PHYSICS 1B – Fall 2009

Electricity

&

Magnetism

Professor Brian Keating

SERF Building. Room 333

19.1 Magnetism

Magnets
Earth's magnetic field
Magnetic Field-force on a moving charge

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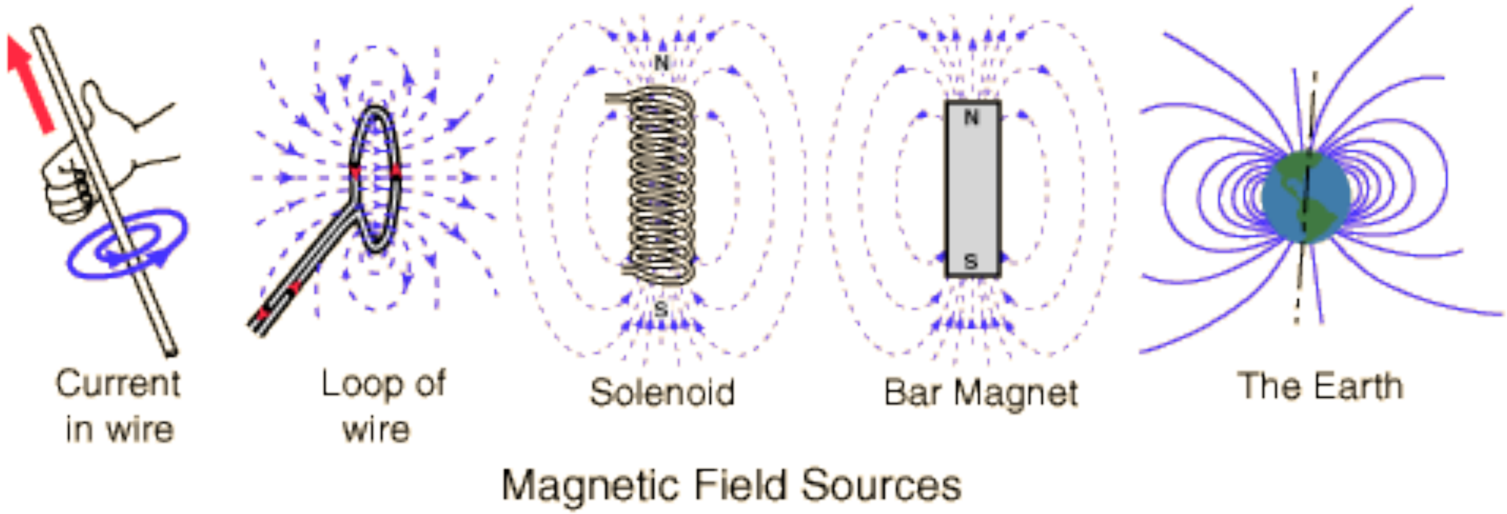


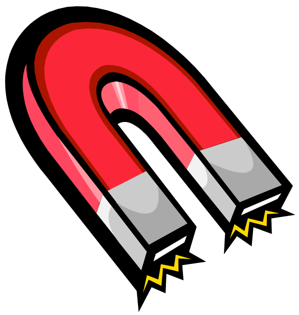
Magnetism
Magnetism results from Magnetic fields that are produced by moving charges. There are many applications of magnetism involving the interconversion of mechanical energy and electrical energy.

Applications-

magnets
Electrical generators
Electrical motors
Magnetic resonance imaging
Magnetic data storage- magnetic tape, computer drives

Magnets

Permanent Magnets- atomic magnetism due to motion of electrons

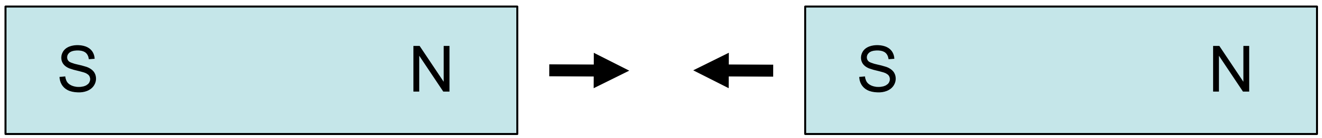


Electro magnets- magnetism results from current flow.

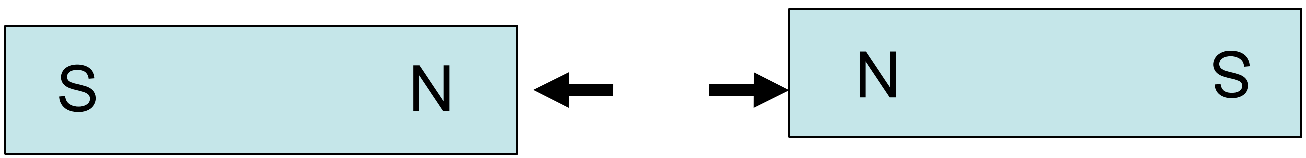
Magnets

A magnet has two poles (magnetic dipole)
North -South

Opposite poles attract



Like poles repel



No Magnetic Monopoles are found (i.e. there is no magnetic equivalent of charge)

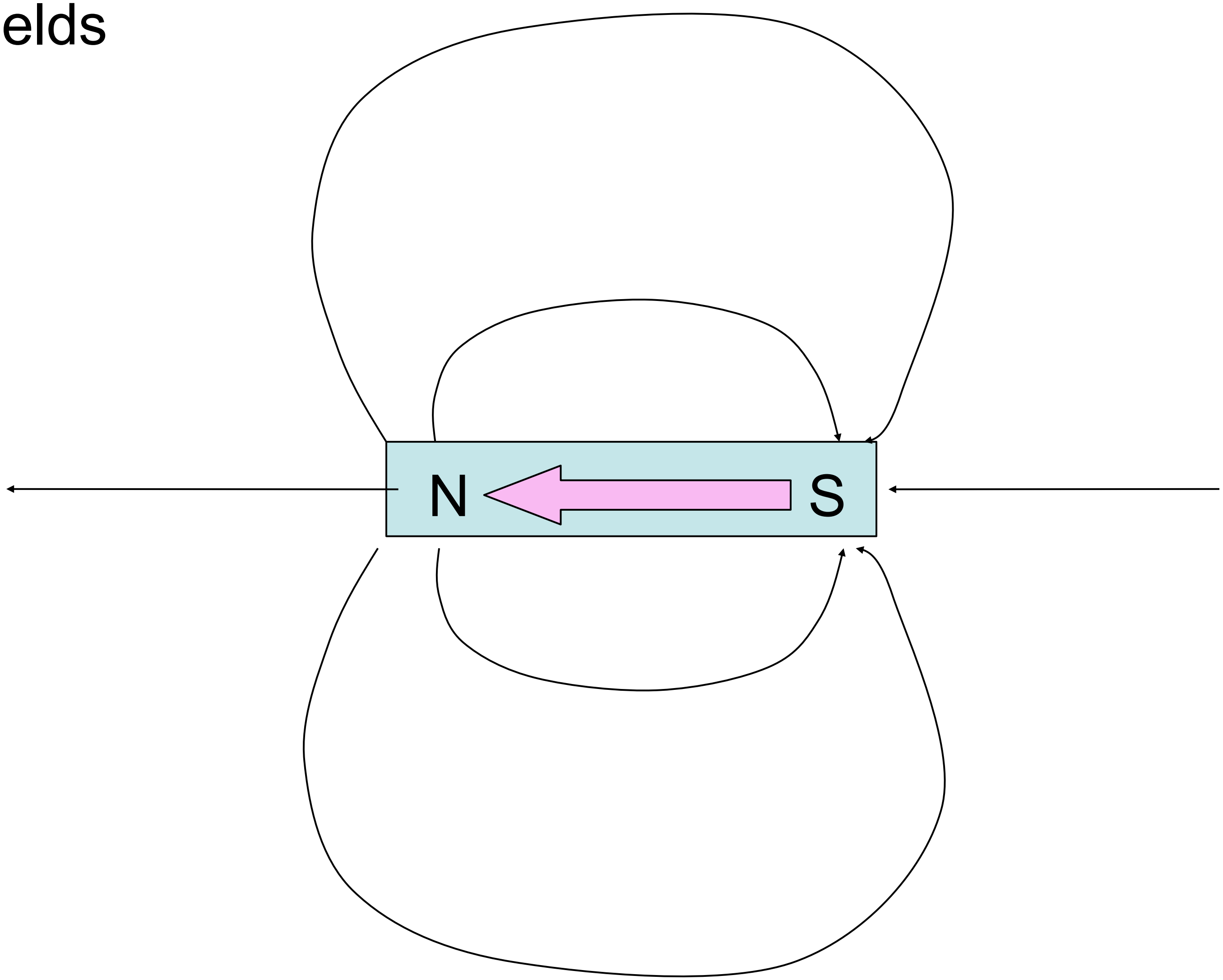
Cut a magnetic in two

GET

NOT

no matter how small the magnet

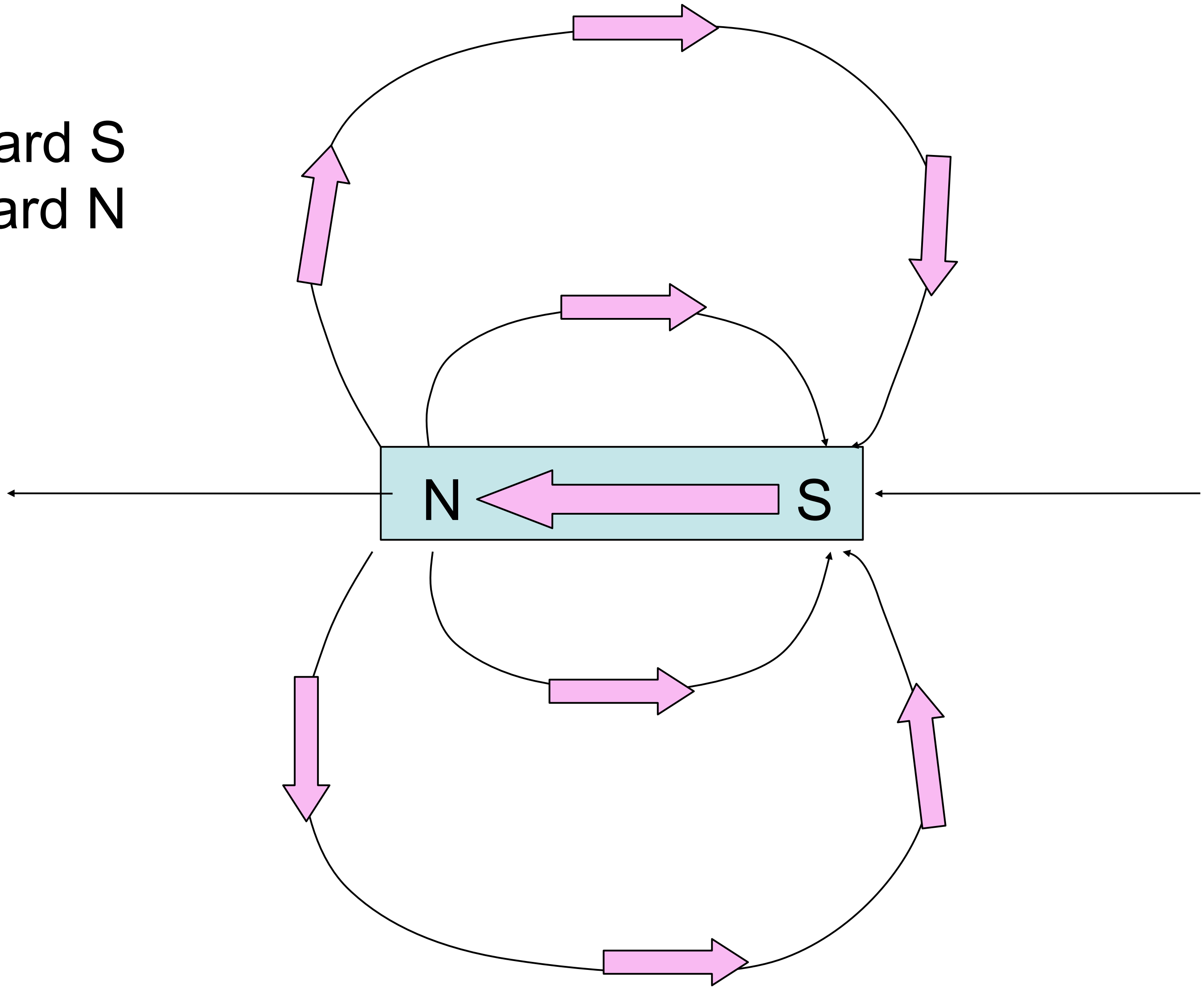
Magnetic Fields



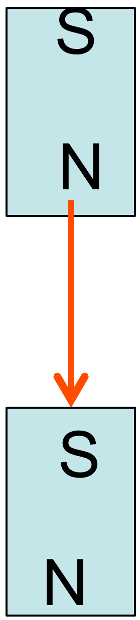
Magnetic field lines around magnetic dipole go from N to S

