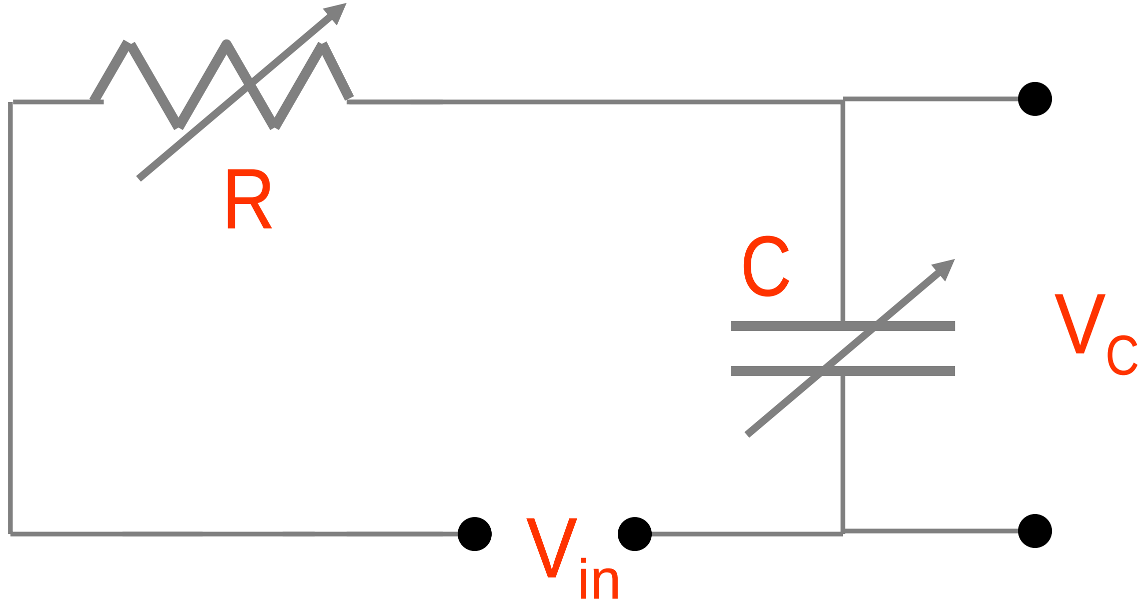
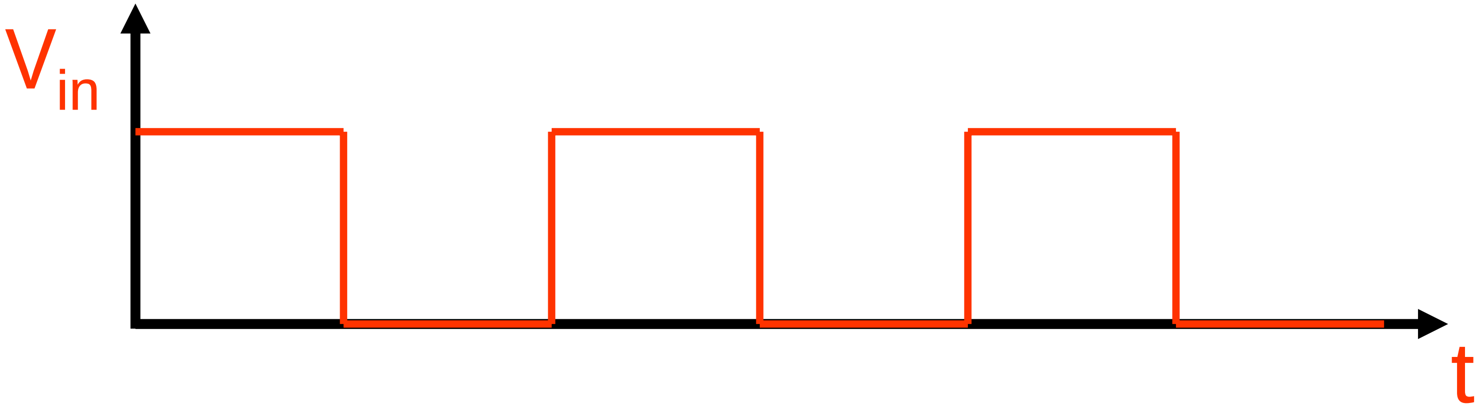
Electricity and Magnetism

- Reminder
  - RC circuits
  - Electric Breakdown Experiment
- Today
  - Magnetism

