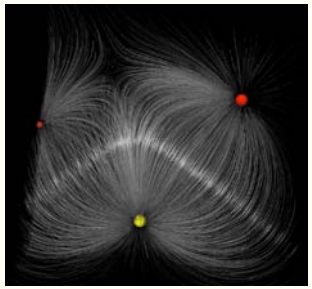


The Electric Force

Electric Charge

Electric Fields

Electron Beams

Electric Charge

- Recall that fundamental particles carry something called electric charge
  - protons have exactly one unit of positive charge
  - electrons have exactly one unit of negative charge
- Electromagnetic force is one of the basic interactions in nature
  - like charges experience repulsive force
  - opposite charges attracted to each other (like gravity)
- Electrical current is flow of charge (electrons)

Charge Balance

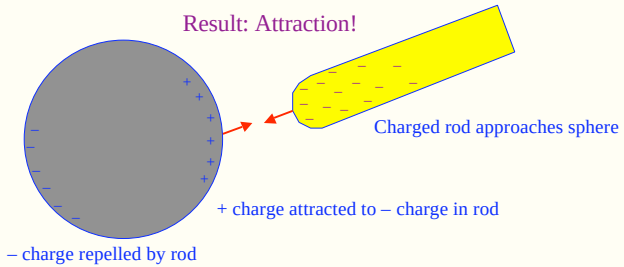
- Neutral atoms are made of equal quantities of positive and negative charges
  - Neutral carbon has 6 protons, 6 electrons, (& neutrons)
- Electrons can be stripped off of atoms
  - Electrons occupy the vulnerable outskirts of atoms
- Usually charge flows in such a way as to maintain neutrality
  - Excess positive charge attracts excess negative charge
  - Your body has 5×10^{28} positive charges and 5×10^{28} negative charges, balanced within millions or billions

Charge Separation

- Can separate charges by rubbing:
  - feet on carpet
  - atmosphere across ground
  - silk on glass
  - balloon on hair!
- Insulators keep charges where they are (no flow)
- Conductors distribute charge equally on surface
  - charge is free to “move about the cabin”
  - why do the charges collect on the surface?

Induced Charge

- Charge can also be coaxed to redistribute itself within an object



Static Electricity

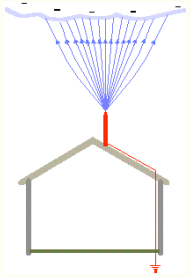
- Rubbing action redistributes charge (unbalanced)
- If enough charge builds up, we get discharge
- Air spark is actually due to "breakdown" of air
  - neutral air molecules separate into ions (electrons are stripped away)
  - current can then flow through the "plasma-field" air
  - In essence, air becomes a "wire" for a short bit
  - this happens at 3 million volts per meter
    - 1 cm spark then at 30,000 volts
    - typical finger-spark may involve a few billion electrons
    - hold onto key to reduce pain of spark

Lightning

- Lightning is an unbelievably huge discharge
- Clouds get charged through air friction
- 1 kilometer strike means 3 billion volts!
- Main path forms temporary "wire" along which charge equalizes
  - often bounces a few times before equal
- Thunder is bang produced by the extreme pressure variations induced by the formation and collapse of the plasma conduit
- www.stormchasing.nl/lightning.html

Lightning Rods

- Perform two functions
  - provide safe conduit for lightning away from house
  - diffuse situation via "coronal discharge"



Charges are attracted to tip of rod, and "electric field" is highly concentrated there.

Charges "leak" away, diffusing charge in what is sometimes called "St. Elmo's Fire", or "coronal discharge"

"Electrostatic" Force

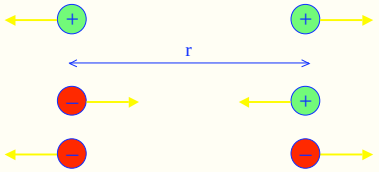
- Two charges, Q_1 and Q_2, separated by distance r exert a force on each other:

$$F = (k \cdot Q_1 \cdot Q_2) / r^2$$

- k is a constant (9×10^9), Q is in Coulombs, r in meters
  - One unit of charge (proton) has $Q = 1.6 \times 10^{-19}$ Coulombs
- Looks a lot like Newton's gravitation in form
- Electron and proton attract each other 10^{40} times stronger electrically than gravitationally!
  - Good thing charge is usually balanced!

