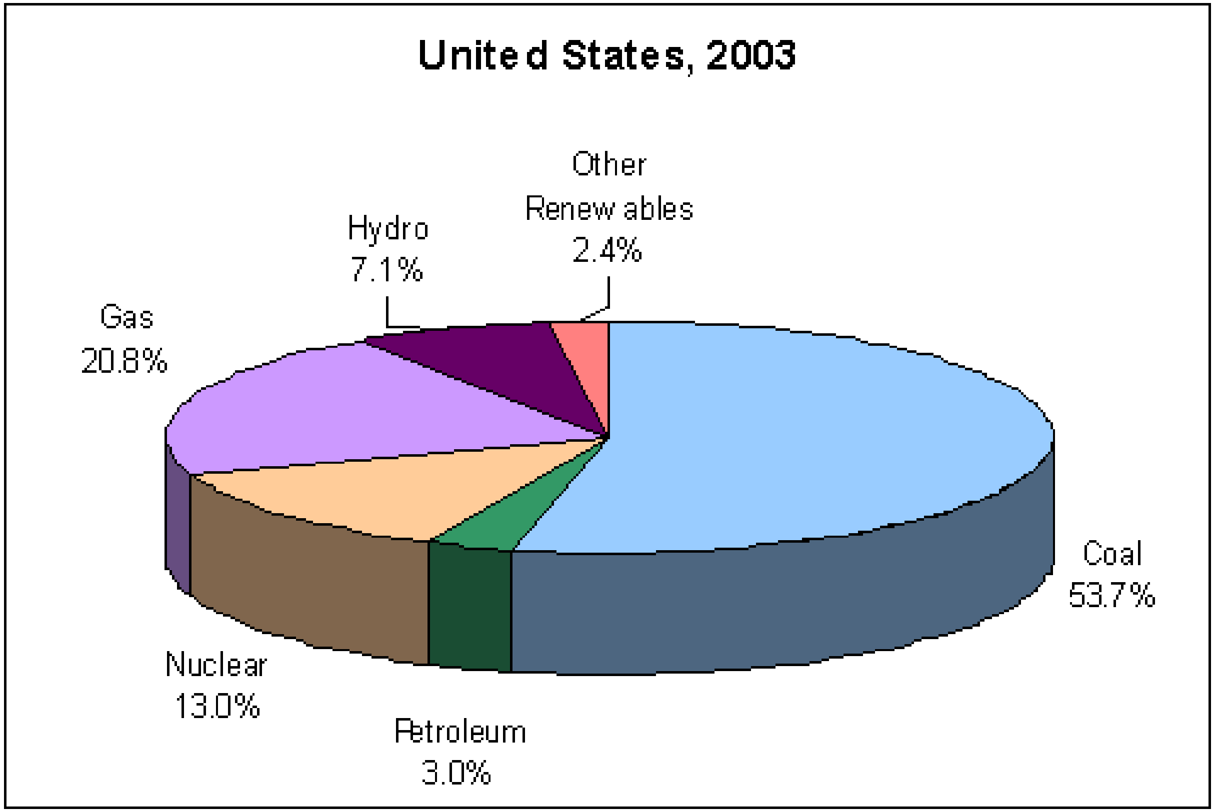
ELECTRICITY

Part 1: Electrostatics.