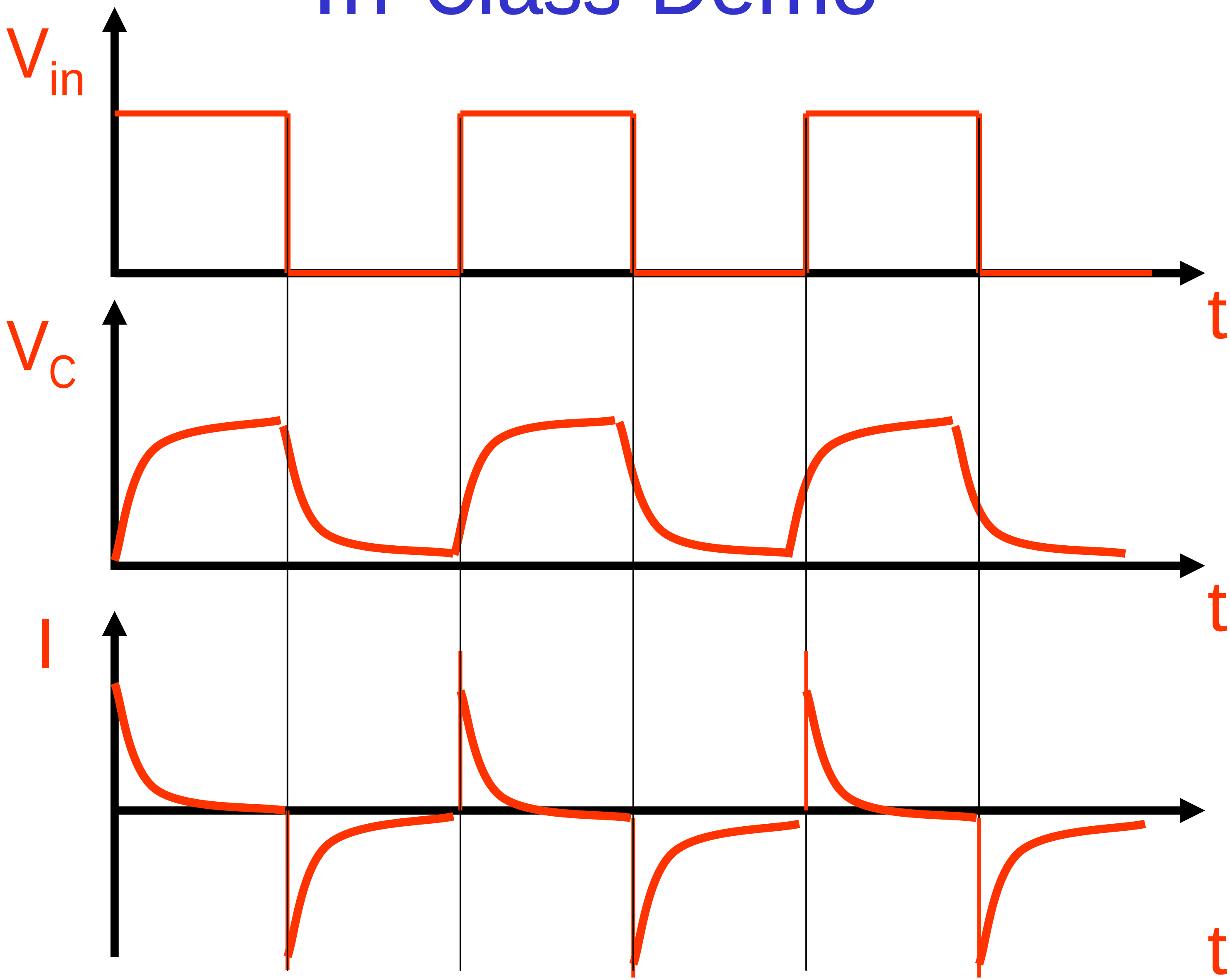
RC Circuits

Variable time constant $\tau = RC$

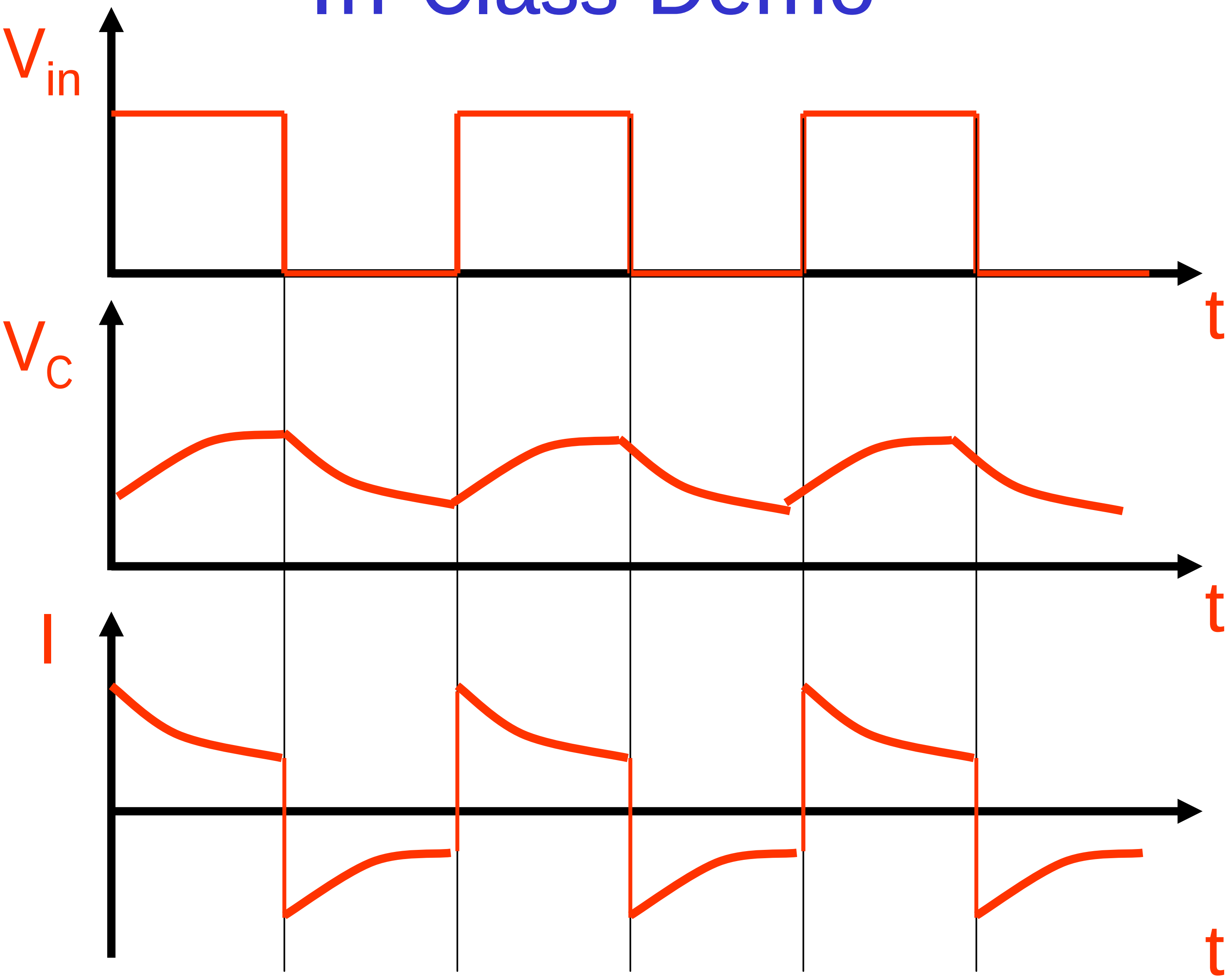




In-Class Demo



In-Class Demo



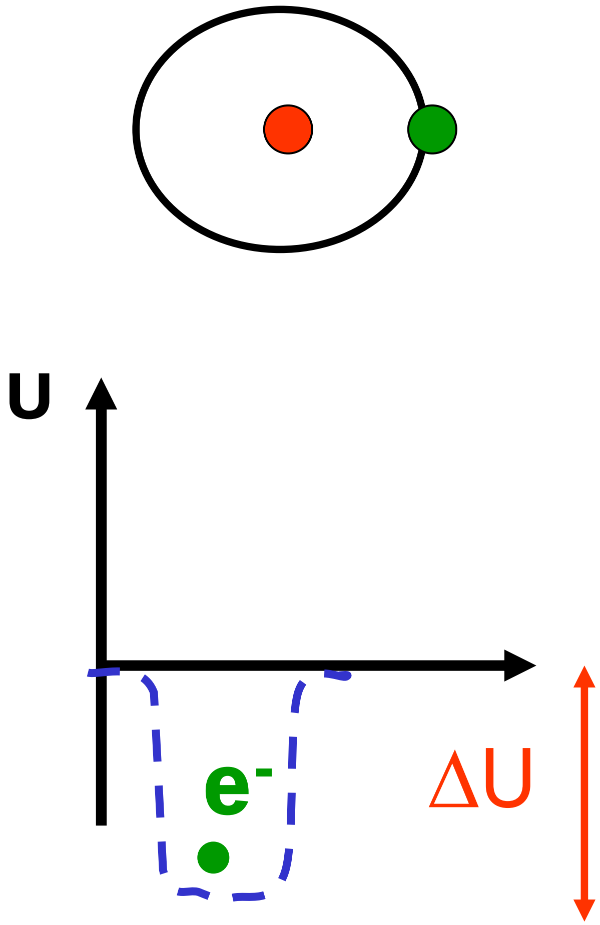
In-Class Demo

- Changes in R or C change τ
- Large τ smoothes out signals
- Sharp edges/rapid changes get removed
  - high frequencies are suppressed
- RC circuits are low-pass filters

Experiment EB

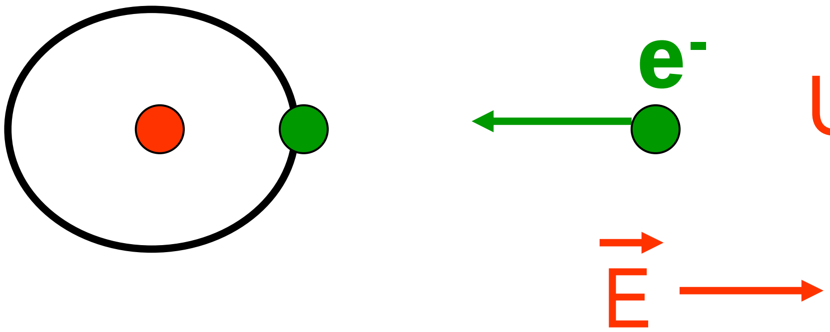
- Electrical Breakdown
  - You have seen many examples
