Wednesday March 22, 2017

Last time:

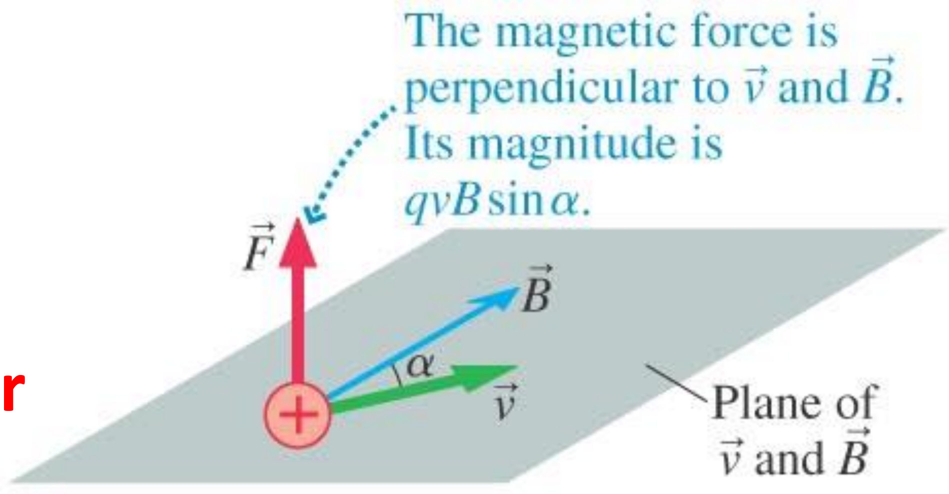
- Introduction to magnetism
- Electric force vs magnetic force on charges
- Vector cross product
- Consequences of magnetic force
- Motion of charges in magnetic fields
- Cyclotron motion, cyclotron frequency, q/m
- Mass spectrometers

Today:

- Charges on helical paths in B-field (aurora)
- The Hall Effect: underpinning of a B-field probe
- Velocity selector via crossed E- and B-fields
- Bainbridge Mass Spectrometer

Magnetic Force on Charges

Magnetic force acts only on a moving charge.



It is perpendicular to both B and v.

