Lecture 17

Chapter 29

Magnetic Fields

Magnetic Fields (1)

- Analogous to electric field, a magnet produces a magnetic field, B

- Set up a B field 2 ways:
- Moving electrically charged particles
  - Current in a wire
- Intrinsic magnetic field
  - Basic characteristic of elementary particles such as an electron

Magnetic Fields (2)

- When charged particle moves through *B* field, a force acts on the particle

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

- Magnitude of F_B is $$\vec{F}_B = |q| vB \sin\phi$$

- where ϕ is the angle between *v* and *B*

- SI unit for *B* is tesla, T $$1T = 1\frac{N}{C \cdot m/s} = 1\frac{N}{A \cdot m}$$

Magnetic Fields (3)

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

- $F_B = 0$ if
  - Charge, $q = 0$
  - Particle is stationary
  - v and B are parallel ($\phi=0$) or anti-parallel ($\phi=180$)

- F_B is maximum if
  - v and B are $\perp$ to each other

Magnetic Fields (4)

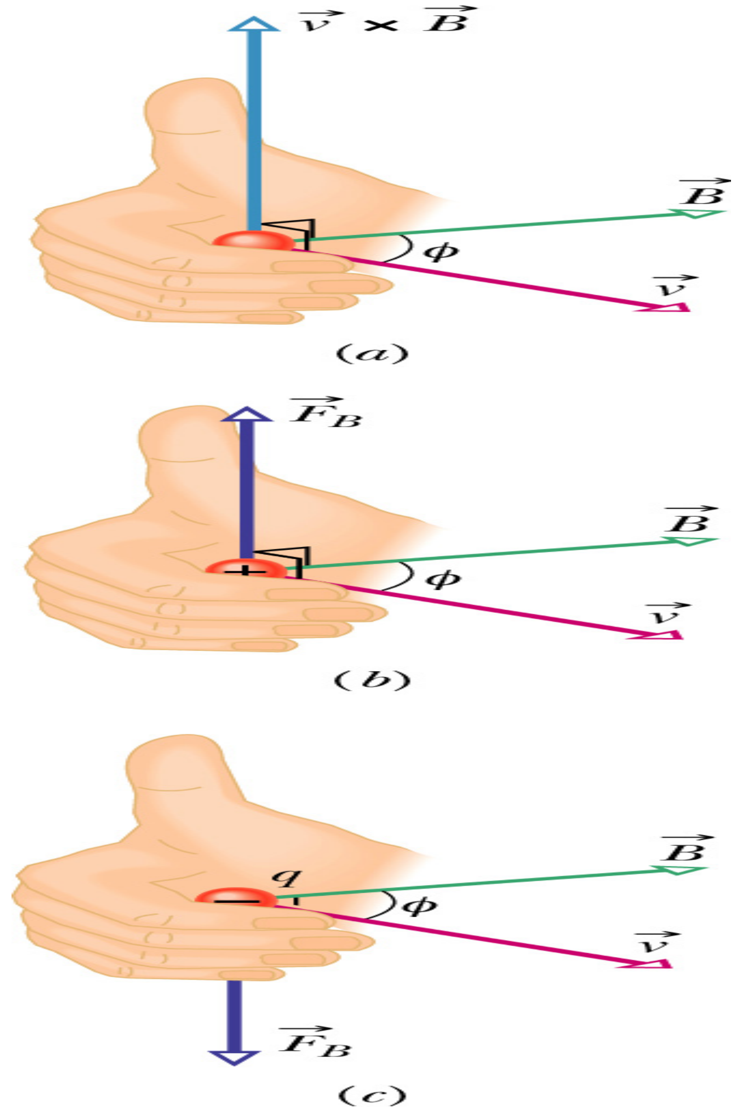
$$\vec{F}_B = q\vec{v} \times \vec{B}$$

- F_B acting on charged particle is always $\perp$ to v and B

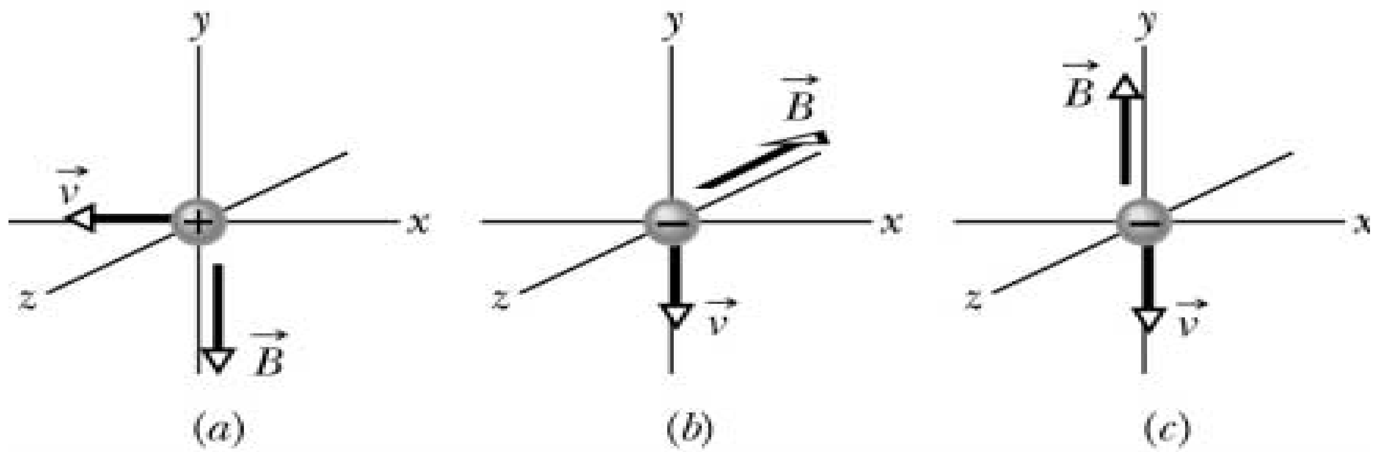
- F_B never has component || to v
- F_B cannot change v or K.E. of particle
- F_B can only change direction of v

