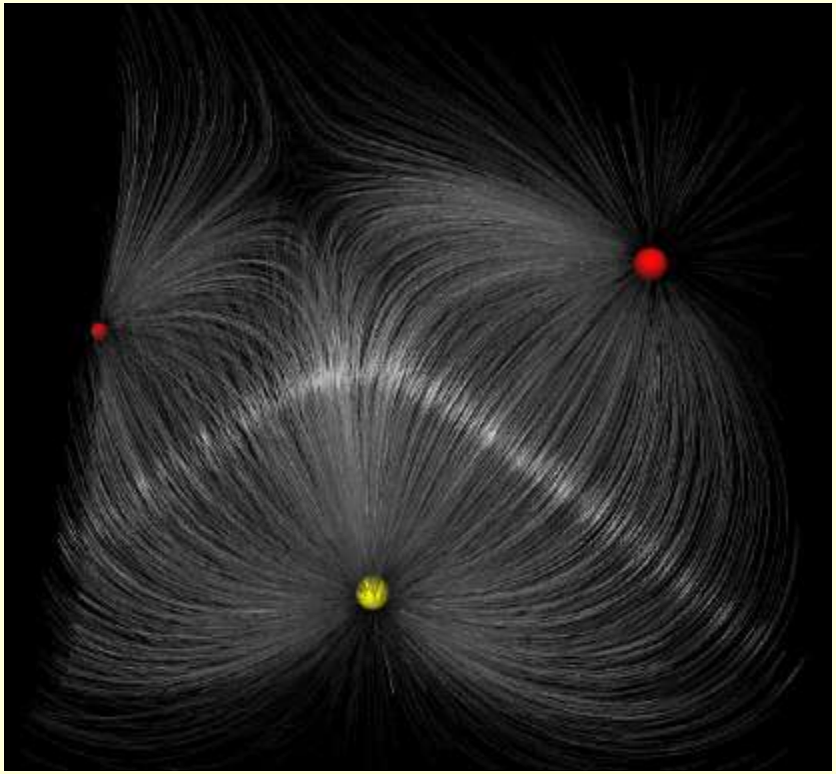


Electrical Interactions & Simple Circuits

Electric Forces and Fields

Charges in Motion

Batteries and Bulbs

Current, Voltage, and Power

Electric Charge

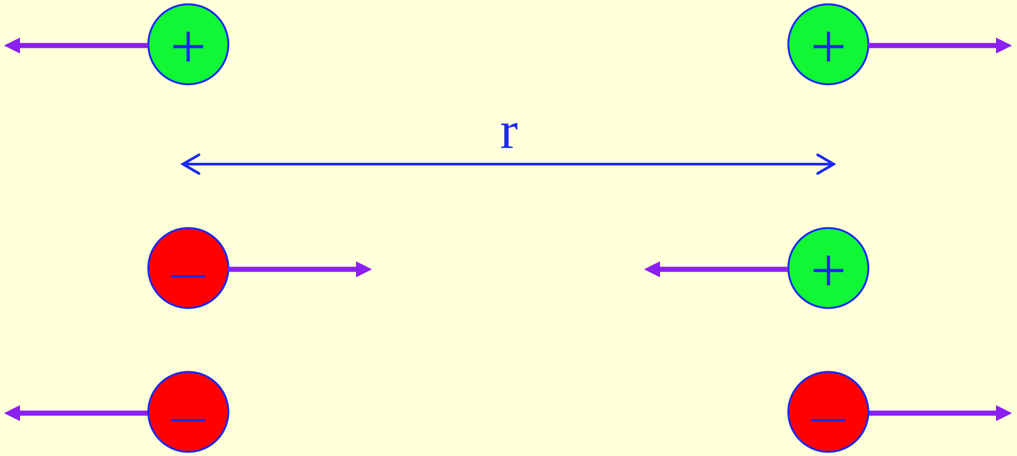
- Fundamental particles carry something called electric charge
    - protons have exactly one unit of positive charge
    - electrons have exactly one unit of negative charge
- Electromagnetic force is one of the basic interactions in nature
    - like charges experience repulsive force (unlike gravity)
    - opposite charges attracted to each other (like gravity)
- Electrical current is the 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 trillions
    - one trillion is small compared to 10^{28}: less than one quadrillionth of our total charge is unbalanced!

