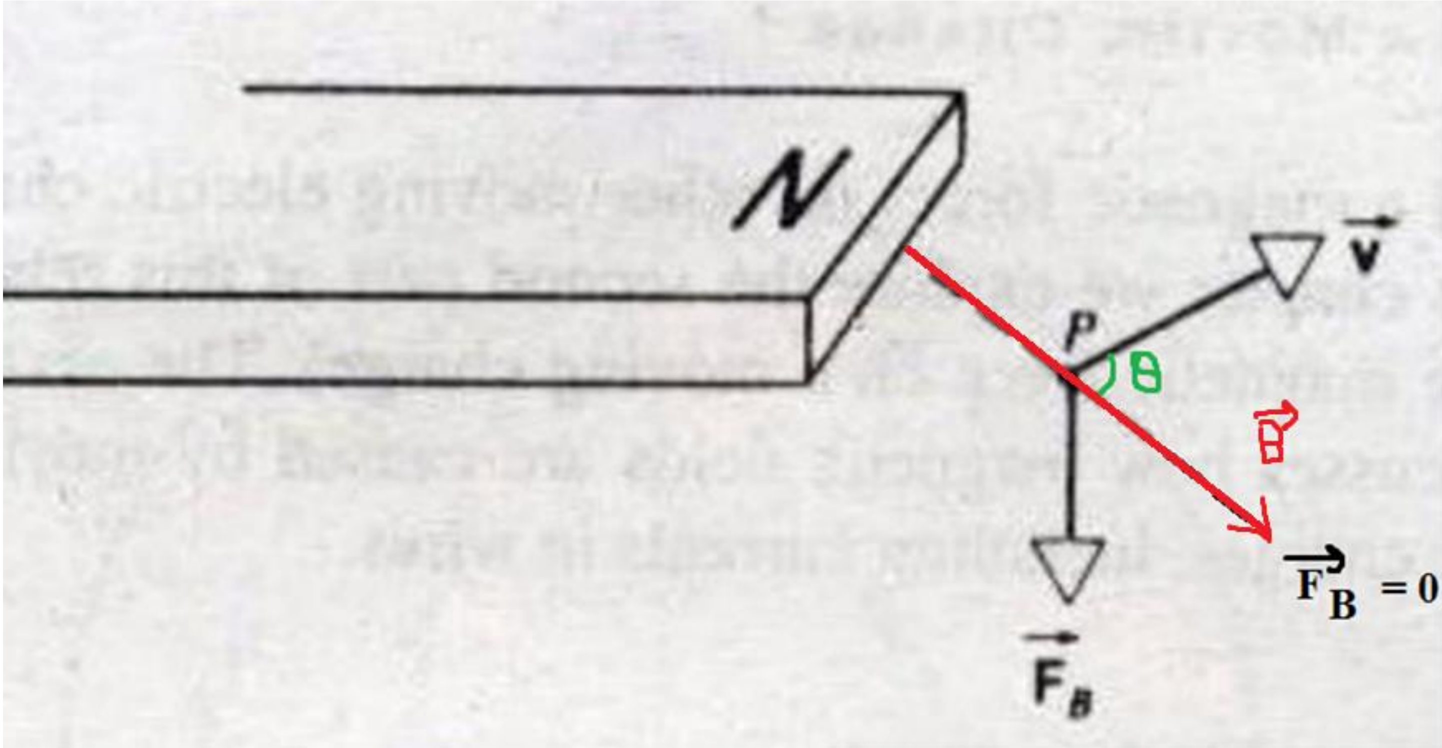

N
P
θ
v
$\vec{F}_B = 0$
$\vec{F}_B$

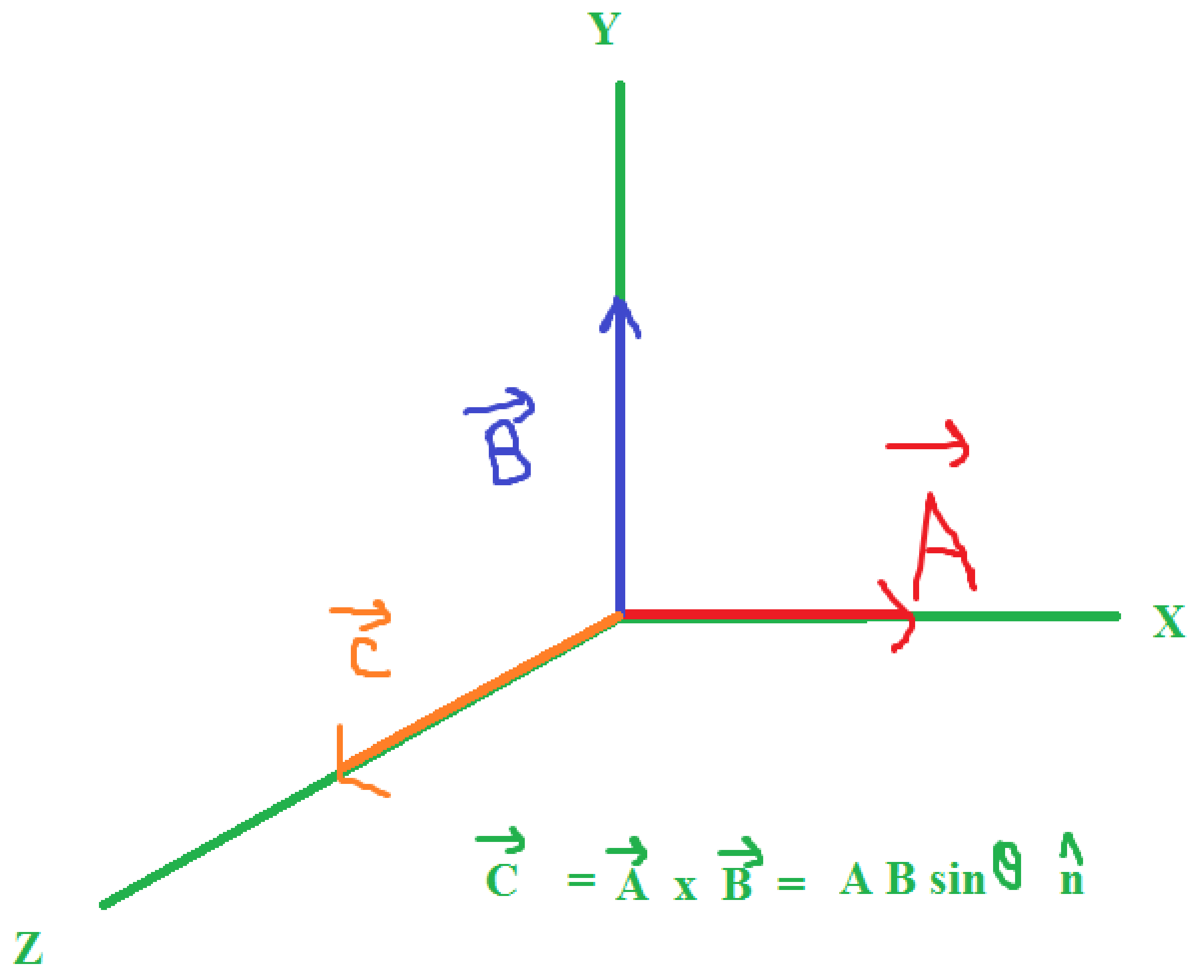
2. Next we project the test charge q through a particular point P with a velocity $\mathbf{v}$. We find that the magnetic force $\mathbf{F}$, if it is present, always acts sideways, that is, at right angles to the direction of $\mathbf{v}$. We can repeat the experiment by projecting the charge through P in different directions; we find that, no matter what the direction of $\mathbf{v}$, the magnetic force is always at right angles to that direction.

3. As we vary the direction of $\mathbf{v}$ through point P, we also find that the magnitude of F changes from zero when $\mathbf{v}$ has a certain direction to a maximum when it is at right angles to that direction. At intermediate angles, the magnitude of F varies as the sine of the angle ϕ that the velocity vector makes with that particular direction. (Note that there are actually two directions of $\mathbf{v}$ for which $\mathbf{F}$ is zero; these directions are opposite to each other, that is, $\phi = 0°$ or $180°$.)