Magnetic Fields (5)

- Right-hand rule – For positive charges the thumb of right hand points in direction of F_B when the fingers sweep v into B through the smaller angle ϕ
- For negative charges F_B points in opposite direction



Magnetic Fields (6)



- Checkpoint #1 - What is the direction of F_B on the particle with the *v* and *B* shown?
- Use right-hand rule - don't forget charge

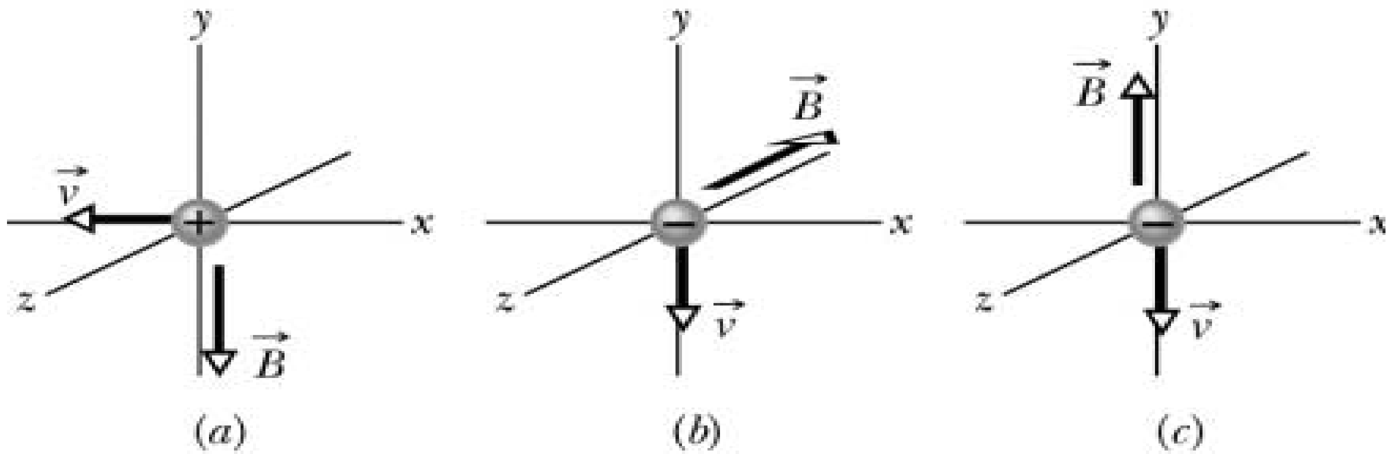
A) +z

B) -x

C) zero

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

Magnetic Fields (7)



- Check yourself using matrix notation
- Write vectors for *v* and *B*

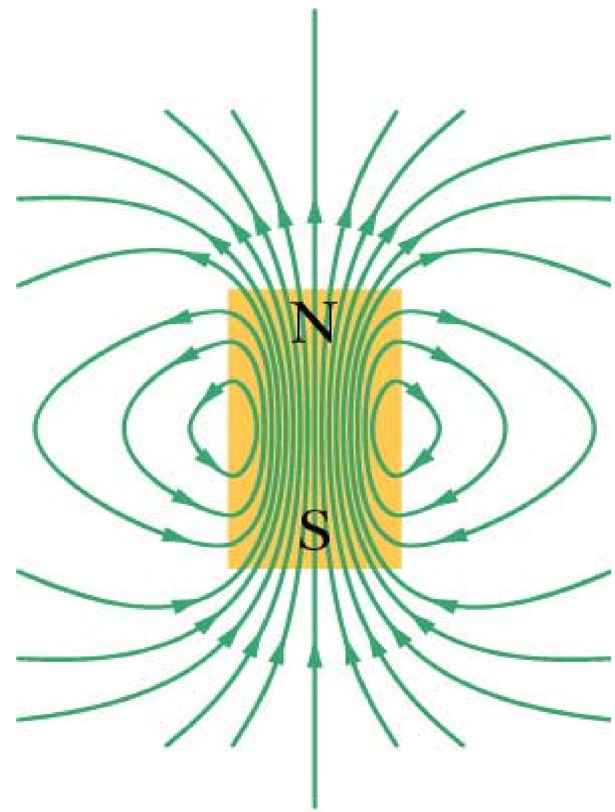
$$\vec{a}\times\vec{b}=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ a_x & a_y & a_z\\ b_x & b_y & b_z\end{vmatrix}=\left(a_yb_z-b_ya_z\right)\hat{i}-\left(a_xb_z-b_xa_z\right)\hat{j}+\left(a_xb_y-b_xa_y\right)\hat{k}$$

