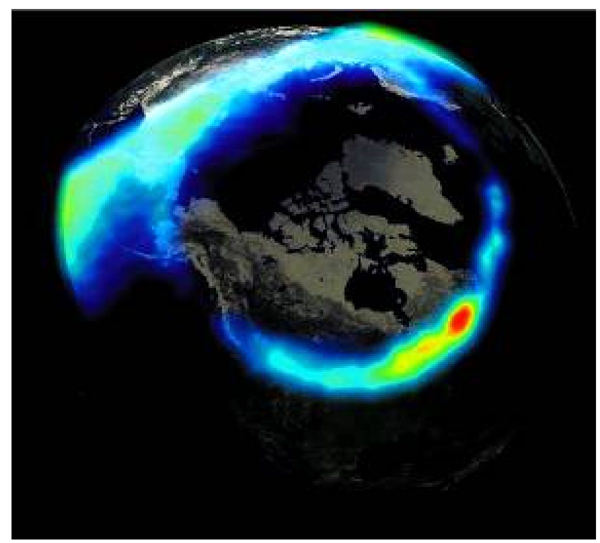
Aurora

Charged particles from solar wind or solar flares get caught in B-field lines in Earth's B-field, funneled to the poles

apod.nasa.gov

Appears as circle surrounding magnetic pole (NASA’s *Polar* Sat.)



gsfc.nasa.gov

Aurora-related youtube vids (copy/paste into your browser):

http://www.youtube.com/watch?v=_Ehb38zzpgo

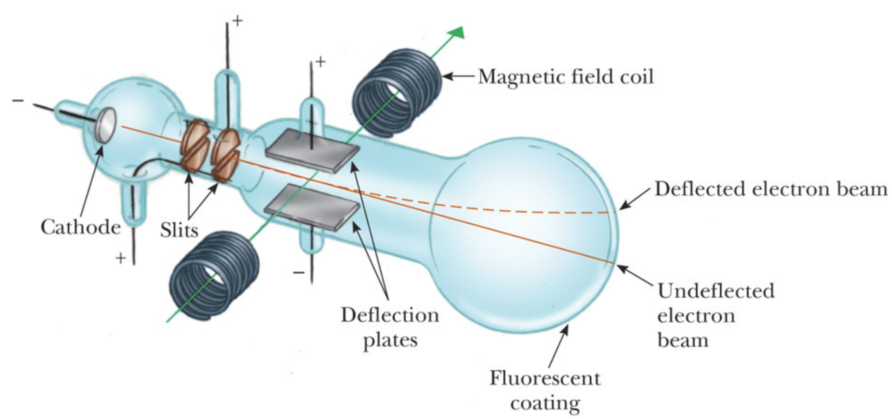
http://www.youtube.com/watch?v=DUzT4skIUWc
(time-lapse view from the ground; with timestamps)

http://www.youtube.com/watch?v=7AmyfuJDMlY
(featuring Saturn's auroras, observed with Cassini; however, there's an error in the animation -- it shows aurora around Earth's geographic, not magnetic, poles; warning: obnoxious ads)

Charge/Mass ratio of particles

J.J. Thomson, 1897

e-’s accelerated in cathode, pass through regions of perp. E & B fields. Deflection measured.



(a)

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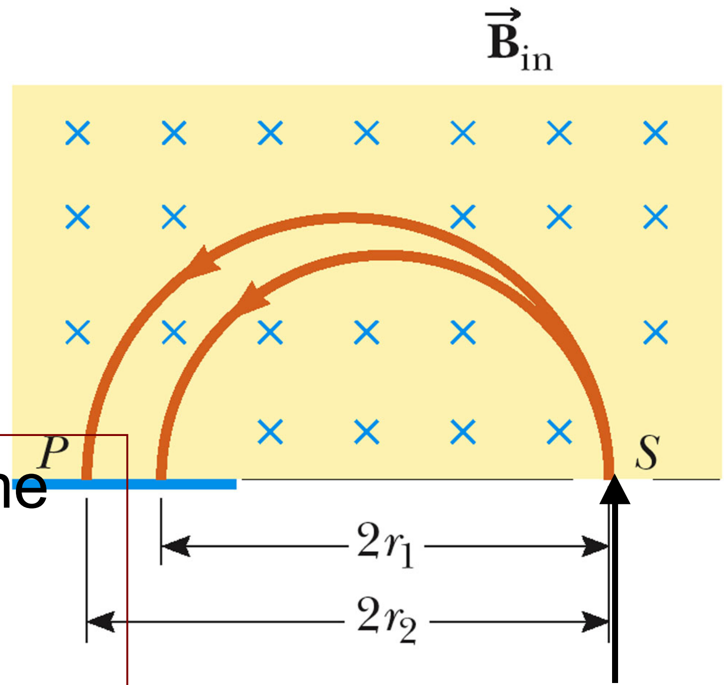
Mass Spectrometers

