Magnetism

- So far in this class we have only talked about electricity and the E-field

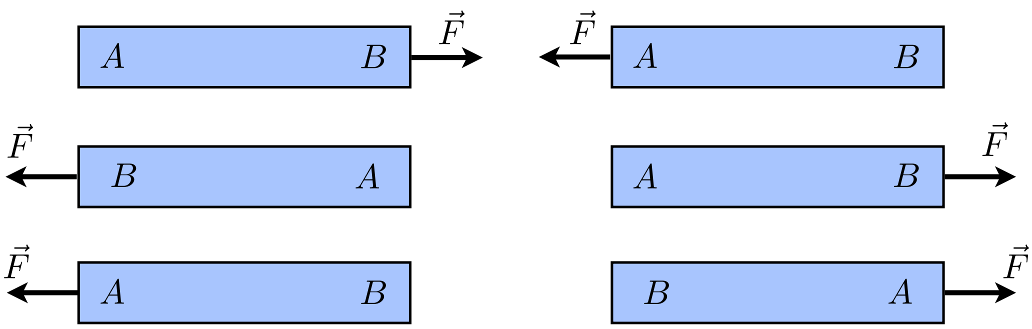
- This class is about electromagnetism, so we now discuss magnetism and the magnetic field.

- Magnetism was known by the Greeks since the 5th century BC.
    - Magnetic rocks of iron-oxide called Magnetite

- 1100AD, Chinese make first compass

- 13th century it is discovered that magnets always have two points of attraction
    - Points of attraction called **Poles**

- It is experimentally confirmed that:



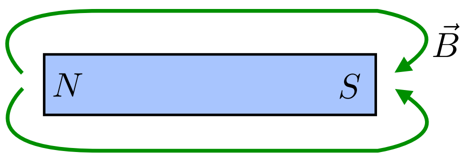
- In electricity we always have two different charges (+) and (-)
  - We can have individual (+) or (-) charges called **monopoles**

- In magnetism, there are always two poles; no A or B alone
  --> there are no magnetic monopoles
  - Magnetics are always **dipoles** (two-poles)

- How do we define the direction of the magnetic field? (B-field)

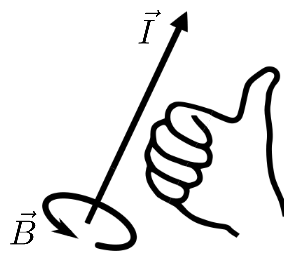
current into the board   current out of the board

- B-field by definition points in the direction of N on compass
- Compass N points toward S of the magnet being measured (i.e Earth)



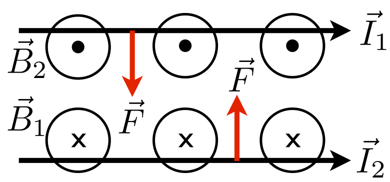
- B-field goes out of N, into S

- With this definition, the B-field follows the **Right Hand Rule (RHR):**
  - Point thumb in direction of current
  - Wrap fingers into circle
  - Direction of fingers gives direction of B-field around wire



- Current in wire causes compass needle to move
  -> current generates force on magnet
  - From action/reaction, magnet should create force on wire with current.

- It is experimentally proven that: $\hat{F} = \hat{I} \times \hat{B}$ (unit vectors)

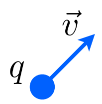


- Use RHR to find B-field direction
- Use RHR to find force direction

- Currents flowing in same direction attract, opposite directions repel.

- How do we define the strength of the B-field?
    - For E-field we had: $\vec{F}_{el} = q\vec{E}$
    - It would be nice to have $\vec{F}_B = q_B\vec{B}$ <u>but there are no magnetic monopoles!</u>

- How do we define the strength of the B-field?



From experiment, force on charge $\vec{F}_B \perp \vec{v}$

Also, $|F_B| \propto \vec{v}$ & $|F_B| \propto q$

- From experiment, we can define **Lorentz Force:**

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

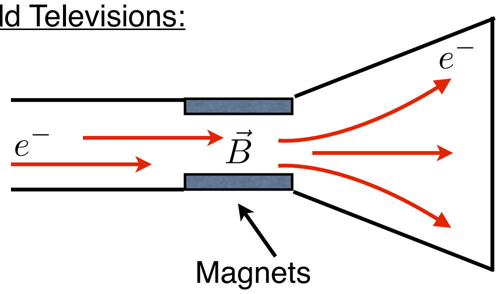
- Force is <u>always</u> perpendicular to v
    - Change direction of v or B, then direction of force changes

- Units of B-field follow from Lorentz force: $[B] = \dfrac{N - \mathrm{sec}}{C - m} \equiv T$ (Tesla)