Magnetic Fields (8)

- Magnetic field lines

- Direction of tangent to field line gives direction of *B* at that point

- Denser the lines the stronger the *B* field

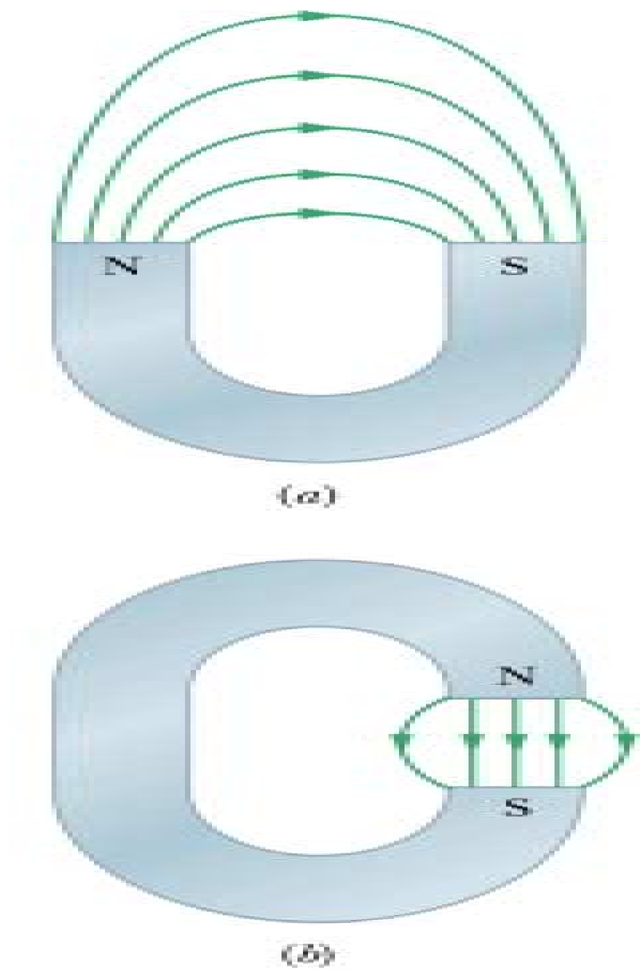


(a)

Magnetic Fields (9)

- Magnetic field lines enter one end (south) of magnet and exit the other end (north)

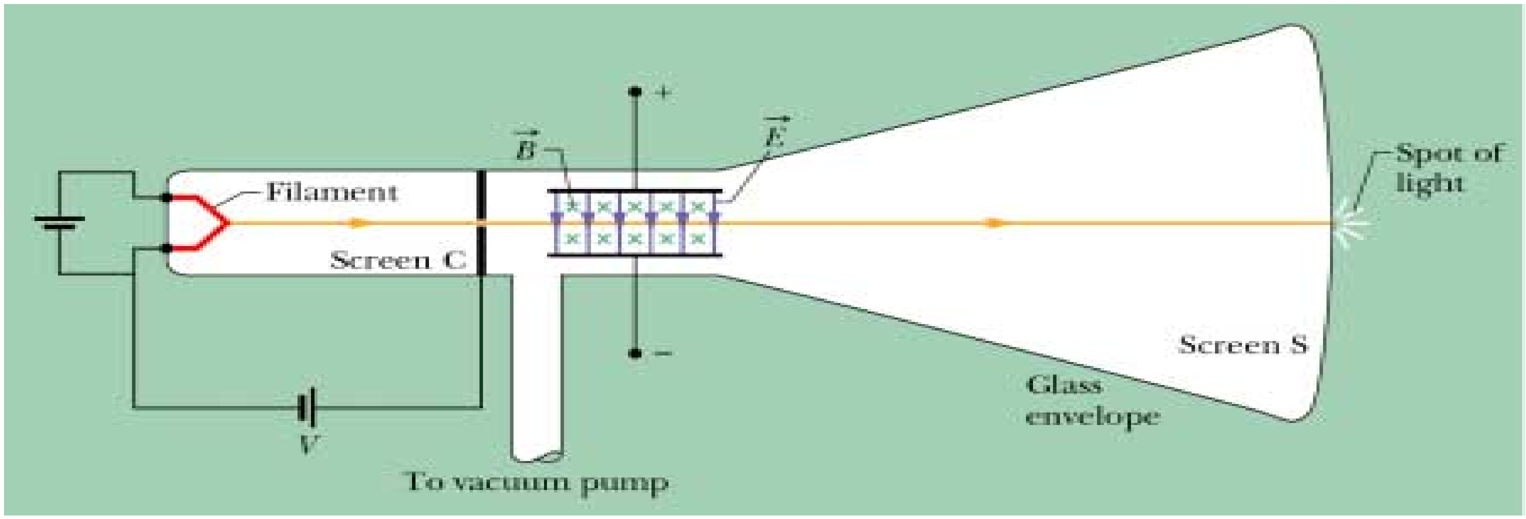
- Opposite magnetic poles attract, like magnetic poles repel



Magnetic Fields (10)

- What happens if there is both an *E* field and a *B* field?
- Both fields produce a force on a charged particle
- If the two fields are $\perp$ to each other call them crossed fields