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



4. Ions with the same charge become separated by mass onto photographic plate: compute charge/mass ratio

3. Molecular ions injected into B-field at velocity v

1. A sample is ionized (impacting with a e^- beam).
2. Positive ions are accelerated by an E-field through veloc selector

Example: A mass spectrometer has a velocity selector at its inlet such that only q=+1 ions with $v = 1\times10^5$ m/s are permitted inside the mass spectrometer, where the B-field is 0.2 T. A mixture of gas containing CO_2^+ is injected. But some of the CO_2 contains Carbon-14. What radii are $^{12}CO_2^+$ and $^{14}CO_2^+$ rotated through, and what is their separation on the photographic plate?

Reminder: mass is for whole molecule.
F_B works on the singular positive charge only.

Assume $m_p = m_n$ for simplicity; ignore masses of electrons sicne they're 1800x less massive than protons/neutrons

Mass ($^{12}CO_2^+$) = $(12+16+16)*1.67\times10^{-27}$kg = $44 * 1.67\times10^{-27}$kg = 73.5×10^{-27} kg
Mass ($^{14}CO_2^+$) = $(14+16+16)*1.67\times10^{-27}$kg = $46 * 1.67\times10^{-27}$kg = 76.8×10^{-27} kg

Reminder: mass is for whole molecule.
F_B works on the singular positive charge only.

$r(^{12}CO_2^+) = mv/qB = (73.5\times10^{-27}\text{ kg} * 10^5\text{ m/s}) / (1.6\times10^{-19}\text{C} * 0.2\text{T}) =$
23.0 cm
$r(^{14}CO_2^+) = mv/qB = (76.8\times10^{-27}\text{ kg} * 10^5\text{ m/s}) / (1.6\times10^{-19}\text{C} * 0.2\text{T}) =$
24.0 cm

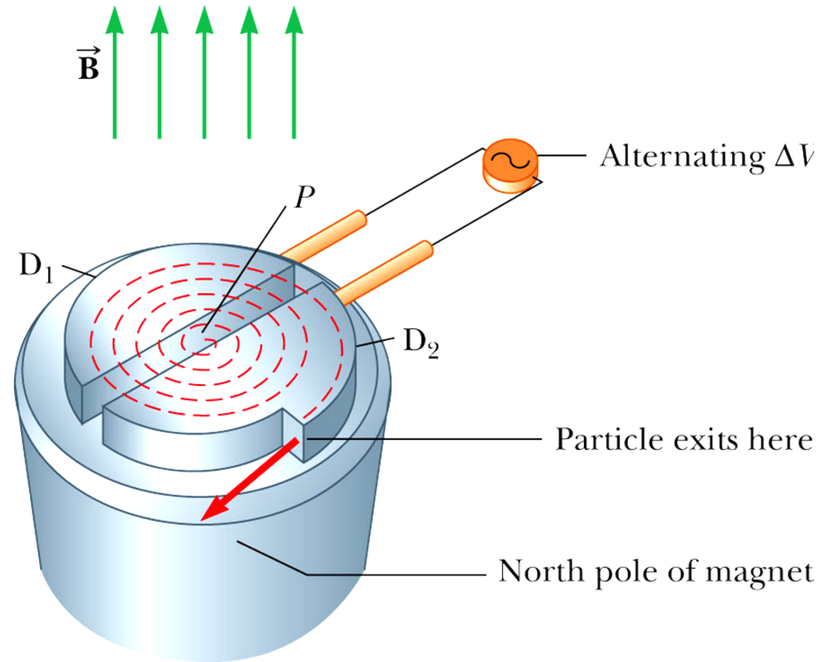
The diameters of the circles traced out will be 46.0 and 48.0 cm, respectively.

The separation on the photographic plate will be 2.0 cm.

Reminder: mass is for whole molecule.
F_B works on the singular positive charge only.