Original slides provided by Dr. Daniel Holland

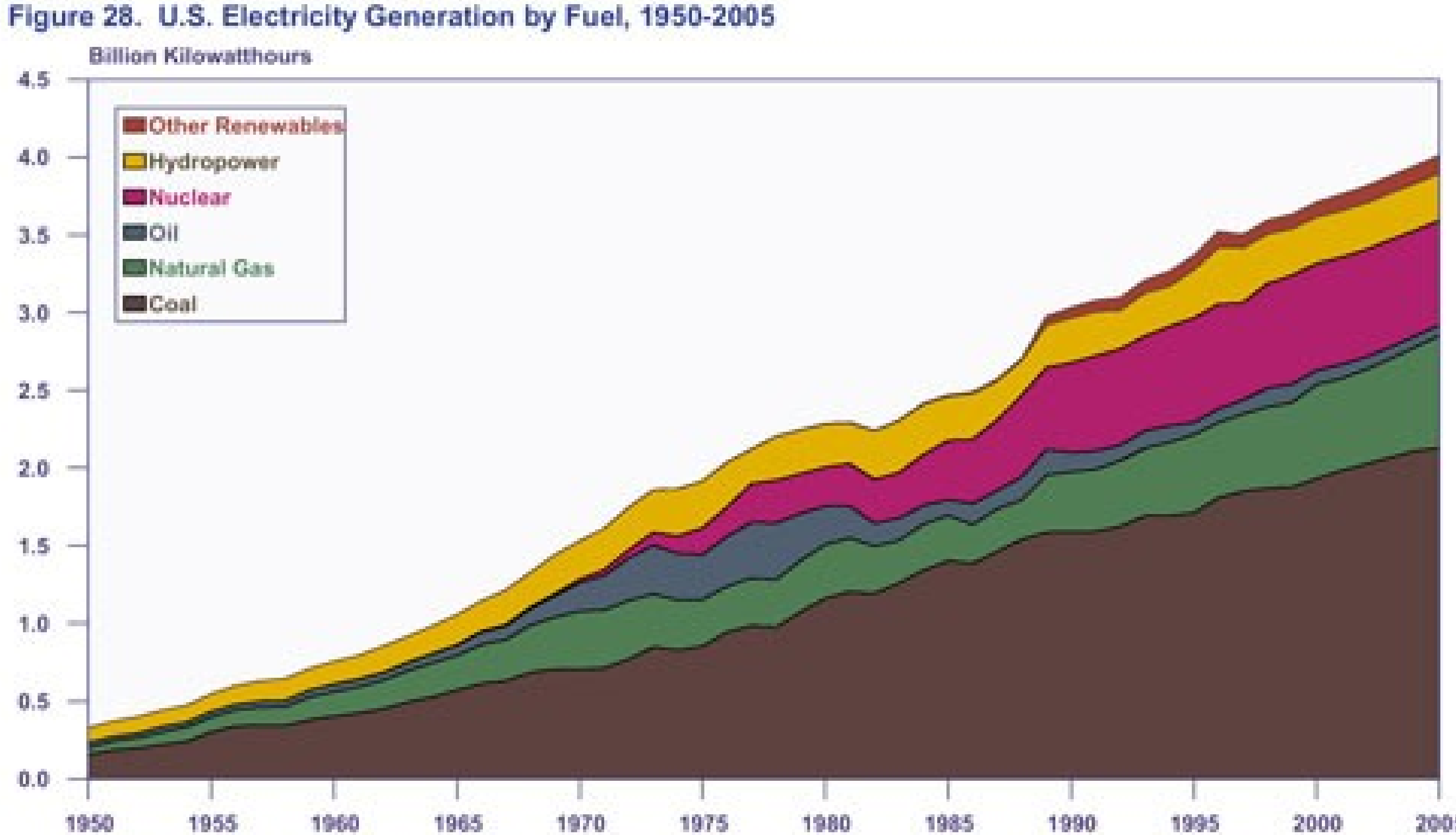
Fuel Source for Electricity 77.5% Fossil Fuel



- One of the three basic energy use sectors.

Audio Link

Electric Power Generation 1950-2005



Sources: **History:** Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; Form EIA-860B, "Annual Electric Generator Report—Nonutility"; and Form EIA-867, "Annual Nonutility Power Producer Report." **Projections:** Energy Information Administration, *Annual Energy Outlook 2000*, DOE/EIA-0383(2000) (Washington, DC, December 1999).

Electrostatics

- There are two types of charges: positive (+) and negative (-).
- Common symbols for charge are q and/or Q.
- Units of charge: Coulomb (C)
- A Coulomb is a lot of charge. Usually deal in micro coulombs and less in electrostatics.
- Fundamental charge: Magnitude of the charge on an electron or proton.
    - $e=1.6\times10^{-19}C$
- Like charges repel, Unlike charges attract.

Definitions

- ***Conductor:*** Material that charges are free to move around in. Examples: metal (silver is best but copper is almost as good)
- ***Insulator*** (Dielectric): Material that charges are NOT free to move around in. Examples: glass, quartz, wood.
- ***Semiconductor****:* Can behave as either depending on conditions: Silicon, Germanium, Gallium-Arsenide.
- Van de Graff demos continued

Forces on electric charges

- Gravitational force on a mass:
    - $F=mg$
- Electric force on a charge:
    - $F=qE$
- E: electric field $=F/q$ is the force per unit charge that a given charge experiences. (vector)
- Note: In general E changes in space and time.