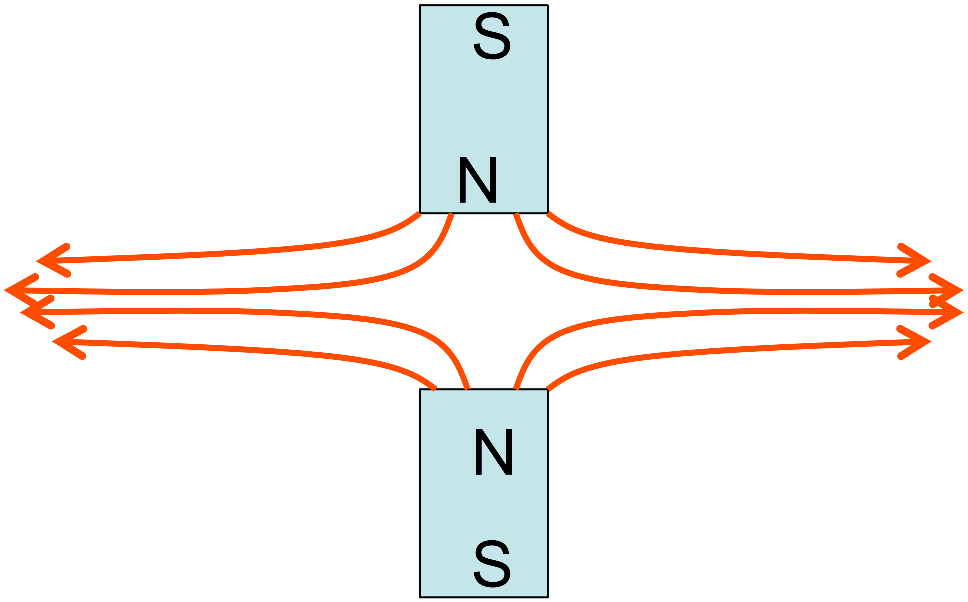
Magnetic dipoles are oriented in magnetic fields parallel to magnetic field lines. e.g. compass needle

N pole toward S
S pole toward N



Magnetic field lines of magnets
Visualized using iron filings- magnetic particles
Originate at N pole- terminate at S pole





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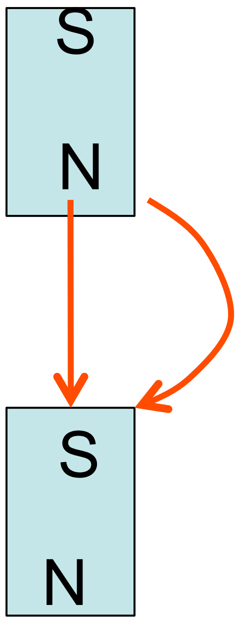

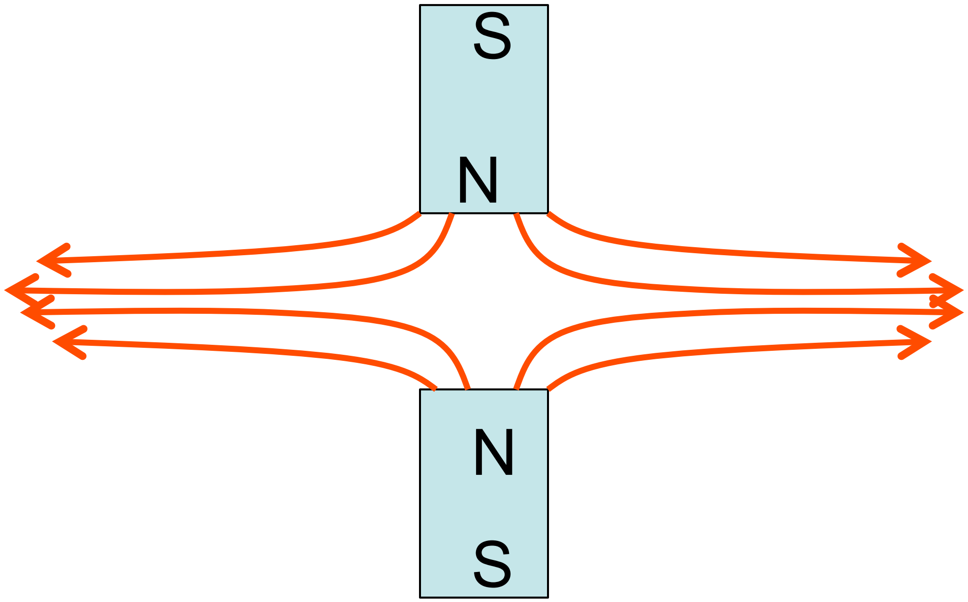

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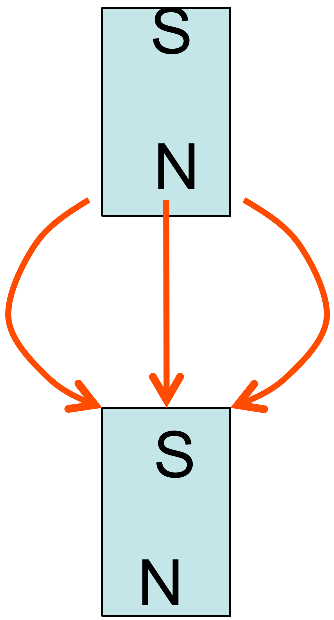

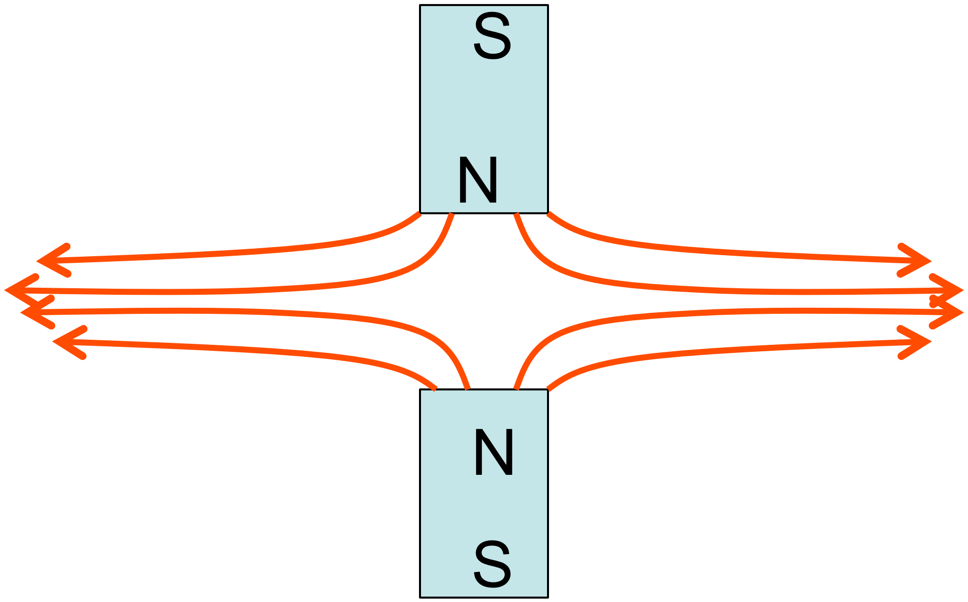

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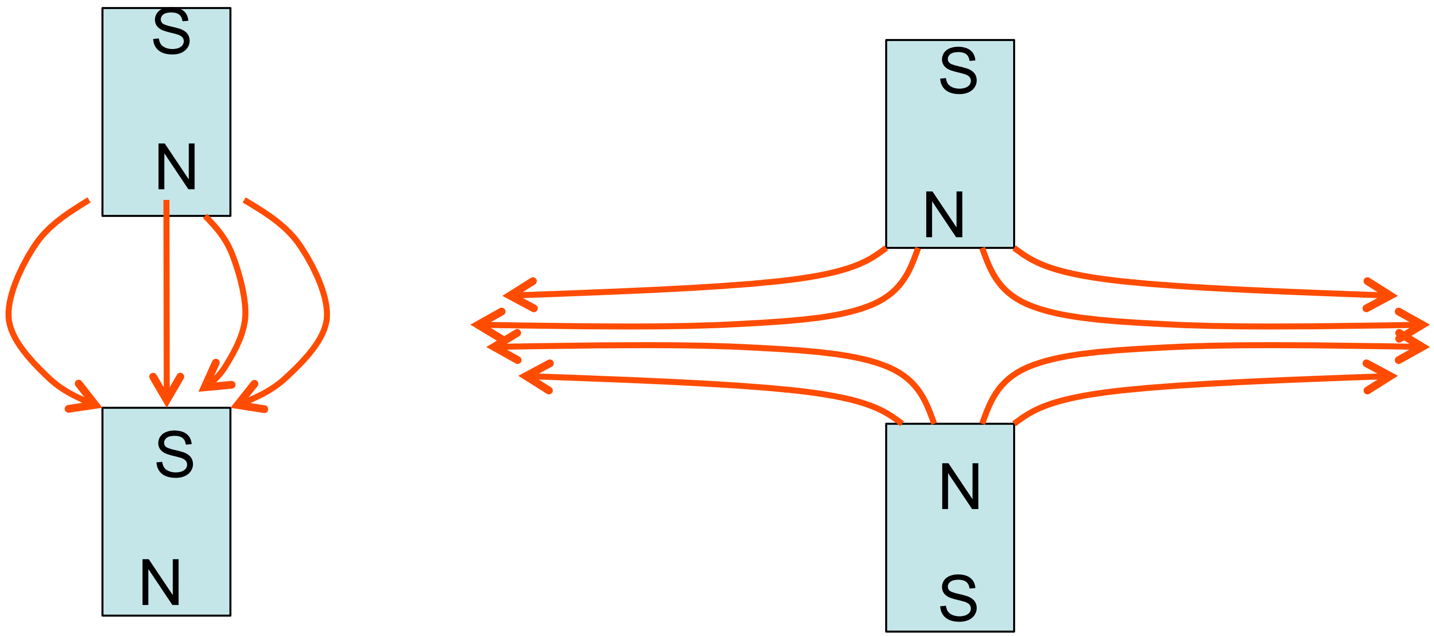