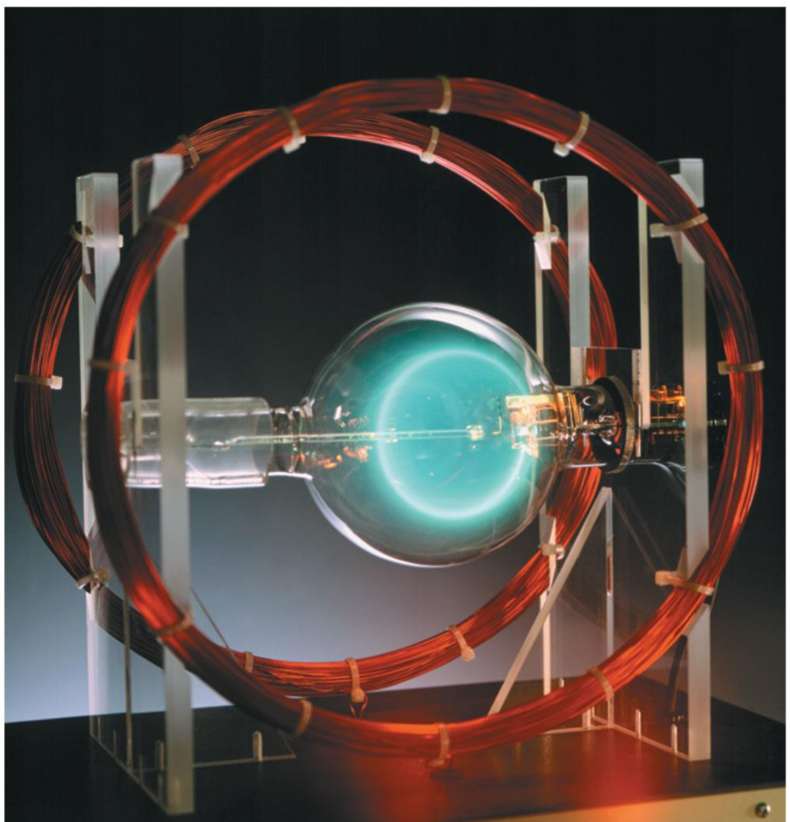
$$\vec{F}_B = q\vec{v} \times \vec{B}$$

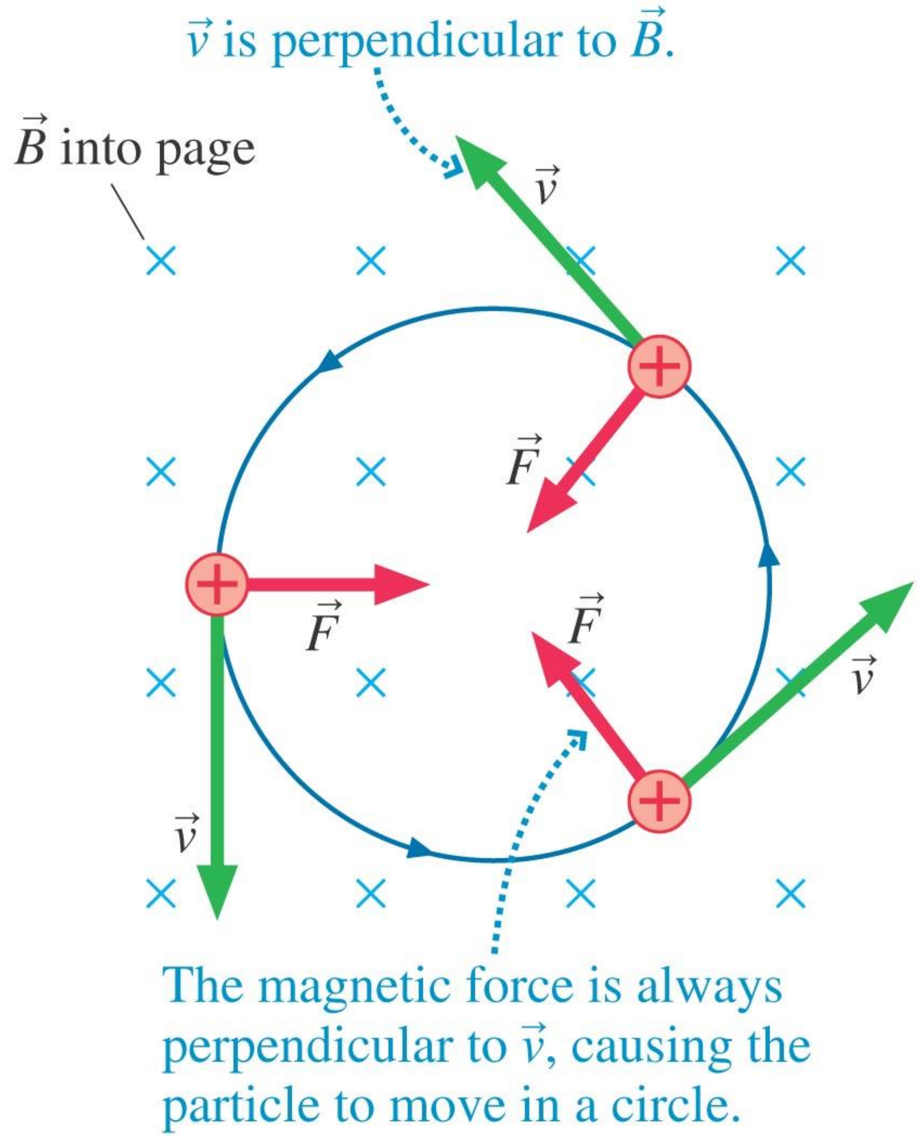
Magnitude: $F_B = qvB\sin\alpha$

Direction: RH rule

Cyclotron Motion

$$\left|\vec{F}_B\right| = |q|\cancel{v}B = m\frac{v^{\cancel{2}}}{R} \qquad \boxed{R = \frac{mv}{|q|B}}$$