The Cyclotron

Used to accelerate charged particles to very high speeds, bombard other particles, induce nuclear reactions



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22.5: Force on a Current-carrying Conductor

Total force = Force on each charge × # of charges in the wire

$\vec{F}_B = (q\, \vec{v}_{dr} \times \vec{B})\, (n\, A\, \ell)$

$F_B = (q\, v_{dr}\, B \sin\theta)\, (n\, A\, \ell)$ (A × ℓ = vol.; n = charges/vol)

But recall that $I = \Delta Q/\Delta T$

and $\Delta Q/\Delta T$ = (q of each charge) × (# of charges per second)

# of charges per second = $A\, n\, v_{dr}$

$(m^2)\,(m^{-3})\,(m/s)$

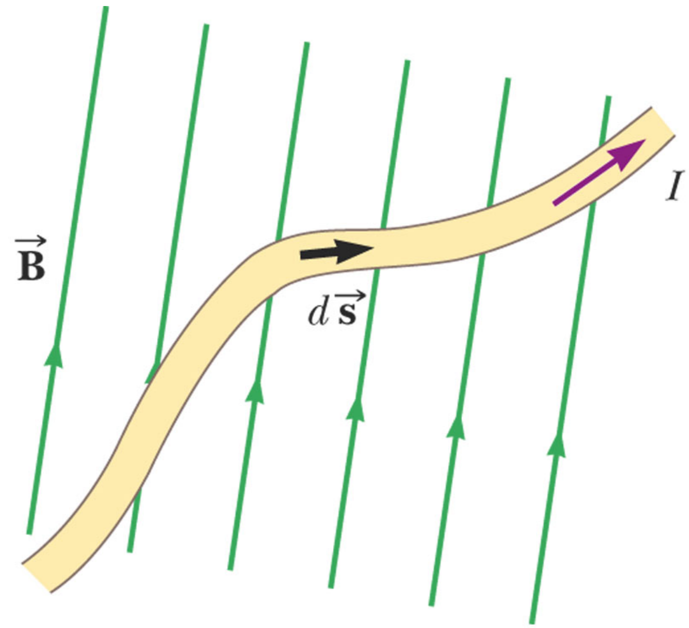
So $I = n\, A\, v_{dr}\, q$

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

$F_B = B\, I\, \ell \sin(\theta)$ or $F_B / \ell = B\, I \sin(\theta)$

More general form: Force on a Wire, Arbitrary Shape

- Consider a small segment of the wire, $d\vec{\mathbf{s}}$
- The force exerted on this segment is $d\vec{\mathbf{F}}_B = I\, d\vec{\mathbf{s}} \times \vec{\mathbf{B}}$
- The total force is $\vec{\mathbf{F}}_B = I \int_a^b d\vec{\mathbf{s}} \times \vec{\mathbf{B}}$



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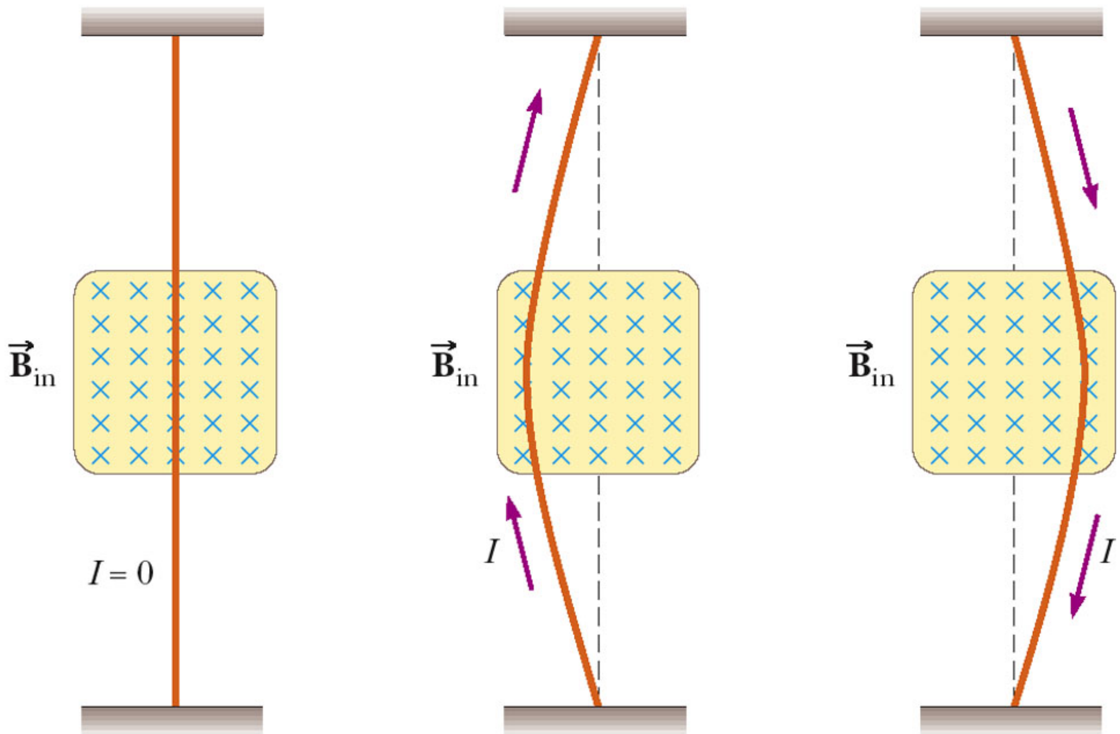

