Magnetic Force

PHY 114-01

Fall 2026

Announcements

- Keep studying for the midterm! Come to office hours with questions.
- Two parts:
  - Conceptual part: T/F with justification. If you do not justify your answer, you can only receive half credit.
  - Quantitative part: similar to the last exam.

Agenda

- Last time:
  - RC Circuits

- This time:
  - Wrap up RC circuits
  - Magnetic Fields
  - Magnetic Force

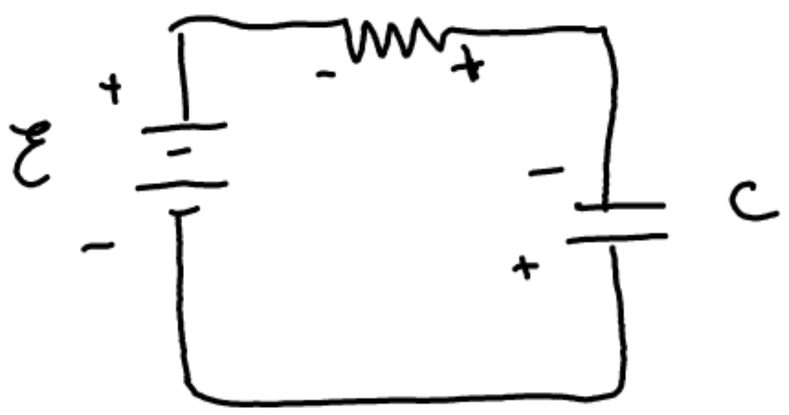
RC - circuits

So far we have only looked at the equilibrium behavior of capacitors, when they are fully charged.

Capacitors change up or discharge over time.

→ $\frac{dQ}{dt} = I$

Now that we can study current, we can study capacitors charging / discharging.



At $t = 0$, let $Q_c = 0$

What are Q_c, V_c at any time t?

start with KVL: $\mathcal{E} - iR - \frac{Q}{C} = 0$

$$\mathcal{E} - \frac{dQ}{dt} R - \frac{Q}{C} = 0$$

$$R \frac{dQ}{dt} + \frac{Q}{C} = \mathcal{E}$$

A differential equation with solution

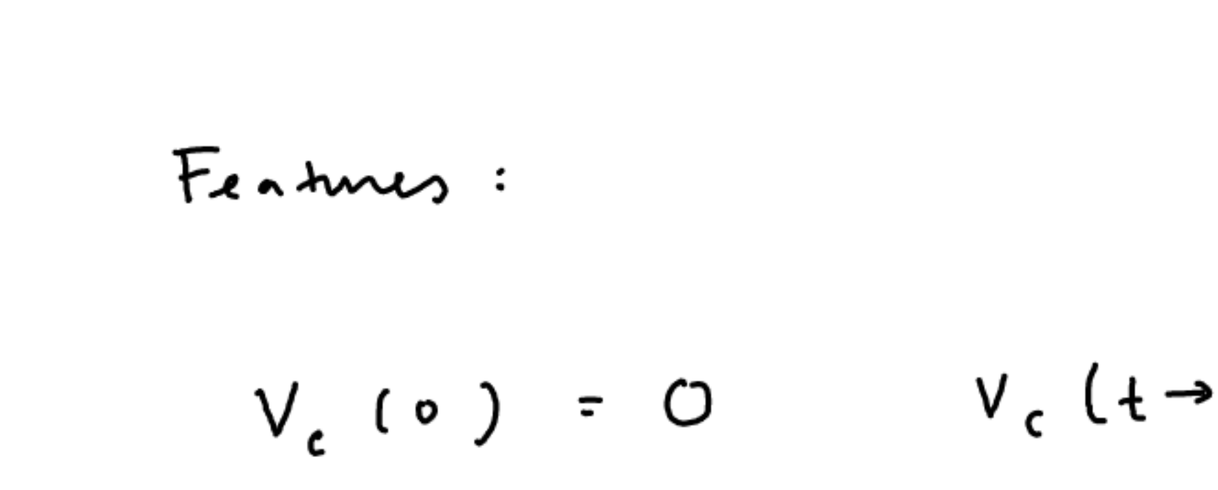
$$Q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right)$$

Thm, $V_C = \frac{Q}{C} = \mathcal{E}\left(1 - e^{-t/RC}\right)$

Features:

$V_C(0) = 0$ $\qquad$ $V_C(t \to \infty) = \mathcal{E}$ ← fully charged

$Q(0) = 0$ $\qquad$ $Q(t \to \infty) = C\mathcal{E}$ ← usual cap. eqn.