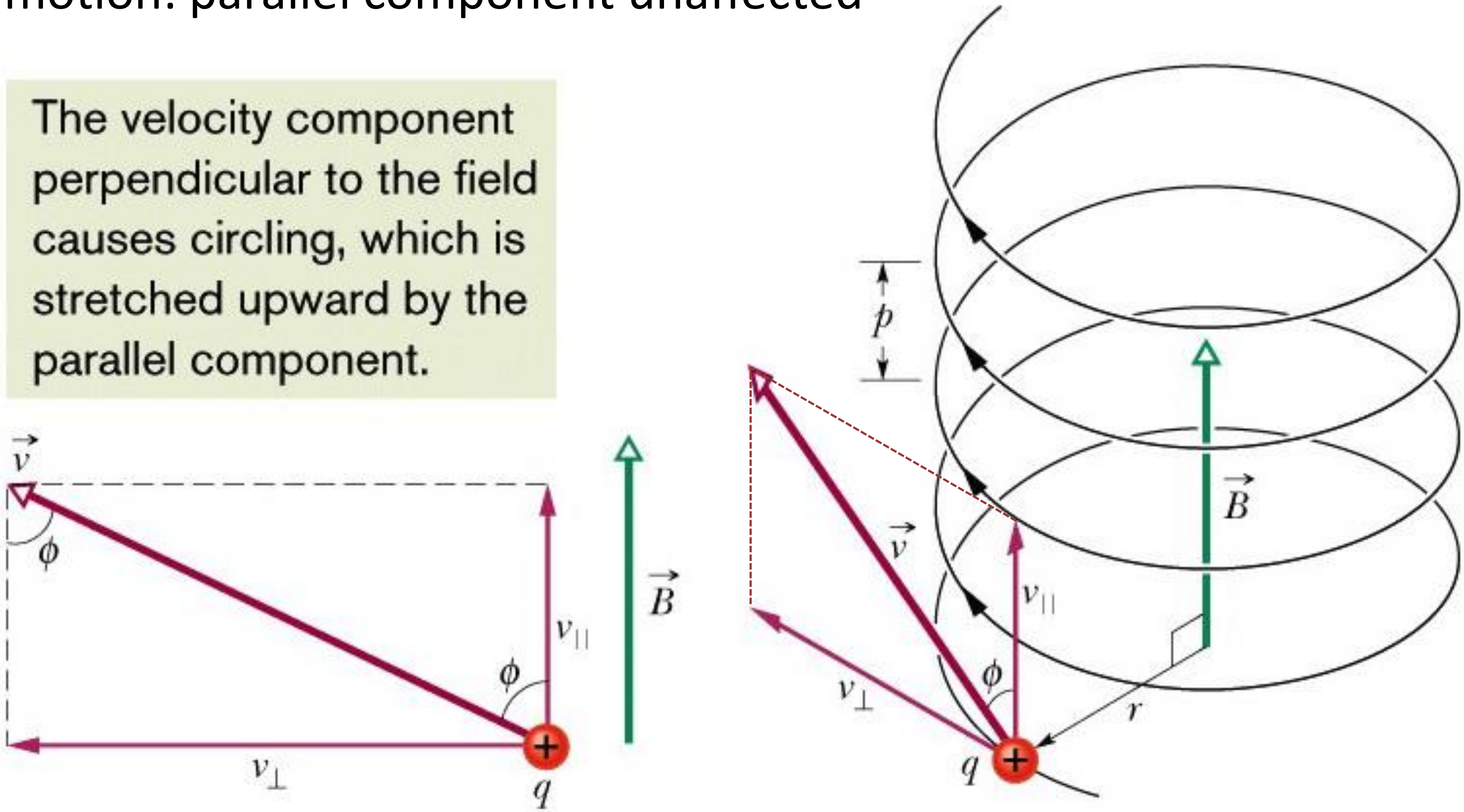




Top Hat Question

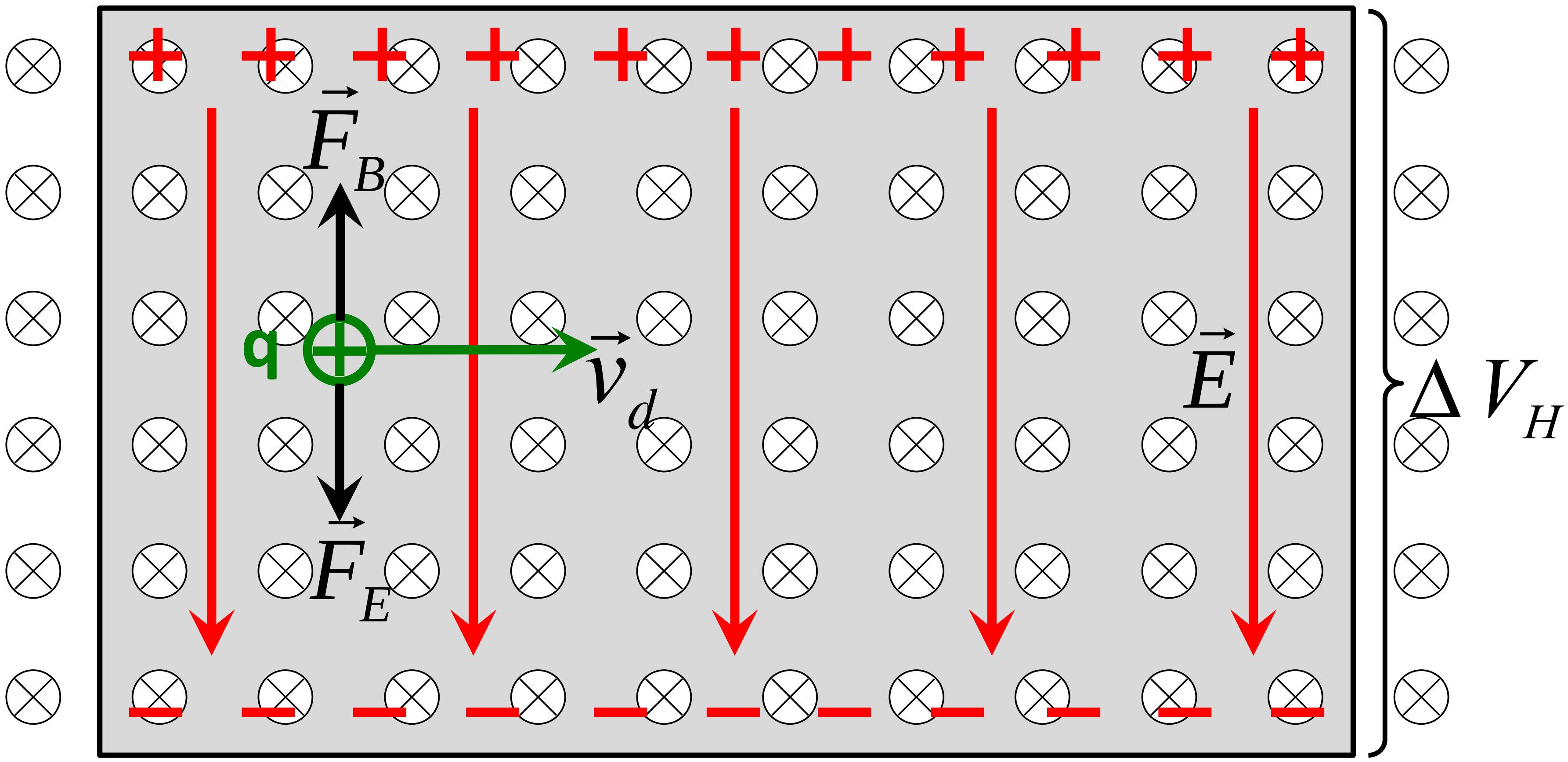
Helical Paths Through a B-field

Splitting up the velocity into a component parallel to B-field and a component perpendicular to B-field immediately leads to helical motion: parallel component unaffected



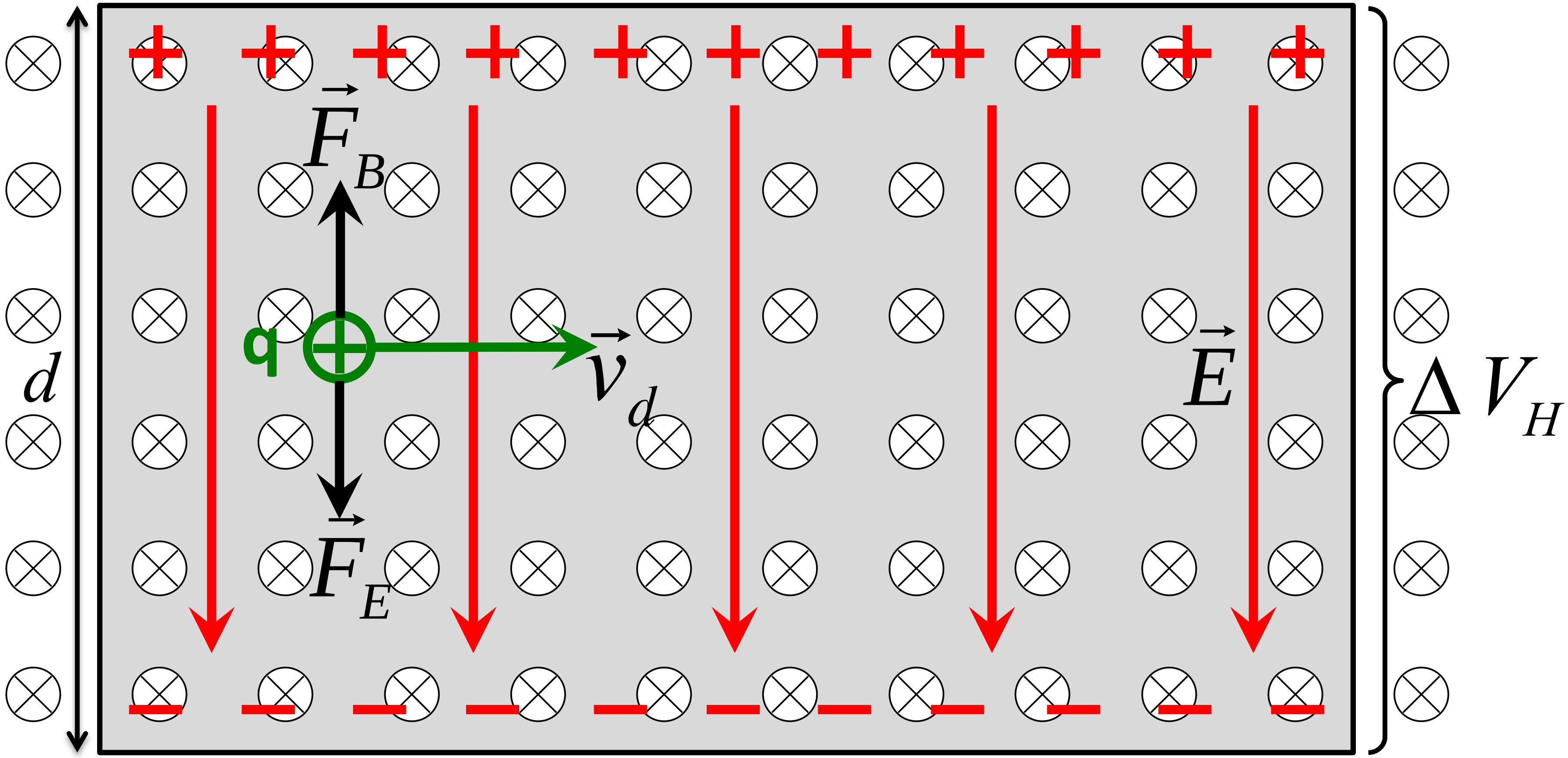
The Hall Effect

Due to the B-field, net charge build up on the edges.



In equilibrium, current still flows. Need to balance the magnetic and electric forces on the charge carriers.