    - Lightning!
    - Sparks (e.g. Faraday Cage Demo!)
    - Fluorescent tubes
  - Study in more detail
  - Reminder: Ionization

Ionization

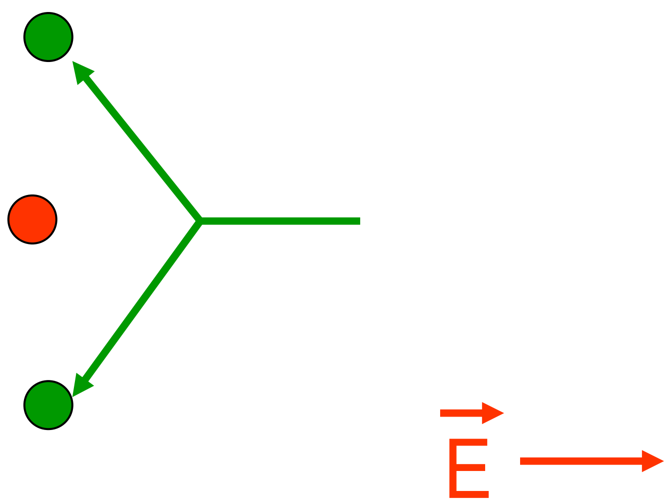


- Electrons and nucleus bound together
- Electrons stuck in potential well of nucleus
- Need energy ΔU to jump out of well
- How to provide this energy?

Impact Ionization



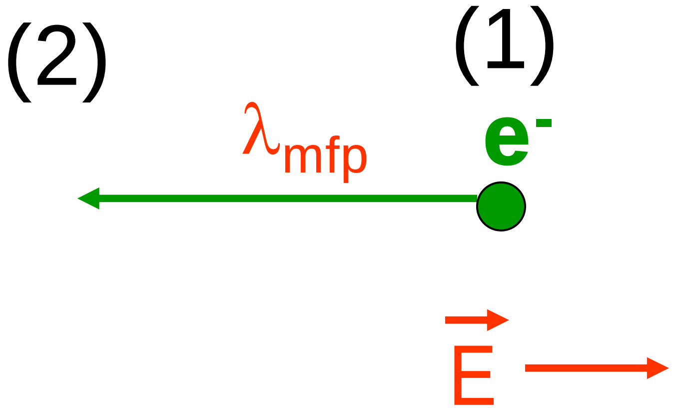
$U_{kin} > \Delta U$



- Define $V_{ion} = \Delta U/q$
- Ionization potential

- One e^- in, two e^- out
- Avalanche?