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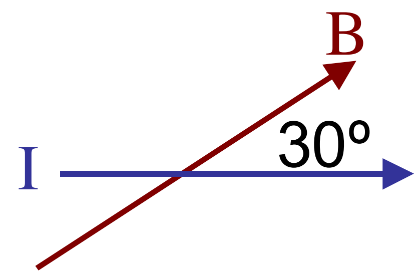
Reminder: Direction of deflection is given by right hand rule:

I = thumb

B = fingers

F_B = out of your palm

Example: Your magnet produces a B-field with strength 0.01 T in the plane of the page as shown. A wire carries 1 Amp from left to right, such that $\theta = 30°$. What's the force per unit length (and its direction)?



$F_B / \ell = B\, I \sin 30° = 0.01\text{T} \times 1\text{A} \times 0.5 = 0.005$ N/m (out of page)

So it's not much.

Suppose the current is 6 Amps and the B-field is 3 T.
$F_B / \ell = 9$ N/m (which is slightly more substantial)

Consider a power transmission line carrying 100 Amps from W to E. What's the total force on 100m of wire due to the Earth's magnetic field (assume a North component only)?
In which direction is the wire deflected (assume charge carriers are e^{-}'s)?
Reminder: the Earth's B-field is 0.5 Gauss = 0.5×10^{-4} T

$F_B = B\, I\, \ell \sin\theta$
$= (0.5 \times 10^{-4}\ \text{T})(100\text{A})(100\text{m}) = 0.5\ \text{N}.$

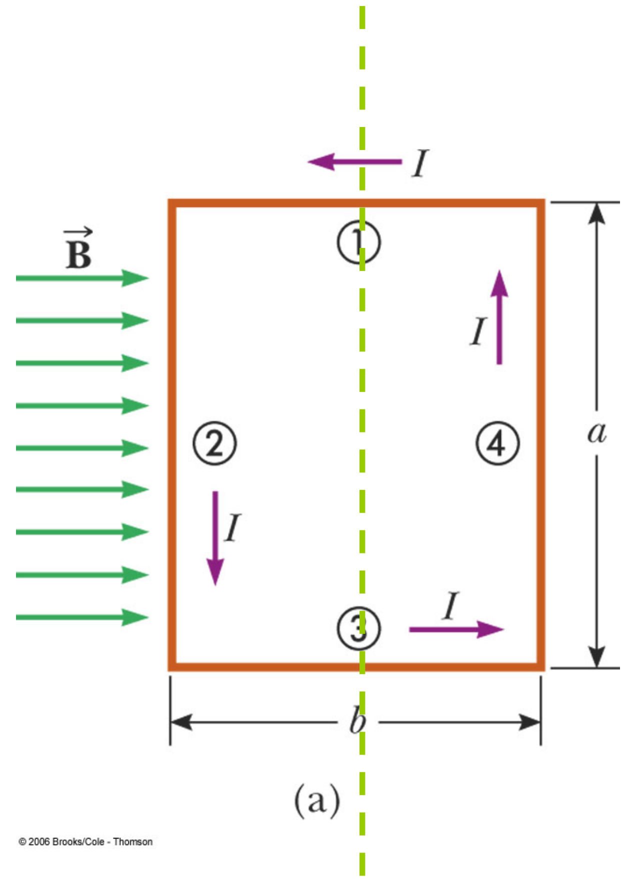
So, again, it's not much.

Direction of deflection = downward

Force on a square loop of current in a uniform B-field.

$F_{top} = 0$ $\theta = 0$; $\sin\theta = 0$; so $F_B = 0$
$F_{bottom} = 0$

$F_{left} = I\,a\,B$ (out of page)
$F_{right} = I\,a\,B$ (into page)



Assume loop is on a frictionless axis

What's the TORQUE on the current loop?