Coulomb Law Illustrated

- Like charges repel
- Unlike charges attract



If charges are of same magnitude (and same separation), all the forces will be the same magnitude, with different directions.

Coulomb Force Law, Qualitatively

- Double one of the charges
  - force doubles
- Change sign of one of the charges
  - force changes direction
- Change sign of *both* charges
  - force stays the same
- Double the distance between charges
  - force four times weaker
- Double both charges
  - force four times stronger

Electric Force a lot like Gravity

- Same $1/r^2$ dependence; charge takes place of mass.
- Does this mean electricity is product of geometry, just like gravity (general relativity)?
  - No, because gravity as geometry accounts for the fact that all masses accelerate the same.
  - This depends on applied force being proportional to inertial mass ($F = ma$).
  - For charged particles, force is proportional to charge, not inertial mass.
  - Different charge-to-mass ratios lead to different accelerations.
    - Proton has 1/2000 charge-to-mass of electron → proton sluggish

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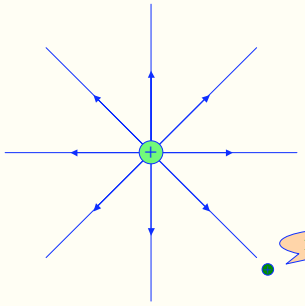
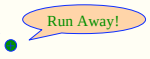
Electric Field

- Can think of electric force as establishing "field" telling particles which way to move and how fast



Electric "field lines" tell a *positive* charge which way to move.

For example, a positive charge itself has field lines pointing away from it, because this is how a positively-charged "test-particle" would respond if placed in the vicinity (repulsive force).



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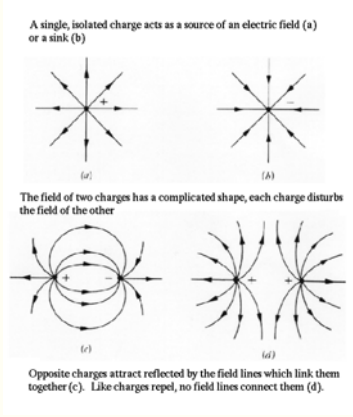
Example Electric Fields Around Charges



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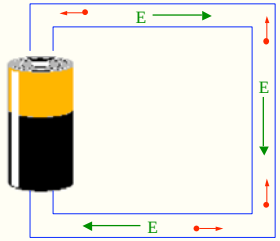
Electric Fields in Circuits

- Point away from positive terminal, towards negative
- Channeled by conductor (wire)
- Electrons flow opposite field lines (neg. charge)



electrons & direction of motion

E Electric field direction

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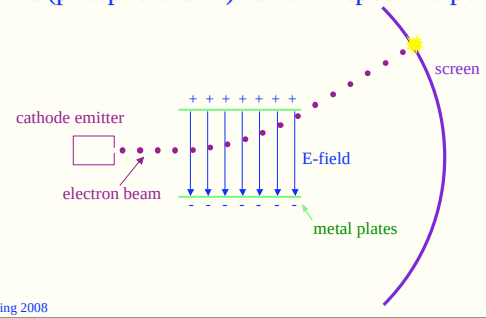
Electron Beams; Cathode Ray Tubes (CRTs)

- Televisions, Oscilloscopes, Monitors, etc. use an electron beam steered by electric fields to light up the (phosphorescent) screen at specified points



Assignments

- Selected readings from Hewitt Chaps. 23, 24, 25, 26 (specific pages listed on assignments page)
- HW 6 due 5/23: 22.E.1, 22.E.5, 22.E.11, 22.E.16, 22.E.20, 22.E.30, 22.E.33, 22.P.1, 23.E.3, 26.E.7, 26.E.9, 26.E.11