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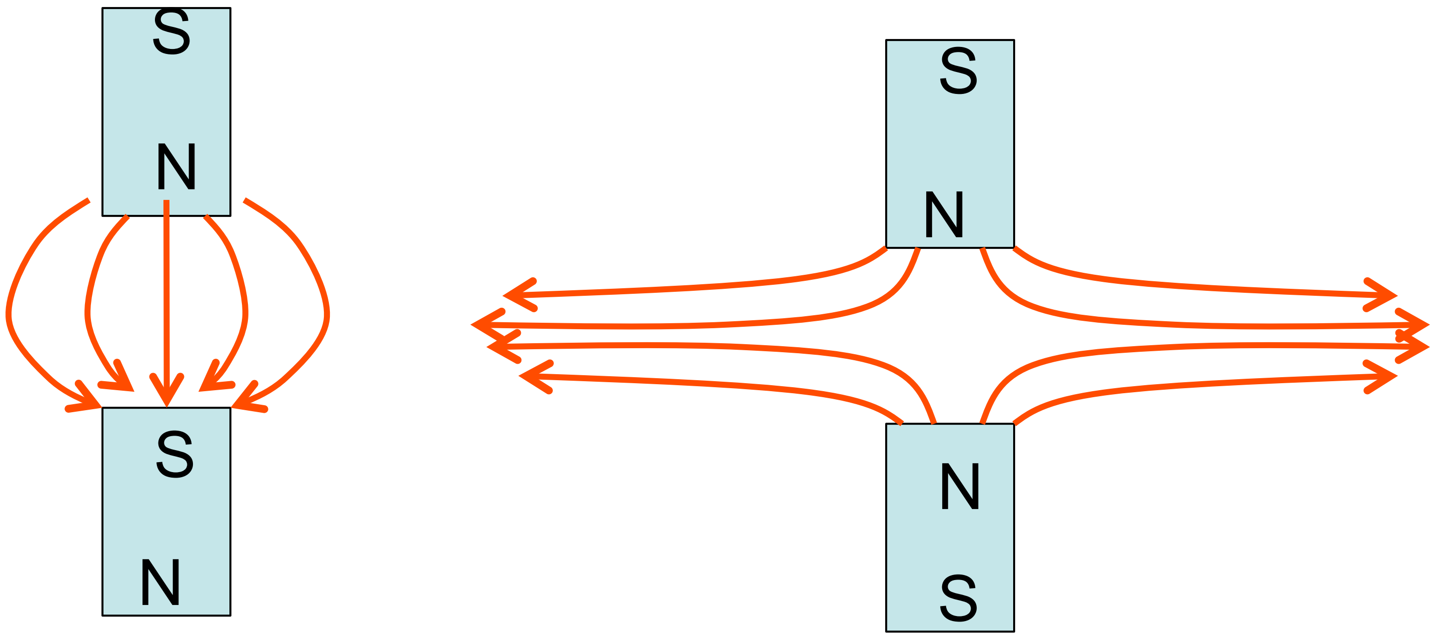
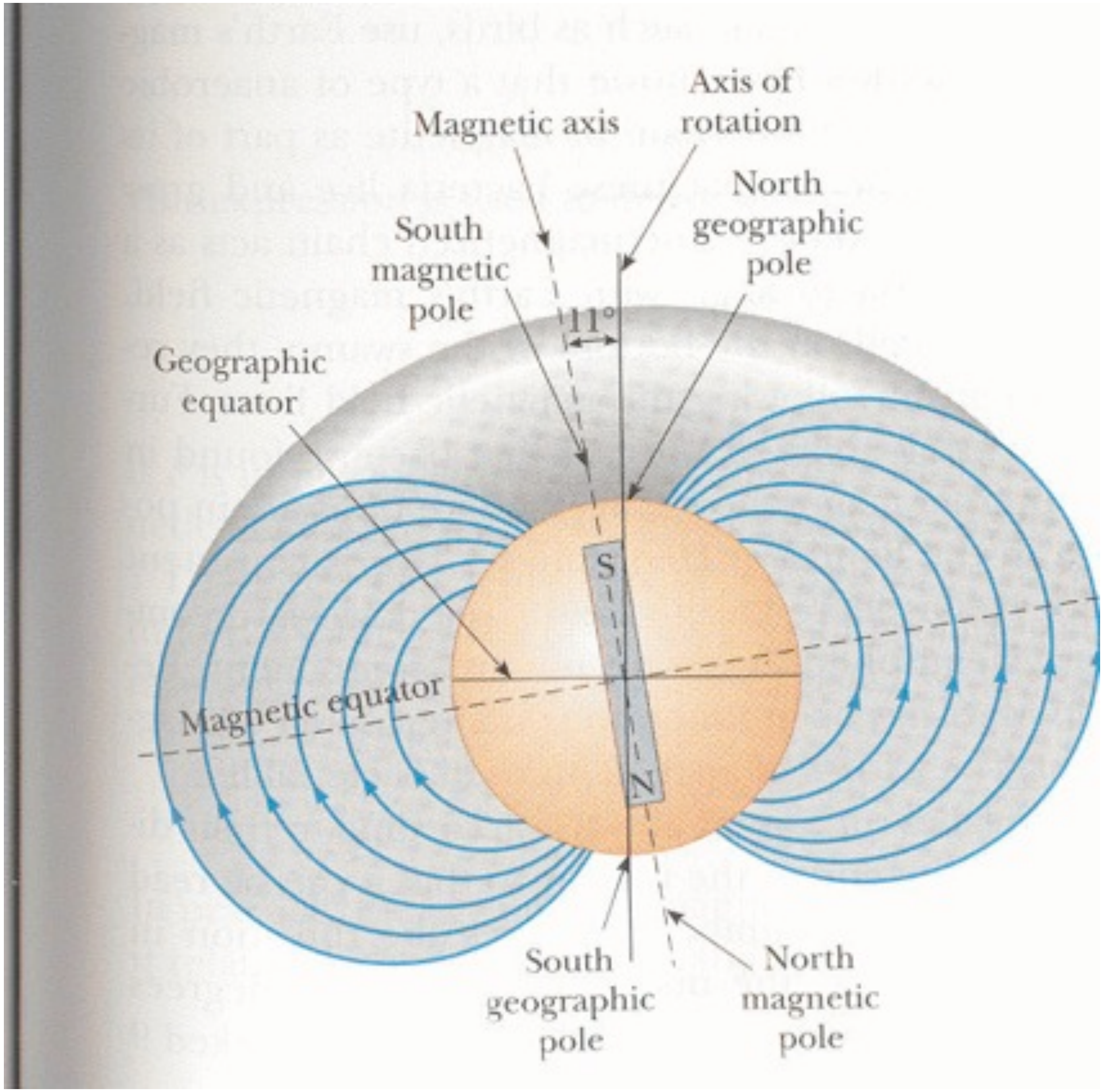


Earth's Magnetic Field



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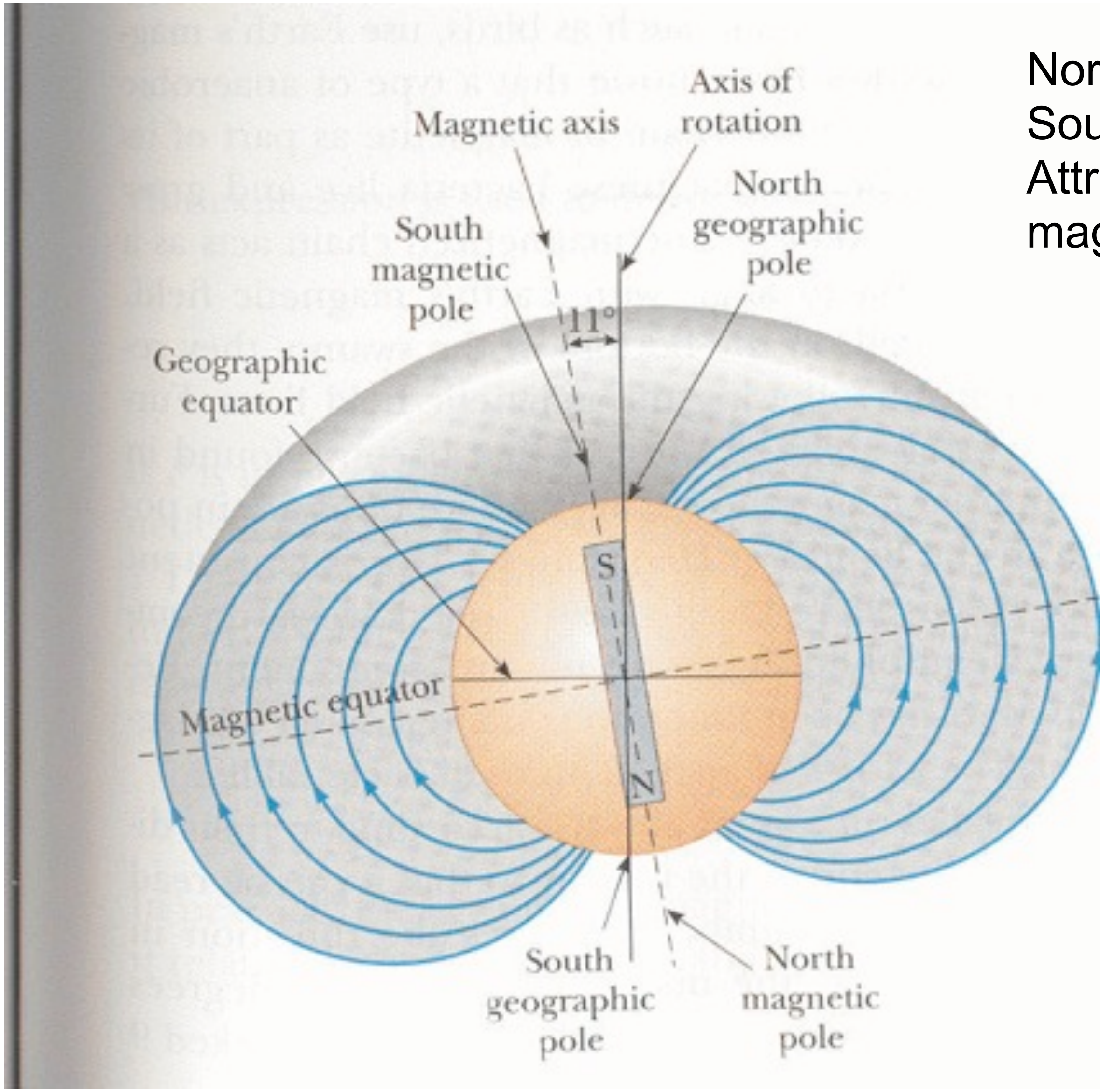
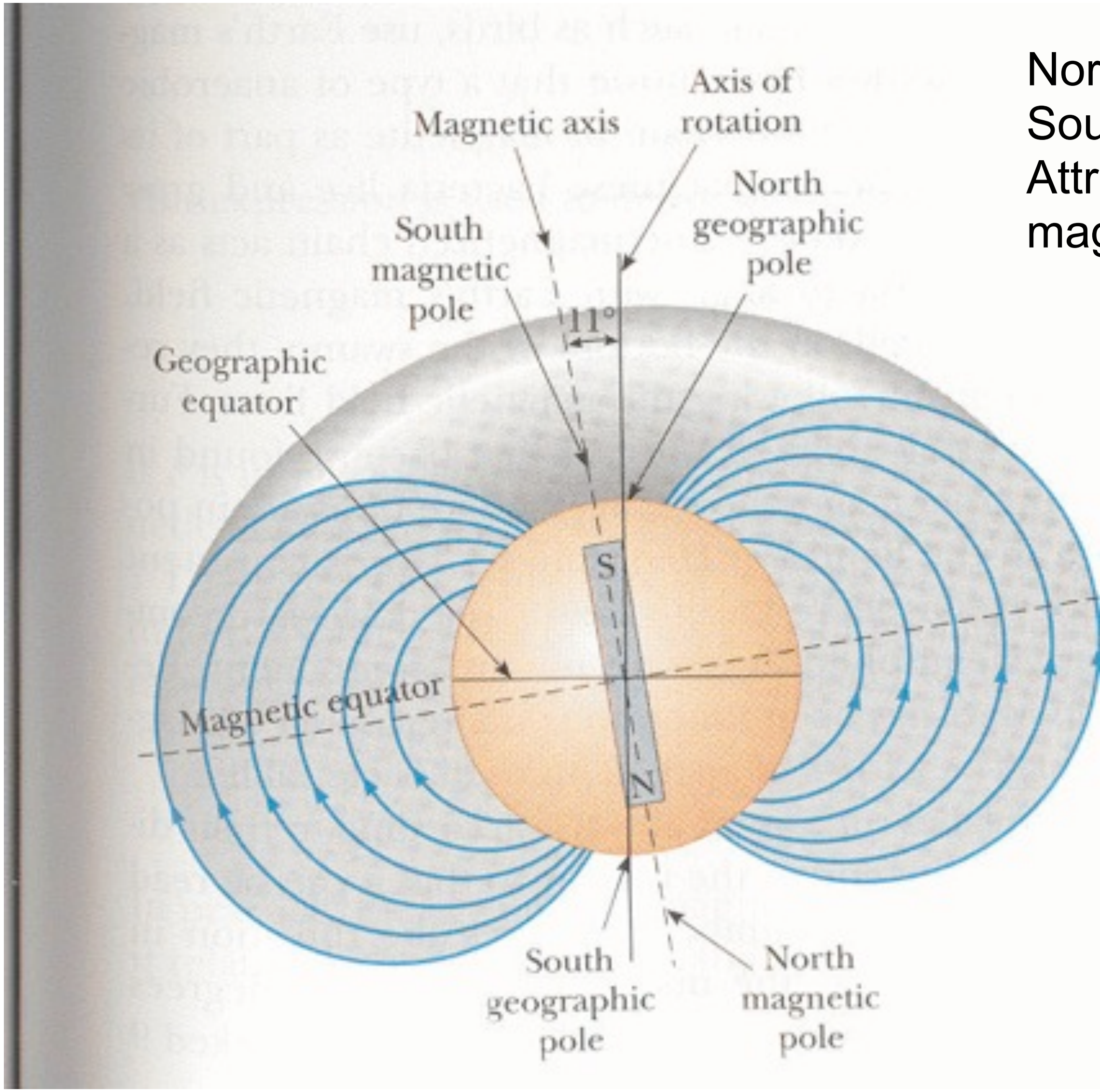