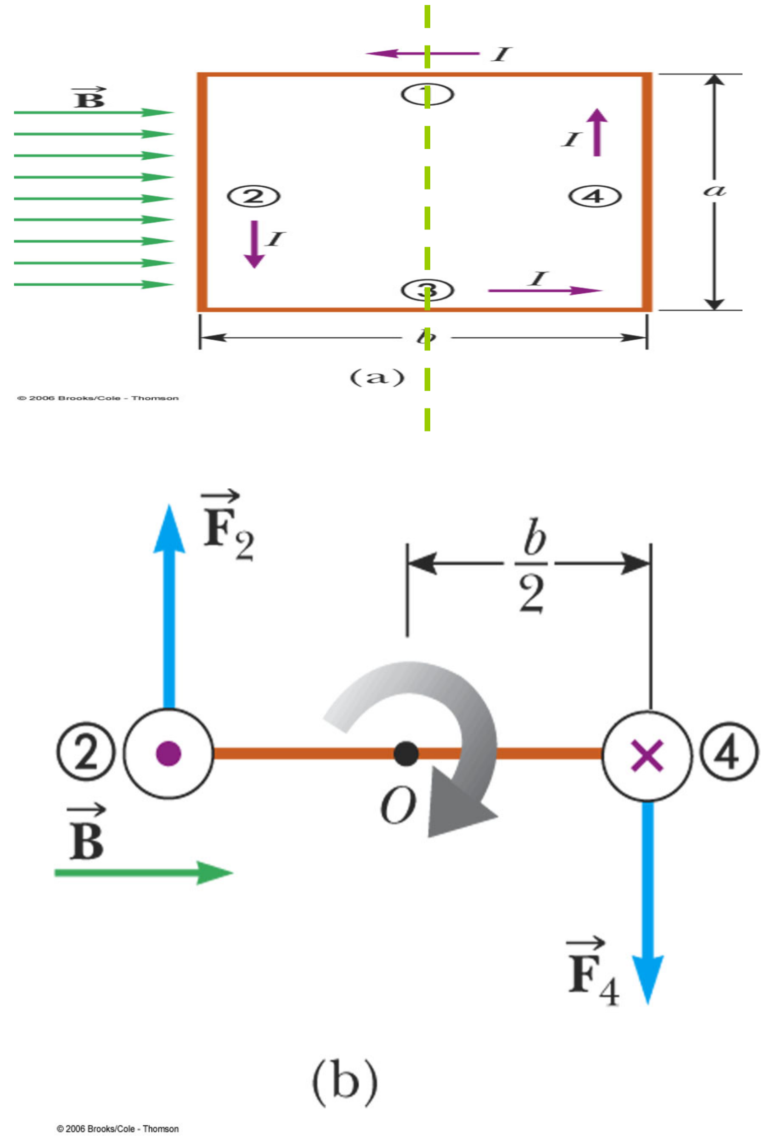
Fig. 22.19b in text is the view along the axis, from the bottom towards the top.

Reminder: torque = $\vec{F} \times \vec{r}$ = F r sinθ

$\tau = F_{left}\ a/2 + F_{right}\ a/2 =$ (B b I + B b I) a/2 = B I A

A = area; θ=90º here

Note direction of torque: clockwise



For 1 loop:

$\tau = BIA \sin\theta$

$\tau_{max} = BIA$

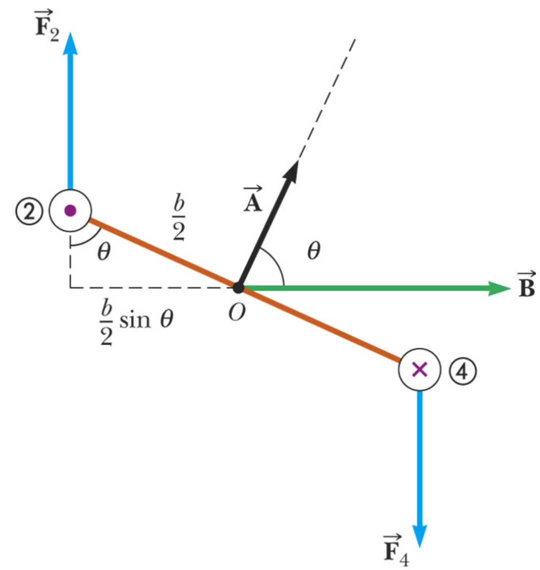
For N turns: Total current = NI

$\tau = BIAN \sin\theta$

Magnetic Moment $\vec{\mu} = IAN$

$\vec{\mu}$ always points perp. to the plane of the loops (points along the normal)

$\tau = \mu B \sin\theta$



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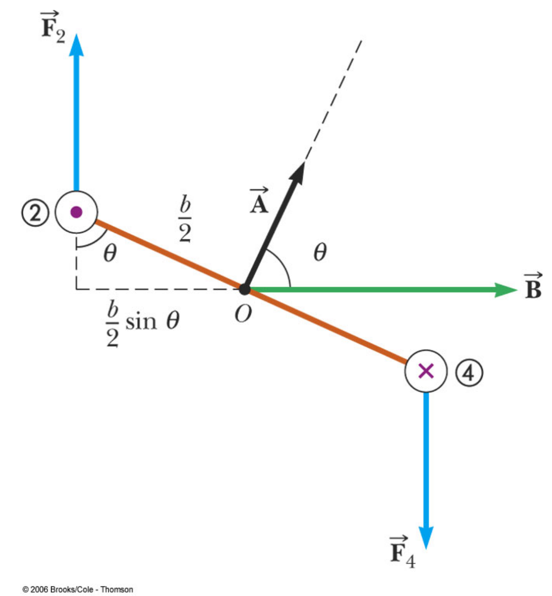
$$\vec{\tau} = I\,\vec{\mathbf{A}} \times \vec{\mathbf{B}}$$