Impact Ionization



λ_{mfp} : Mean Free Path

- To get avalanche we need:

ΔU_{kin} between collisions (1) and (2) $> V_{ion} * e$

- Acceleration in uniform Field

$\Delta U_{kin} = V_2 - V_1 = e\, E\, d_{12}$

- Avalanche condition then

$E > V_{ion} / \lambda_{mfp}$

Impact Ionization

How big is Mean Free Path?

(i) If Density n is big -> λ_{mfp} small

(ii) If size σ of molecules is big -> λ_{mfp} small

Effective cross-section

$$\lambda_{mfp} = 1/(n\,\sigma)$$

Impact Ionization

Avalanche condition $E > V_{ion} / \lambda_{mfp} = V_{ion}\, n\, \sigma$

Experiment EB: Relate E, V_{ion}, σ

Example: Air

$n \sim 6\times10^{23}/22.4\ 10^{-3}\ m^3 = 3 \times 10^{25}\ m^{-3}$

$\sigma \sim \pi r^2 \sim 3 \times (10^{-10} m)^2 = 3 \times 10^{-20}\ m^2$

$V_{ion} \sim 10\ V$

Need $E > 3 \times 10^{25}\ m^{-3} \times 3 \times 10^{-20}\ m^2 \times 10\ V \sim 10^7\ V/m$

For $V \sim 800\ V$: $V = E\, d \rightarrow d = 800/10^7\ m \sim 0.1\ mm$

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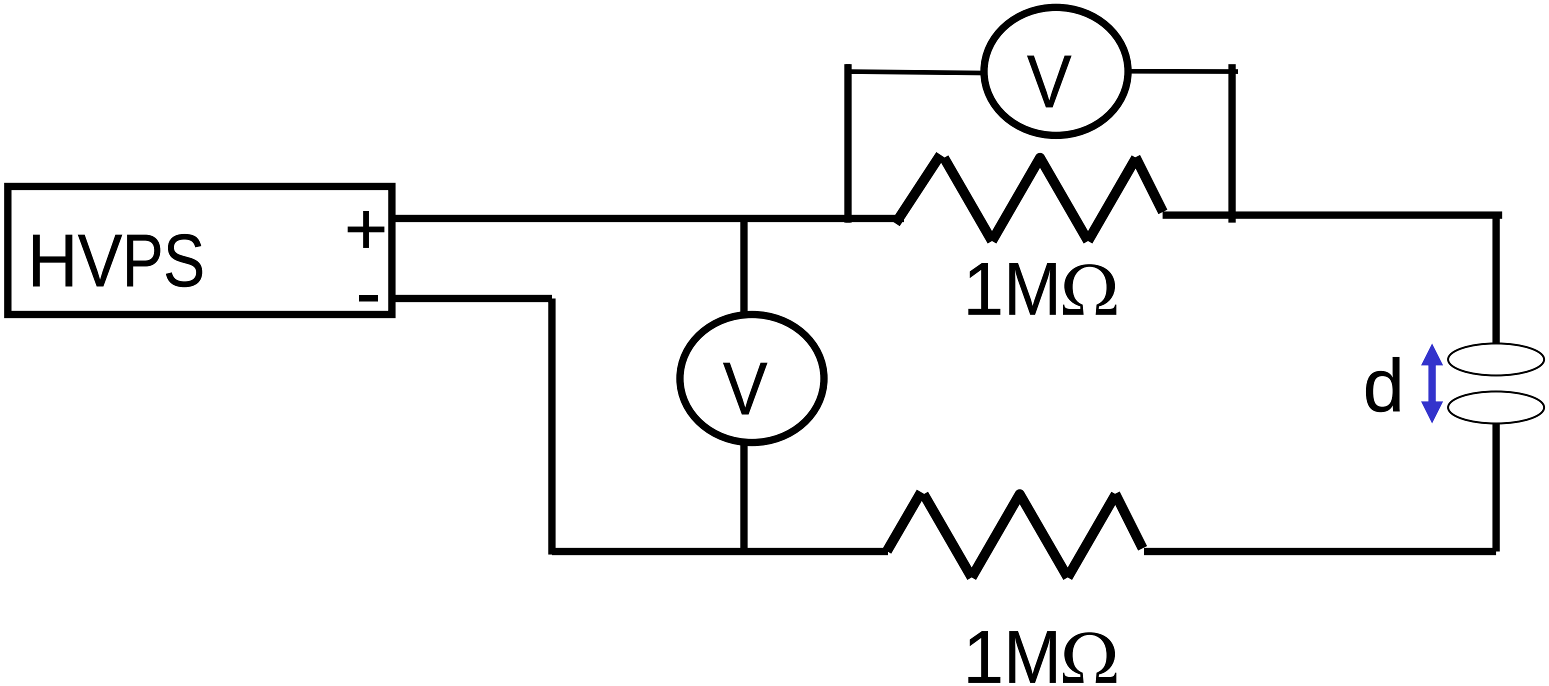
Experiment EB

