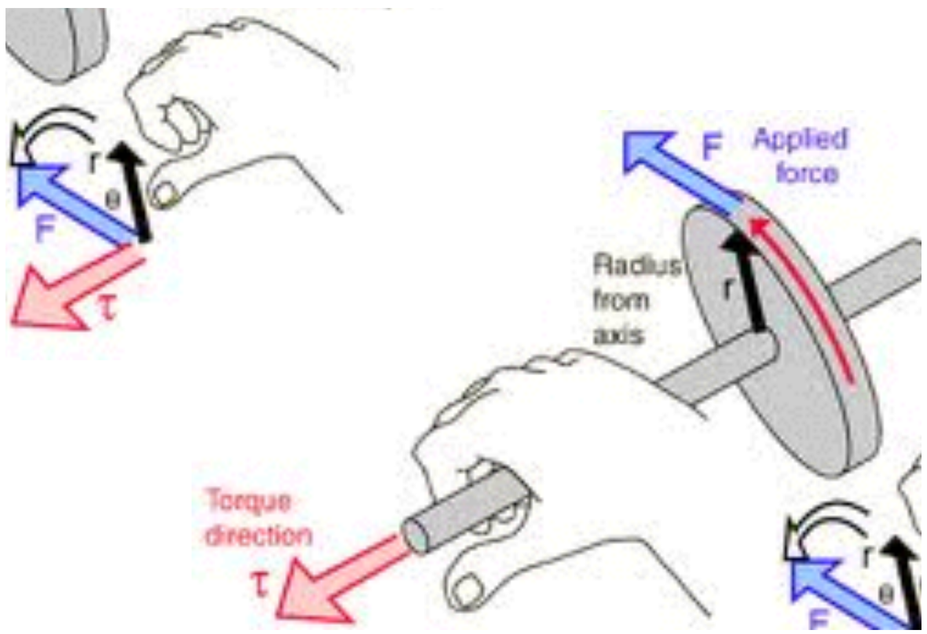
Ampère Law

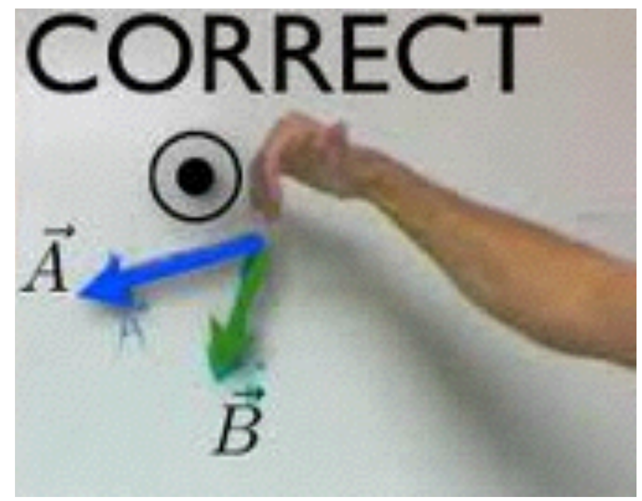
Lecture 20

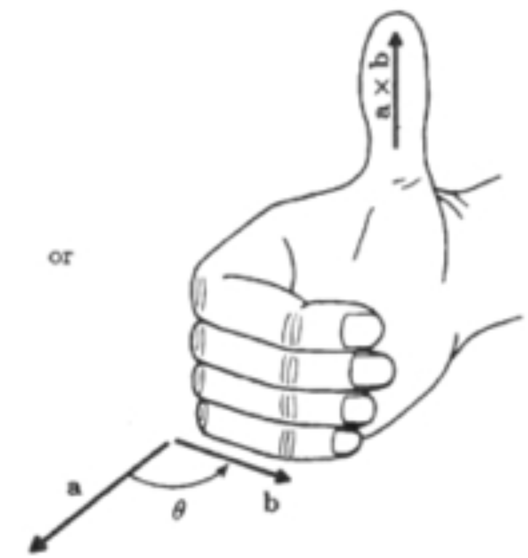
Announcements

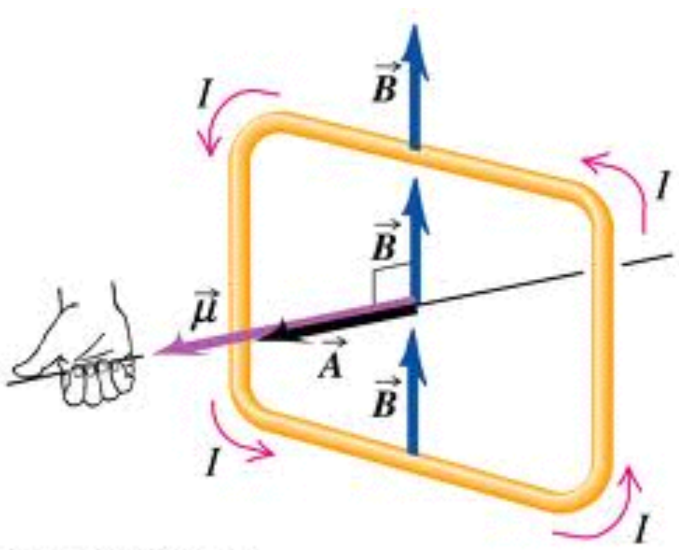
- Reading for Wednesday: 28-1 to 28-3

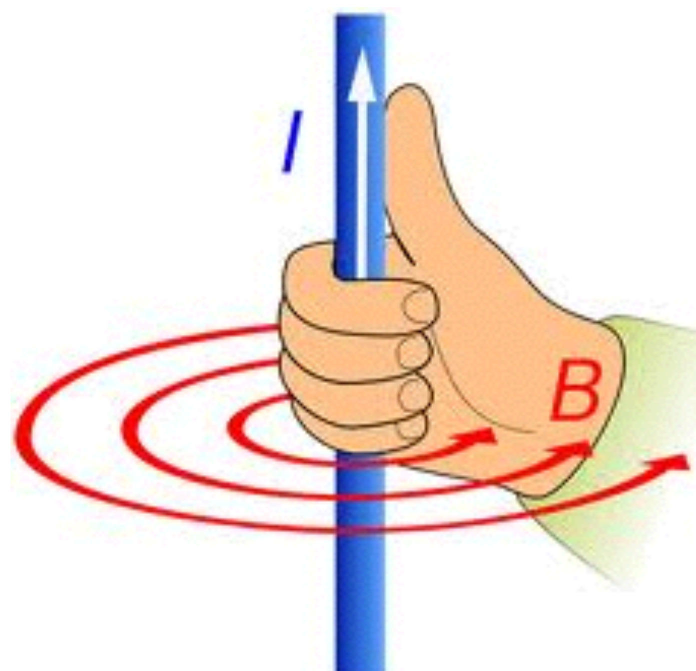
Review: Right Hand Rules

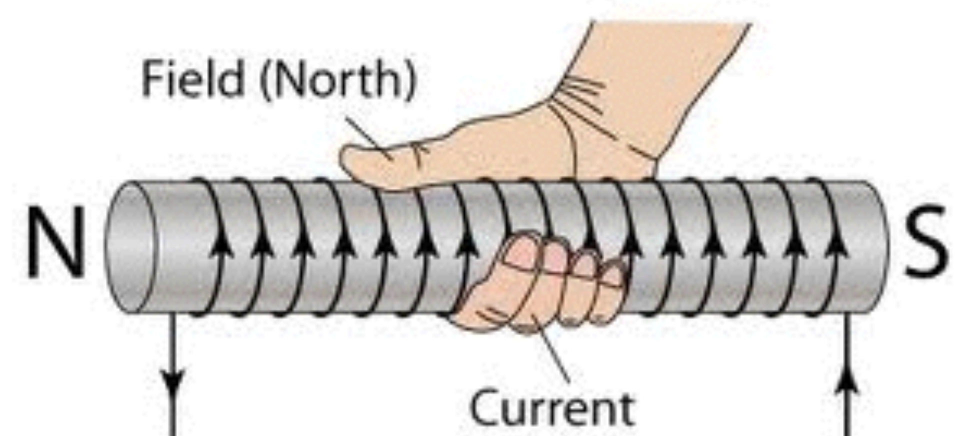












Aside…

- Electric Constant (**Permittivity** of free space):

$$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C}^2/\mathrm{N} \cdot \mathrm{m}^2$$

- Magnetic Constant (**Permeability** of free space):

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T} \cdot \mathrm{m}/\mathrm{A}$$

Just for fun clicker…

Railgun

From Wikipedia, the free encyclopedia

For railroad artillery, see Railway gun. For other uses, see Rail-gun (disambiguation).
See also: Coilgun

A **railgun** is an electrically powered electromagnetic projectile launcher based on similar principles to the homopolar motor. A railgun comprises a pair of parallel conducting rails, along which a sliding armature is accelerated by the electromagnetic effects of a current that flows down one rail, into the armature and then back along the other rail.[2]

Railguns are being researched as a weapon with a projectile that would not use explosives nor propellant, but rather rely on electromagnetic forces to achieve a very high kinetic energy, somewhat similar to a kinetic energy penetrator. While current kinetic energy penetrators such as an armour-piercing fin-stabilized discarding-sabot can achieve a muzzle velocity on the order of Mach 5, railguns can potentially exceed Mach 10, and thus far exceed conventionally delivered munitions in range and destructive force, with the absence of explosives to store and handle as an additional advantage. Railguns have long existed as experimental technology but the mass, size and cost of the required power supplies have prevented railguns from becoming practical military weapons. However, in recent years, significant efforts have been made towards their development as feasible military technology. For example, in the late 2000s, the U.S. Navy tested a railgun that accelerates a 3.2 kg (7 pound) projectile to hypersonic velocities of approximately 2.4 kilometres per gave the project the Latin motto "Velocitas Eradico", Latin for "I, [who am] speed, eradicate".

In addition to military applications, NASA has proposed to use a railgun from a high-altitude aircraft to fire a small forces involved would necessarily restrict the usage to only the sturdiest of payloads.