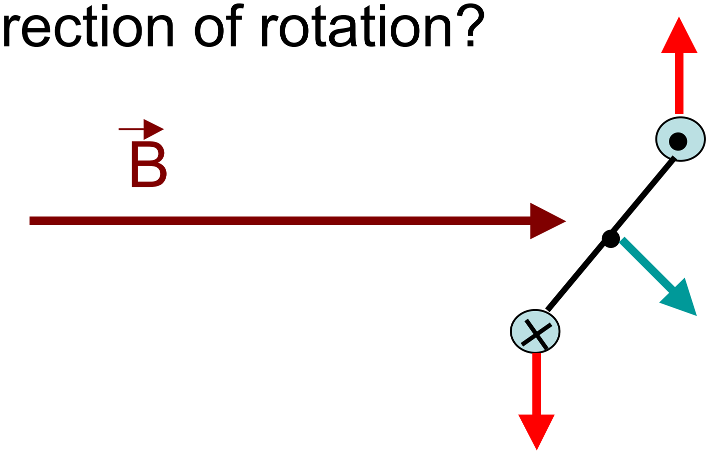
- The product $I\vec{A}$ is defined as the ***magnetic dipole moment***, $\vec{\mu}$ of the loop (for ANY loop shape)
- SI units: A m^2
- Torque in terms of magnetic moment:

$$\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}}$$

For a coil with N turns of wire:

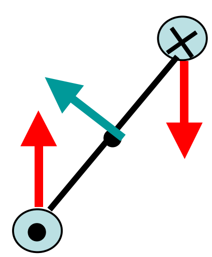
$\vec{\mu} = NI\vec{A}$

A coil consisting of 100 turns, each carrying 3A of current and having an area 0.2 m^2, is oriented such that its normal makes a angle of 45° with a B-field of 0.5T. Find the total torque on the coil. What's the direction of rotation?