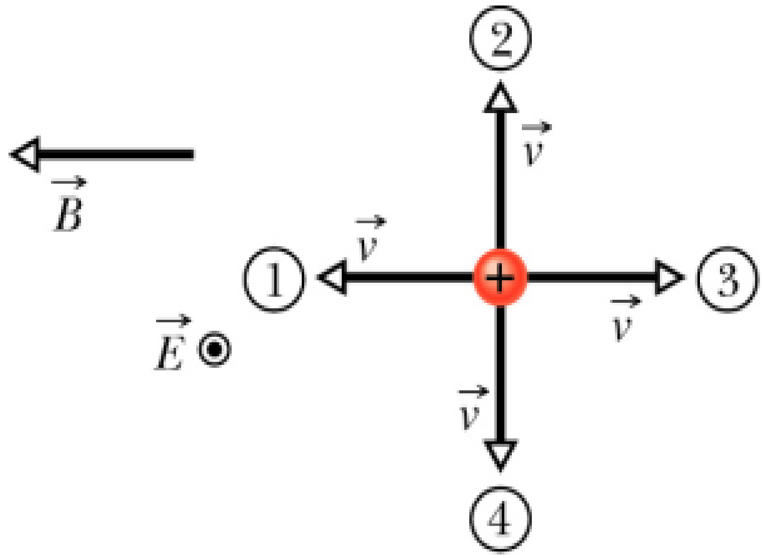
Magnetic Fields (11)



- Cathode ray tube – used in television
- Can deflect a beam of electrons by
  - *E* field from charged parallel-plates
  - *B* field from magnet
- Adjust *E* and *B* fields to move electron beam across fluorescent screen

Magnetic Fields (12)

- Checkpoint #2 – *E* field out of page, *B* field to left
- A) Rank 1,2, and 3 by magnitude of net *F* on particle, greatest first



- What direction is F_E at 1?

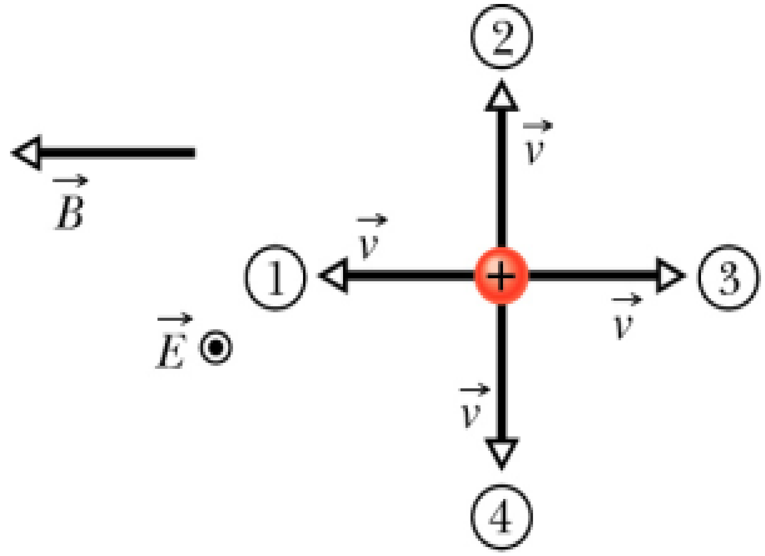
  Out of page

- Is it the same for all directions of *v* ?

  YES

Magnetic Fields (13)

- What is direction of F_B for 1,2,3 and 4?



1) $F_B = 0$

2) F_B out of page

3) $F_B = 0$

4) F_B into page

- A) Rank magnitude of net *F* for 1, 2 and 3.