Review: Fundamental law(s) of Electrostatics

- **Coulomb Law**: (Solution to DE) E field generated by charge

$$\vec{E} = \frac{kq}{r^2}\hat{r} \qquad\qquad d\vec{E} = \frac{dq}{4\pi\epsilon_0}\frac{\hat{r}}{r^2}$$

or

Gauss Law: (DE) Relationship between charge of E field

Integral Equation:

$$\oint_{\mathcal{M}} d^2A\ \hat{n}\cdot\vec{E} = Q_{\rm inside}/\epsilon_0$$

Differential Equation (DE):

$$\vec{\nabla}\cdot\vec{E} = \rho/\epsilon_0$$

Review: Fundamental law(s) of B field generation

Biot-Savart Law: (Solution to DE) B generated by current:

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{\ell} \times \hat{r}}{r^2}$$

or

Ampère Law: (DE) Relationship between current and B field

Integral Equation:

$$\oint d\vec{\ell} \cdot \vec{B} = \mu_0 \, I_{\text{inside}}$$

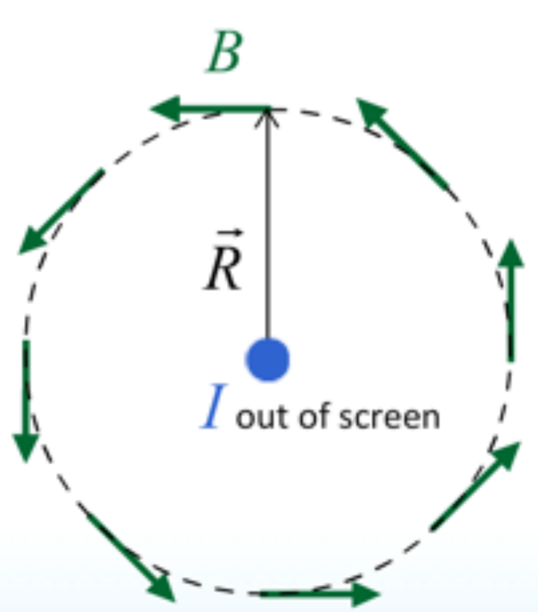
Differential Equation (DE):

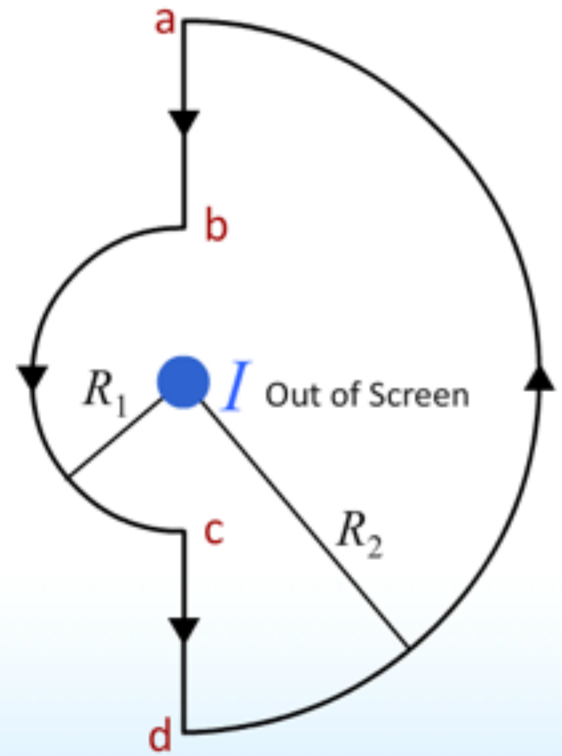
$$\vec{\nabla} \times \vec{B} = \mu_0 \, \vec{j}$$

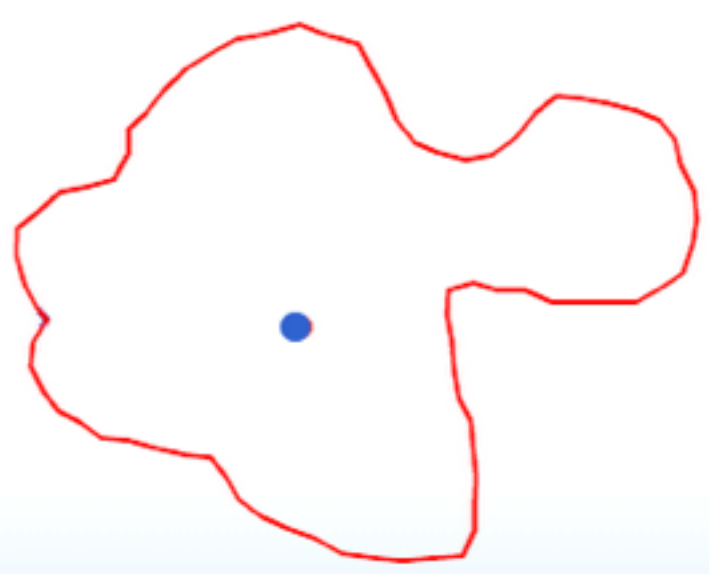
Ampère Law

- New physical law (same physics as Biot-Savart)
- Line integral over a closed loop:

$$\oint \vec{d\ell} \cdot \vec{B} = \mu_0 \, I_{\text{inside}}$$

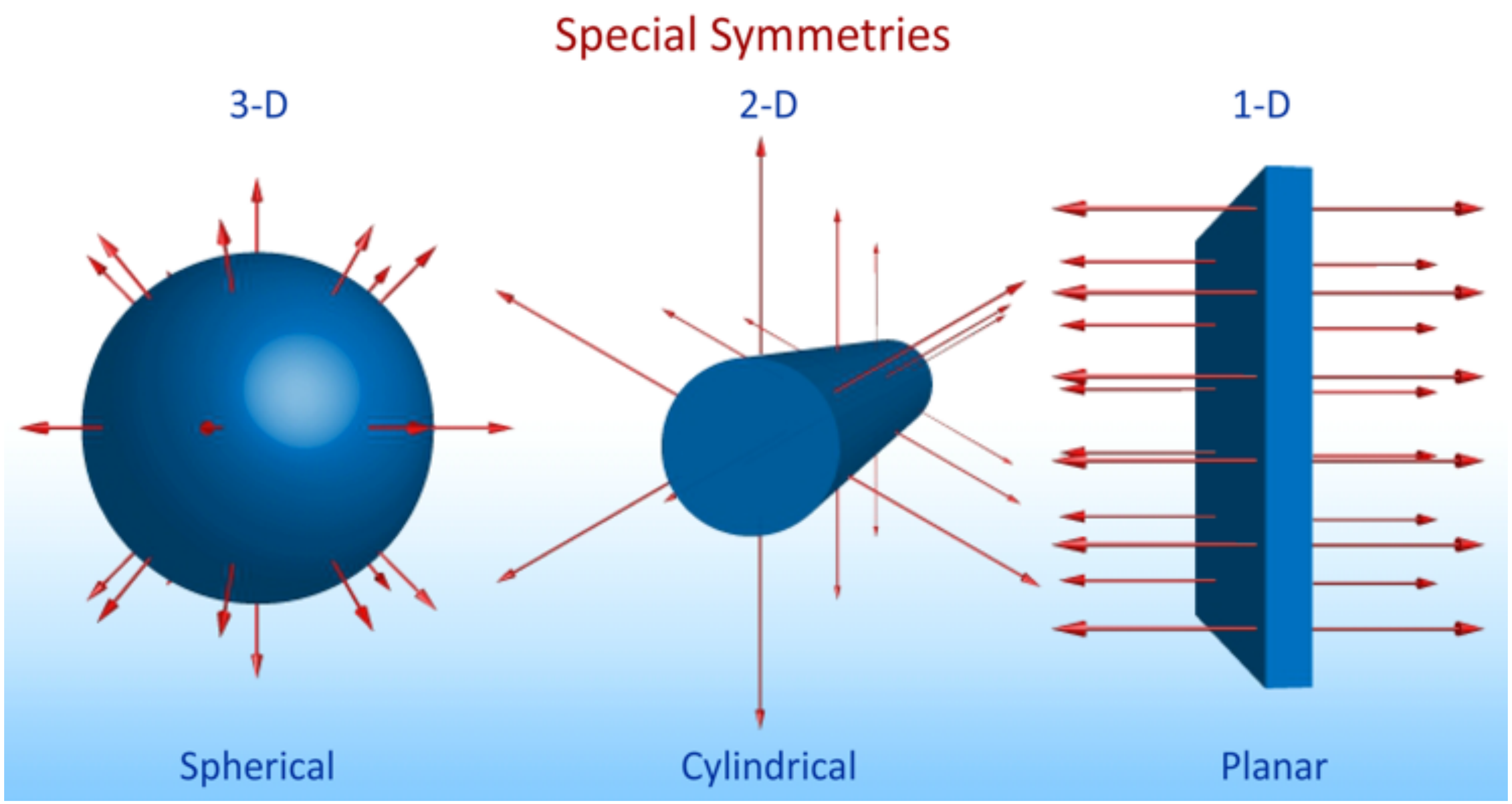






Review: Gauss Law and computing E

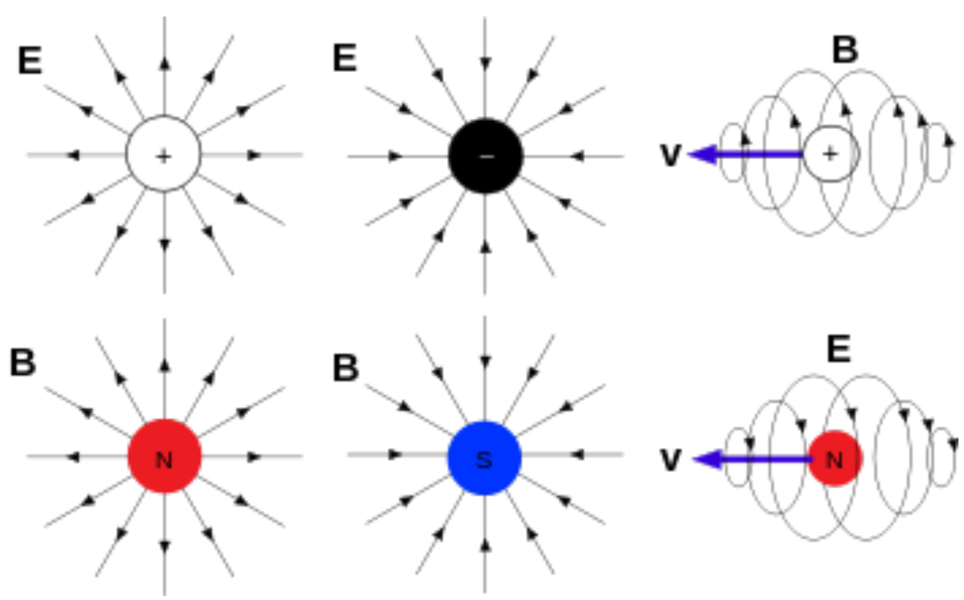
$$\oint d^2A \ \hat{n} \cdot \vec{E} = \frac{Q_{\rm enclosed}}{\epsilon_0}$$



By the way: Gauss Law for B

- No magnetic monopoles (except on 2/14)

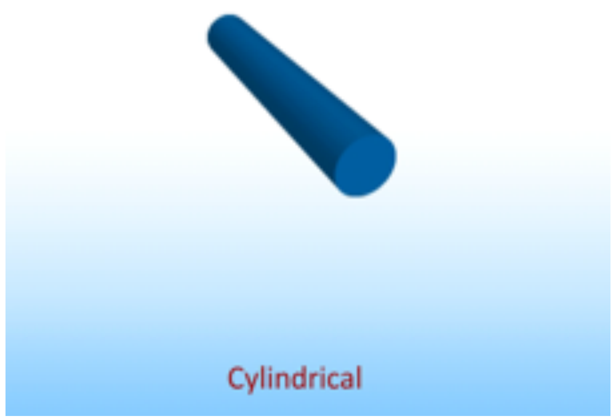
$$\oint d^2A \; \hat{n} \cdot \vec{B} = \frac{Q^M_{\mathrm{enclosed}}}{\epsilon_0^M} = 0$$