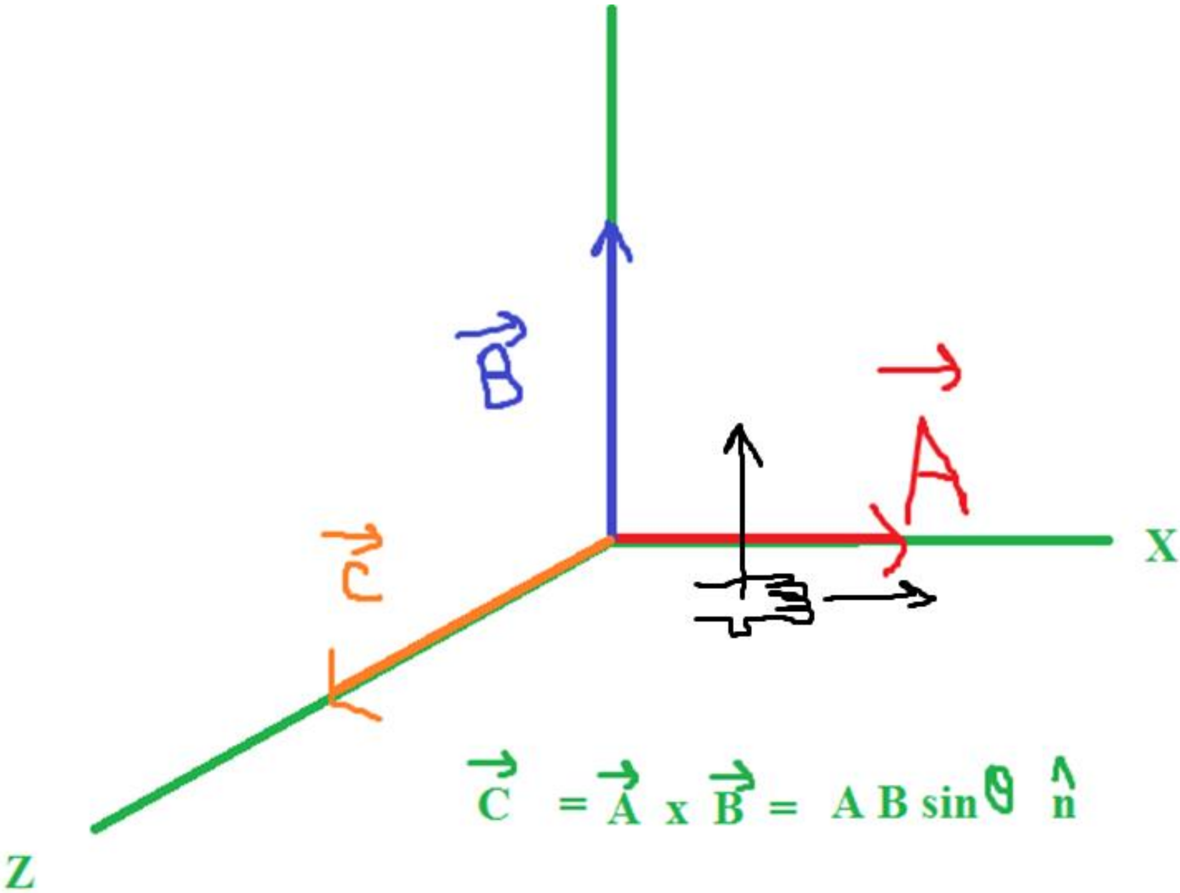
4. As we vary the magnitude of the velocity, we find that the magnitude of F varies in direct proportion.

5. We also find that F is proportional to the magnitude of the test charge q, and that $\mathbf{F}$ reverses direction when q changes sign.