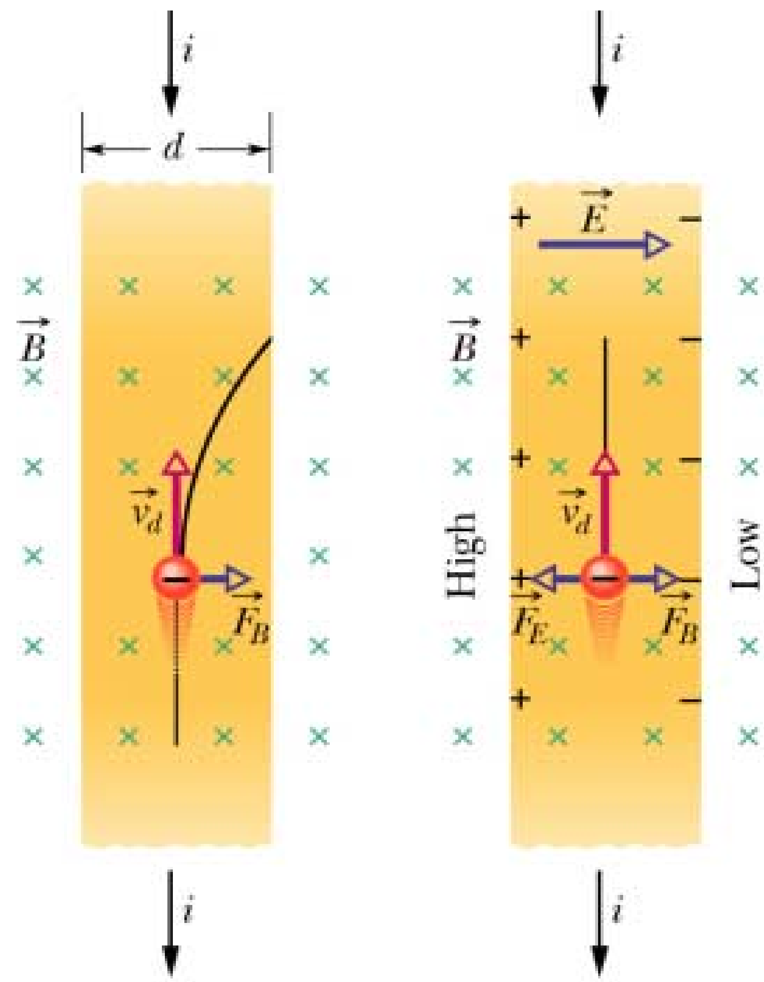
2, then 1 & 3 tie

- B) Which direction could have net *F* of zero?

Direction 4

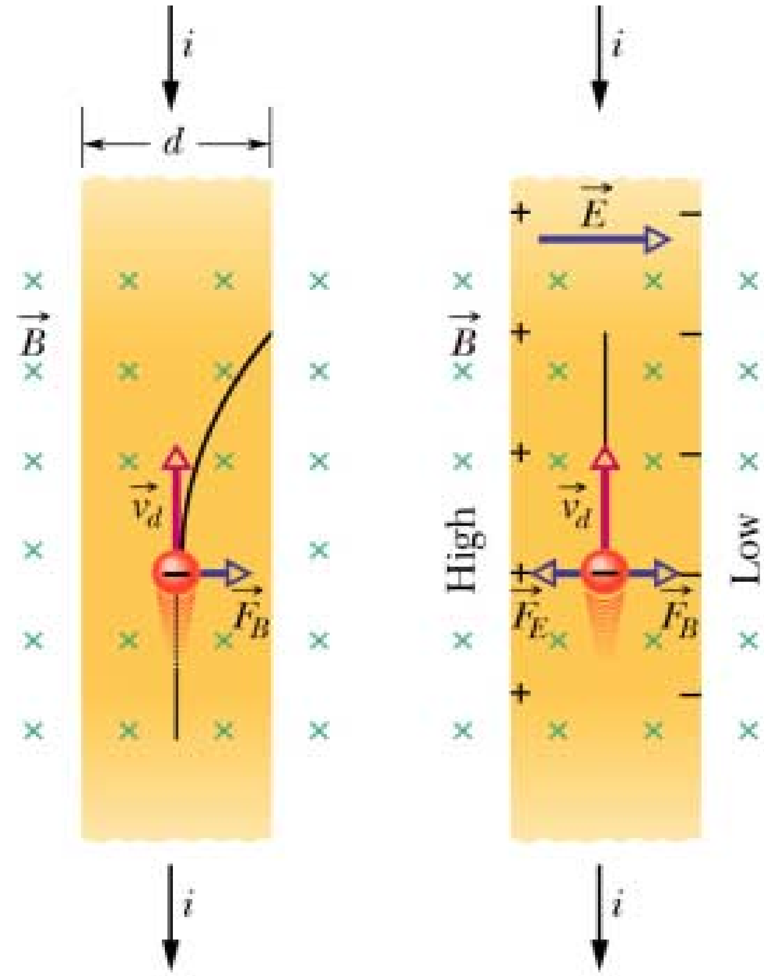
Magnetic Fields (14)

- Electrons moving in a wire (= current) can be deflected by a *B* field called the Hall effect
- Creates a Hall potential difference, *V*, across the wire
- Can measure the wire's charge density when at equilibrium $F_E = F_B$



Magnetic Fields (15)

- Electrons have drift velocity, v_d in direction opposite the current, i
- B field into page causes force, F_B to right
- Electrons pile up on right hand side of strip
- Leaves + charges on left and produce an E field inside the strip pointing to right