The Hall Effect

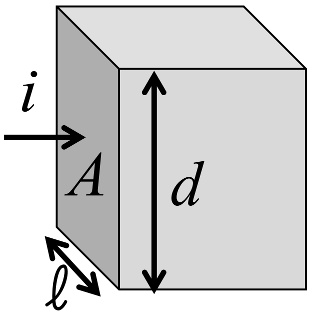


$$F_B = q v_d B \qquad F_E = q\frac{\Delta V_H}{d} \qquad q\frac{\Delta V_H}{d} = q v_d B \qquad \boxed{\Delta V_H = v_d B d}$$

The Hall Effect

We have just found that the voltage established across a conductor carrying a current in a magnetic field is

$$\Delta V_H = v_d B d$$



We previously related the drift speed to the current via

$$v_d = \frac{i}{neA}$$ where $A = \ell d$ and n is a material property

We can then relate the Hall voltage to known quantities:

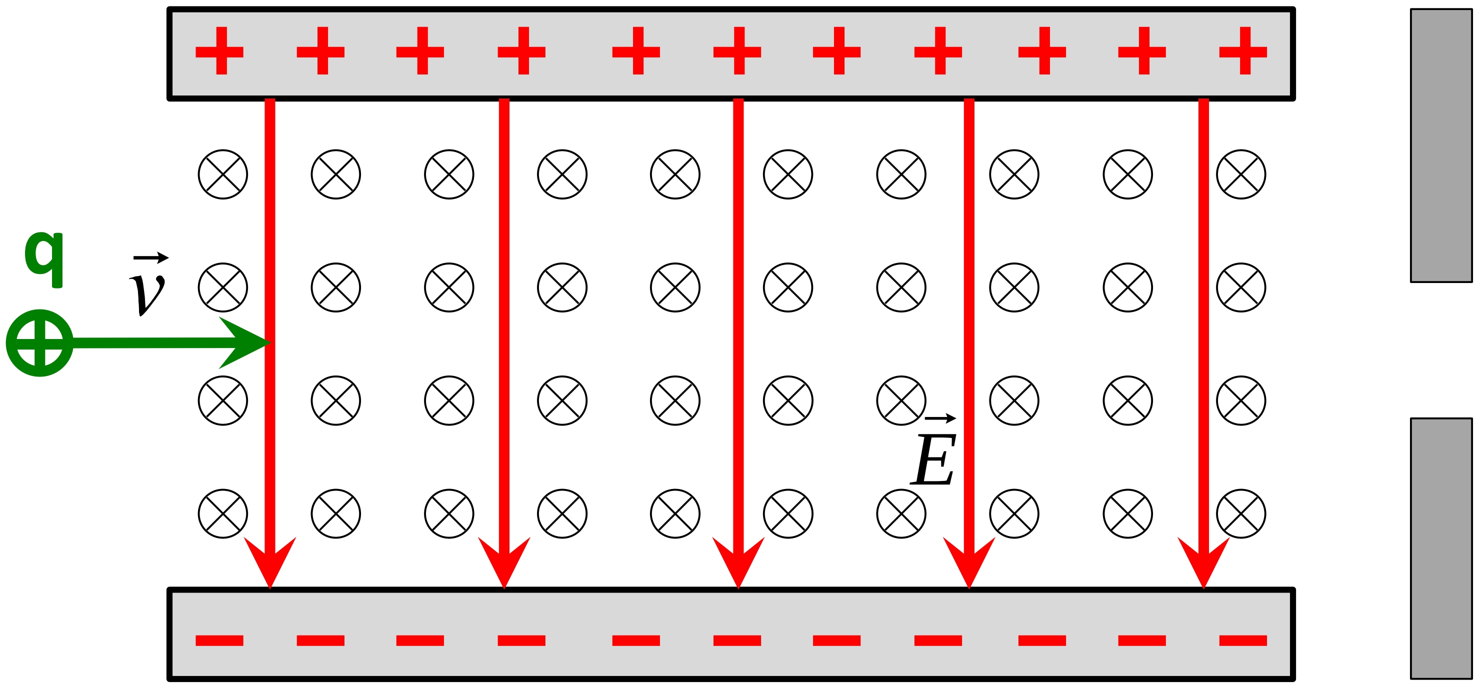
$$\Delta V_H = \frac{i}{ne\ell \cancel{d}} B\cancel{d} = \frac{iB}{ne\ell}$$

In practical applications, you measure ΔV_H to find B:

$$\boxed{B = \frac{ne\ell}{i}\Delta V_H}$$

How the B-field probe used in the next lab works

Similar concept: velocity selector

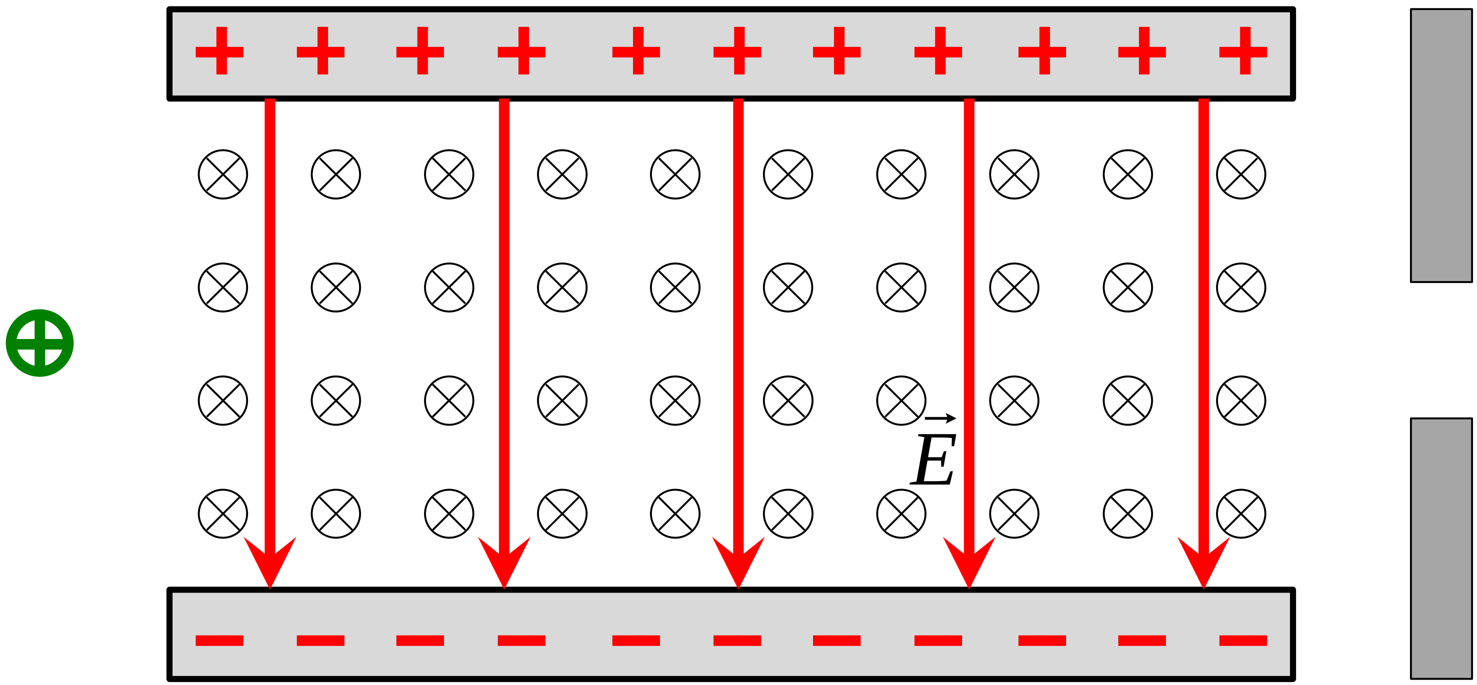


In a velocity selector, you send a charge through a region with crossed E and B fields, which leads to electric and magnetic forces:

$$\vec{F}_e = q\vec{E} \qquad \vec{F}_B = q\vec{v} \times \vec{B} \qquad qE = qvB \qquad v = \frac{E}{B}$$