N
P
θ
$\vec{B}$
$\vec{v}$
$\vec{F}_B$
$\vec{F}_B = 0$



$$\vec{C} = \vec{A} \times \vec{B} = A\,B \sin\theta \;\hat{n}$$



$$\vec{C} = \vec{A} \times \vec{B} = A\,B \sin\theta\ \hat{n}$$

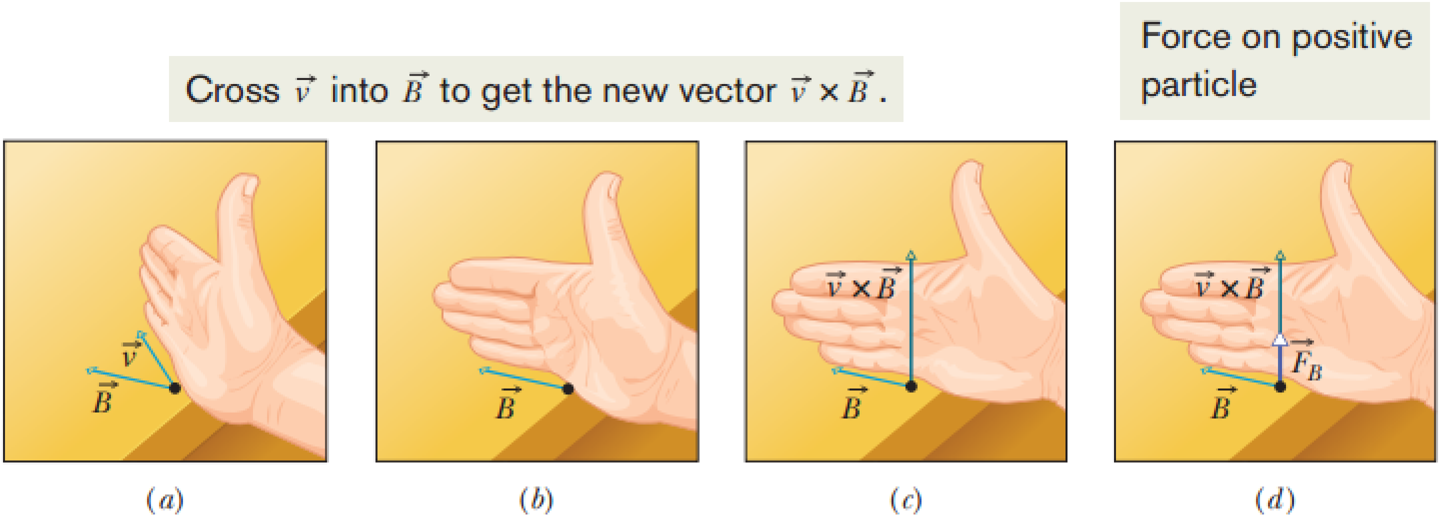
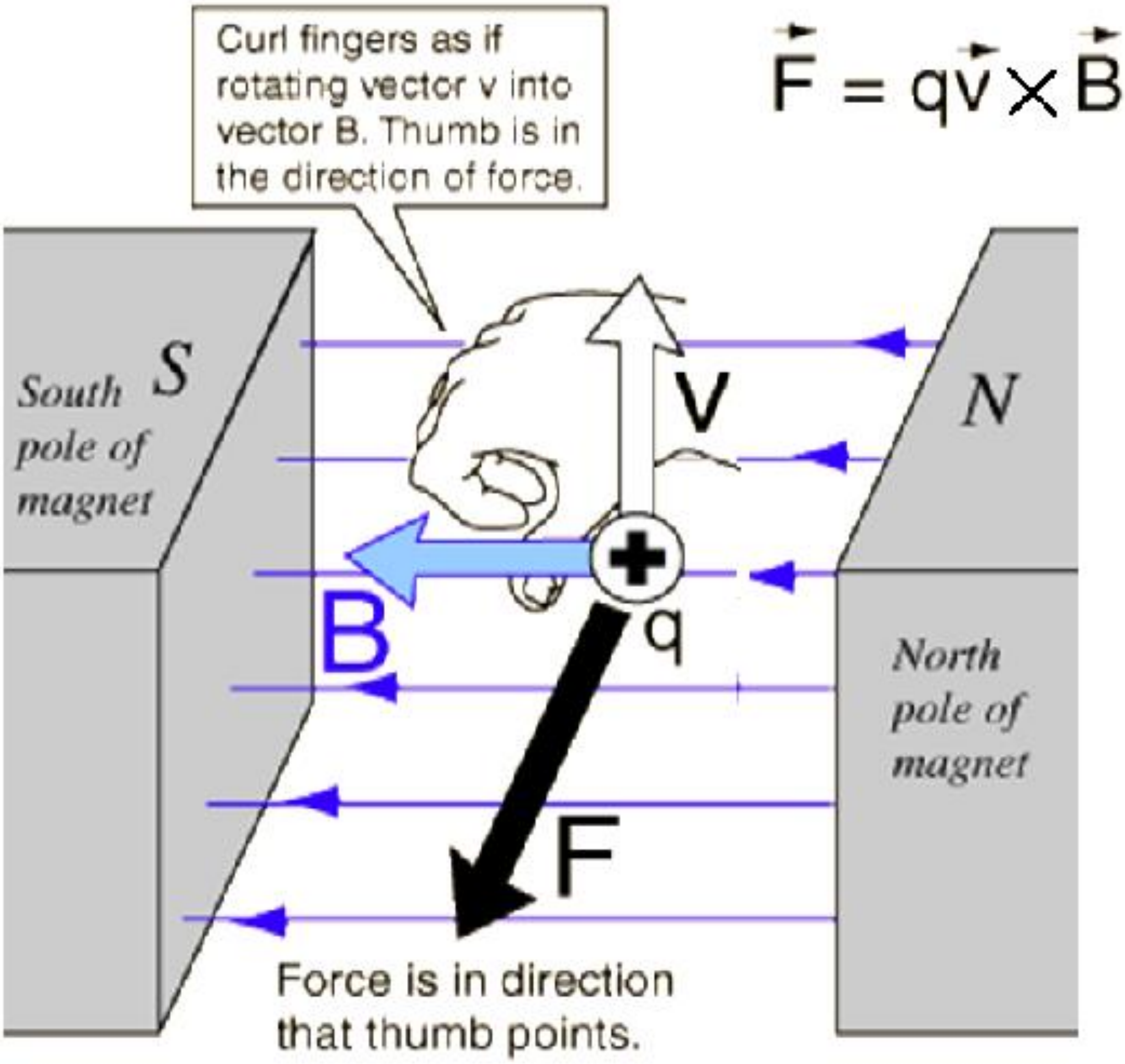