North pole is actually a South magnetic pole Attracts North pole of a magnet

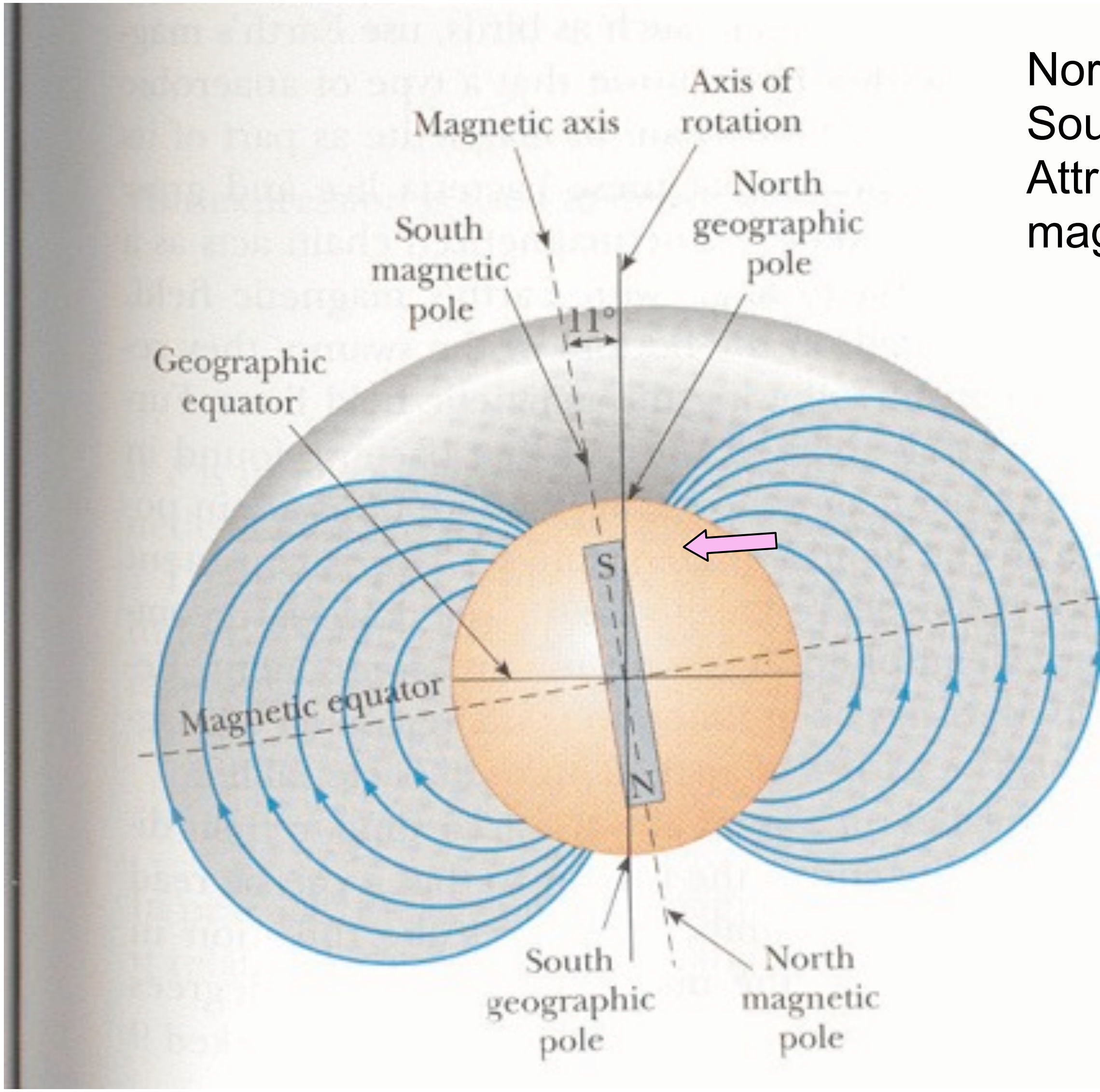
Earth's Magnetic Field



North pole is actually a South magnetic pole
Attracts North pole of a magnet

Earth's magnetic field has a vertical component
Points down in Northern hemisphere
Points up in Southern hemisphere
Zero at the magnetic equator

Earth's Magnetic Field



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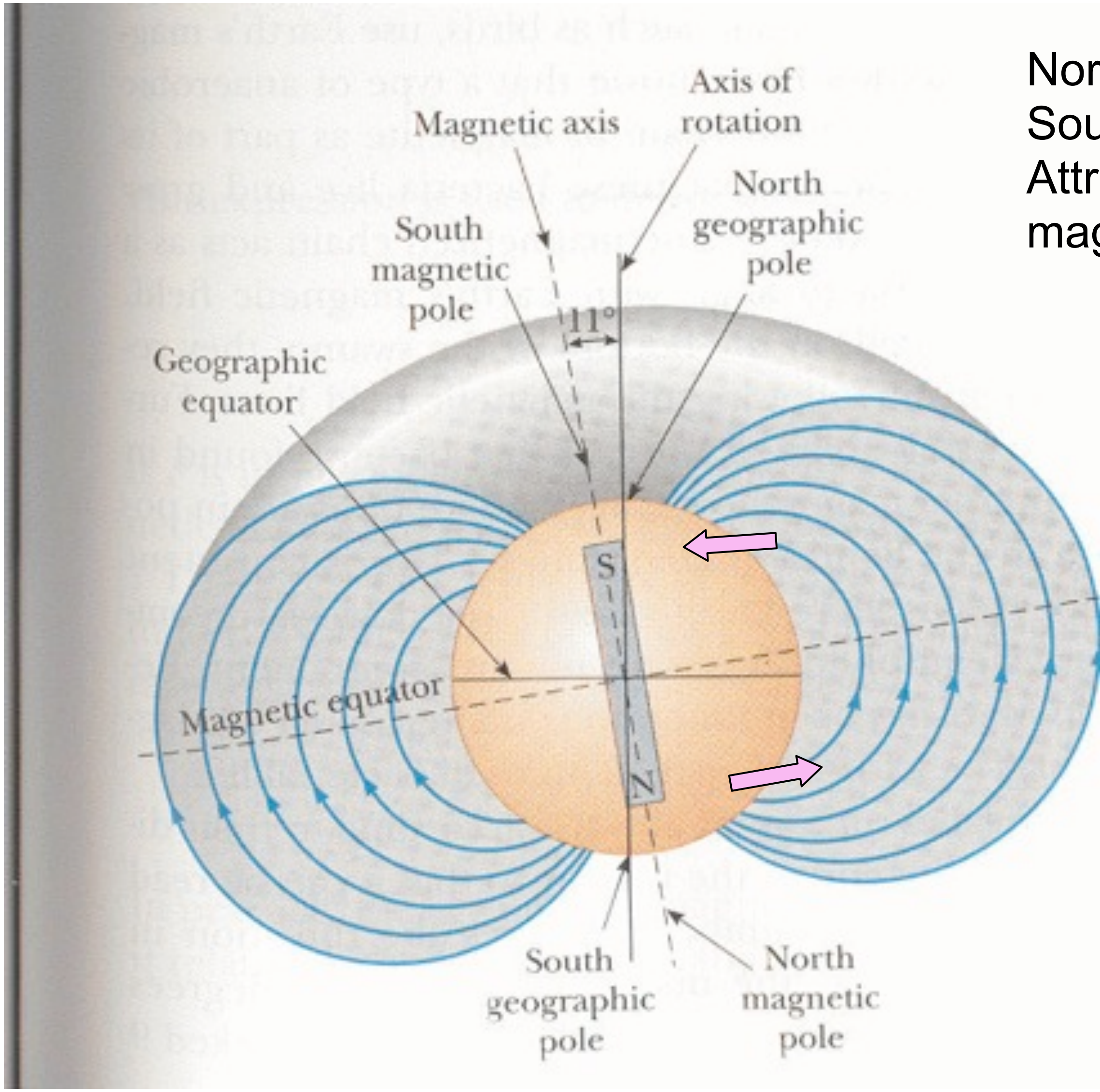

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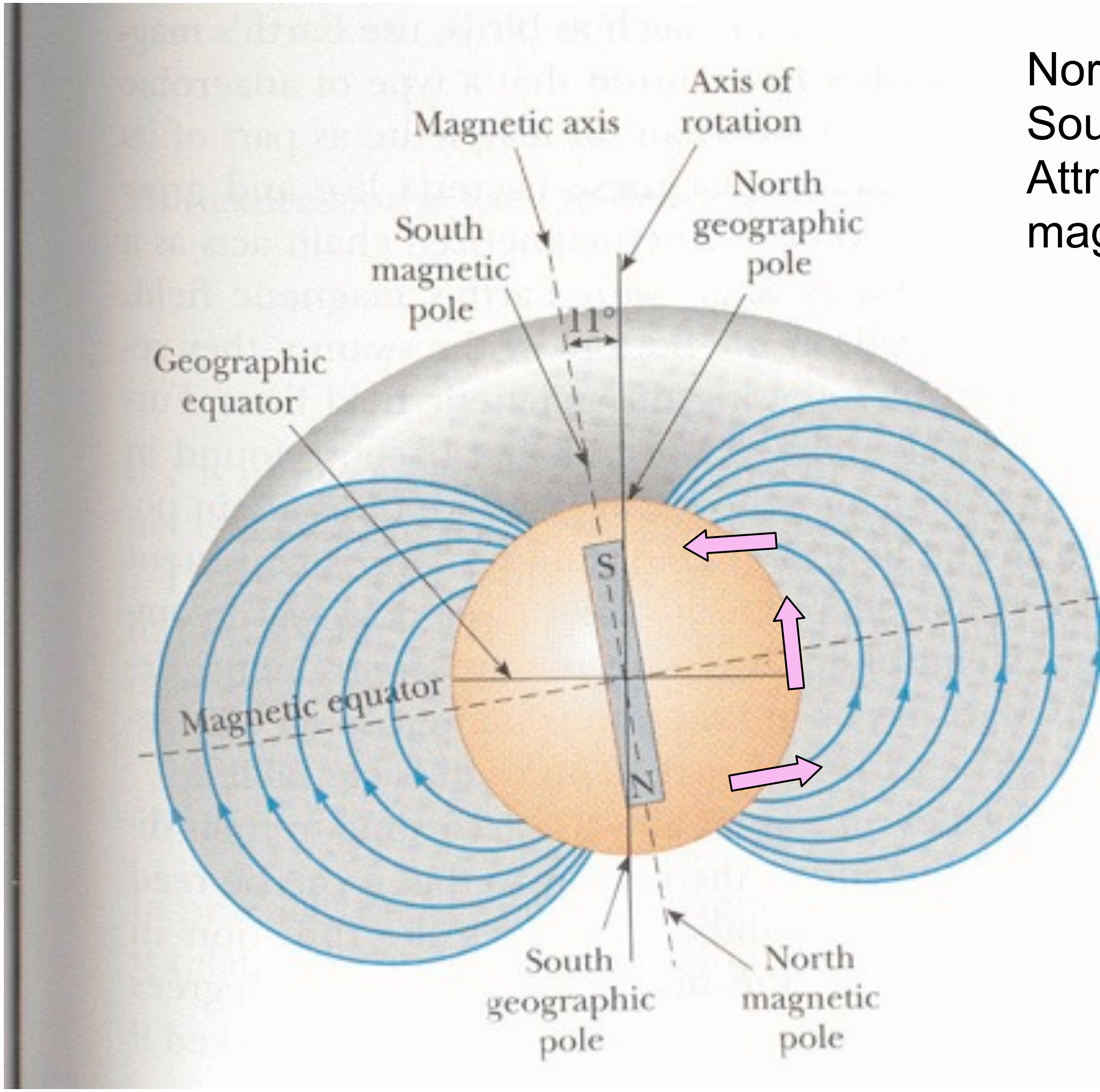

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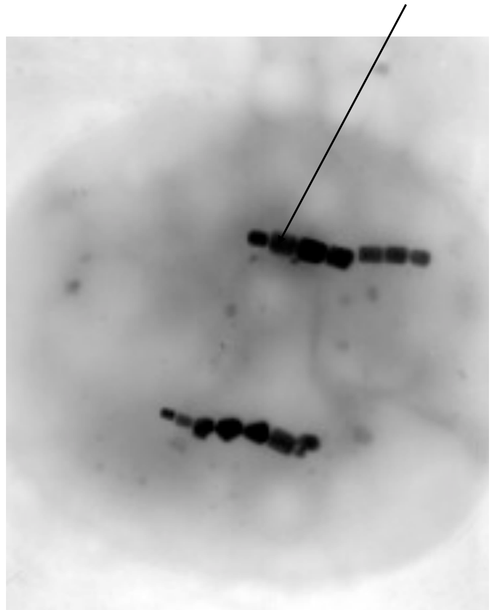
Magnetic bacteria