If the forces balance ($F_{net} = 0$) the charge makes it through the slit

Similar concept: velocity selector



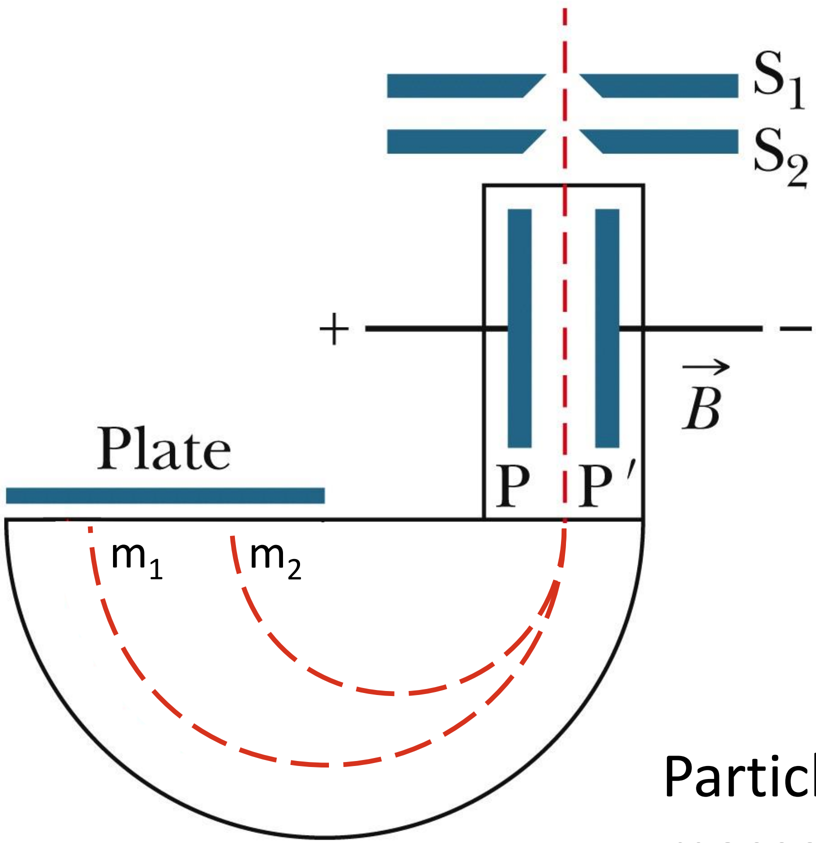
If the forces don't balance the charge hits the wall

$$qE - qvB = ma$$

We pick the E and B magnitudes to select the speeds we want

Bainbridge Mass Spectrometer

Accelerate charges through ΔV so they all have same Kinetic Energy



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The slits S_1 and S_2 ensure the beam of particles is collimated.

The beam enters a region of crossed E and B-fields

A narrow slit ensures only particles with a specific speed enter

Particles with same KE but different masses and charges will have different radius in B field

Wednesday March 22, 2017 – lecture 2

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Today:

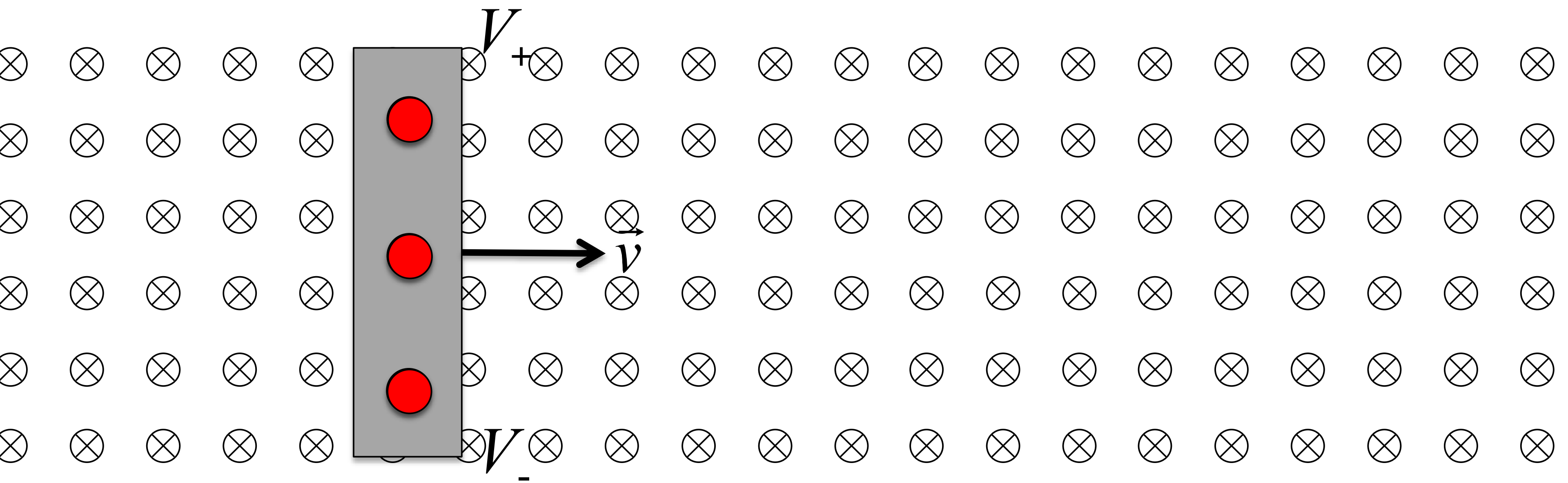
- Conductors moving through B-fields: Hall(ish) Effect
- Magnetic force on current carrying wires
- Torque on a current loop

Conductors moving in B-fields

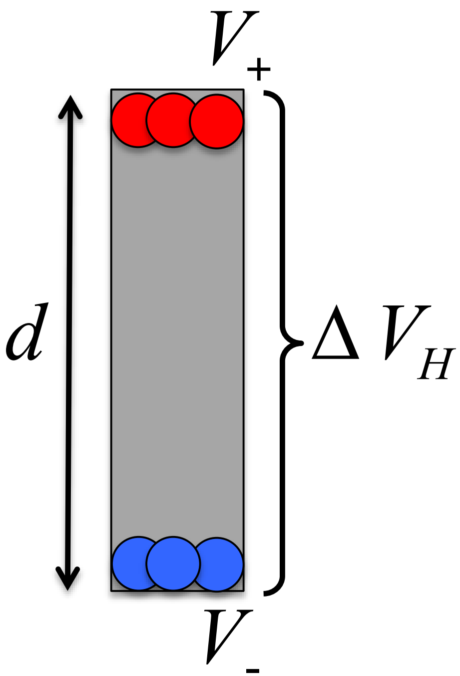
We’ve seen that free charges moving in a B-field feel a force perpendicular to the field and the charge’s velocity:

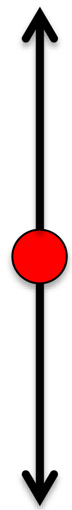
$$\vec{F}_B = q\vec{v} \times \vec{B}$$

Conductors are full of charges that are free to move around (yet they have to stay confined to the conductor itself). If a conductor moves in a magnetic field, these charges also feel a magnetic force



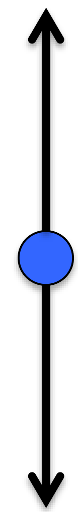
Conductors moving in B-fields





$$F_B = q v B$$

$$F_E = q\frac{\Delta V_H}{d}$$



$$F_E = q\frac{\Delta V_H}{d}$$

$$F_B = q v B$$

In equilibrium, forces balance, leading to a constant voltage

$$q\frac{\Delta V_H}{d} = qvB$$

$$\boxed{\Delta V_H = vBd}$$

Forces on Current-Carrying Wires

Current in wires is nothing more than charges in motion. It doesn't matter if we consider $-q$ moving opposite i or $+q$ moving in the same direction as i

In a magnetic field, these charges feel a force and get deflected from their normal straight path. For a single charge:

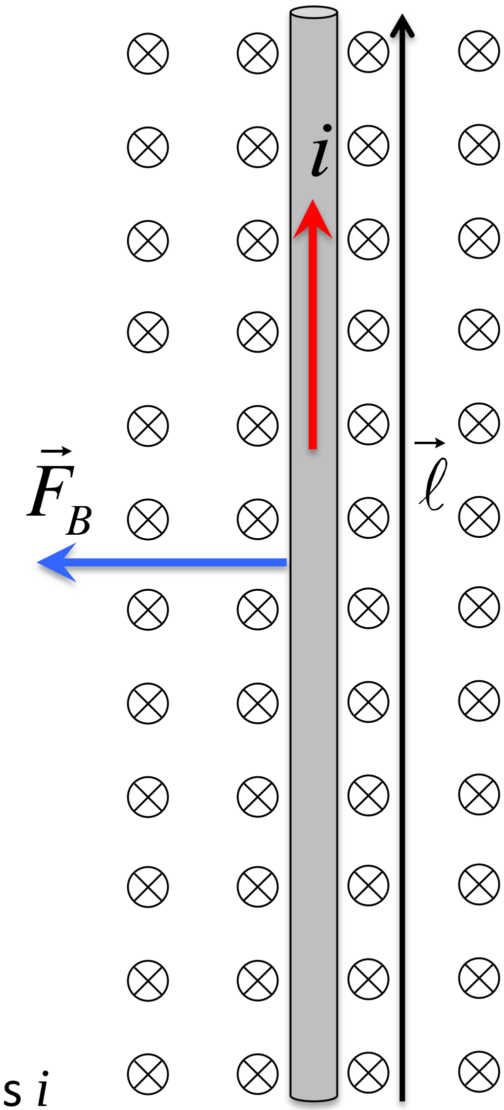
$$\vec{F}_B = q\vec{v}_d \times \vec{B}$$

For N charges moving through the wire:

$$Nq\vec{v}_d = \left(nAq\vec{v}_d\right)\ell = i\vec{\ell}$$

$$\boxed{\vec{F}_B = i\vec{\ell} \times \vec{B}}$$

Length of wire, direction same as i

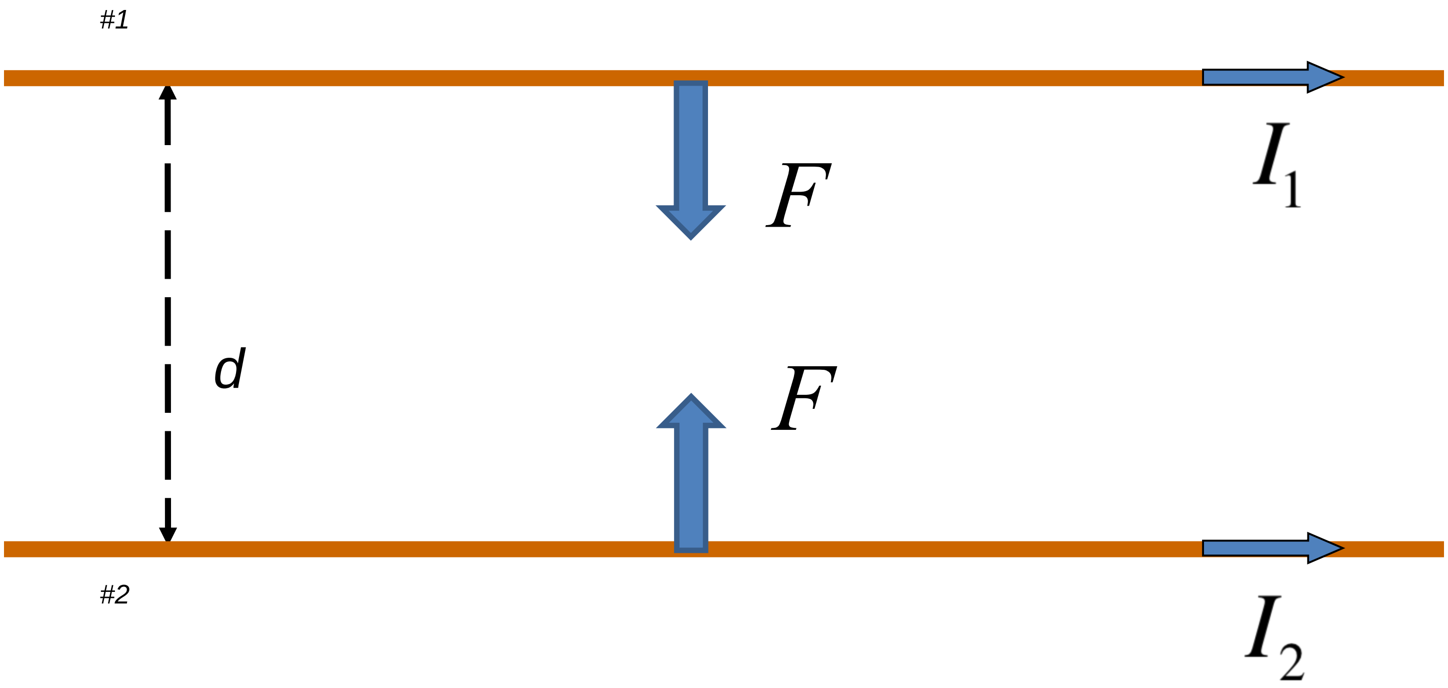


Force Between Two Parallel Wires

Derive an expression for the magnetic force on wire #2 due to the magnetic field created by the current flowing in wire #1.