- 1T is very strong B-field, typically use smaller units called **Gauss**

$$1 \text{ G} = 10^{-4} \text{ T}$$

<u>ex. Old Televisions:</u>



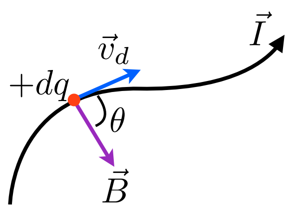
- Electrons are sent toward screen
- Electrons pass through B-field
- Deflected electrons hit screen to produce image

- If we have both E-field and B-field, what is the total force?

$$\vec{F}_{\text{total}} = q\vec{E} + q\vec{v} \times \vec{B}$$

- B-field can never do work on a charge. Why? $\vec{F}_B \perp \vec{v} \rightarrow \int \vec{F}_B \cdot d\vec{r} = 0$

<u>More quantitative :</u>



- If I=0, electrons have huge velocities
    - velocities are in random directions
    - each electron has force, but net force = 0
- If I > 0, then there is small drift velocity
- Although electrons move, we still think of positive charges as the current

- The force on charge +dq at point P is:

$$d\vec{F}_B = dq\vec{v}_d \times \vec{B}$$ ← local magnetic field at P

- but recall that $I = dq/dt$, so can rewrite as: $d\vec{F}_B = Idt\vec{v}_d \times \vec{B}$

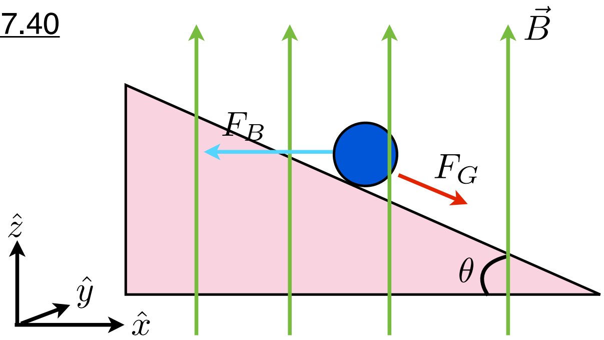
- The drift velocity time dt is just the distance the charges travel in time dt: $\vec{v}_d dt = \vec{dl}$

- The force expressed in terms of current and distance along wire is

$$d\vec{F}_B = I\vec{dl} \times \vec{B} = IdlB\sin\theta$$

- This is local force, total force requires integral over the length of wire: $\int_{\text{wire}} \vec{F}_B$

<u>ex. 27.40</u>



A conducting rod of length L and mass m slides down an inclined plane with angle theta, in a B-field pointed in the +z-direction. What is the direction and magnitude of a current I needed to keep the rod at its current position?

First, find force on rod from gravity: $F_G = mg\sin\theta$

Use RHR to find direction of force:

If current into board, $\hat{I} \times \hat{B} = \hat{x}$, this adds to F_G ,not correct

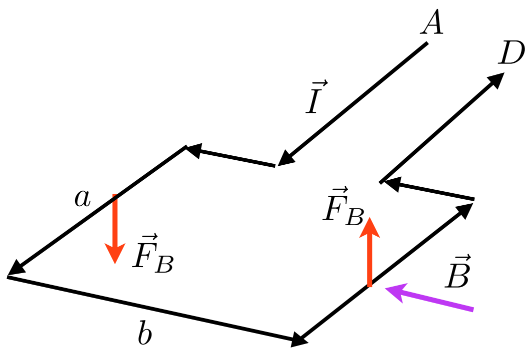
Current must be out of the board $\boxed{\text{(-y-direction)}}$

Since current and B-field are perpendicular: $F_B = ILB$

Want only the component along incline: $F_{B\text{incl}} = ILB\cos\theta$

Setting $F_{B\text{incl}} = F_G$: $\boxed{I = \frac{mg}{LB}\tan\theta}$

ex. current carrying loop



- What is the force on each loop segment?

- recall $\hat{F} = \hat{I} \times \hat{B}$

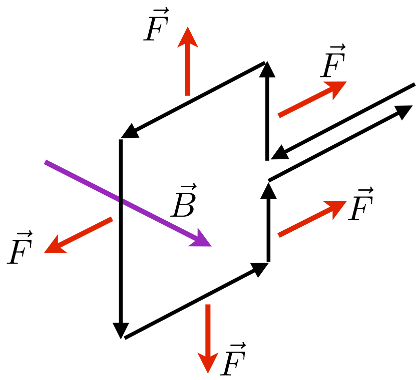
- only 2 segments have a force

$$F_B = IaB$$

- Force creates a torque on the loop:

$$\tau = Fd = IBa\frac{b}{2} + IBa\frac{b}{2} = IBab$$

- Torque changes direction when current goes opposite direction



- What is the force on each loop segment?

- Current is always perpendicular to B-field

- Force on one-side of loop is cancelled by opposite side force.

- No torque on loop.