Migrate to north pole in northern hemisphere

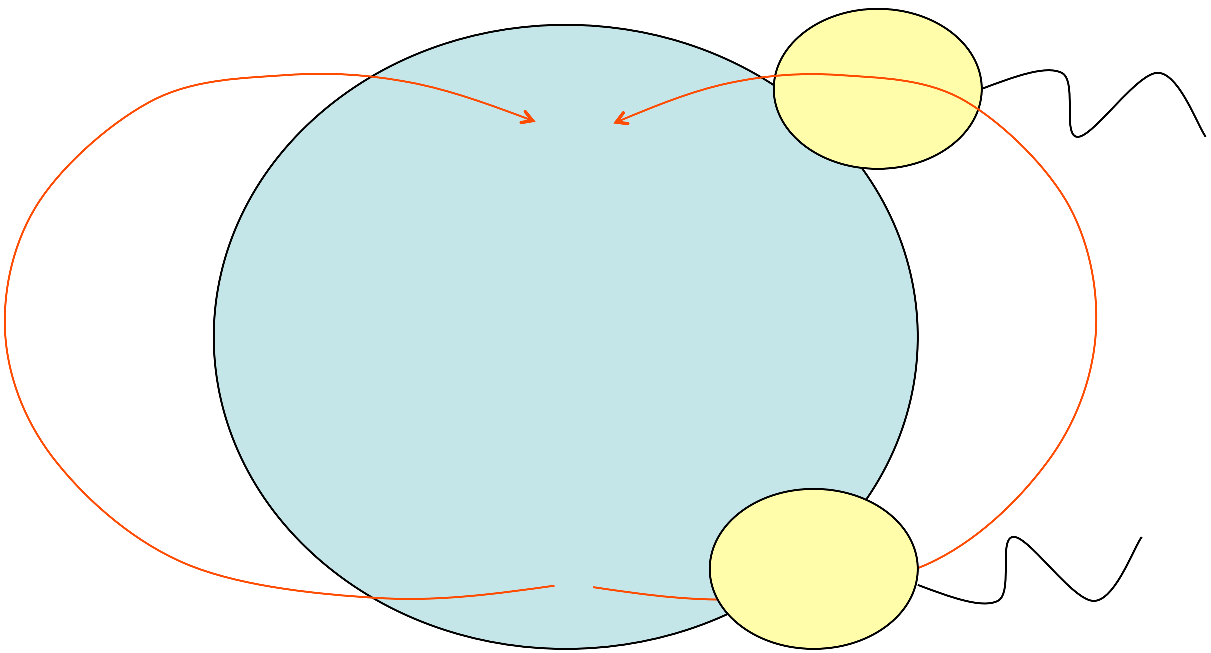
Migrate to south pole in southern hemisphere

Generally downward to the mud

Magnetic particles



Electron micrograph

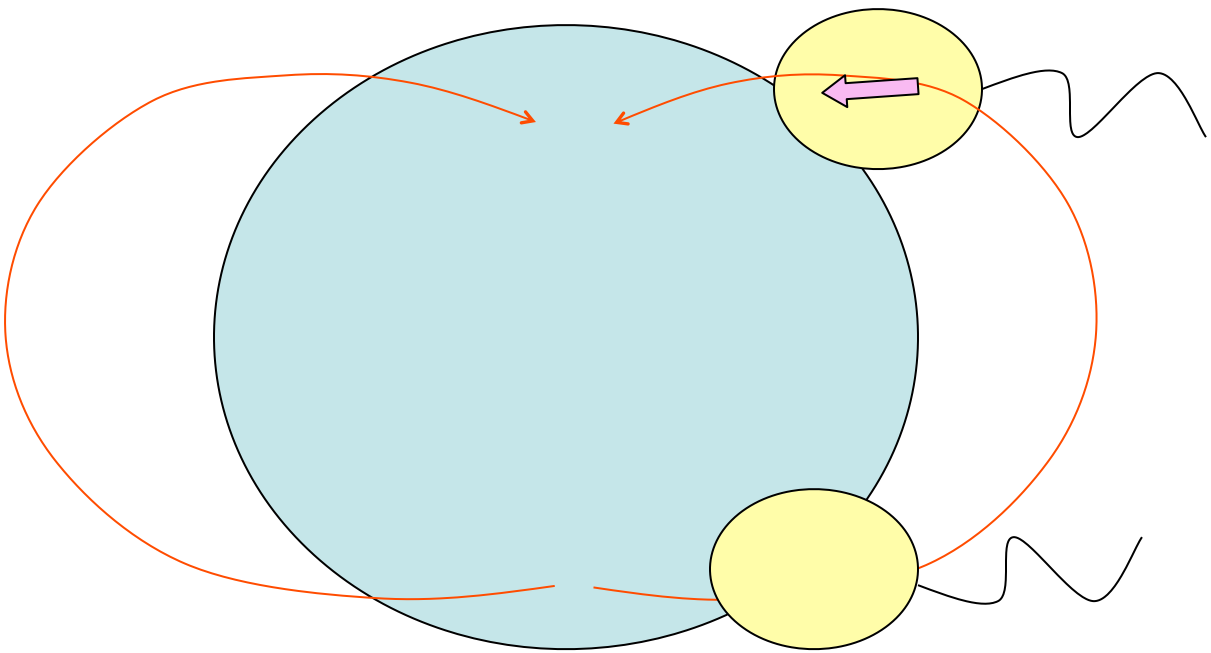


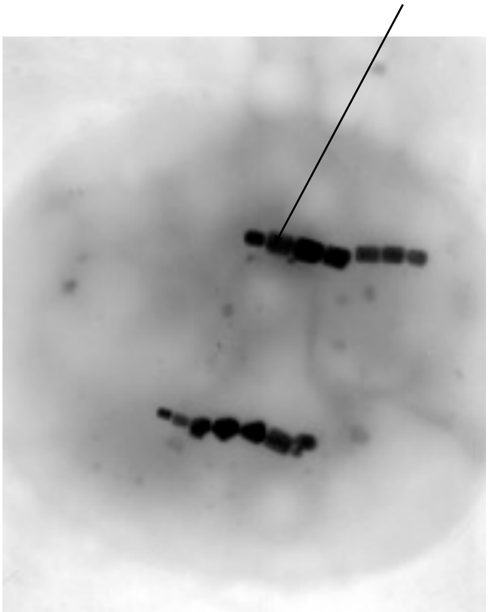
Magnetic bacteria

Migrate to north pole in northern hemisphere

Migrate to south pole in southern hemisphere

Generally downward to the mud





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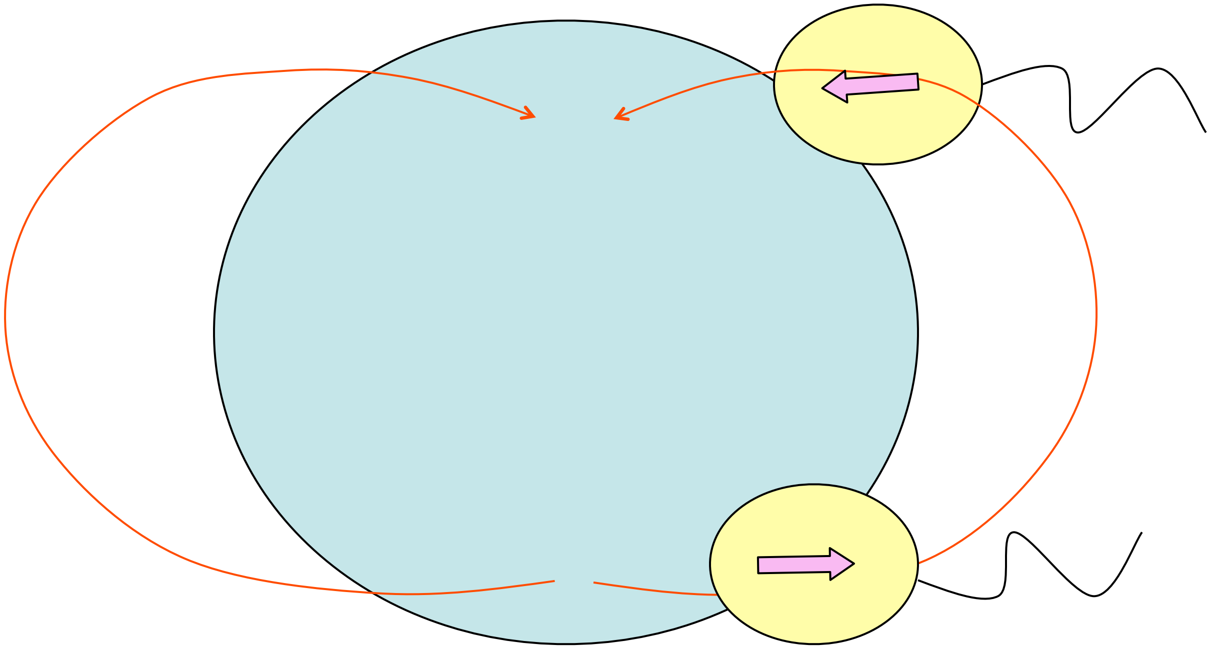
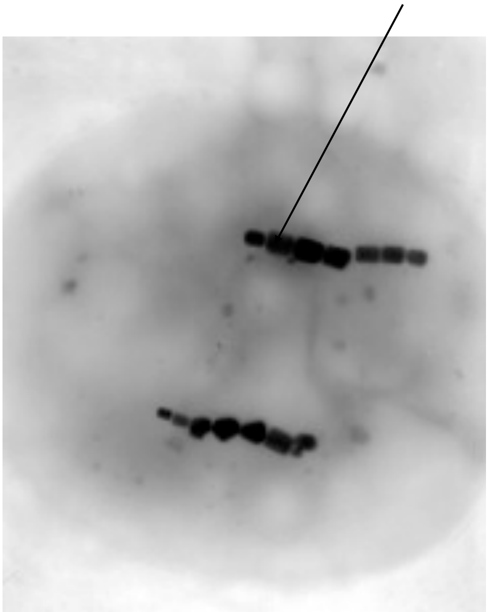
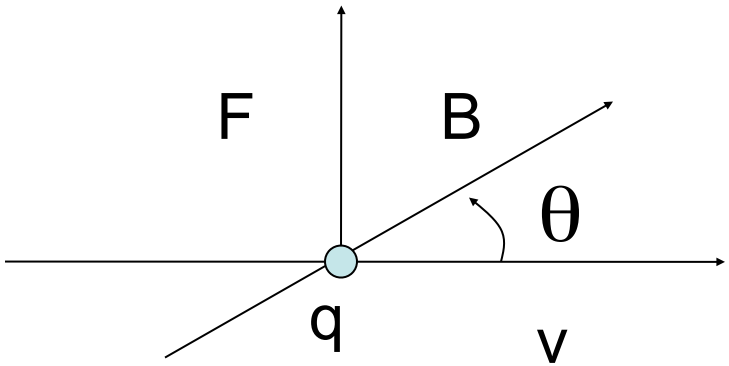


Magnetic particles



Electron micrograph

Magnetic field produces force on moving charges

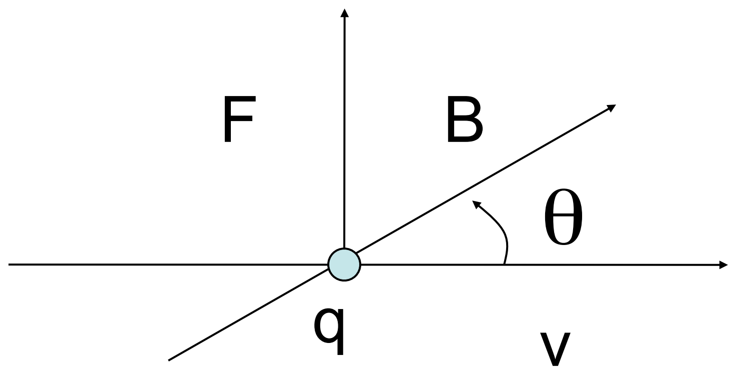


A charge q moving with velocity v in a magnetic field B experiences a force F.

$$F = qvB\sin\theta$$

Force
Depends on the velocity and magnetic field
Depends on angle between v and B
Is max when v and B are perpendicular
Is perpendicular to the direction of B and v