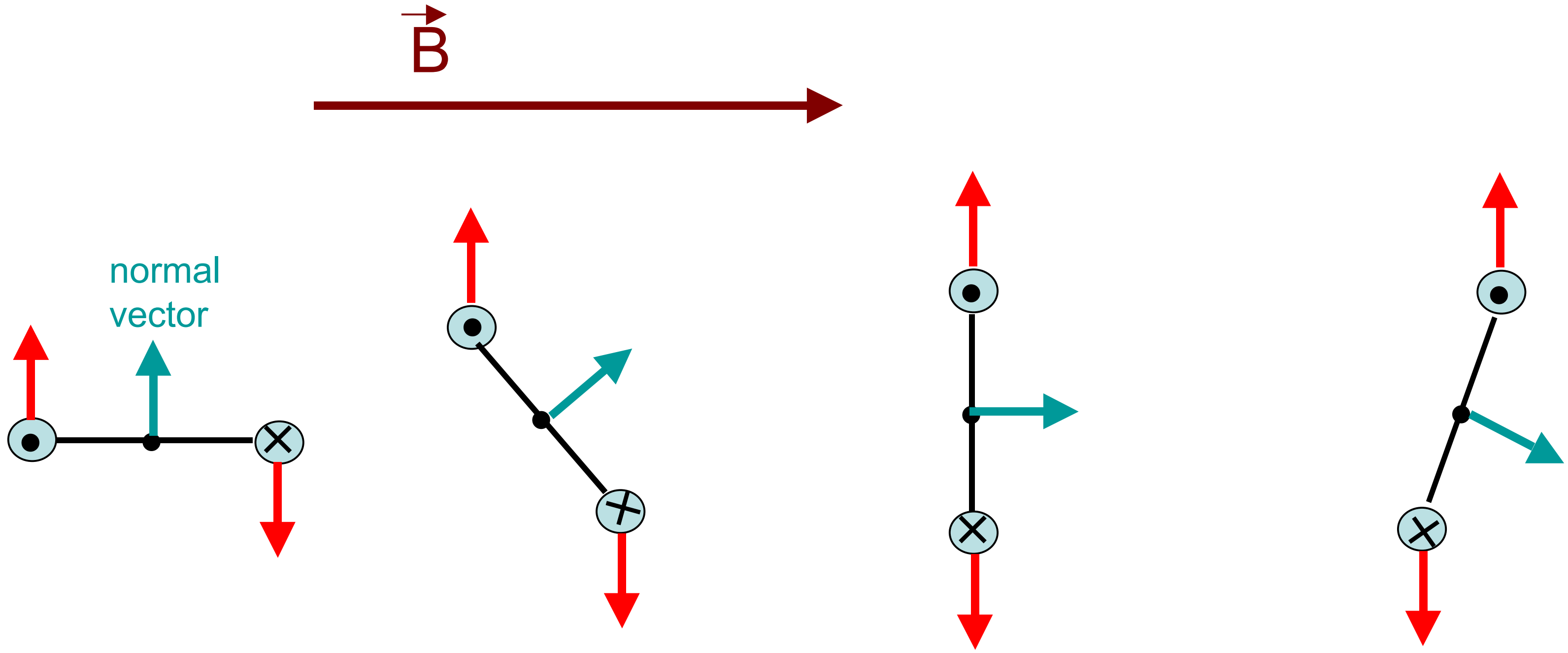


$$\tau = BIANsin\theta = (0.5T)(3A)(100)(0.2m^2)sin45^\circ = 21.2\ Nm$$

What would happen if the current were flowing in the opposite direction?



Same magnitude of τ, but rotation is now CW



#1: θ=90º

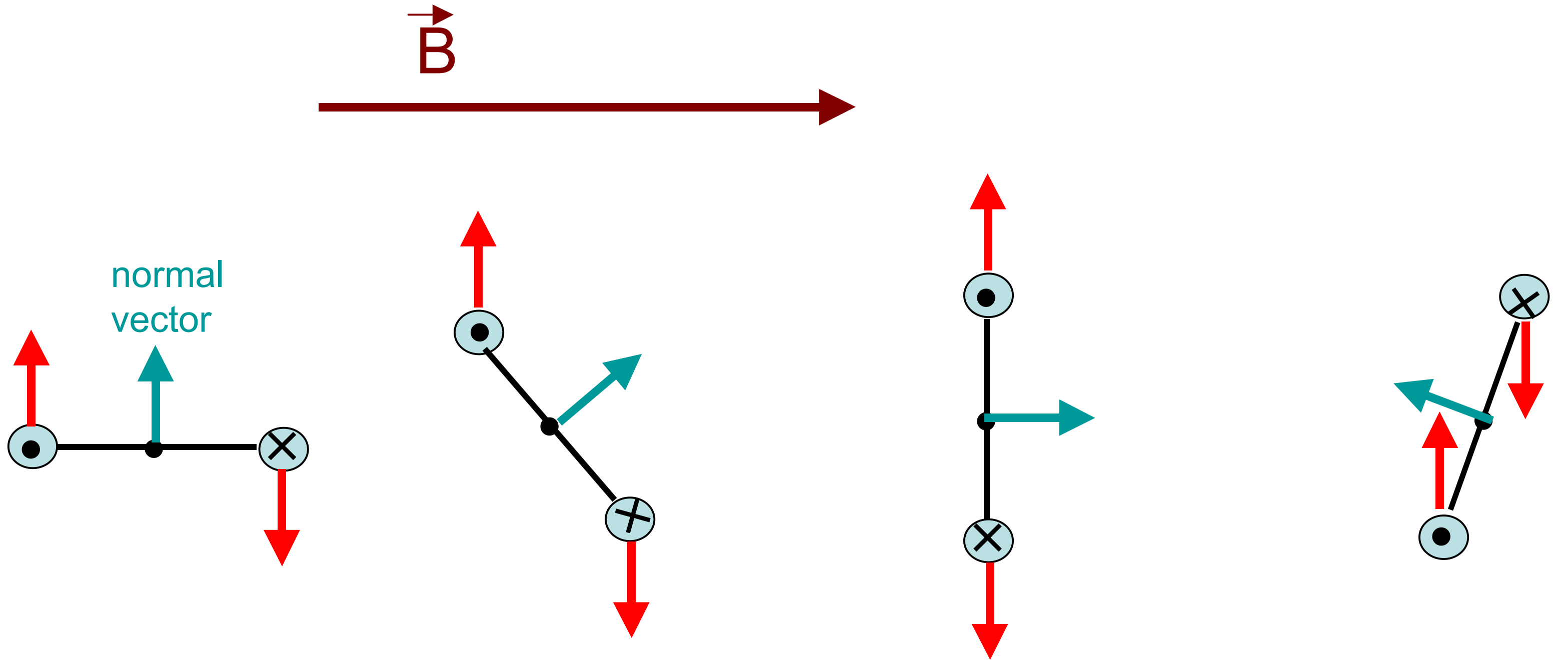
#2: 0º < θ <90º

#3: θ=0º

#4: 90º < θ <180º

torque acts to align plane of loop perpendicular to B-field (align normal vector with B-field), as in #3