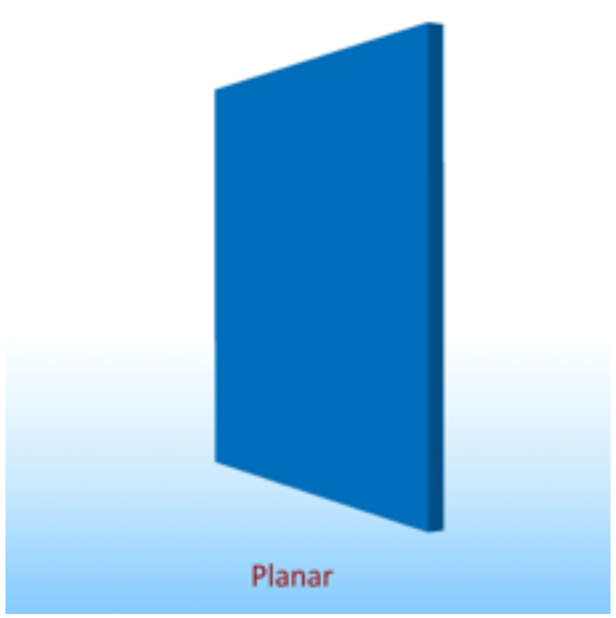


New: Ampère Law and computing B

$$\oint \vec{d\ell} \cdot \vec{B} = \mu_0 \, I_{\text{inside}}$$

1. Identify **symmetry** (only 2 options)
2. Draw B field/field lines
3. Choose a Ampère Loop
4. Compute B

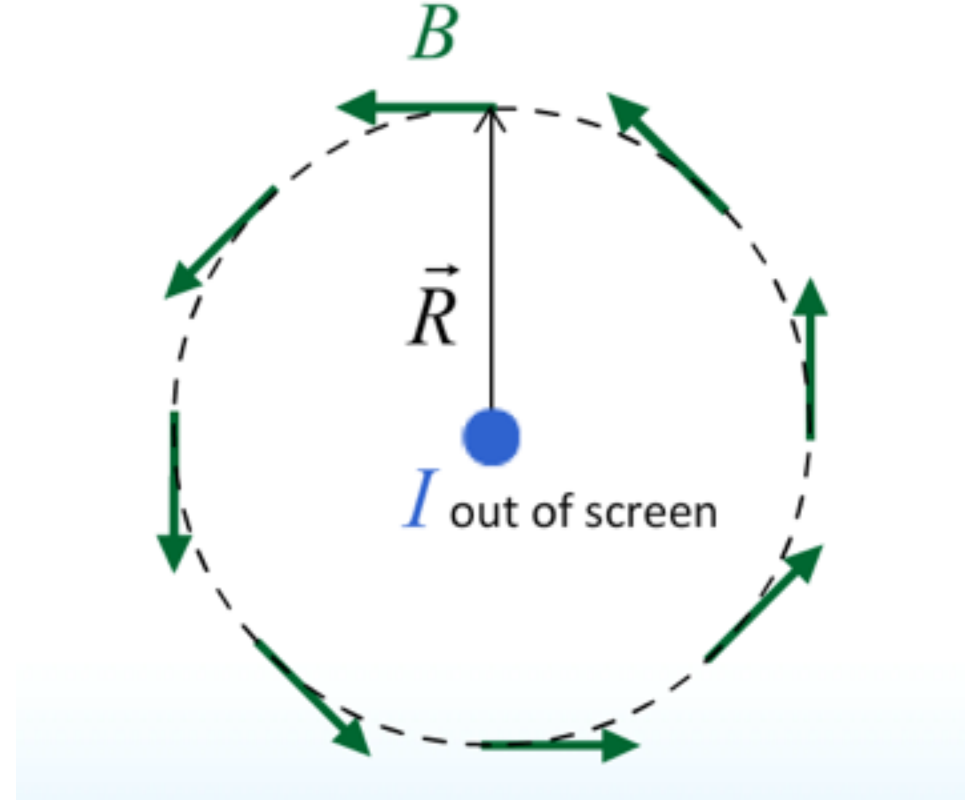




Ampère Law: Infinite Wire (1)