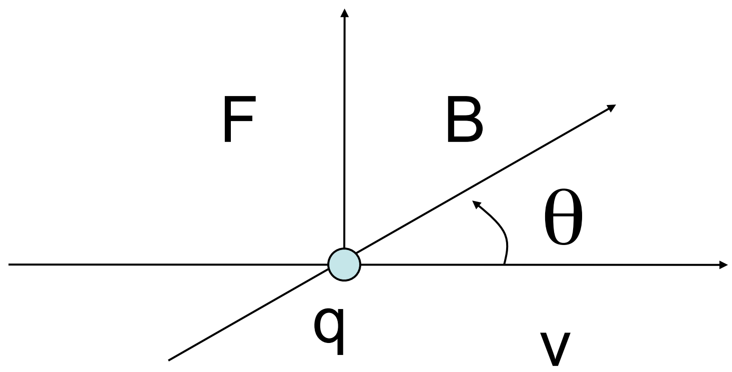
Right hand rule

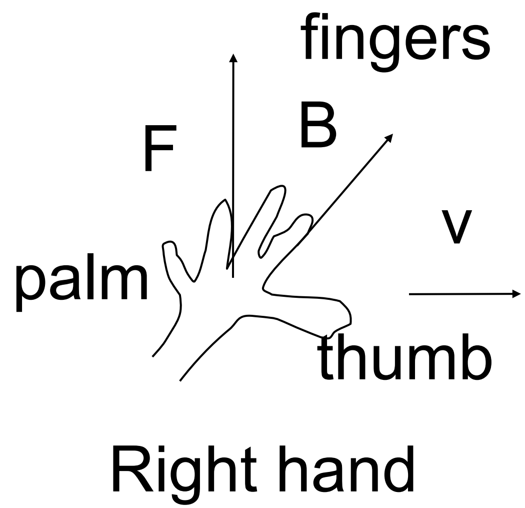


F is perpendicular to the plane of v and B

direction of F given by the right hand rule

Right hand rule





F is perpendicular to the plane of v and B

direction of F given by the right hand rule

Magnetic field magnitude defined

$$F = qvB\sin\theta$$

$$B = \frac{F}{qv\sin\theta}$$

Units of B $\quad \frac{Ns}{Cm} \quad$ Tesla (T)

Also $\quad \frac{weber}{m^2} \quad \left(\frac{Wb}{m^2}\right)$

Also commonly used gauss (g)

10^4 gauss=1Tesla

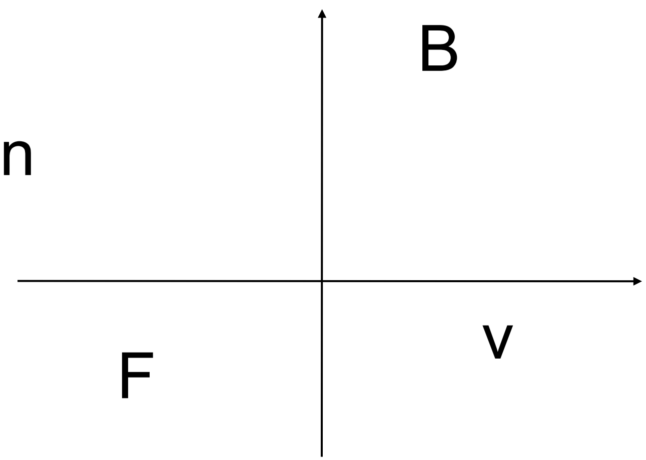
Typical magnetic field strengths

	Field (T)	
Earth's field	0.5×10^{-4}	(0.5 g)
Bar magnets	10^{-2}	
Laboratory magnet	5	
Superconducting Magnet	20-30	

A proton is moving at 10^4 m/s from left to right In a magnetic field of 0.4 T that is in the upward direction. (a) Find the magnitude of the force. (b) Find the direction of the force. (c) What would be the force if the particle was an electron?

(a) F=

(b) direction

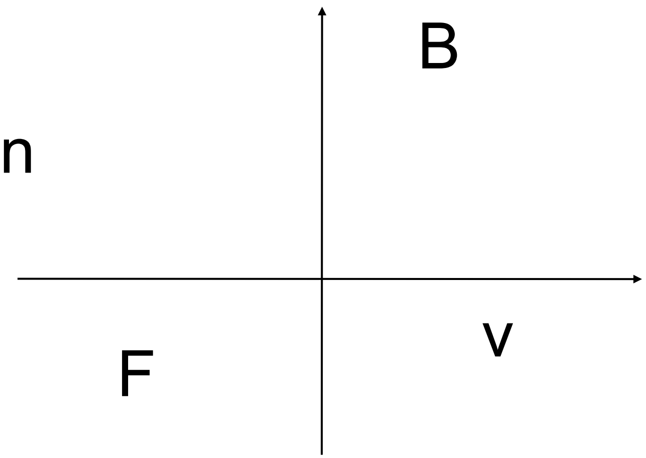


(c) For electron,

A proton is moving at 10^4 m/s from left to right In a magnetic field of 0.4 T that is in the upward direction. (a) Find the magnitude of the force. (b) Find the direction of the force. (c) What would be the force if the particle was an electron?

(a) F= $qvB\sin\theta$

(b) direction



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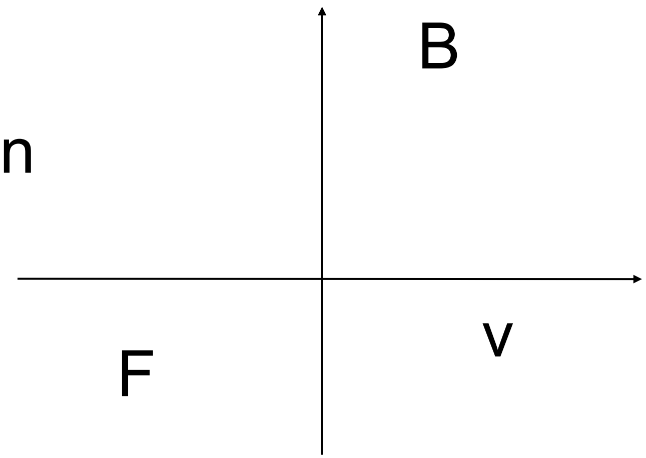
(a) F= $qvB\sin\theta = 1.6x10^{-19}(10^4)(0.4)(1) = 6.4x10^{-16}N$

(b) direction



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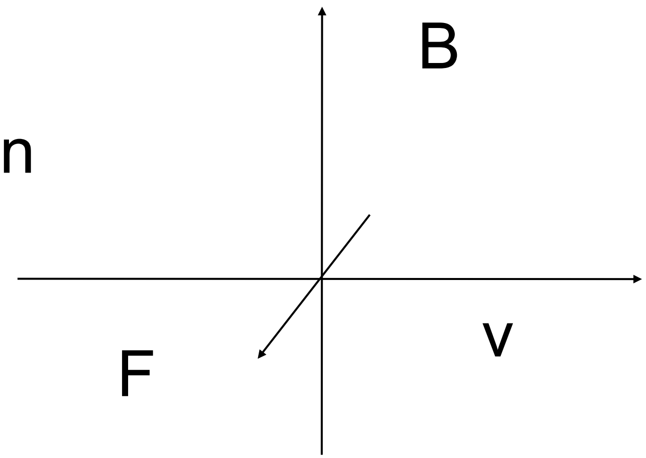

F outward from the page

(c) For electron,

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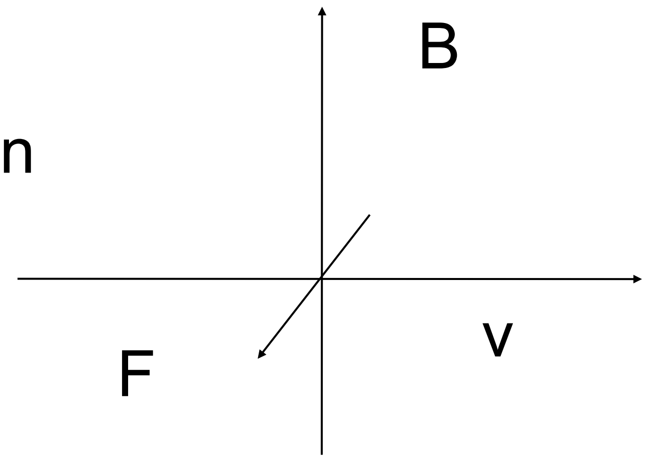
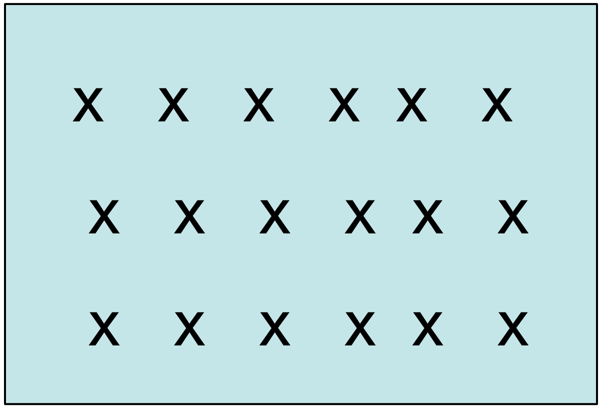


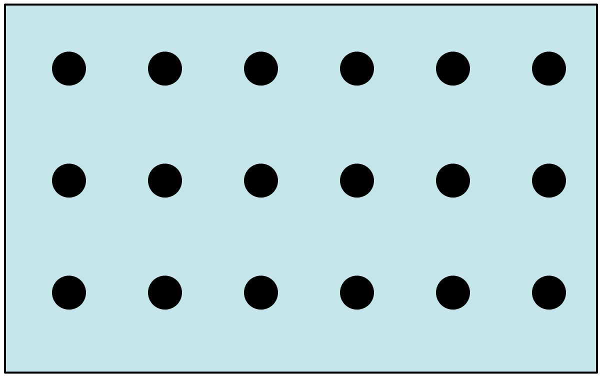
F outward from the page

(c) For electron,
q negative, the force would have the same magnitude but opposite direction. Into the page

Magnetic field notations



B field into page



B field out of the page

think of arrows

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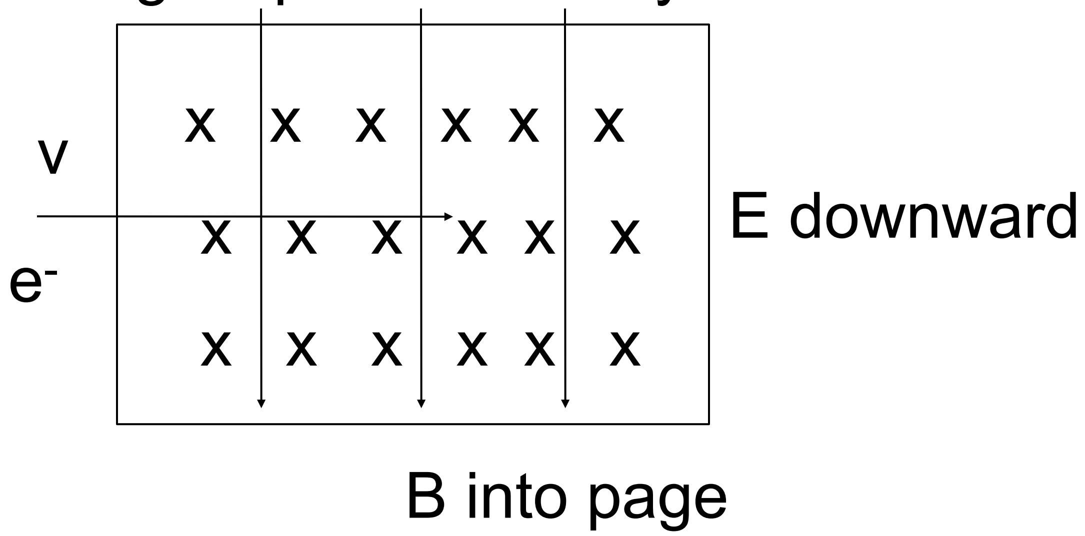
Velocity selector

Perpendicular E and B fields can be used to select electrons having a specific velocity