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.

"Electrostatic" Force: the Coulomb Law

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

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

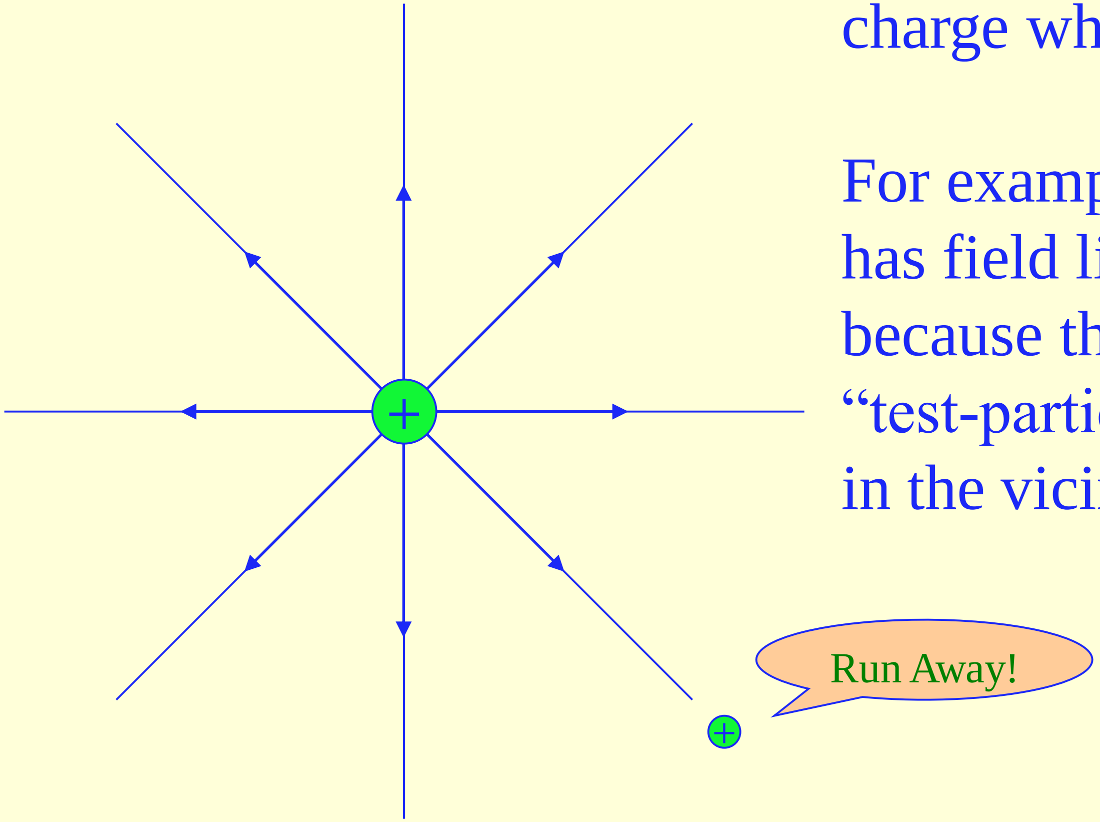
- k is a constant (9×10^9), Q is in Coulombs, r in meters
  - One unit of charge (proton) has $Q = 1.6\times10^{-19}$ Coulombs
- Looks a lot like Newton's gravitation in form
- Electron and proton attract each other 10^{40} times stronger electrically than gravitationally!
  - Good thing charge is usually balanced!
- A typical finger spark involves the exchange of a trillion electrons, or about 10^{-7} Coulombs