Figure (a)–(c) The right-hand rule (in which $\vec{v}$ is swept into $\vec{B}$ through the smaller angle ϕ between them) gives the direction of $\vec{v} \times \vec{B}$ as the direction of the thumb. (d) If q is positive, then the direction of $\vec{F}_B = q\vec{v} \times \vec{B}$ is in the direction of $\vec{v} \times \vec{B}$.



Curl fingers as if rotating vector v into vector B. Thumb is in the direction of force.
$\vec{F} = q\vec{v} \times \vec{B}$
South pole of magnet
S
N
V
B
q
North pole of magnet
F
Force is in direction that thumb points.

The magnetic force on a negative charge

The force acting on the charge due to magnetic force will be;

$$F_B = q(\vec{v} \times \vec{B}) \quad \text{— (i)}$$

For negative charge, the magnetic force will be;

$$F_B = -e(\vec{v} \times \vec{B})$$

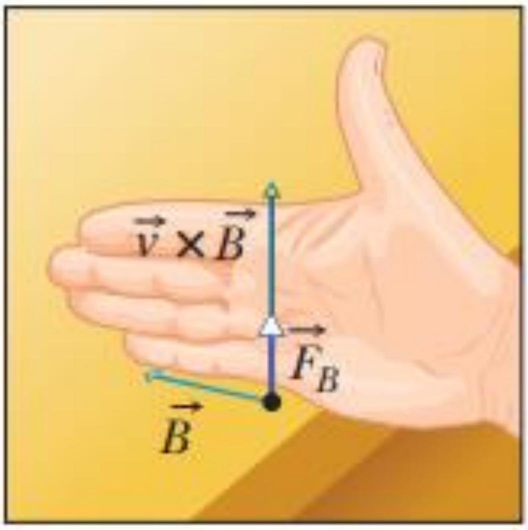
For negative charge, the magnetic force will be;