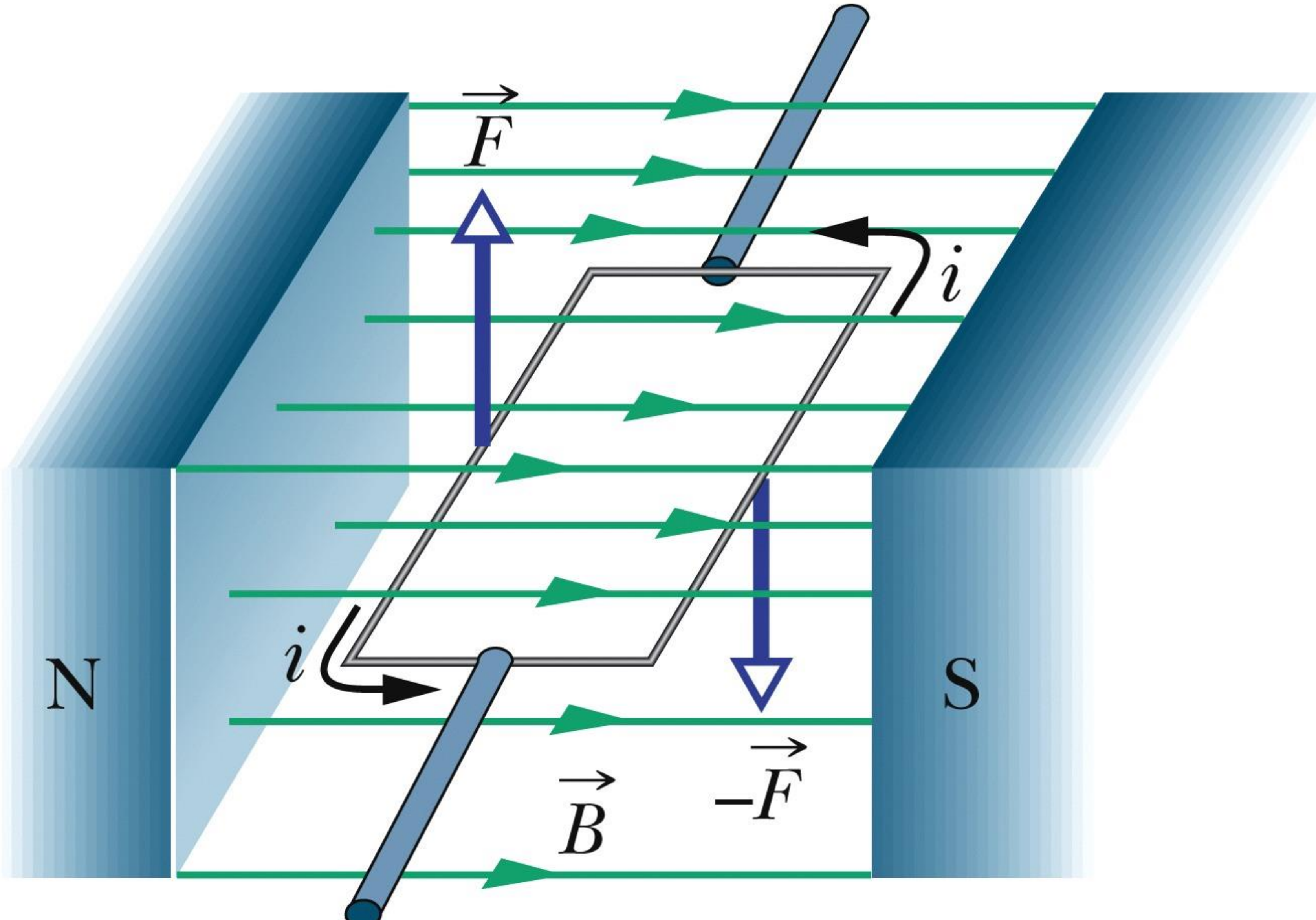
Top Hat Question

Force Between Two Parallel Wires



Derive an expression for the magnetic force on wire #2 due to the magnetic field created by the current flowing in wire #1.