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 Field

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



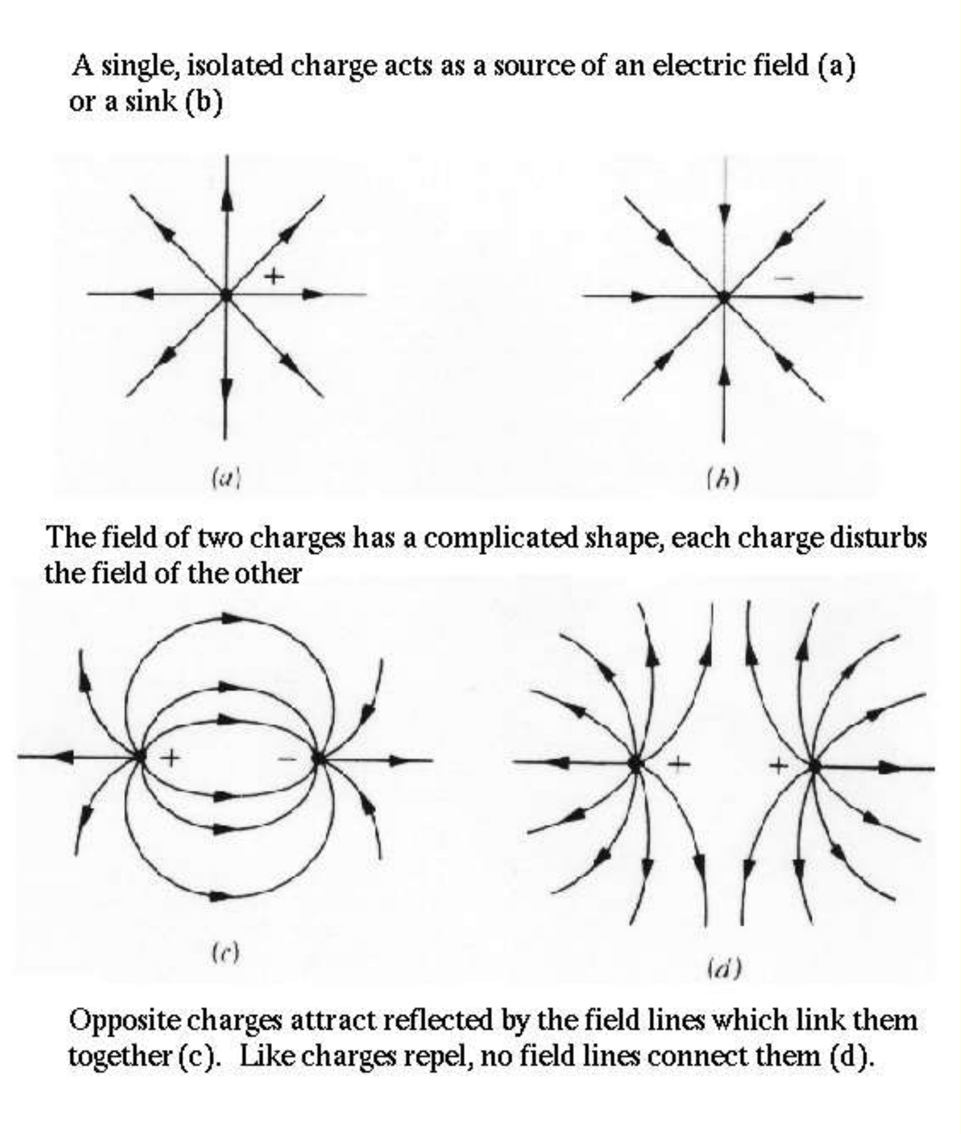
Electric “field lines” tell a *positive* charge which way to move.

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).