RC time constant

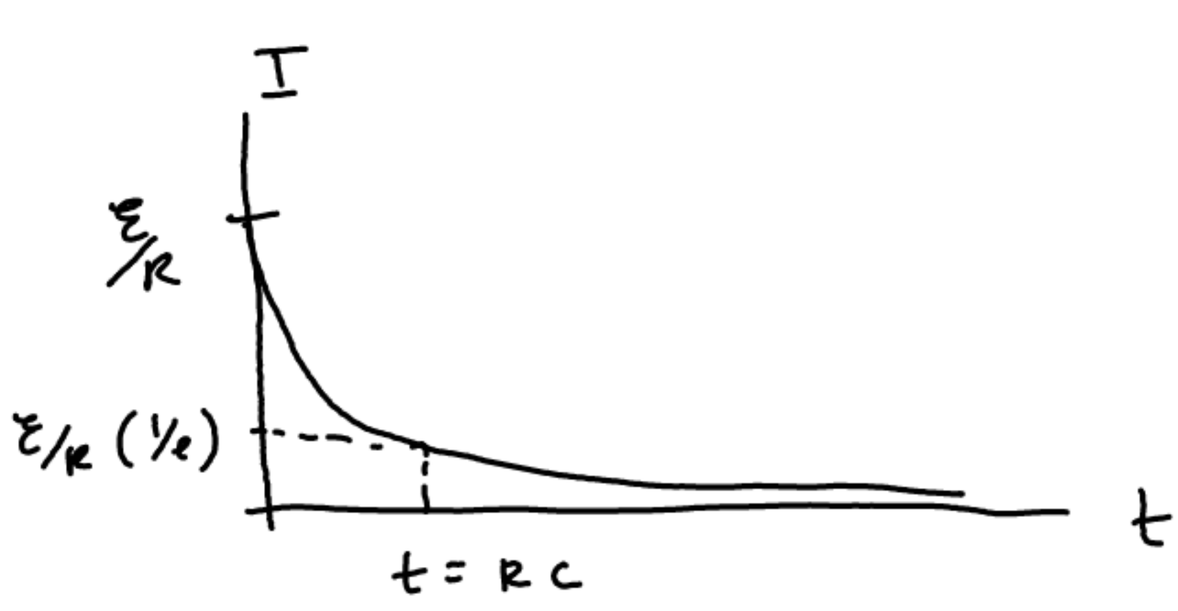
sets changing rate

$[RC] = [\Omega \cdot F]$

$= \left[\frac{V}{C/s} \cdot \frac{C}{V}\right] = [s]$

If $Q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right)$

then $I(t) = \frac{dQ}{dt} = \frac{\mathcal{E}}{R} e^{-t/RC}$

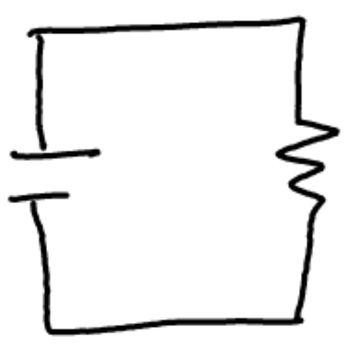


current will stop flowing when the capacitor is fully charged.

We can also <u>discharge</u> a capacaitor.

Let $Q(t=0) = Q_0$

$V_c(t=0) = Q_0/C$



charge will flow out of the capacitor through the resistor.