- If we move a charge in an electric field, we do work on it.
- $W = Fd = qEd$
- Define Voltage as $V=Ed$ (Not exact, but it will do.)
- Note $V=W/q$: work done per unit charge in moving it through an electric field. (Or potential energy per unit charge.)
- Equivalent to raising mass up in a gravitational field.

UNITS OF E & V

- $V=PE/q$ (Joule/Coulomb=Volt)

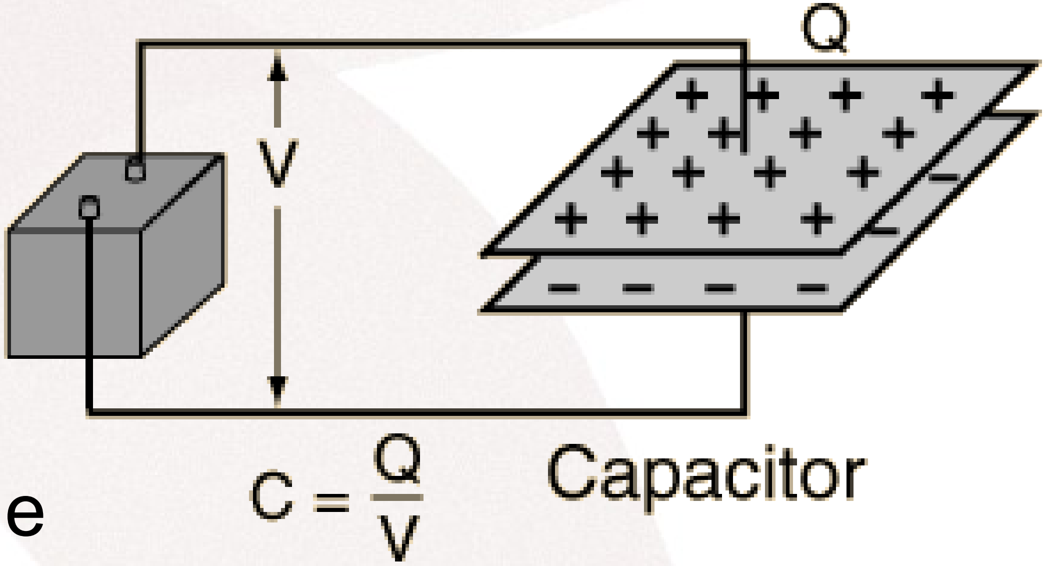
- $E=F/q$ (Newton/Coulomb)

  OR

- $E=V/d$ (Volt/meter)