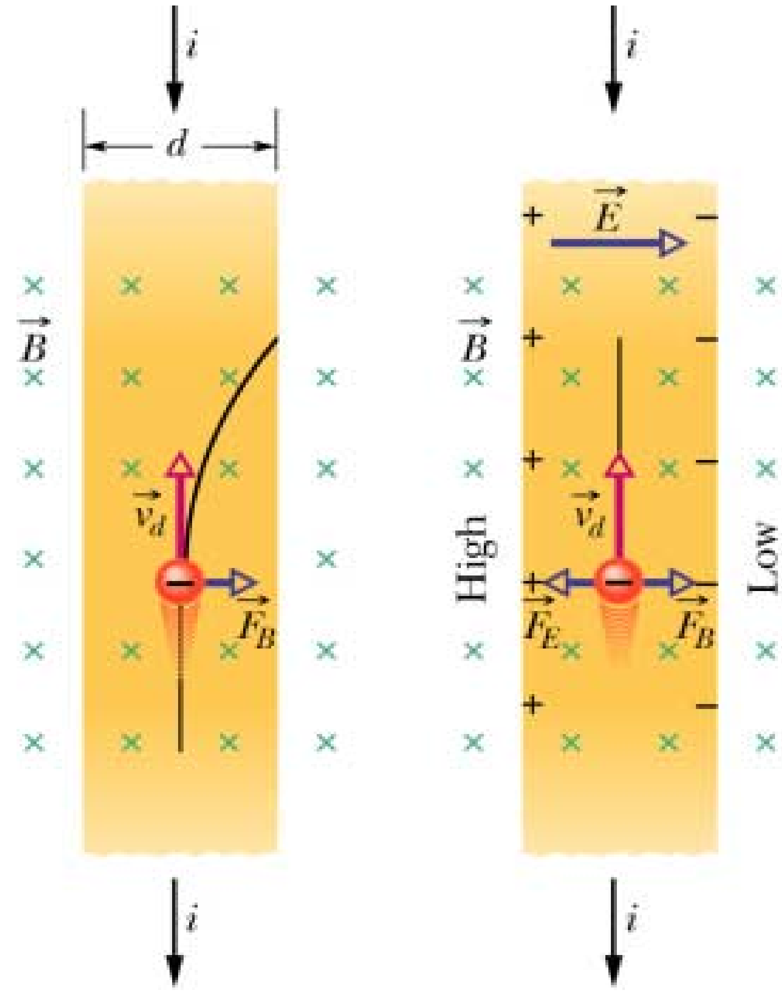


Magnetic Fields (16)

- E field on electron produces a F_E to the left
- Quickly have equilibrium where $F_E = F_B$
- E field gives a V across the strip

$$V = Ed$$

- Left side is at a higher potential



Magnetic Fields (17)

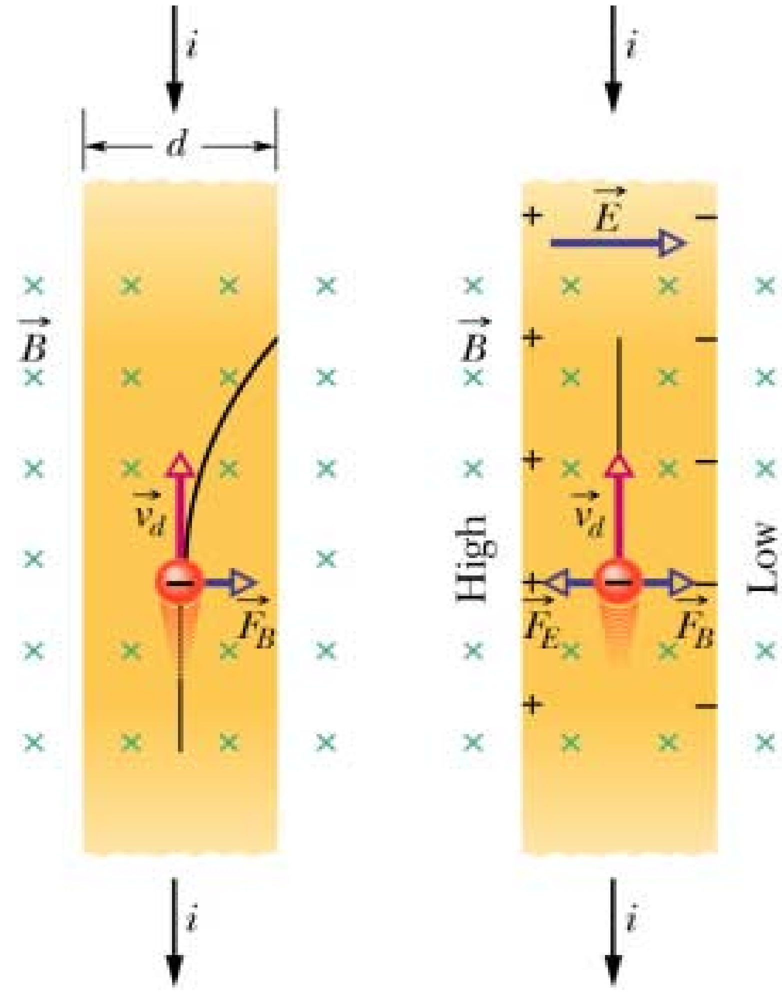
- Can measure the number of charge carriers per unit volume, *n*, at equilibrium