(if released from rest in this position, it won't rotate)



#1: θ=90º

#2: 0º < θ <90º

#3: θ=0º

#4: 90º < θ <180º

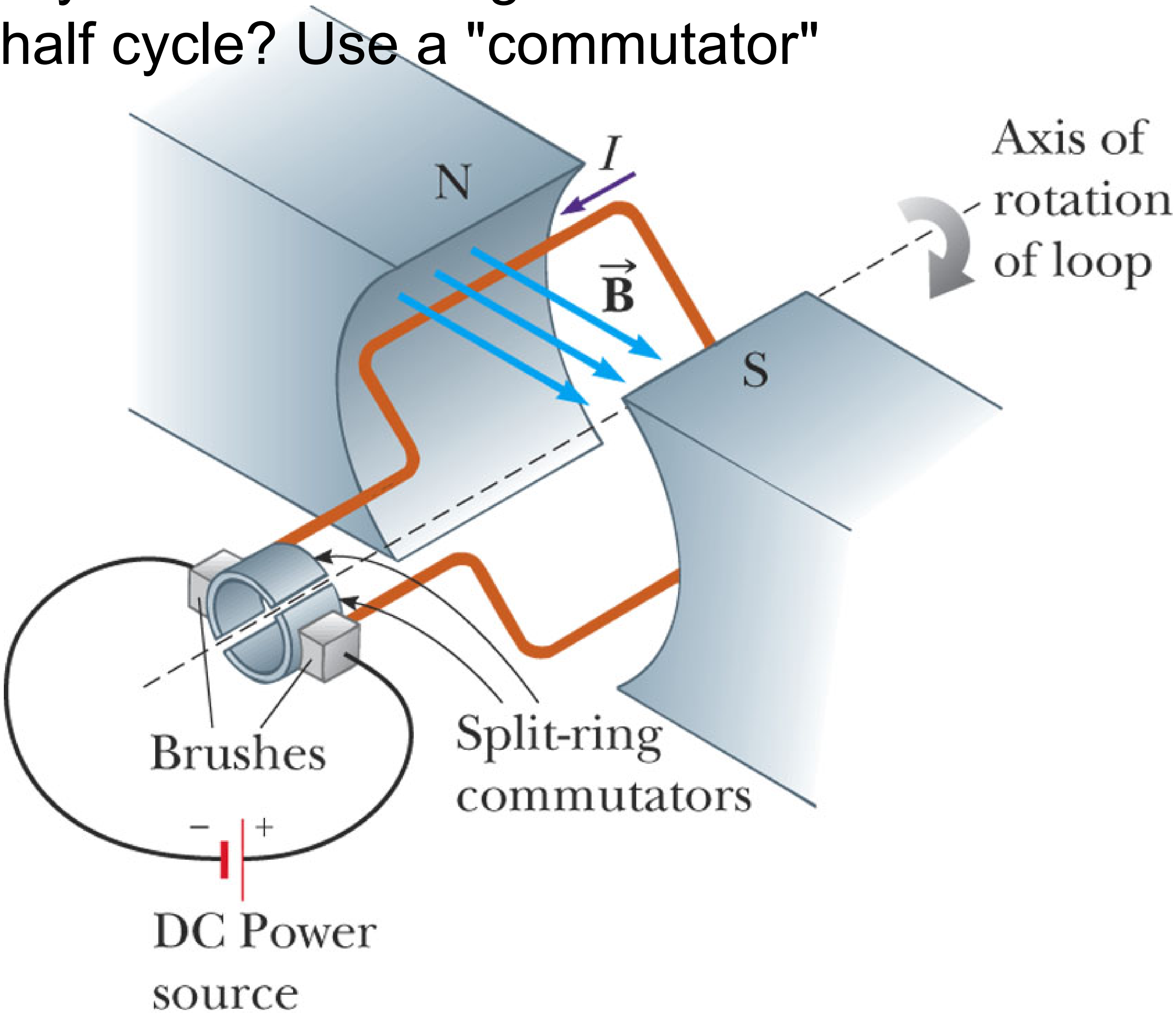
As loop is rotating, what would happen if we switched the direction of current immediately after #3?

The loop would continue to rotate clockwise!

Electric motors

•If direction of current is switched every time τ is about to change sign, then τ will never change sign!
•Loop will rotate nonstop: we have an electric motor (electrical energy converted to mechanical (rotational) energy)!
•Fans, blenders, power drills, etc.
•Use AC current (sign changes naturally), or if you only have DC current available….

How do you switch the sign of current every half cycle? Use a "commutator"



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