CAPACITOR

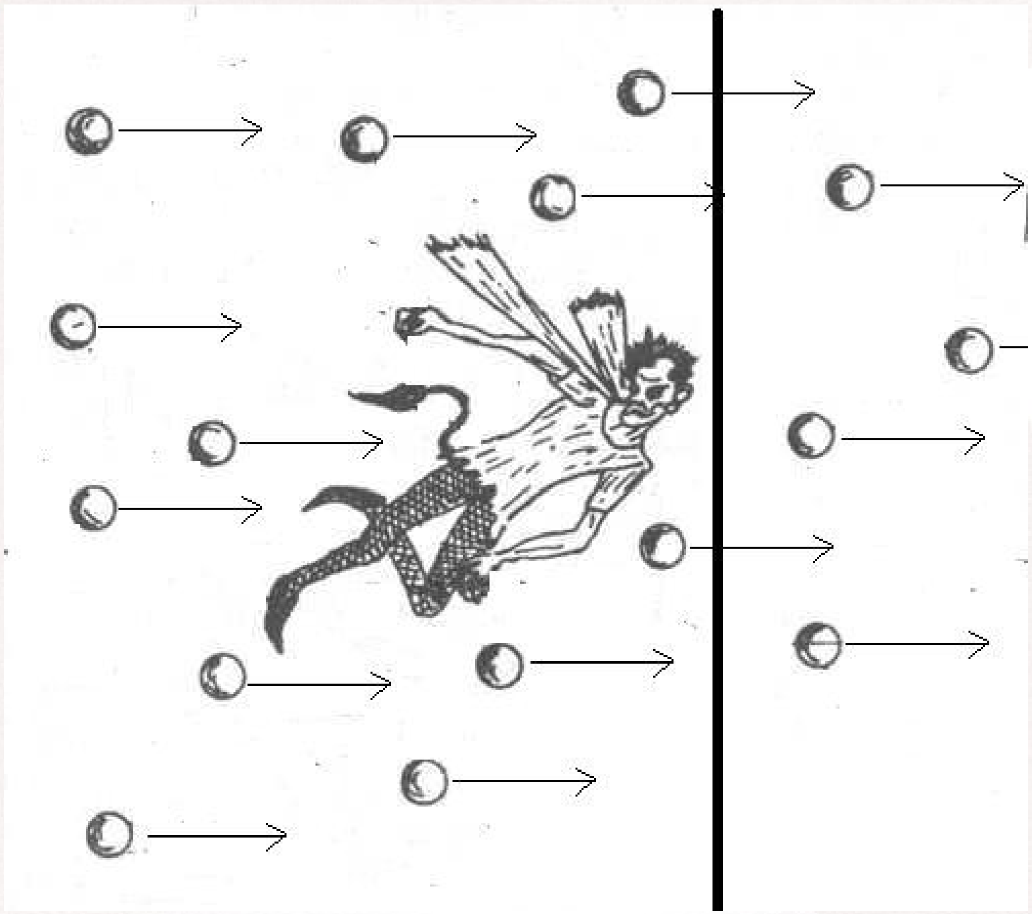
- Device for storing charge
- Two conductors separated by an insulator.
- Battery moves charge from one plate to another.