Analogy to Gravity field:

- On the surface of the earth, the force due to gravity is $F = mg$, where g is the gravitational acceleration
  - g is a vector, pointing down
  - tells masses how to move (how much force on mass, m)
- Since we know gravity is $F = GMm/r^2$, $g = GM/r^2$
  - acceleration due to gravity is independent of the mass of the "test body"
- Electric force is $F = kQq/r^2$
- Electric field is just $E = kQ/r^2$ so that $F = qE$
  - q is the charge analog to mass
  - E is the analog to gravitational acceleration: tells how a "test charge", q, will respond (what's the force on it?)
  - units of E work out to volts per meter (V/m)

Example Electric Fields Around Charges

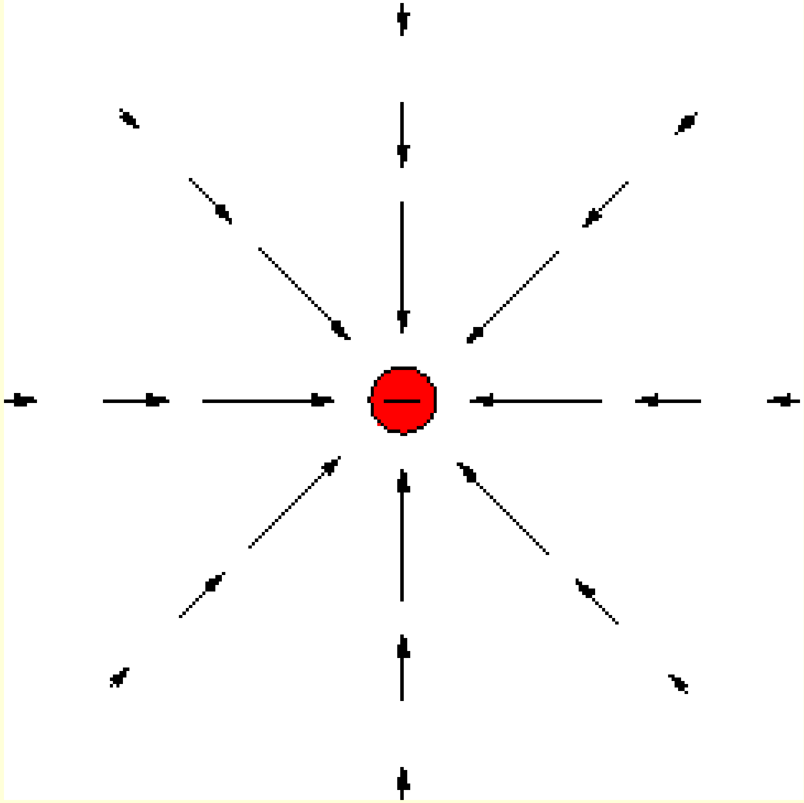


A single, isolated charge acts as a source of an electric field (a) or a sink (b)

The field of two charges has a complicated shape, each charge disturbs the field of the other

Opposite charges attract reflected by the field lines which link them together (c). Like charges repel, no field lines connect them (d).

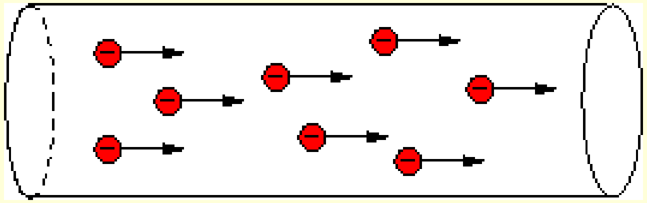
But Realistic Picture Folds in Strength



- Previous pictures conveyed direction, but did not account for $1/r^2$ strength of the E-field
- The E-field gets weaker as one goes farther away from a charge
- In essence, there is an electric field vector (strength and direction) at every point in space
- This picture shows a sampling of the E-field vectors at 24 points in space around a negative charge

Electric Current

- Electric current is simply the flow of charge



- Electrons flowing in a wire constitute a current
- Measured in Coulombs per second, or Amperes
  - Colloquially, Amp (A)
  - refers to amount of charge crossing through cross-sectional area per unit time
- Electrons have a charge of -1.6×10^{-19} Coulombs
  - so (negative) one Coulomb is 6×10^{18} electrons
  - one amp is 6×10^{18} electrons per second
  - subtle gotcha: electrons flow in direction opposite to current, since current is implicitly *positive* charge flow, but electrons are *negative*

The Quest for Light

- Given a battery, a light bulb, and one piece of wire, how would you get the bulb to light?