Torque on a current loop



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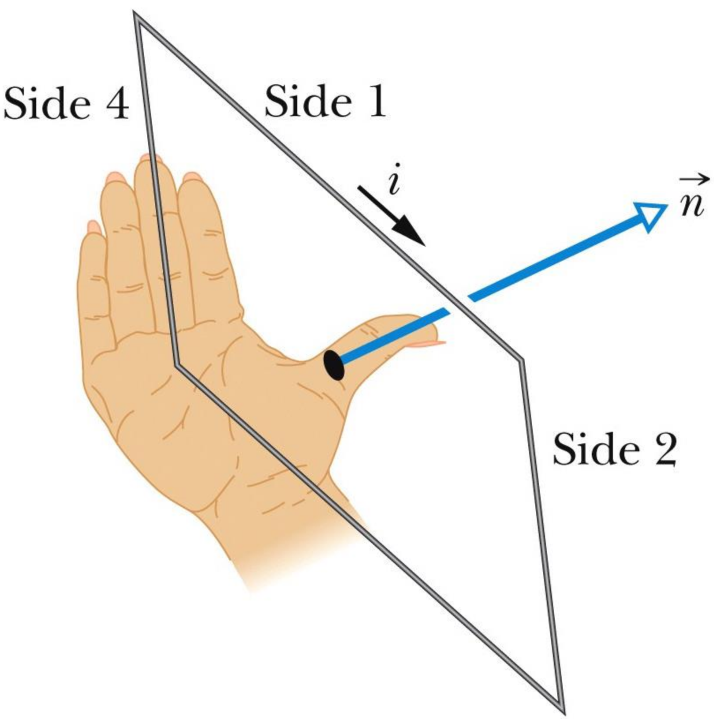
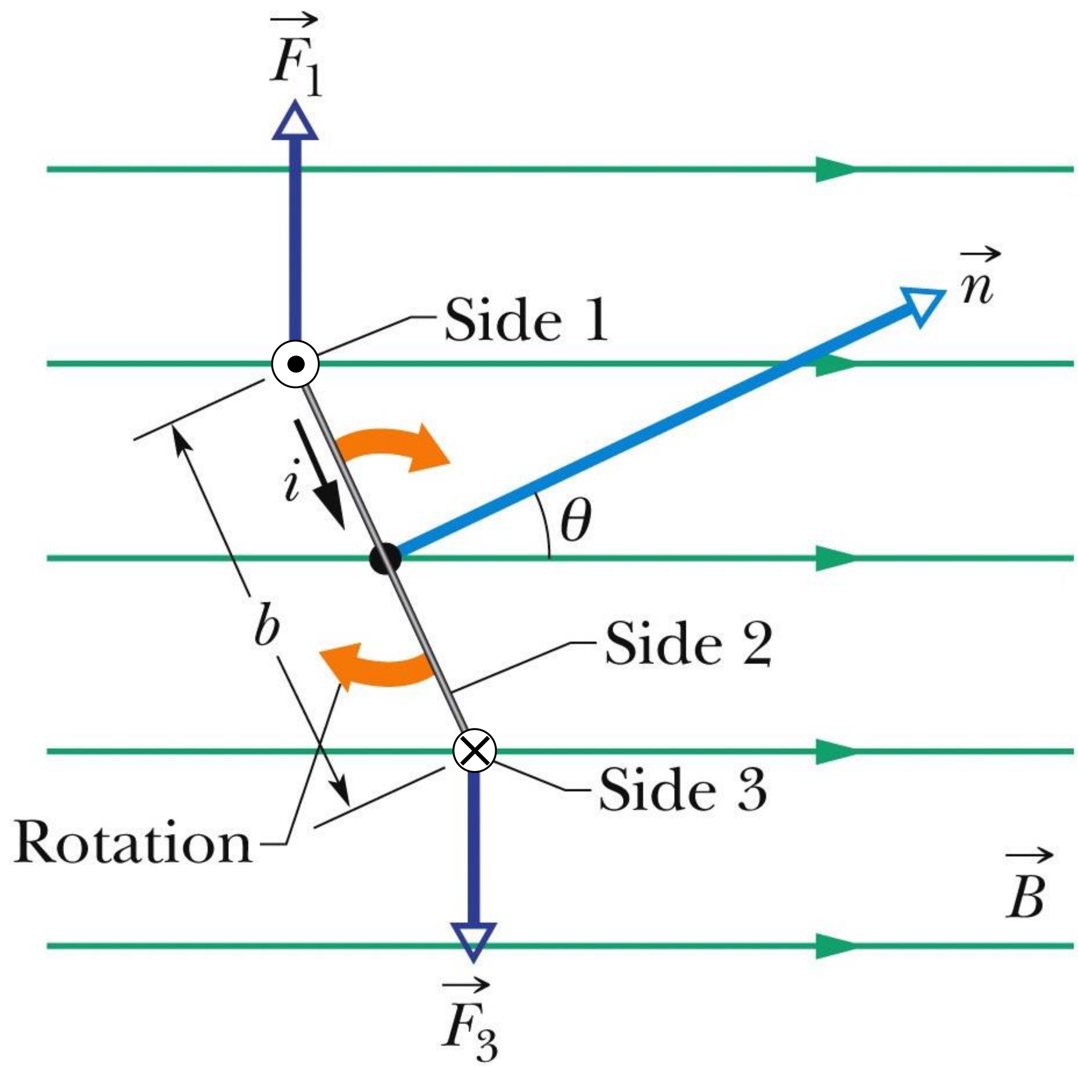
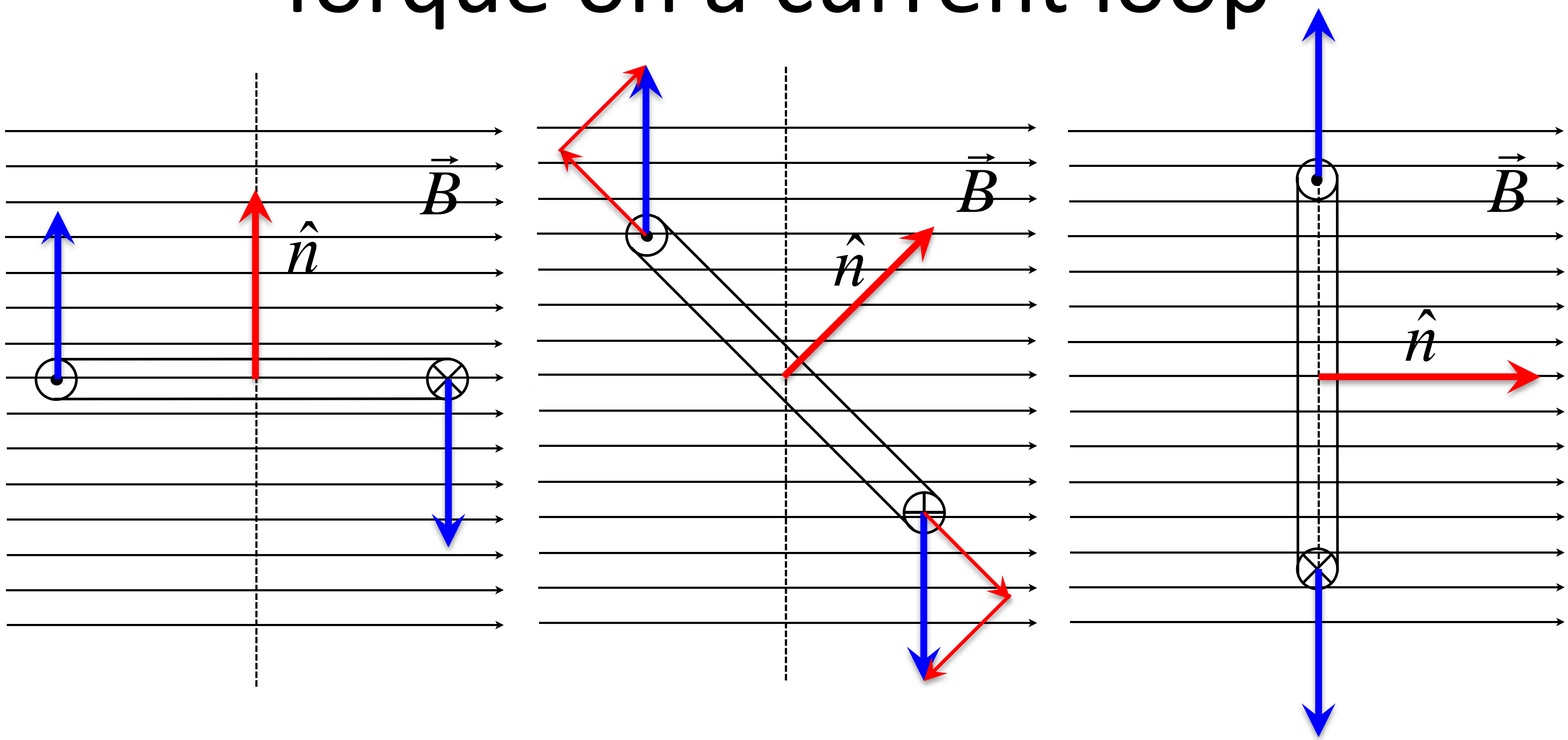
Torque on a current loop

Pick the normal vector to the loop area by RHR: curl your fingers in the direction of i, thumb points in direction of n





Torque on a current loop



The normal vector is at right angles to the B-field: all magnetic force causes rotation of the loop

The normal vector is at some angle to the B-field: some of the magnetic force causes rotation of the loop

The normal vector is parallel to the B-field: none of the magnetic force causes rotation of the loop

Conclusion: components of magnetic force (anti)parallel to normal vector that cause torque