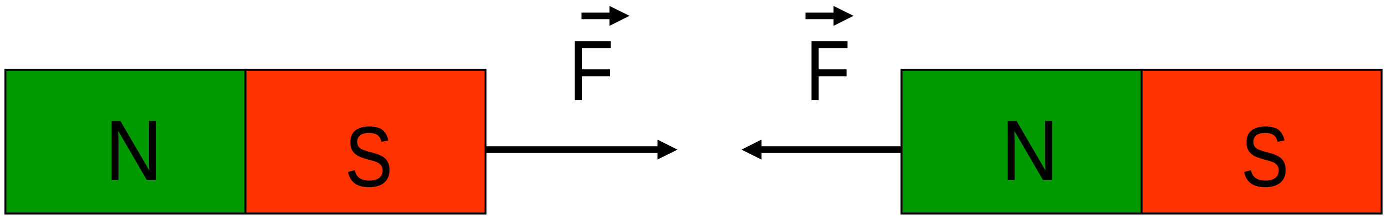


Magnetism

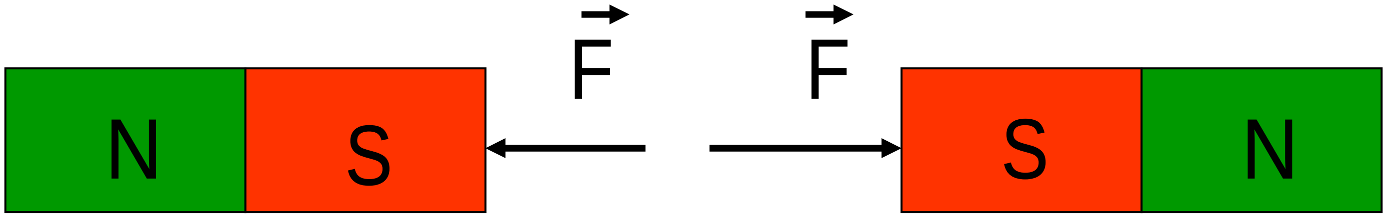
- Magnets: Materials with ‘strange’ properties
- Magnets have been known for thousands of years
- It took until end of 19^{th} century to understand the theory of Magnetism