Force due to B =

Force due to E =

Forces cancel

velocity of un-deflected electron =

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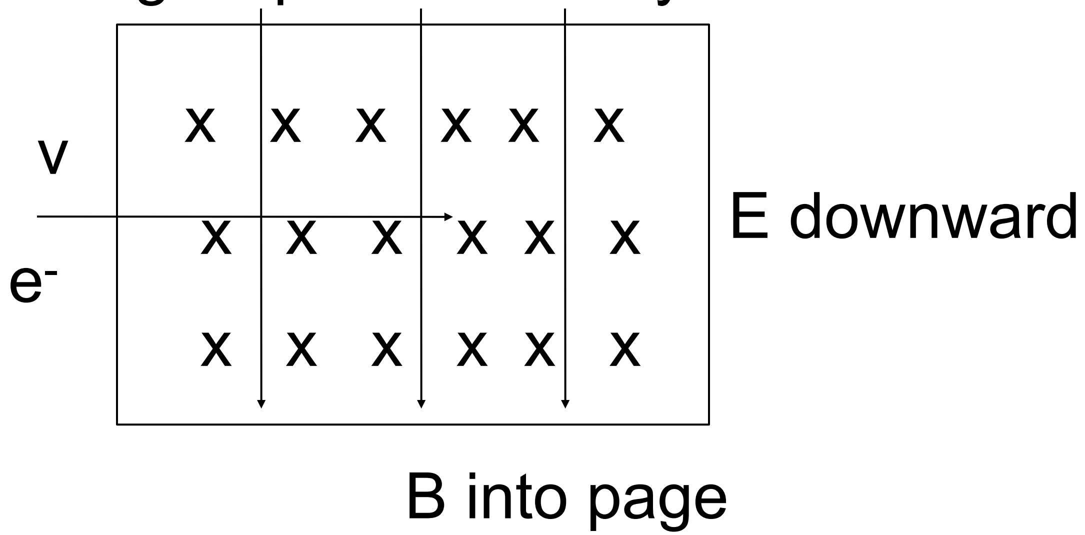

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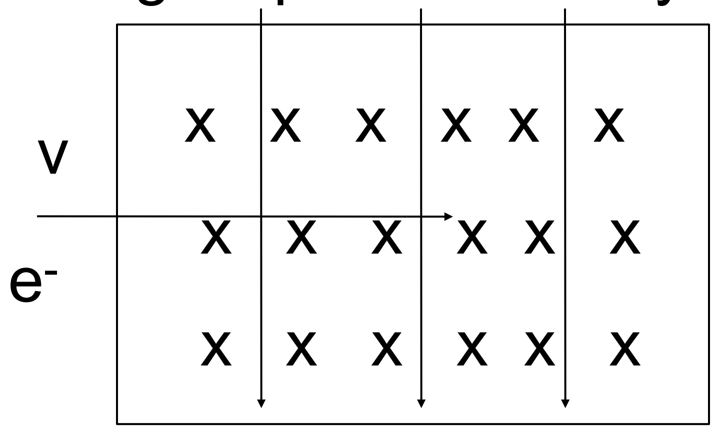

E downward

B into page

Force due to B = evB (downward, q is negative)

Force due to E =

Forces cancel

velocity of un-deflected electron =

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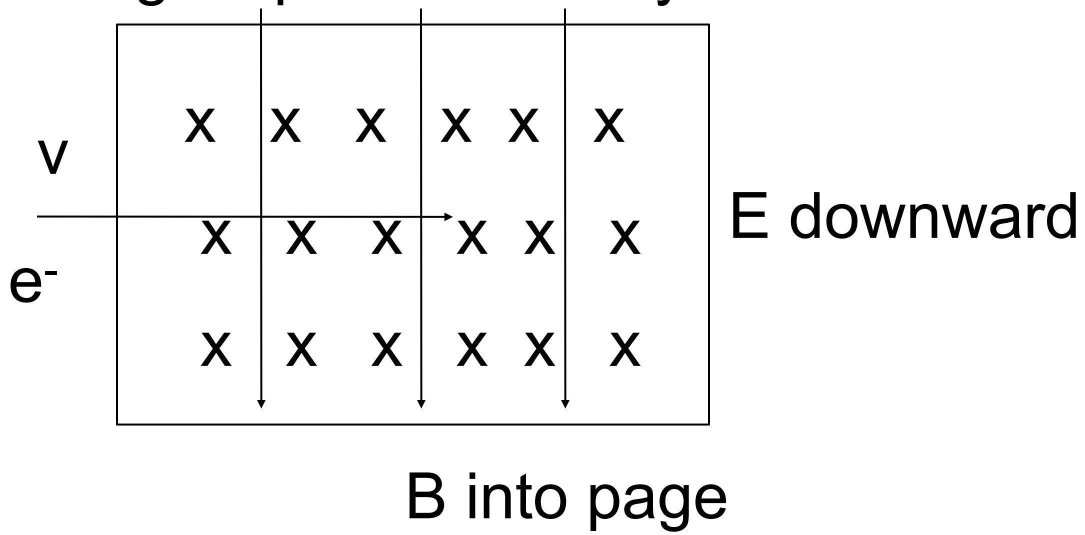

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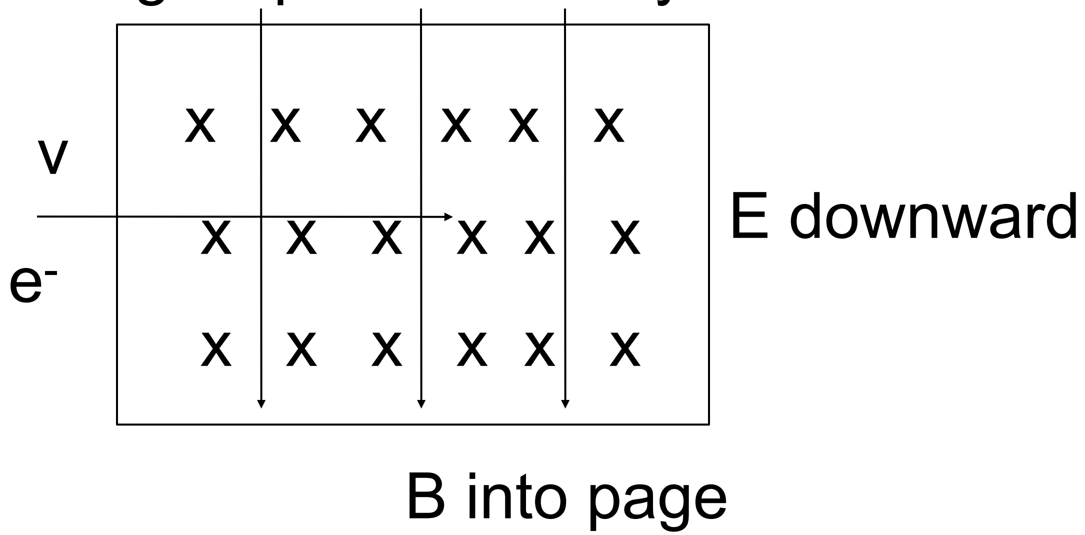

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Force due to E = eE (upward, q is negative)

Forces cancel

velocity of un-deflected electron =

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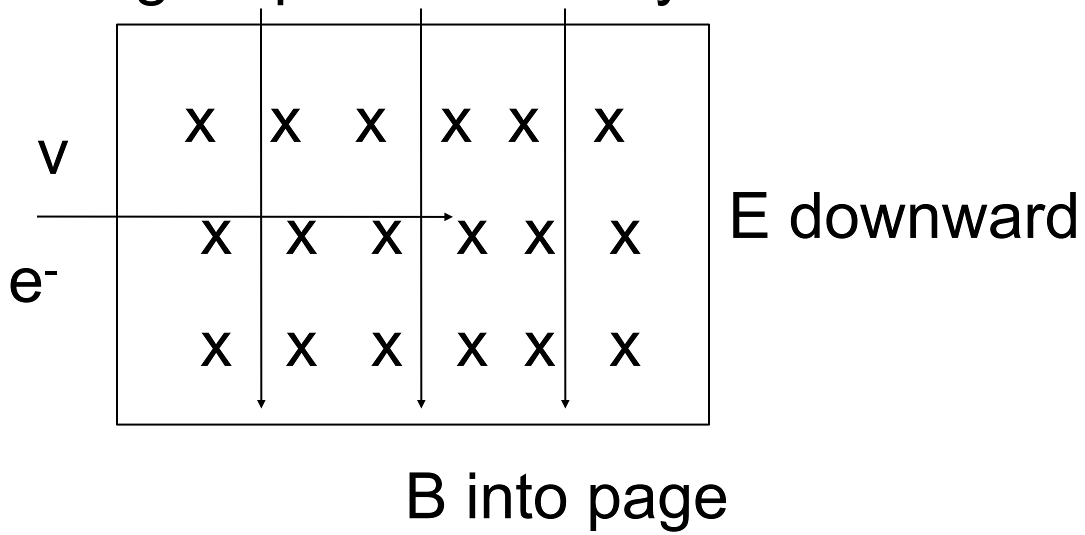
Perpendicular E and B fields can be used to select electrons having a specific velocity



Force due to B = evB (downward, q is negative)

Force due to E = eE (upward, q is negative)

Forces cancel $F_m=F_E$

velocity of un-deflected electron =

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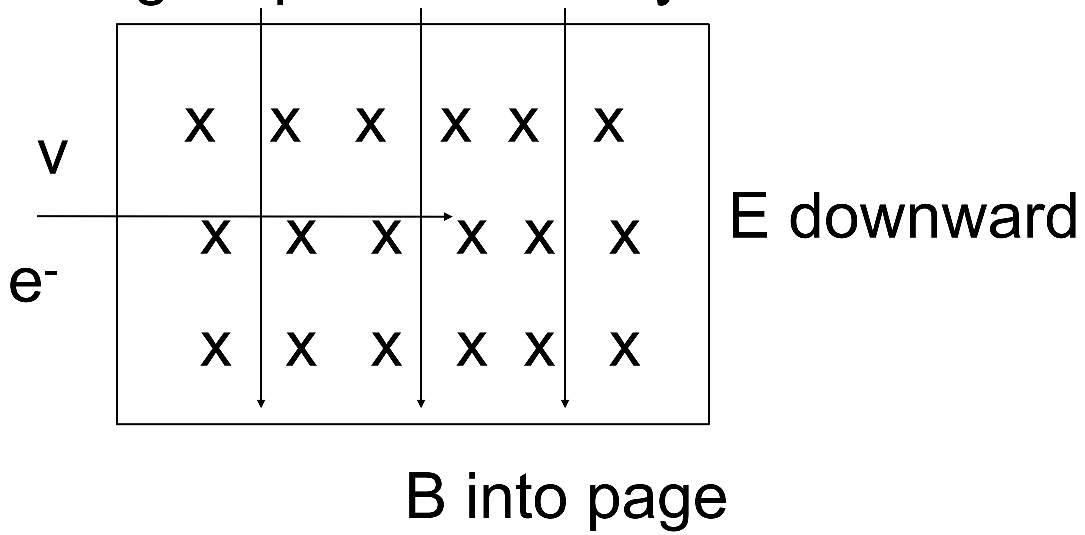

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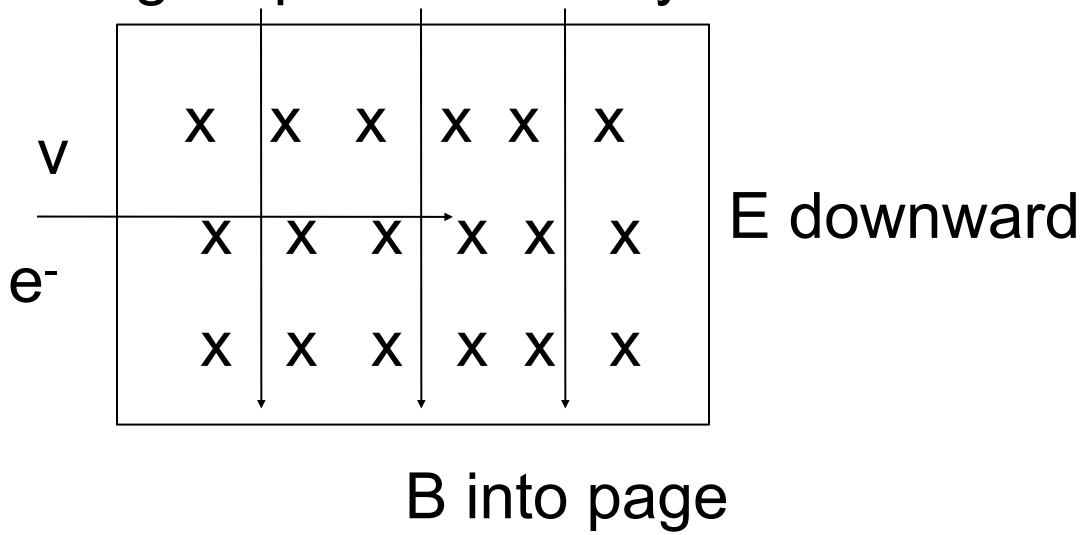

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Force due to E = eE (upward, q is negative)