(Overhead)

1. Identify **symmetry**
2. Draw B field/field lines
3. Choose a Ampère Loop
4. Compute B

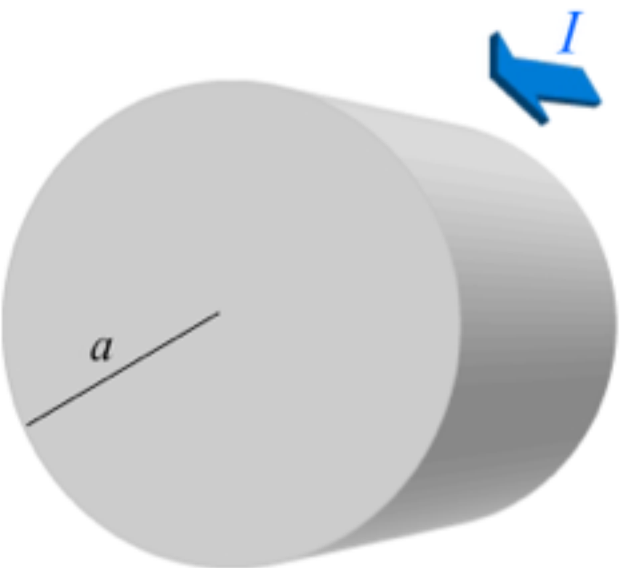


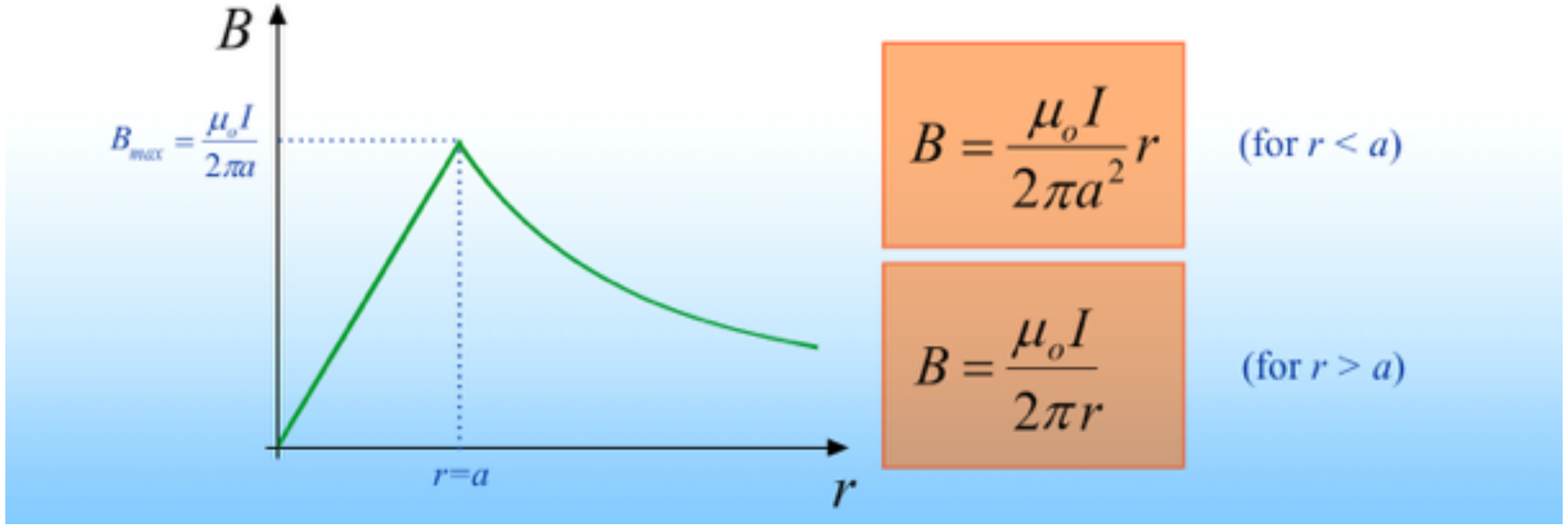
$$B = \frac{\mu_0 I}{2\pi R}$$

Ampère Law: Infinite Wire (2)

(Overhead)

- Why is n const?
- Why must wire be infinite?