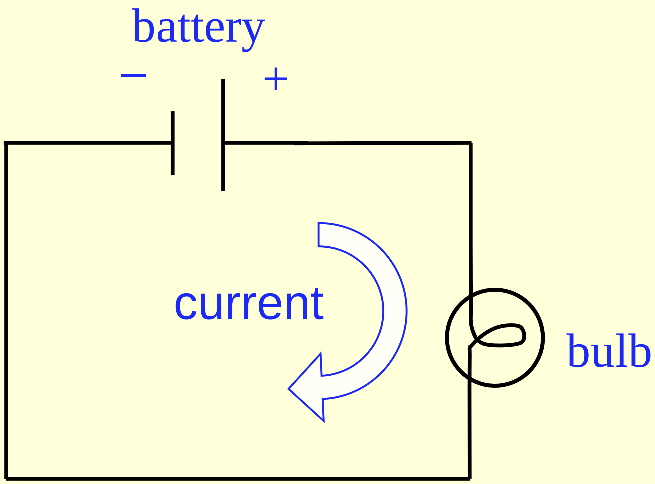
Would This Work?

Would This Work?

Would This Work?

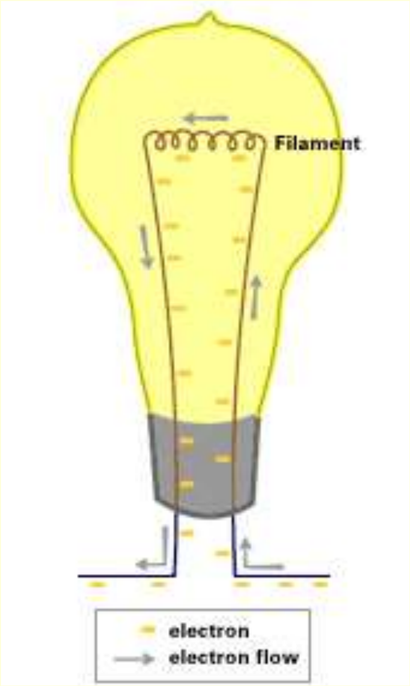
The Central Concept: Closed Circuit

Circuit in Diagram Form



In a closed circuit, current flows *around* the loop

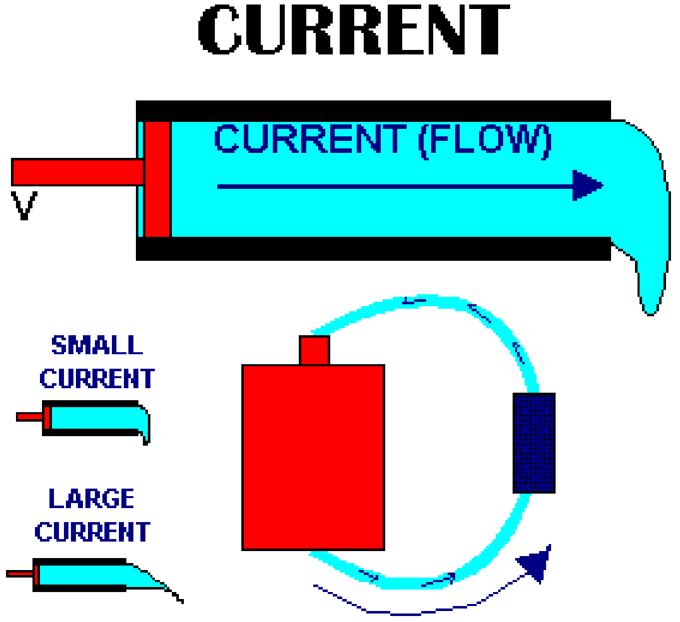
electrons flow *opposite* the indicated current direction! (repelled by negative terminal)



Current flowing through the filament makes it glow.