$$F_E = F_B$$

$$F_E = qE \qquad F_B = q\vec{v} \times \vec{B}$$

$$eE = ev_d B \sin(90)$$

$$E = v_d B$$



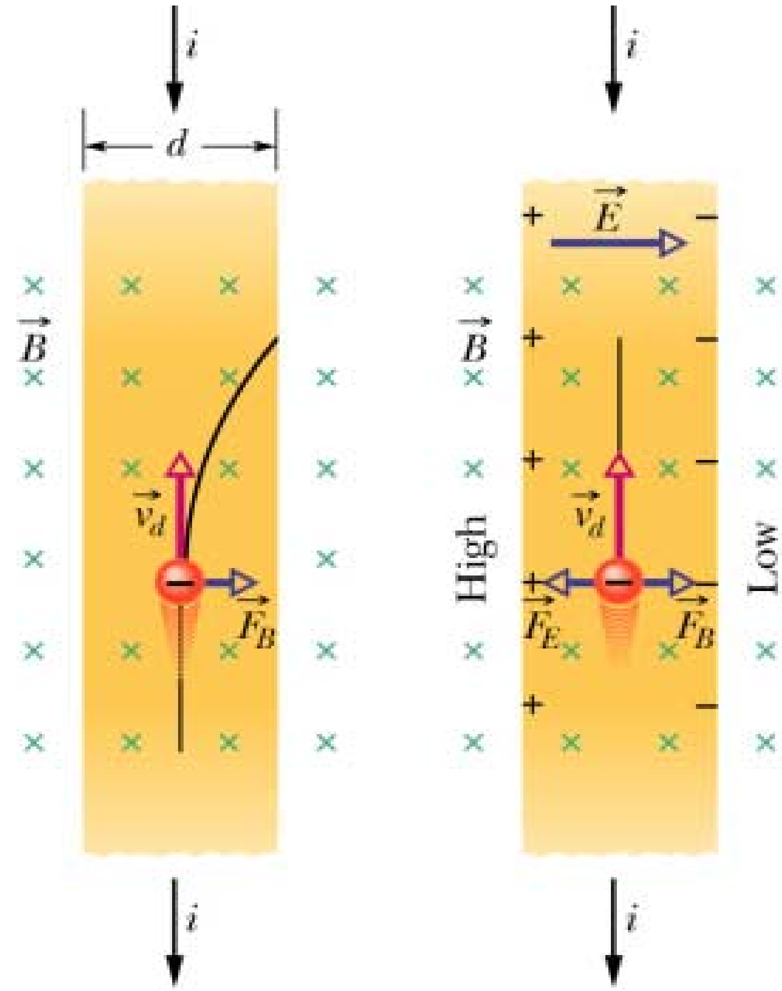
Magnetic Fields (18)

- Remember from Chpt. 27 that drift speed is

$$v_d = \frac{J}{ne} = \frac{i}{neA}$$

$$E = v_d B = \frac{iB}{neA}$$

$$n = \frac{iB}{EeA}$$

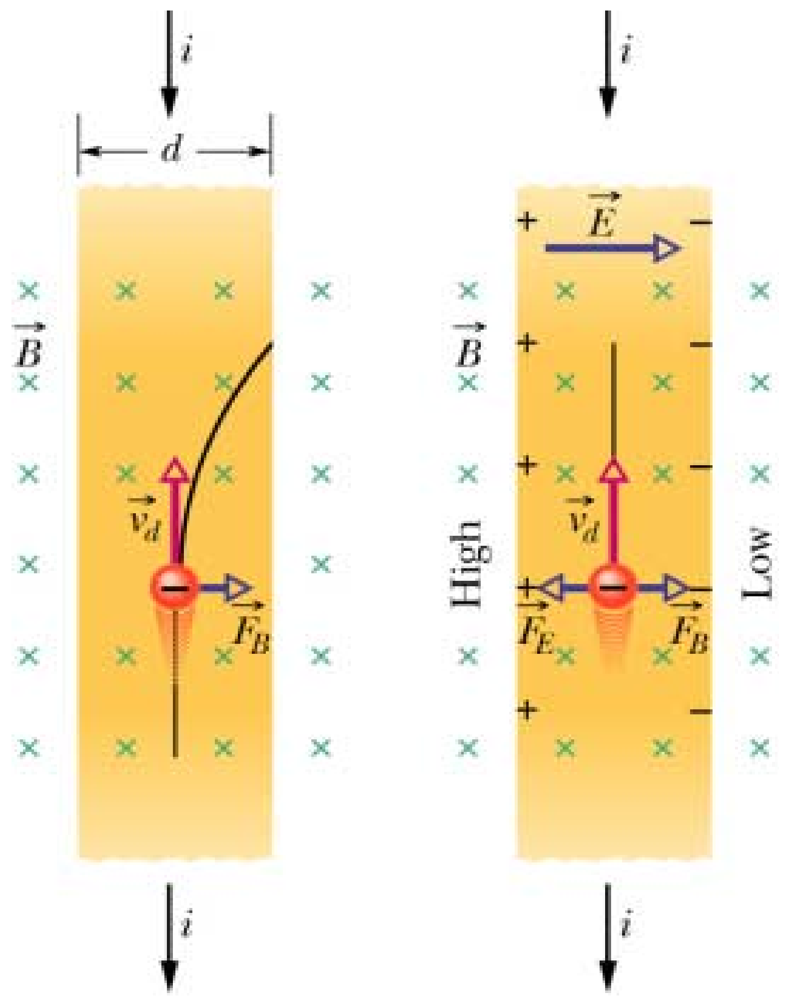


Magnetic Fields (19)