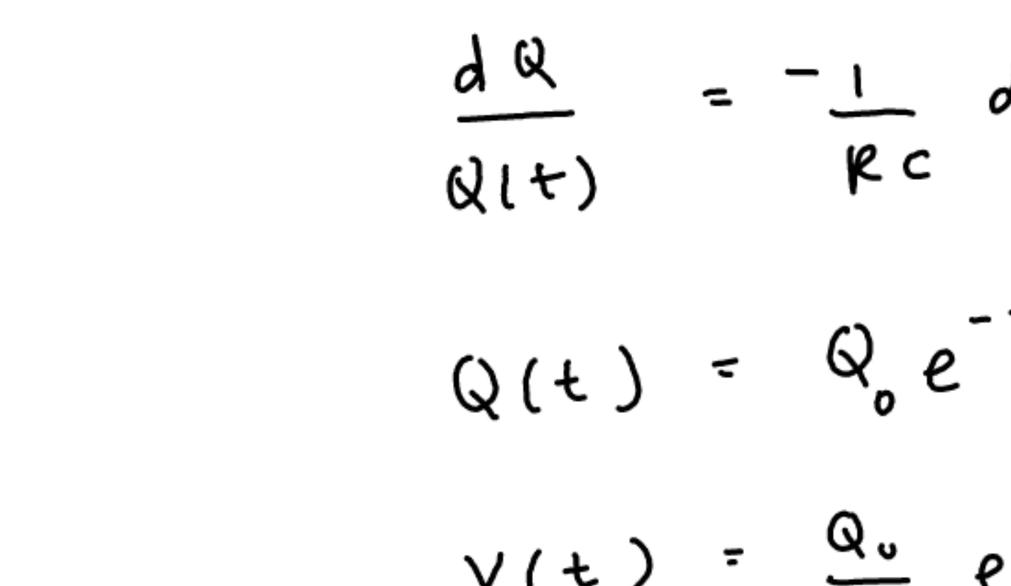
KVL: $V_c(t) = -iR$

$$\frac{Q(t)}{C} = -\frac{dQ}{dt} R$$

$$\frac{dQ}{Q(t)} = -\frac{1}{RC} dt$$

$$Q(t) = Q_0 e^{-t/RC}$$

$$V(t) = \frac{Q_0}{C} e^{-t/RC}$$

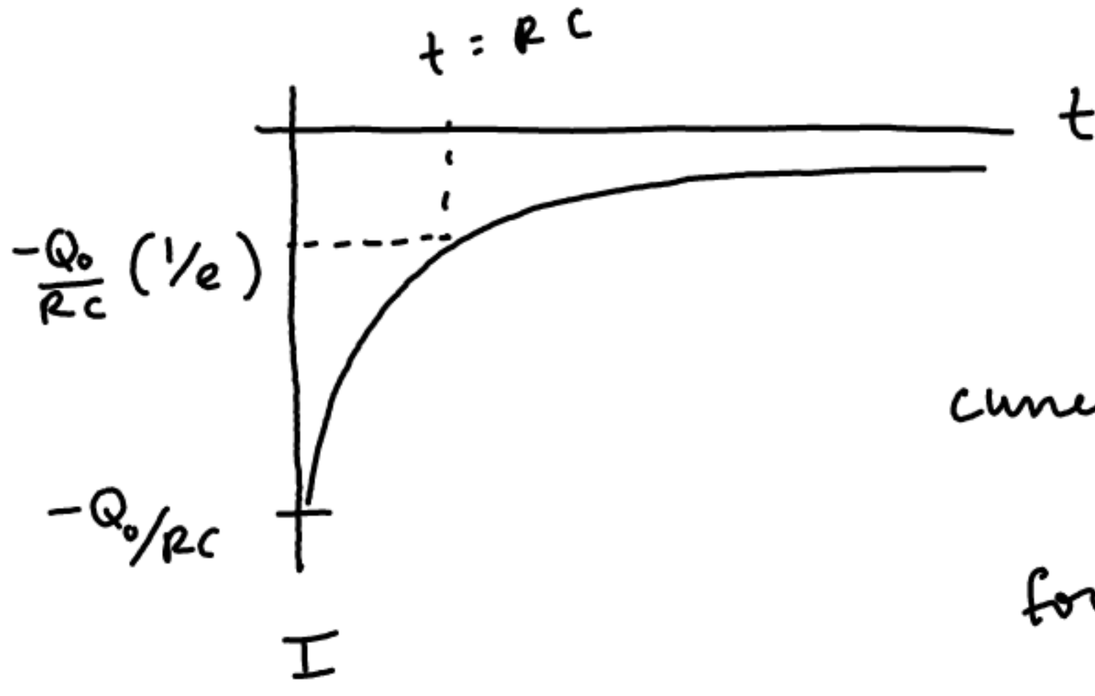


Q discharges exponentially

Same time constant RC

If $Q(t) = Q_0 e^{-t/RC}$

Then $I(t) = \frac{dQ}{dt} = -\frac{Q_0}{RC} e^{-t/RC}$



current is negative

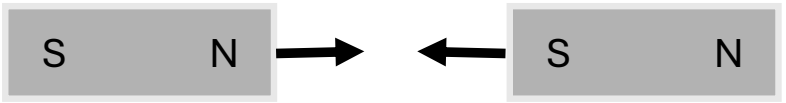
for discharging

stops when fully discharged

Bar Magnets



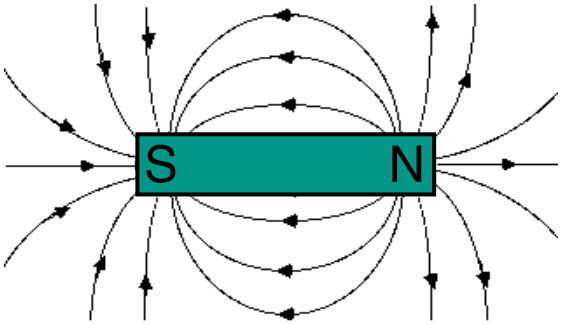
like poles repel