No Loop → No Current → No Light

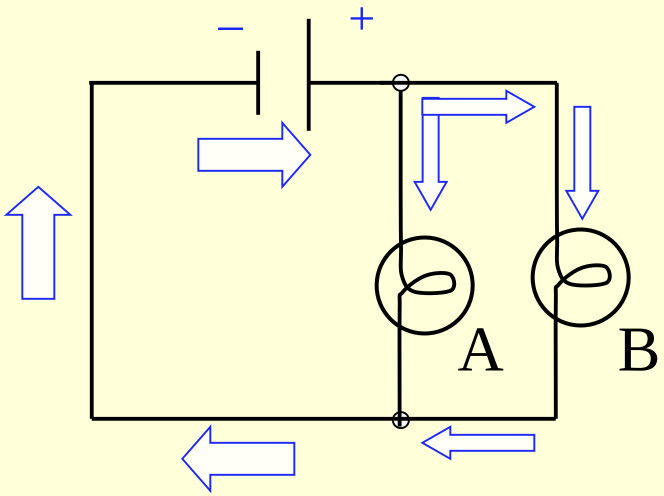
Current is the Central Concept



It sometimes helps to think of current as flow of water, which is more familiar to us. High current means lots of water flow per unit time. Low current is more like a trickle.

In electronics, it is the flow of *charge*, not water, that is described by the word current. And it's always *electrons* doing the flowing (thus *electron*ics)

Currents Divide and Merge at Junctions



How much would the current *through the battery* change if I unscrewed one of the 2 bulbs?

How would the *brightness of "A"* change if I unscrewed "B"?

Answer

- The battery is supplying an equal amount of current to each of the two bulbs. If one of the bulbs is disconnected, the current through the battery will be halved.
- Unscrewing “B” would not affect the current through “A” so it will stay the same brightness.
- Why wouldn’t more current flow through A?
  - The battery does not supply constant current (is there current even when the battery is disconnected?)

What *Does* a Battery Provide?

- Batteries *do* supply current
  - just not a *constant* current
- More relavently, batteries supply a *constant voltage*
  - D-cell is about 1.5 volts
- What is a voltage?
- Voltage is much like a potential energy
  - the higher the voltage, the more work can be done
  - it takes one Joule to push one Coulomb through one Volt
  - so a Volt is a Joule per Coulomb (J/C)

Voltage, Current, and Power

- One Volt is a Joule per Coulomb (J/C)
- One Amp of current is one Coulomb per second
- If I have one volt (J/C) and one amp (C/s), then multiplying gives Joules per second (J/s)
  - this is power: J/s = Watts
- So the formula for electrical power is just:

$P = VI$: power = voltage × current

- More work is done per unit time the higher the voltage and/or the higher the current

Announcements/Assignments

- **Next up:**
  - a simple model for molecules/lattices
  - waves
  - energy from food and the demands of exercise
- **Assignments:**
  - First Q/O due Friday, 4/8 by 5PM via WebCT
  - read chapter 2: pp. 52–57, 65–66; chapter 6: pp. 190–191; chapter 3: pp. 79–84; chapter 8: 263–271, 277–278 on E-field
  - read chapter 3, pp. 79–84, chapter 6 pp. 190–191
  - HW2: Chapter 1: E.8, E.13, E.20, E.21, E.23, E.25, P.8, P.10, P.13, P.14, C.5; Chapter 2: E.28, E.30, P.10, P.11: due 4/08

Assignments

- Read pp. 304–309, 317–318, 324–331 to go along with *this* lecture
- Read pp. 224–231, 332–333, 407 for *next* lecture
- HW2 due 4/20: 7.E.1, 7.E.4, 7.P.1, 7.P.2, 7.P.3, 3.P.2, 3.P.4, plus eight additional *required* problems available on assignments page