Magnetic Force

- New Force between Magnets
- Unlike Poles attract

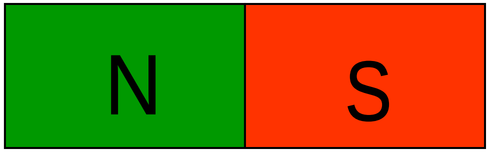


- Like Poles repel



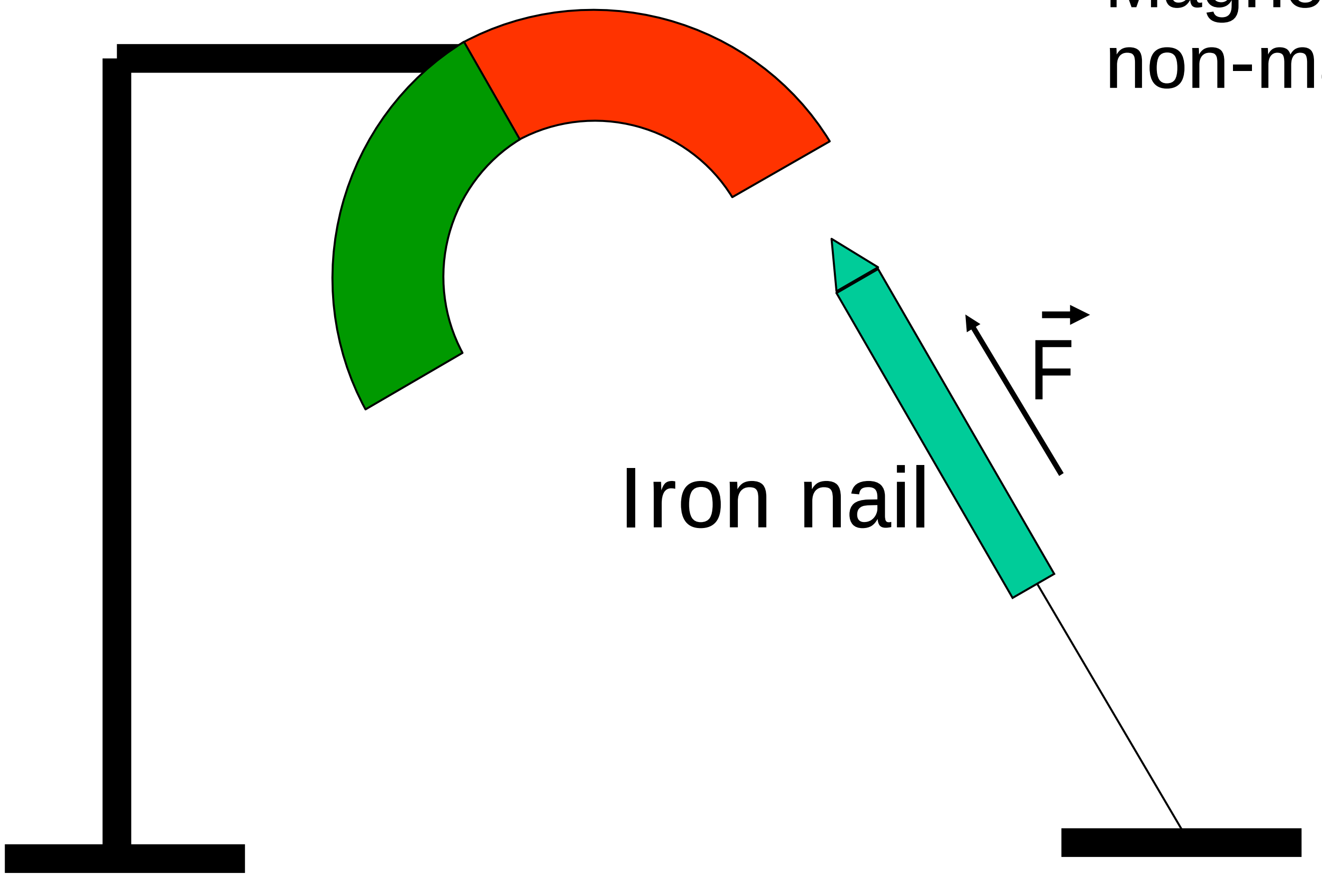
Magnets

- Permanent Magnets



- Two poles (called ‘north’ and ‘south’)
- Let’s look at some properties

Magnetic Force

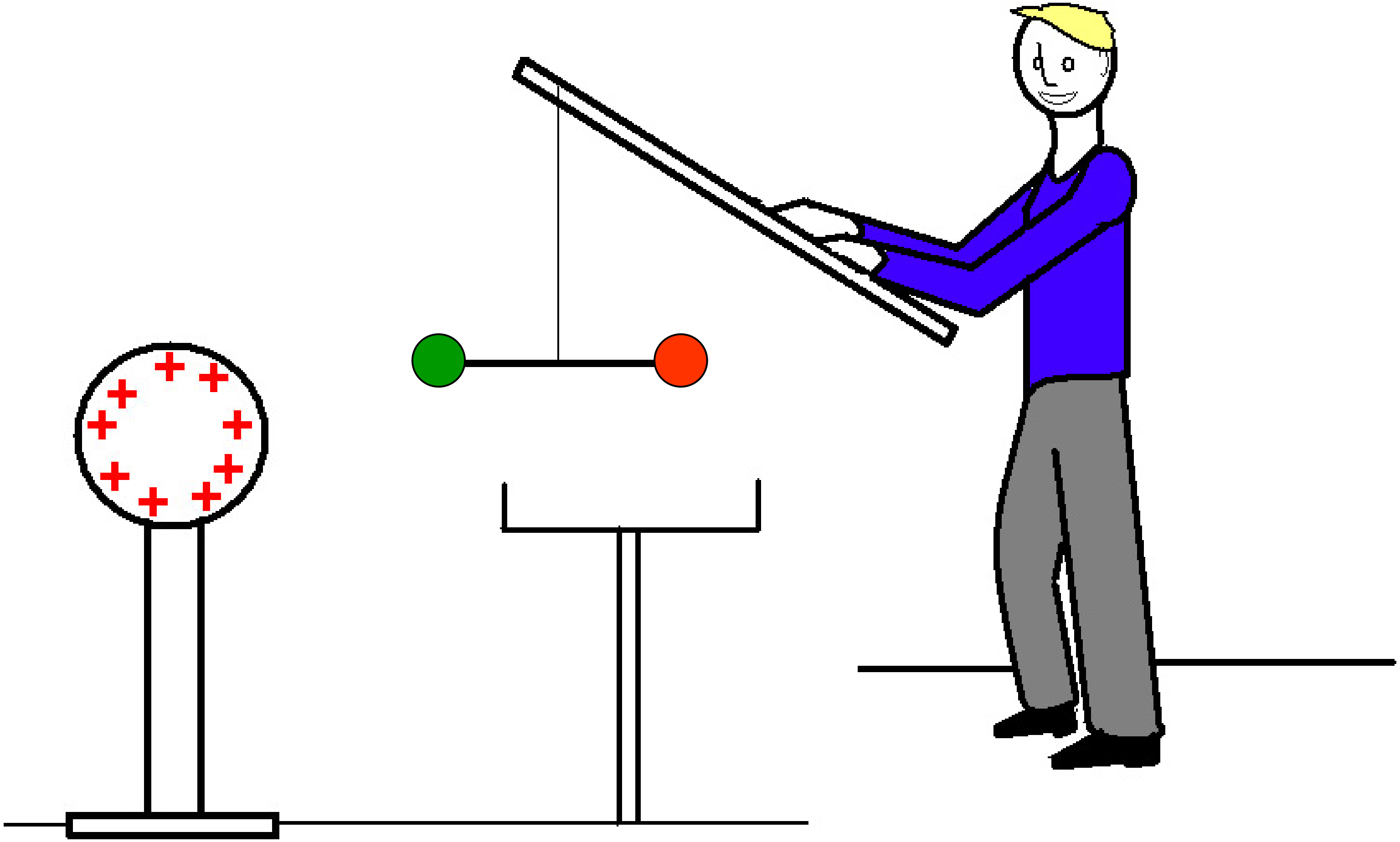


- Magnets also attract non-magnets!

Magnetic Force

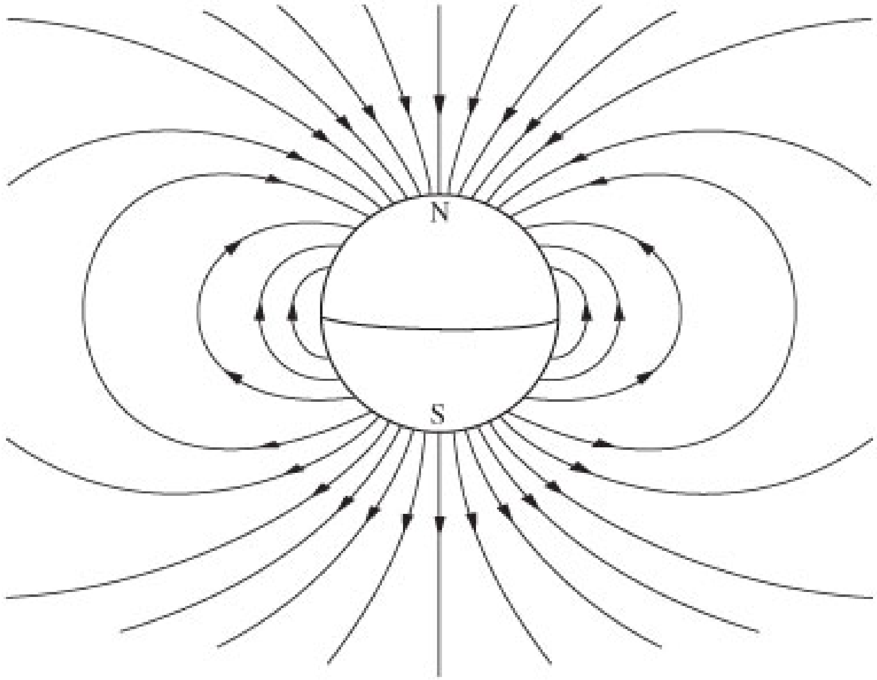
- New phenomenon
- Magnets carry no net charge!
- Although not understood, magnetic phenomena have been used for a long time -> In-Class Demo!