$$F_B = -e(\vec{v} \times \vec{B})$$

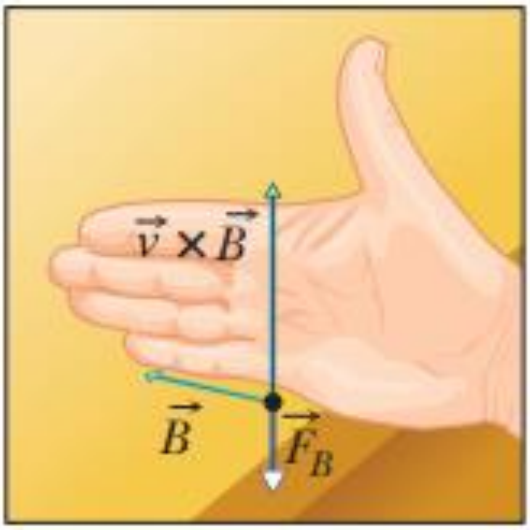
And;

$$F_B = e(\vec{B} \times \vec{v}) \quad \text{— (ii)}$$

Force on positive particle



Force on negative particle



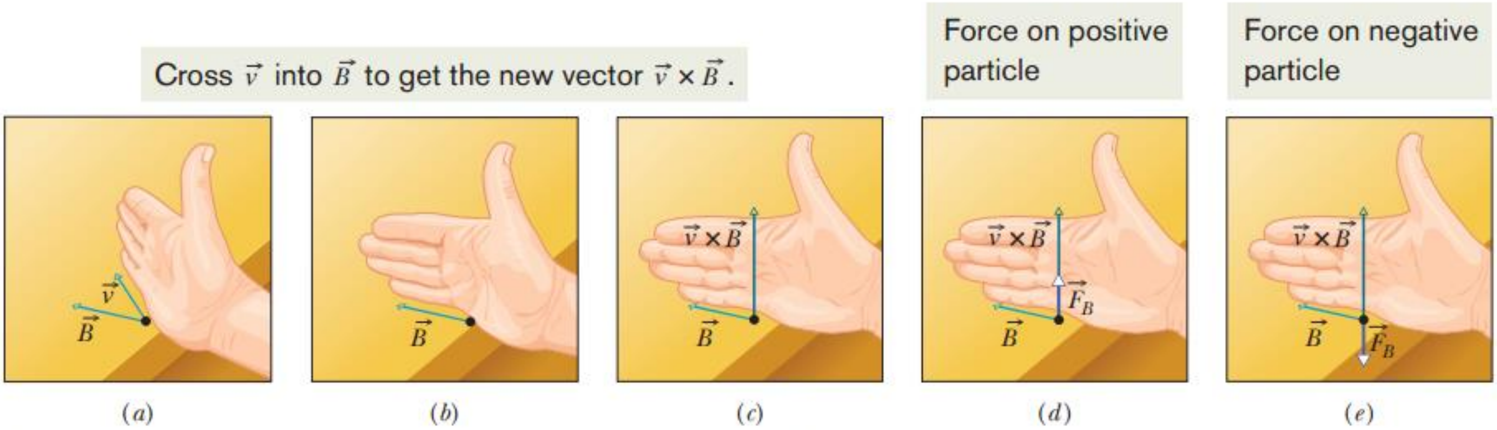


Figure (*a*)–(*c*) The right-hand rule (in which $\vec{v}$ is swept into $\vec{B}$ through the smaller angle ϕ between them) gives the direction of $\vec{v} \times \vec{B}$ as the direction of the thumb. (*d*) If q is positive, then the direction of $\vec{F}_B = q\vec{v} \times \vec{B}$ is in the direction of $\vec{v} \times \vec{B}$. (*e*) If q is negative, then the direction of $\vec{F}_B$ is opposite that of $\vec{v} \times \vec{B}$.