Electricity

Part 2: Electric Current

Electric current is the amount of charge moving past a point



Maxwell [illegible] nting the charges [illegible] iven point

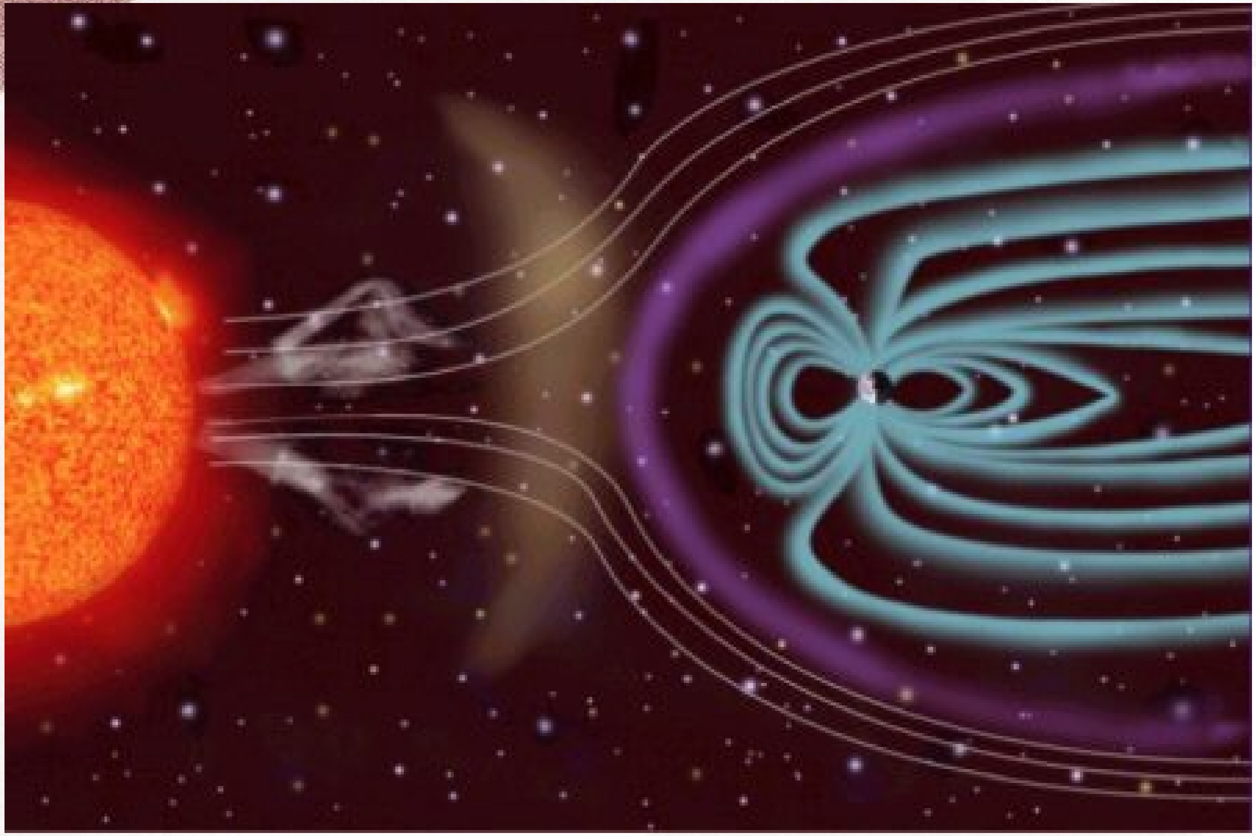
Definition of current

- I = current
- ΔQ = amount of charge that passes point.
- Δt = time for charge to pass by.