Electric Dipole in Electric Field



Compass

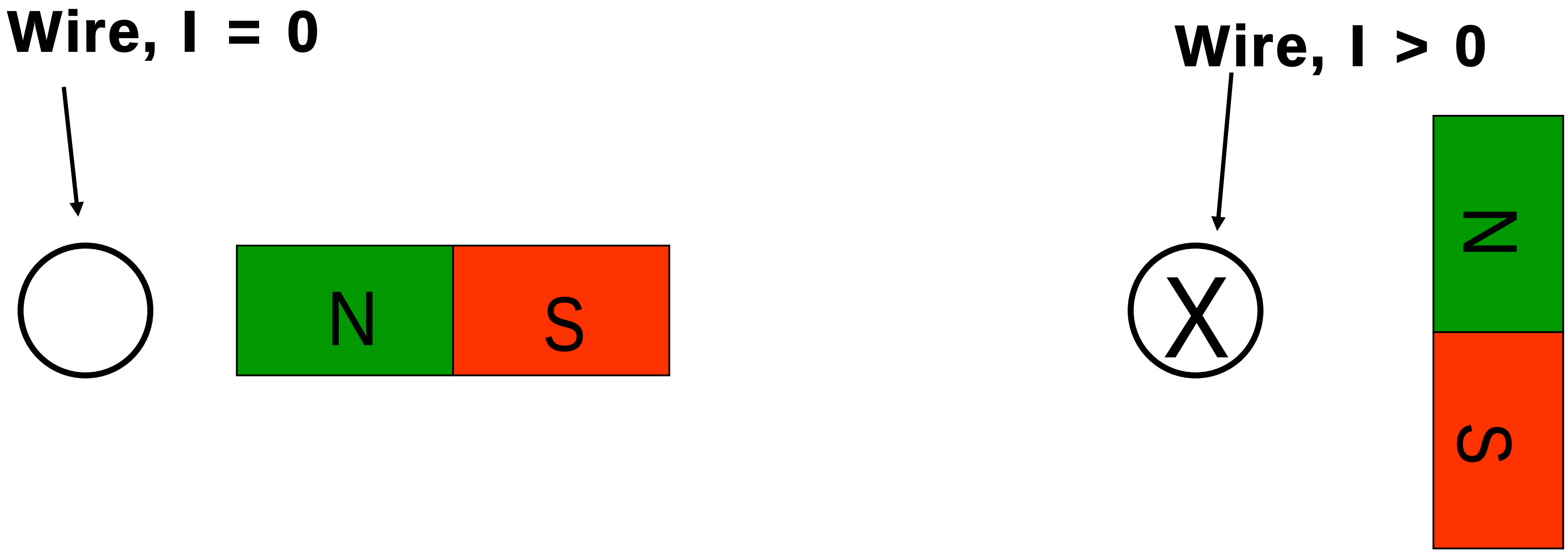
- Freely rotating magnets point towards earth's (magnetic) north pole



Magnetic Field

- Magnets align themselves with Magnetic Field
  - like Electric Dipoles in Electric Field
- What is the Source of the Magnetic Field?

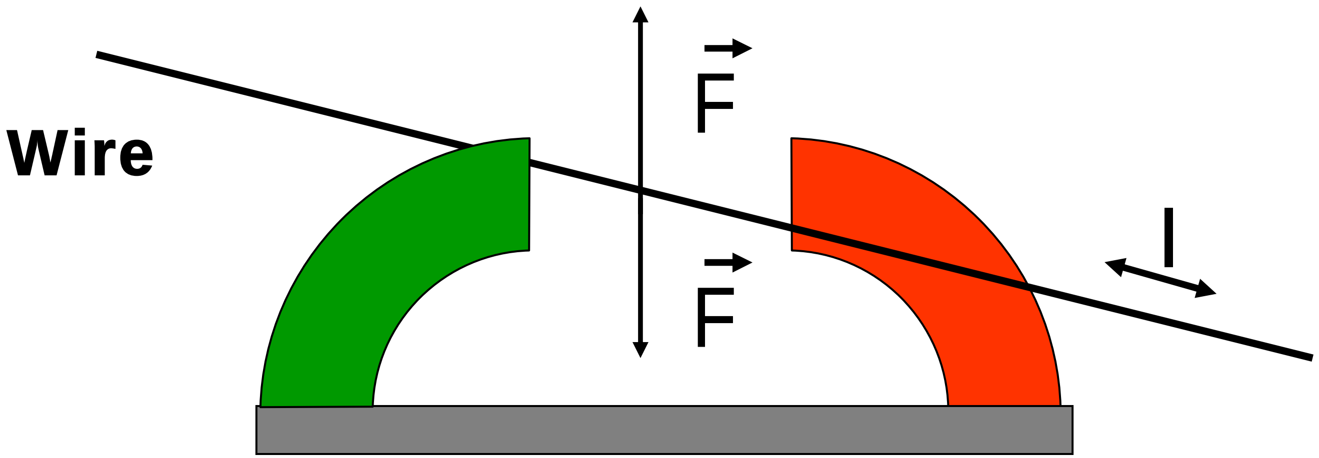
Current and Magnet



Source of the Magnetic Field

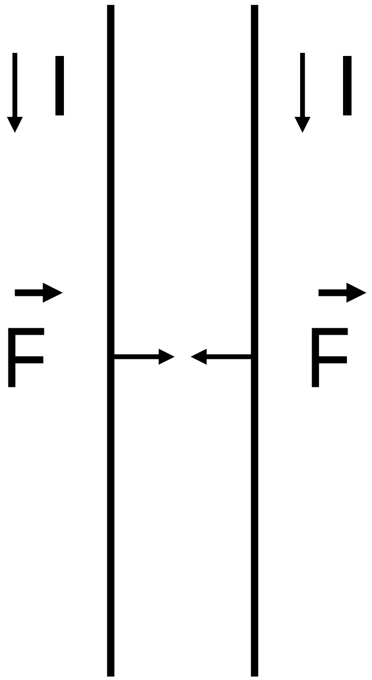
- No effect due to Static Charges
- But: An Electric Current affects Magnet
- Does Magnet affect Current?