- Replacing *E* by

$$V = Ed$$

$$n = \frac{iB}{EeA} = \frac{iBd}{VeA}$$



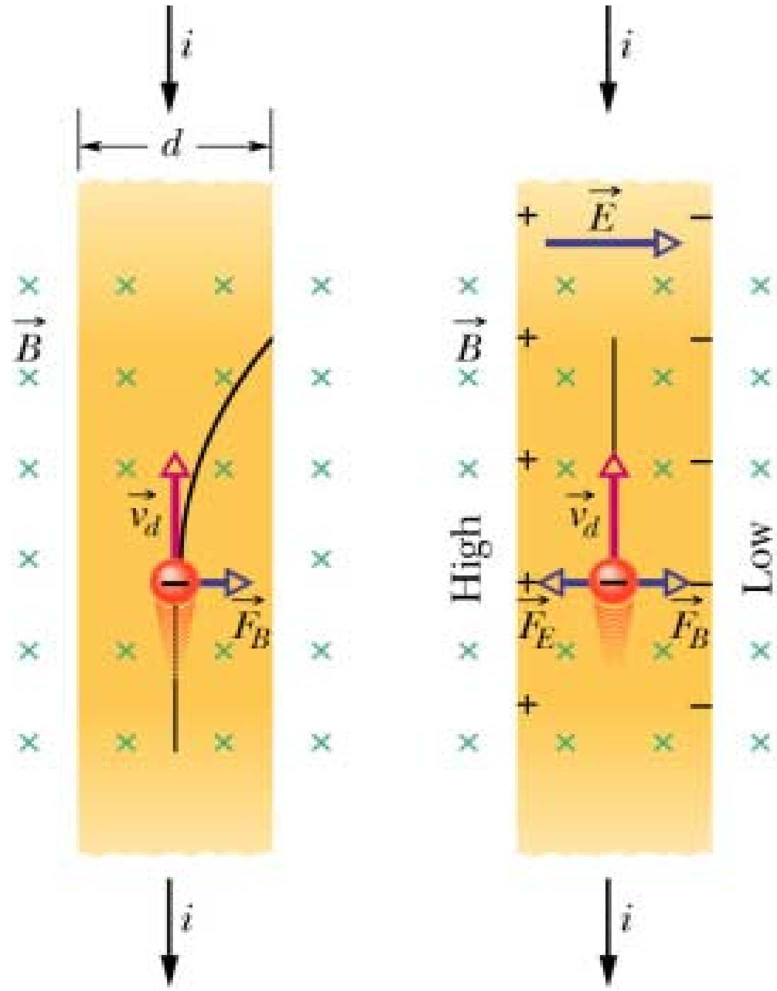
Magnetic Fields (20)

- If *l* is the thickness of the strip

$$l = \frac{A}{d}$$

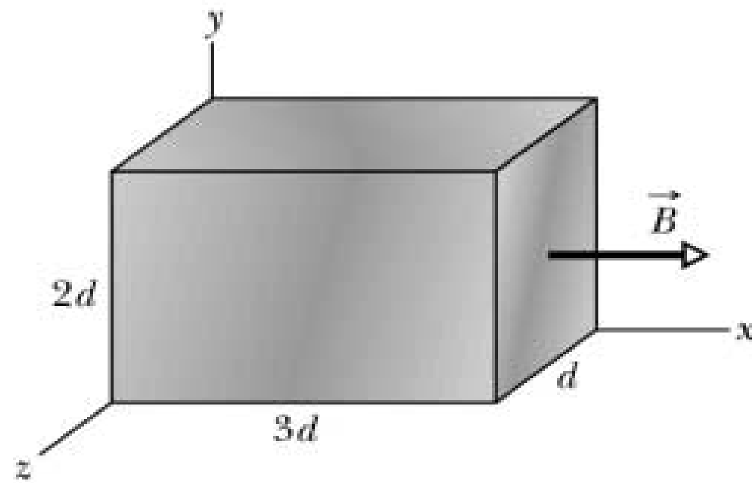
- Finally get

$$n = \frac{iB}{Vle}$$



Magnetic Fields (21)

- Checkpoint #3 – Have 6 choices for velocity, *v* of rectangle in ± x, ±y, and ±z
- A) Rank 6 choices by *V* across solid, greatest first
- First figure out direction of for each *v*



$$F_B = q\vec{v} \times \vec{B}$$

- For ±x, F_B is zero (ϕ=0,180)
- For ±y, F_B is into (out of) page across distance *d*
- For ±z, F_B is moving up (down) page across 2*d*

Magnetic Fields (22)

- A) Rank 6 choices by *V* across solid, greatest first
- $F_E = F_B$ but opposite direction

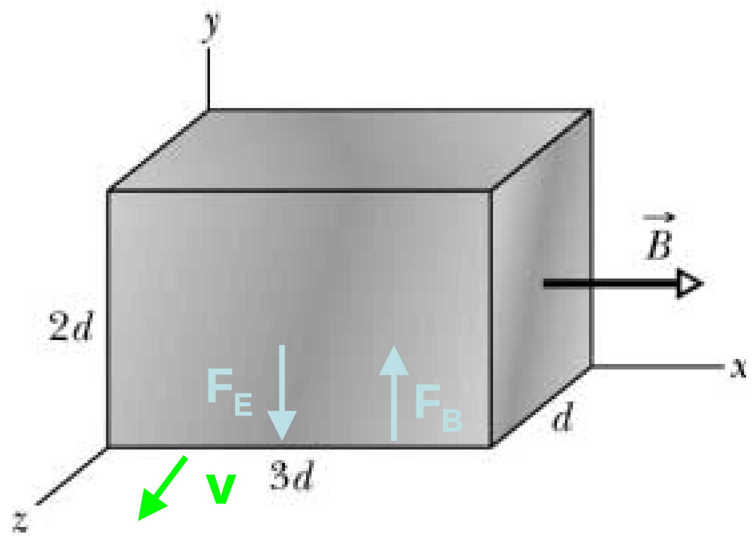
$$E = vB \qquad V = Ed$$

- So

$$V = vBd$$

- Found ±z to be across 2d, ±y across d and ±x to be zero

±z, ±y, ±x



Magnetic Fields (23)

- B) For which direction is the front face at lower *V* ?

- Get *V* across front face if *v* is in y direction
- To get lower *V* at front face F_E must point from back to front so want F_B into page

+y