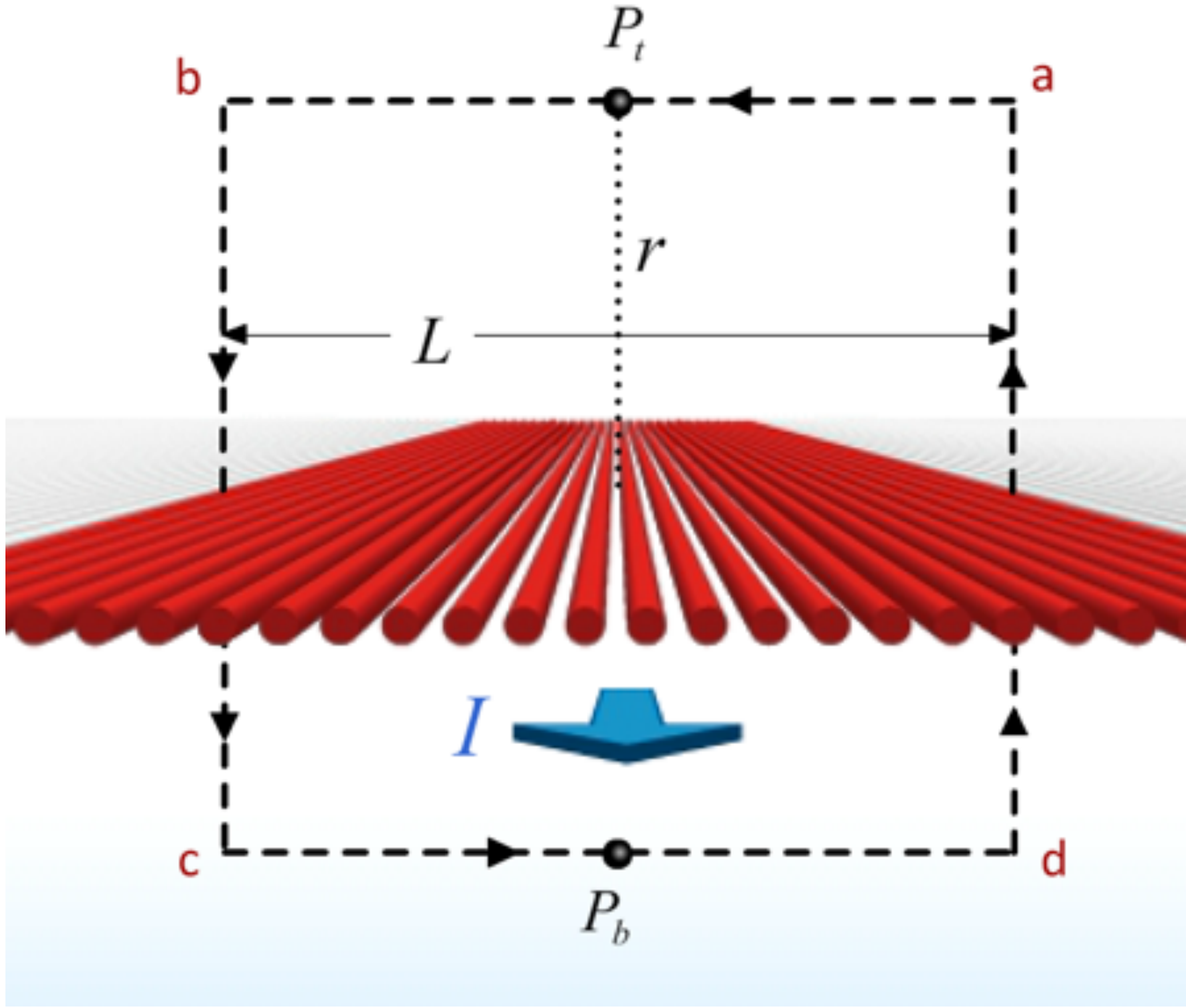


Clicker…

Ampère Law: Infinite Sheet

(Overhead)