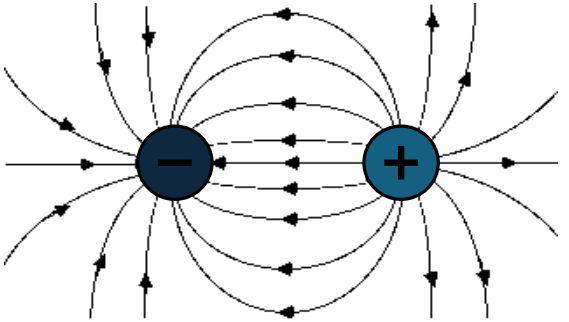
opposite poles attract

How do the magnets exert forces on each other?

via the magnetic field



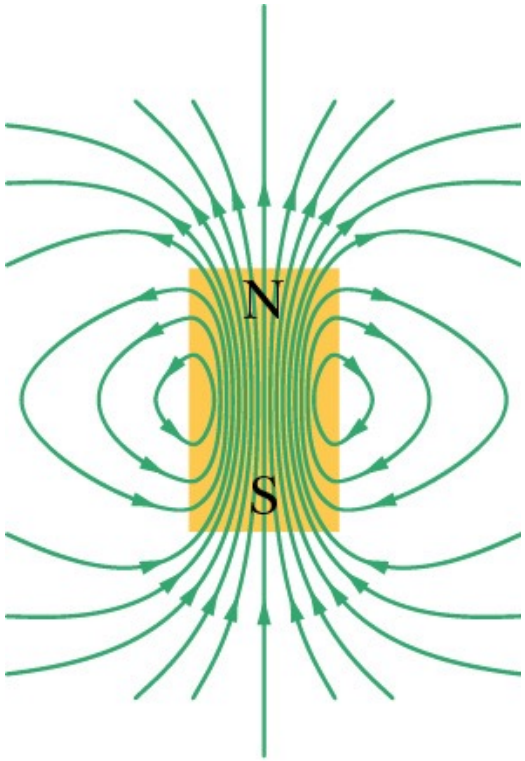
Magnetic Dipole



Electric Dipole

Magnetic Fields (B-fields)

- external field lines
  - ✓ originate on N pole, end on S pole
  - ✓ Tangent of line → direction of B
  - ✓ Density of lines → magnitude of B

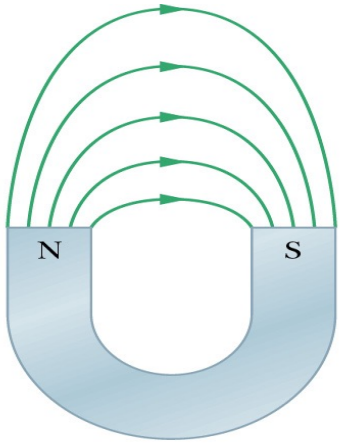


- magnetic field has symbol B
- B is a vector (like E-field)
  - ➢ SI unit for magnetic field is tesla (T)
  - ➢ other common unit is gauss (G)
  - ➢ 1 tesla = 10^4 gauss