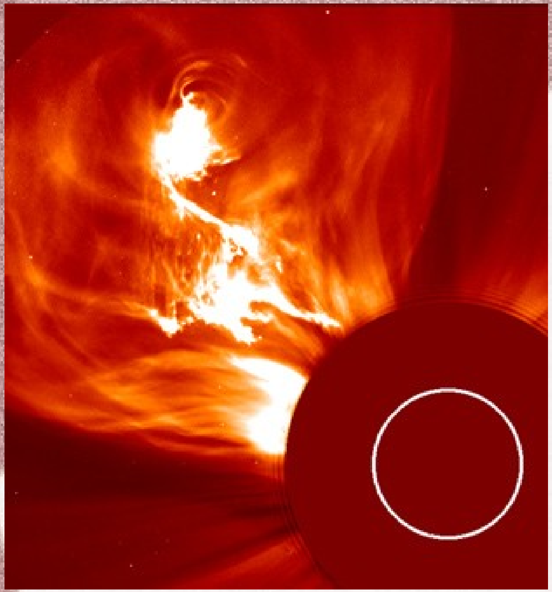
$$I = \frac{\Delta Q}{\Delta t}$$

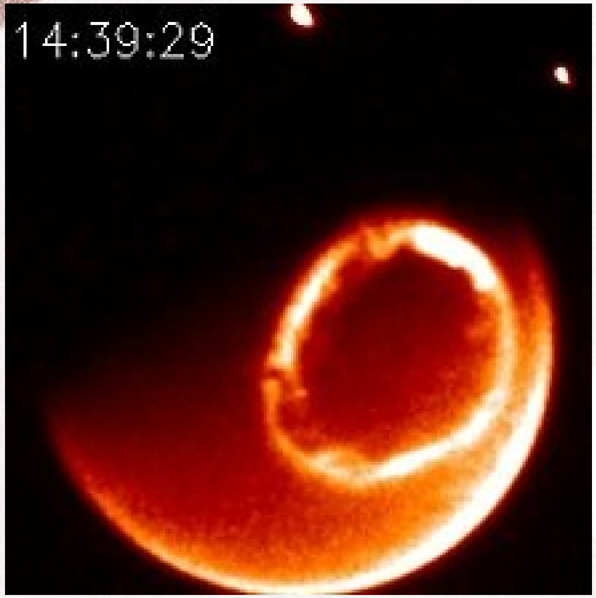
1 Ampere (Amp) = 1 Coulomb/second

Examples of Currents



Solar w[illegible]cting with
the ear[illegible]etic field



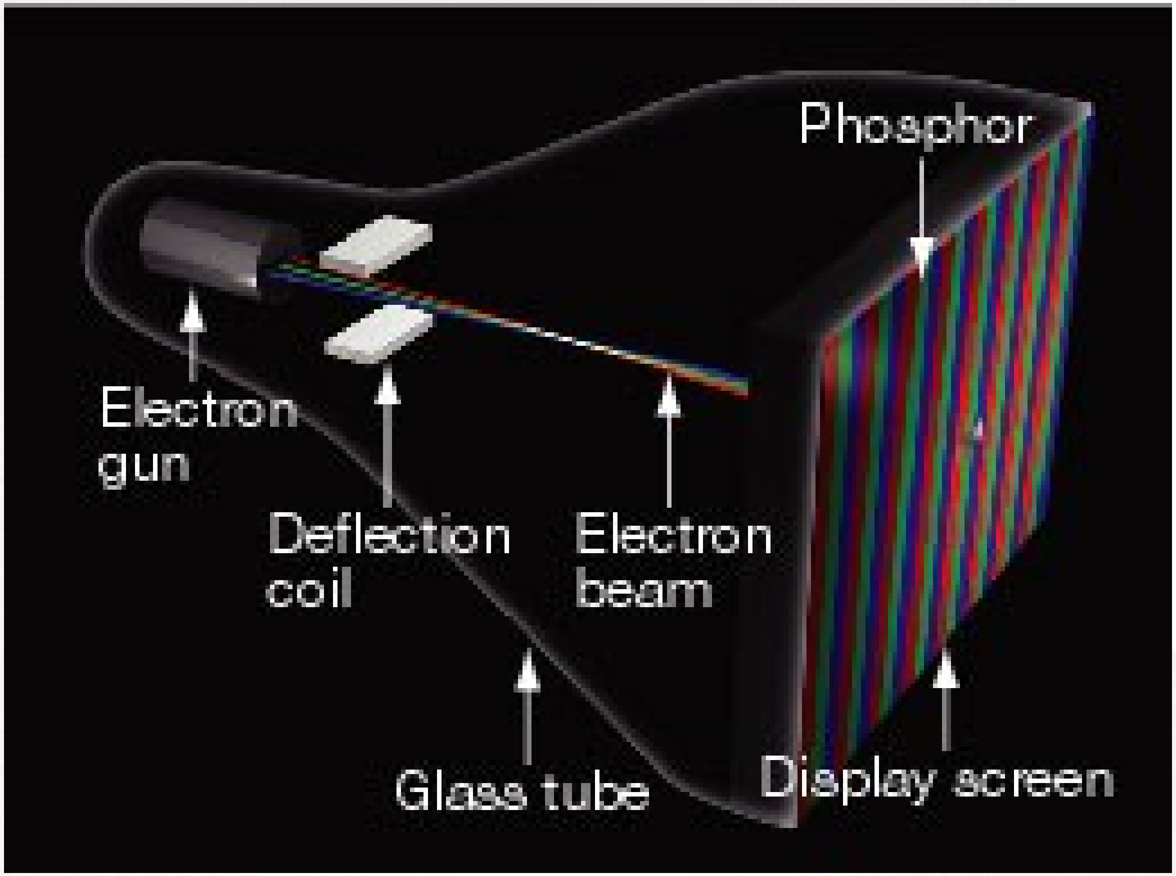


1) Coronal Mass Ejection

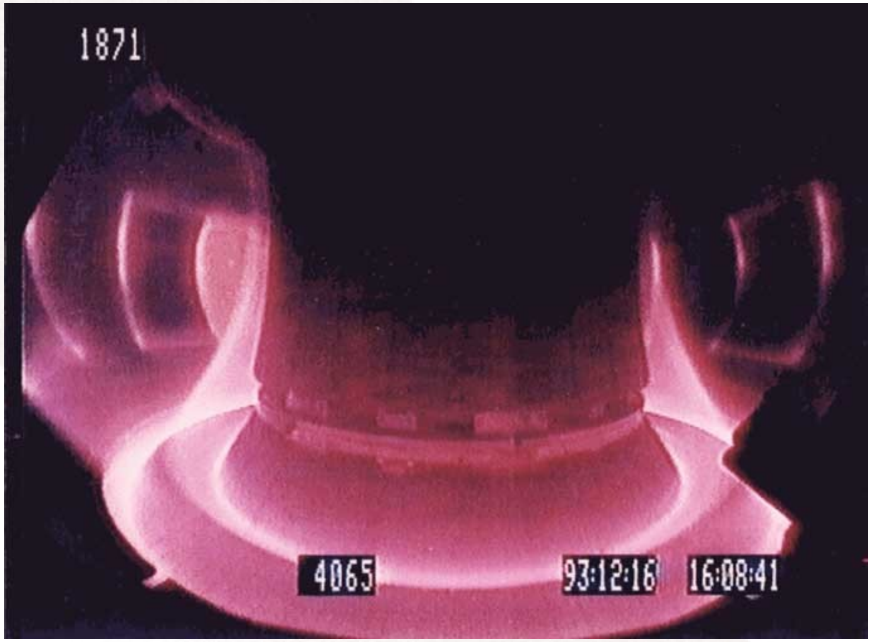
2) Aurora from space

3) Aurora from ground

3 electron beams in a color TV



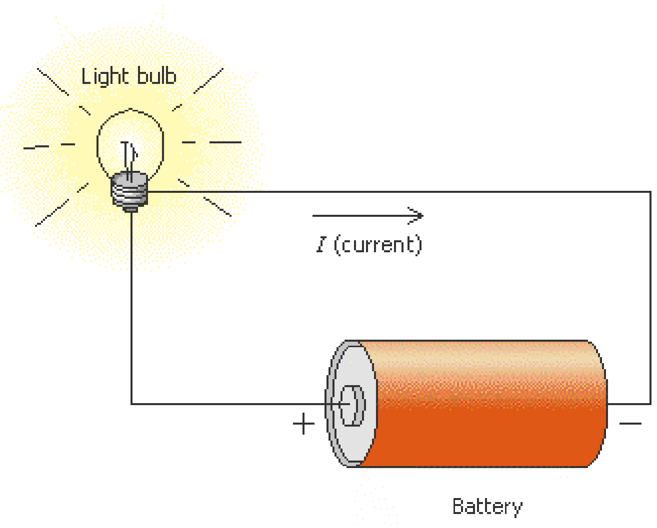
Tokamak Fusion Experiments
JET discharge