Magnet and Current

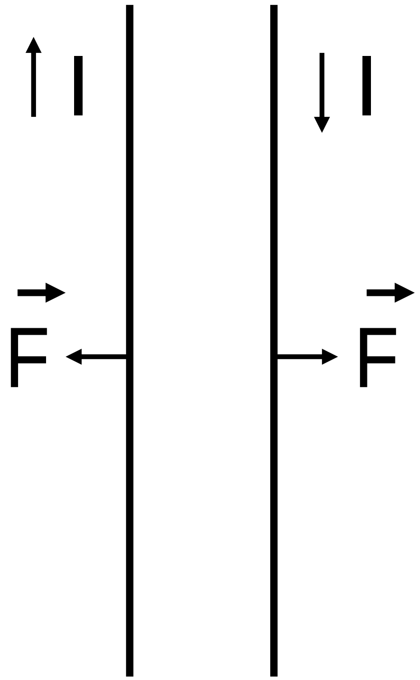


- Force on wire if I != 0
- Direction of Force depends on Sign of I
- Force perpendicular to I

Current and Current



Attraction

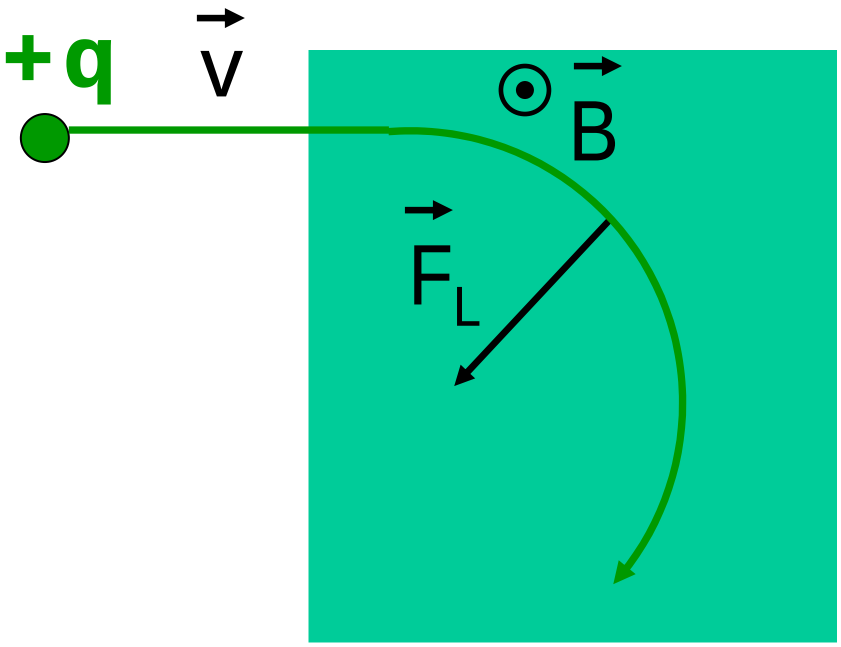


Repulsion

Summary

- Observed Force between
  - two Magnets
  - Magnet and Iron
  - Magnet and wire carrying current
  - Wire carrying current and Magnet
  - Two wires carrying currents
- Currents (moving charges) can be subject to and source of Magnetic Force

Free Charges and Magnetic Field



$$\vec{F}_L = q\,(\vec{E} + \vec{v} \times \vec{B})$$

Lorentz Force

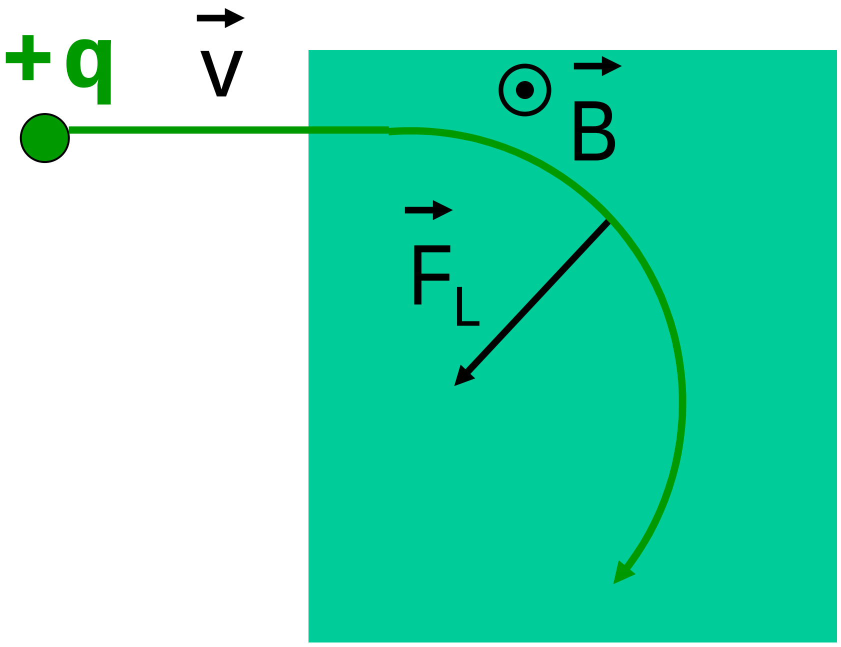
$$F_{acc} = m\,v^2/R = F_L$$

$[B] = N/(A\ m) = T$ (Tesla)

$$\rightarrow R = m\,v/(q\,B)$$

Cyclotron Radius

Magnetic Field and Work



$$\vec{F}_L = q\,\vec{v} \times \vec{B} \quad \text{(for } E = 0\text{)}$$