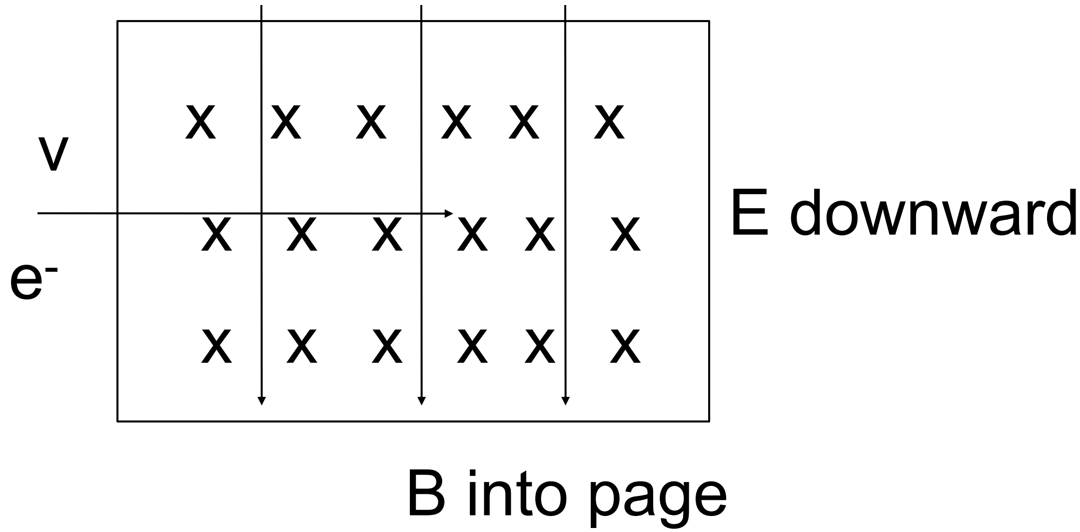
Forces cancel $F_m = F_E$ $evB = eE$

velocity of un-deflected electron = $v = \dfrac{E}{B}$

Problems in Magnetism

- Magnetic Force Problems
- Electron moving in a Magnetic Field (like electron moving in electric field produced by a parallel plate capacitor).

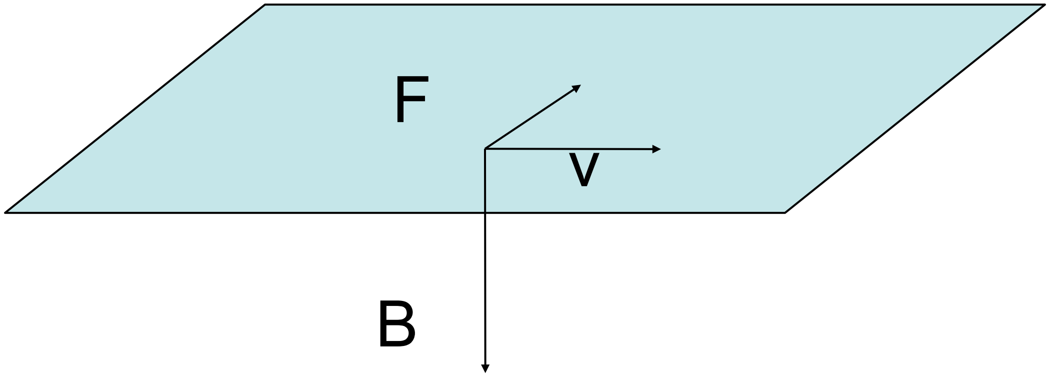
A velocity selector has perpendicular electric and magnetic field of E= 1000 V/m and B= 0.3 T. Find the velocity of the electrons that pass through undeflected.
What would happen to faster electrons? Slower?



$$v = \frac{E}{B} = \frac{1000}{0.3} = 3.3x10^{3} m/s$$

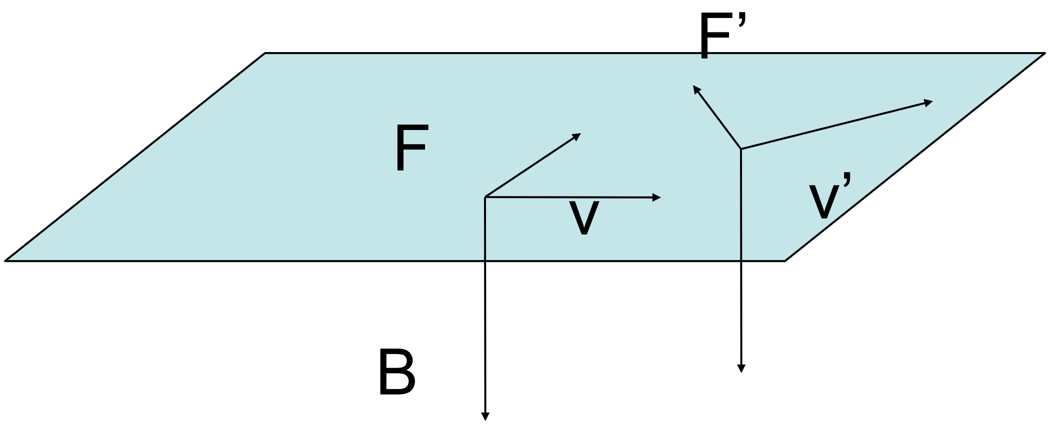
Motion of a charged particle in a magnetic field

F is in a plane perpendicular to B



(uniform magnetic field)

Motion of a charged particle in a magnetic field

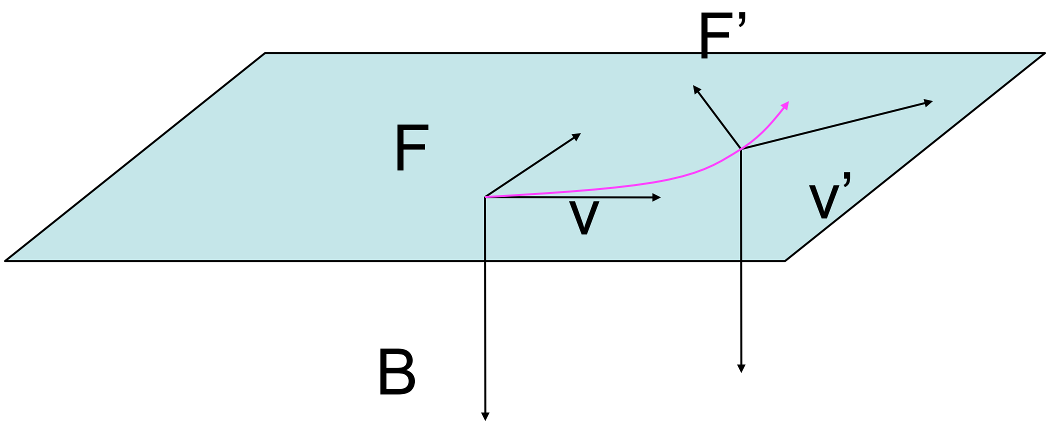


(uniform magnetic field)

F is in a plane perpendicular to B

After Δt particle is in the same plane

Motion of a charged particle in a magnetic field



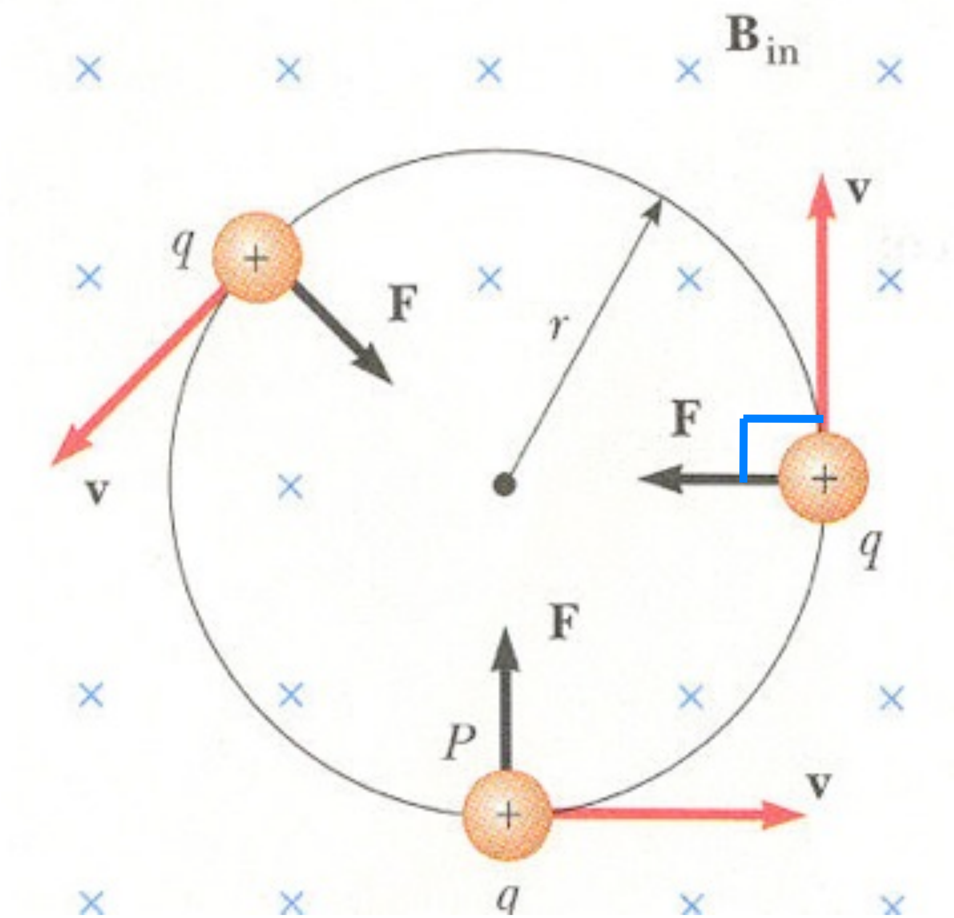
(uniform magnetic field)

F is in a plane perpendicular to B

After Δt particle is in the same plane

Particle moves in a plane perpendicular to B

Motion of particle in plane perpendicular to B



$$F = qvB = \frac{mv^2}{r}$$

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

The particle moves in a circular path

A proton with $v=1x10^6$ m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

A proton with $v=1x10^6$ m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

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

A proton with $v=1x10^6$ m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

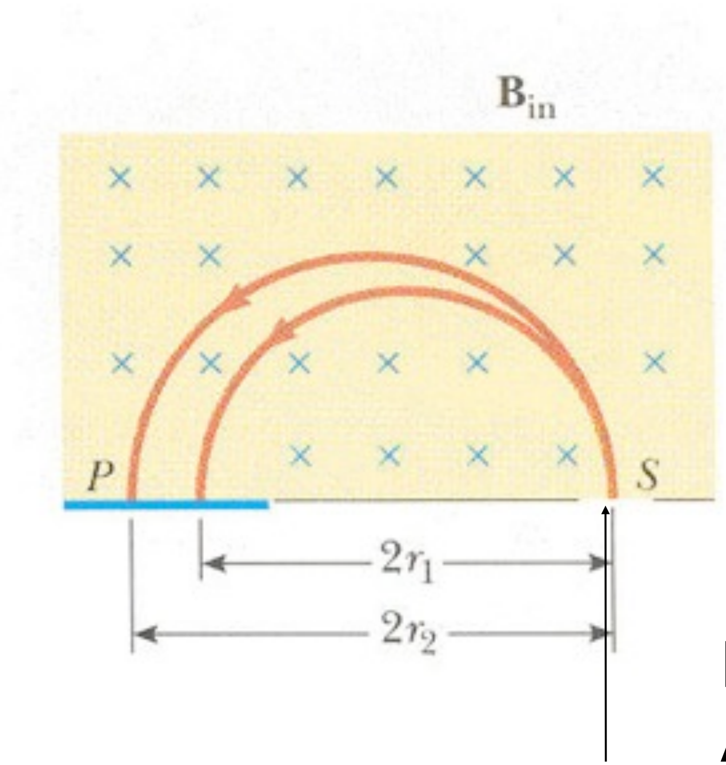
$$r = \frac{mv}{qB}$$

$$r = \frac{1.67x10^{-27}(1x10^{6})}{1.6x10^{-19}(0.2)}$$

$$r = 5.2x10^{-2}m = 5.2cm$$

Application

Mass spectrometer



Molecular ions
At velocity v

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

Ions separated by mass

A mass spectrometer with a ion velocity selector at the inlet selects ions with $v=5x10^4$ m/s. What B field is necessary to rotate a molecular ion CO_2^+ with a mass of $6.67x10^{-26}$ kg through radius of 0.20 m?

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$$qvB = \frac{mv^2}{r}$$

$$B = \frac{mv}{qr} = \frac{(6.67x10^{-26})(5x10^4)}{(1.6x10^{-19})(0.2)} = 1.04x10^{-1}T$$