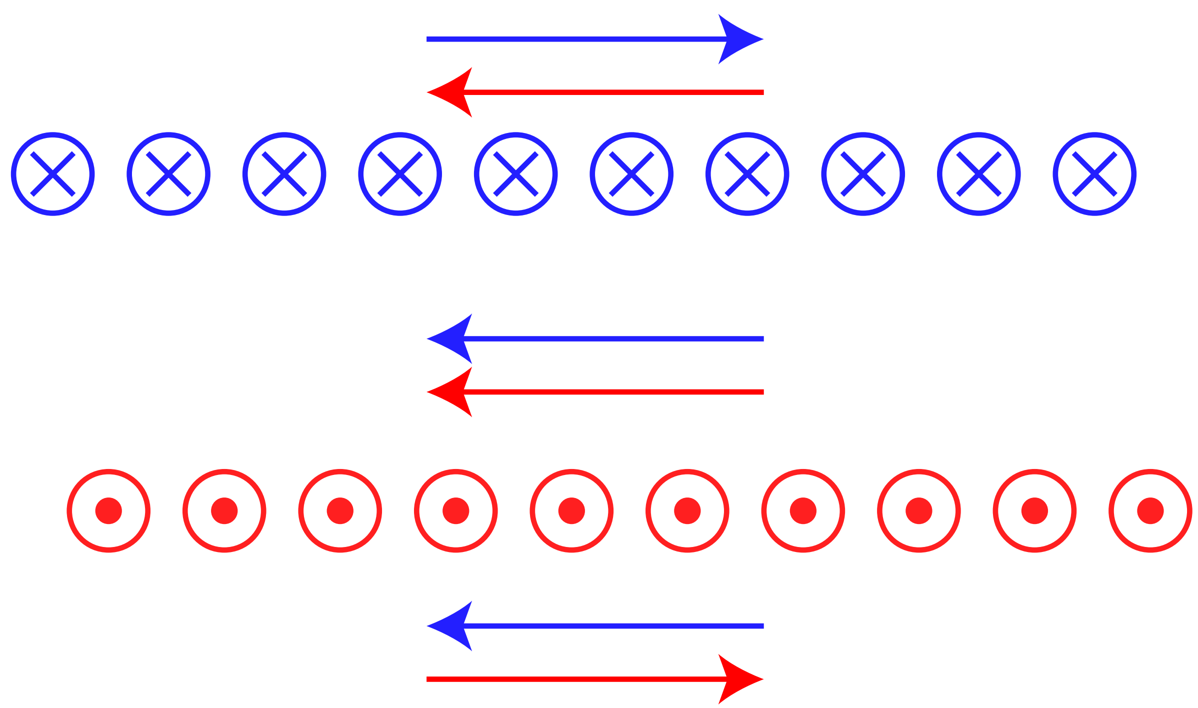
1. Identify **symmetry**
2. Draw B field/field lines
3. Choose a Ampère Loop
4. Compute B

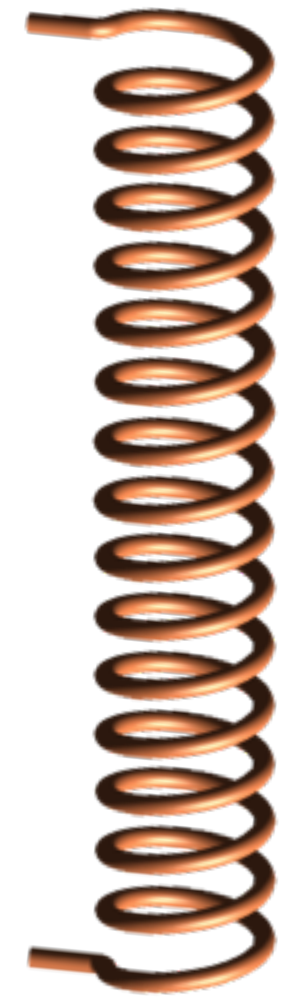


$$B = \frac{1}{2}\mu_0 n I$$

B field for an ∞ solenoid

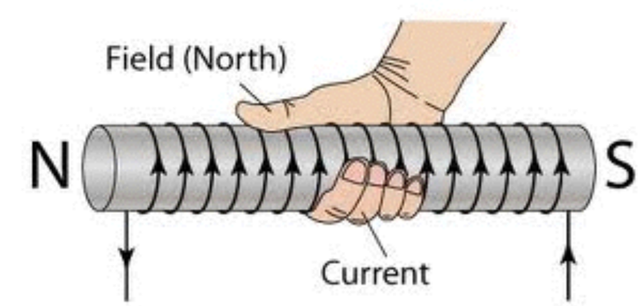
- Intuitive picture: ~ 2 infinite sheets





- Field is ~ zero outside

$$B = \mu_0 n I$$



Electrodynamics & the Maxwell Equations

- Gauss Law (E): $$\oint_{\mathcal{M}} d^2A \; \hat{n} \cdot \vec{E} = Q_{\rm inside}/\epsilon_0$$
- Gauss Law (B): $$\oint_{\mathcal{M}} d^2A \; \hat{n} \cdot \vec{B} = 0$$
- Ampère Law: $$\oint_{\partial\mathcal{M}} \vec{d\ell} \cdot \vec{B} = \mu_0 I + \mu_0 \epsilon_0 \frac{d}{dt} \int_{\mathcal{M}} d^2A \, \hat{n} \cdot \vec{E}$$
- Faraday Law: $$\oint_{\partial\mathcal{M}} \vec{d\ell} \cdot \vec{E} = -\frac{d}{dt} \int_{\mathcal{M}} d^2A \, \hat{n} \cdot \vec{B}$$