Magnetic Fields

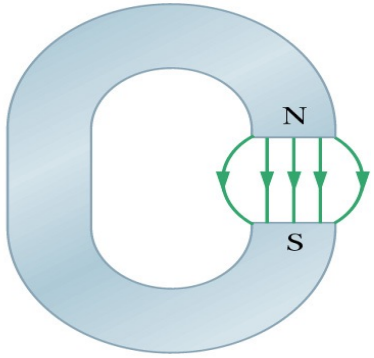
Other common shapes for magnets

- bend the bar magnet to make a
  - horseshoe magnet
  - C magnet



(a)

- these arrangements increase the magnetic field strength between the poles of the magnet
  - field lines are closer together
  - this is useful for many applications

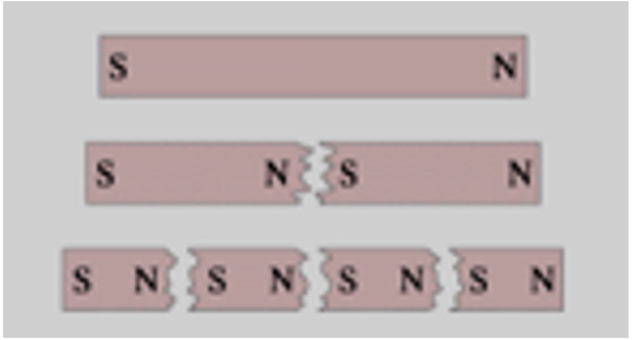


(b)

Isolated Magnetic "Poles"?

- **Can we have an isolated magnetic pole (called a *magnetic monopole*)?**
  - **it would be a magnetic North or a South Pole all by itself! (just like an electric + or - charge)**
- **How can we isolate this *magnetic charge* ?**

  Cut a bar magnet in half:

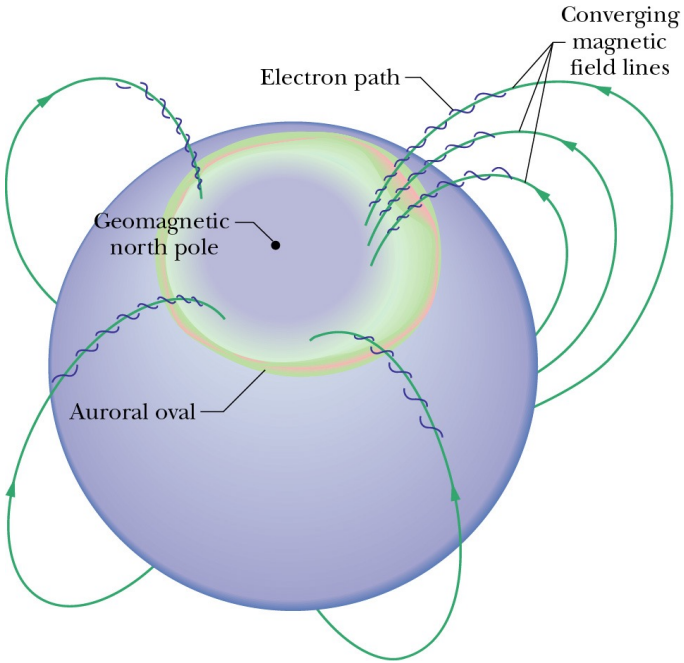


What you get is a bunch of little magnets!

No attempt yet has been successful in finding magnetic monopoles in nature!
All of our theories say they do not exist.

The Earth Is a Big Magnet

- **as well as being useful for navigation the Earth's magnetic field also protects us from *cosmic rays*.**
- **these are high energy charged particles streaming from the sun (mostly)**



  - when they hit a living cell they may cause damage to the cell
  - the Earth's magnetic field deflects them, prevents them from reaching the surface (and us)

Aurora Borealis



Magnetic Force

- If there is no magnetic monopole, how does the magnetic field create a magnetic force?
  - Discuss: what are some examples of magnetic forces in the real world?

- Magnetic fields exert forces on *moving charges*

- $\vec{F}_B = q\vec{v}\times\vec{B}$, the Lorentz force
  - Force is "sideways" – perpendicular to both v and B.
  - If v=0, then F=0
  - Units: [F] = [C][m/s][T] =[N] → [T] = [N]/[A m]