Current is not confined to wires, but it usually is in most electronics

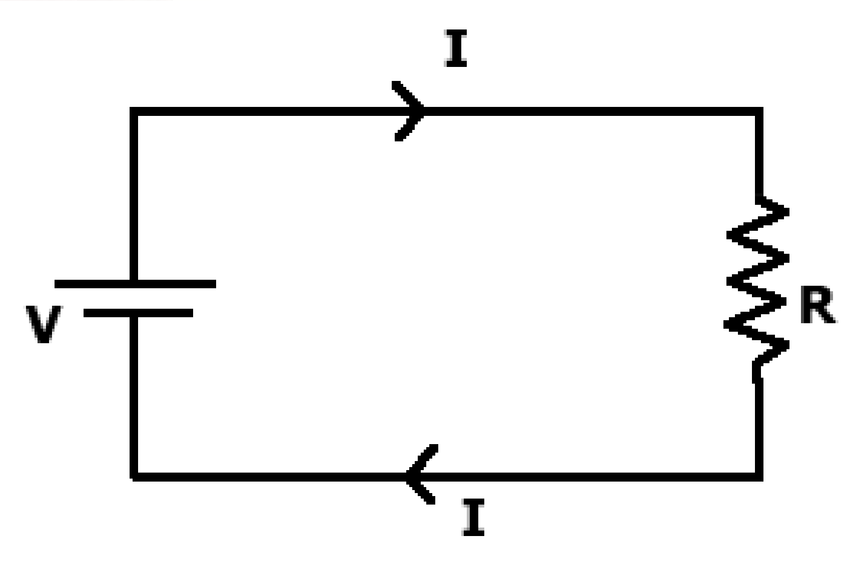
Simple circuit

- When a charged particle passes through the battery, it gains energy.
- When the particle passes through the light bulb it gives up the energy as heat.



Ohm's Law
V=IR

- V= Voltage of the Battery.
- I=current in circuit.
- R=Resistance in the bulb/resistor. (Depends on materials and geometry.)



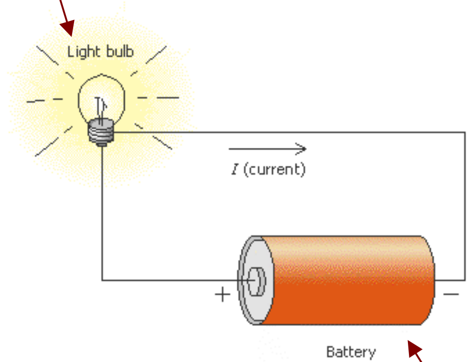
Units of Resistance

- $R=V/I$ (volts/amps)
- By definition, 1Ohm = 1 volt/amp,

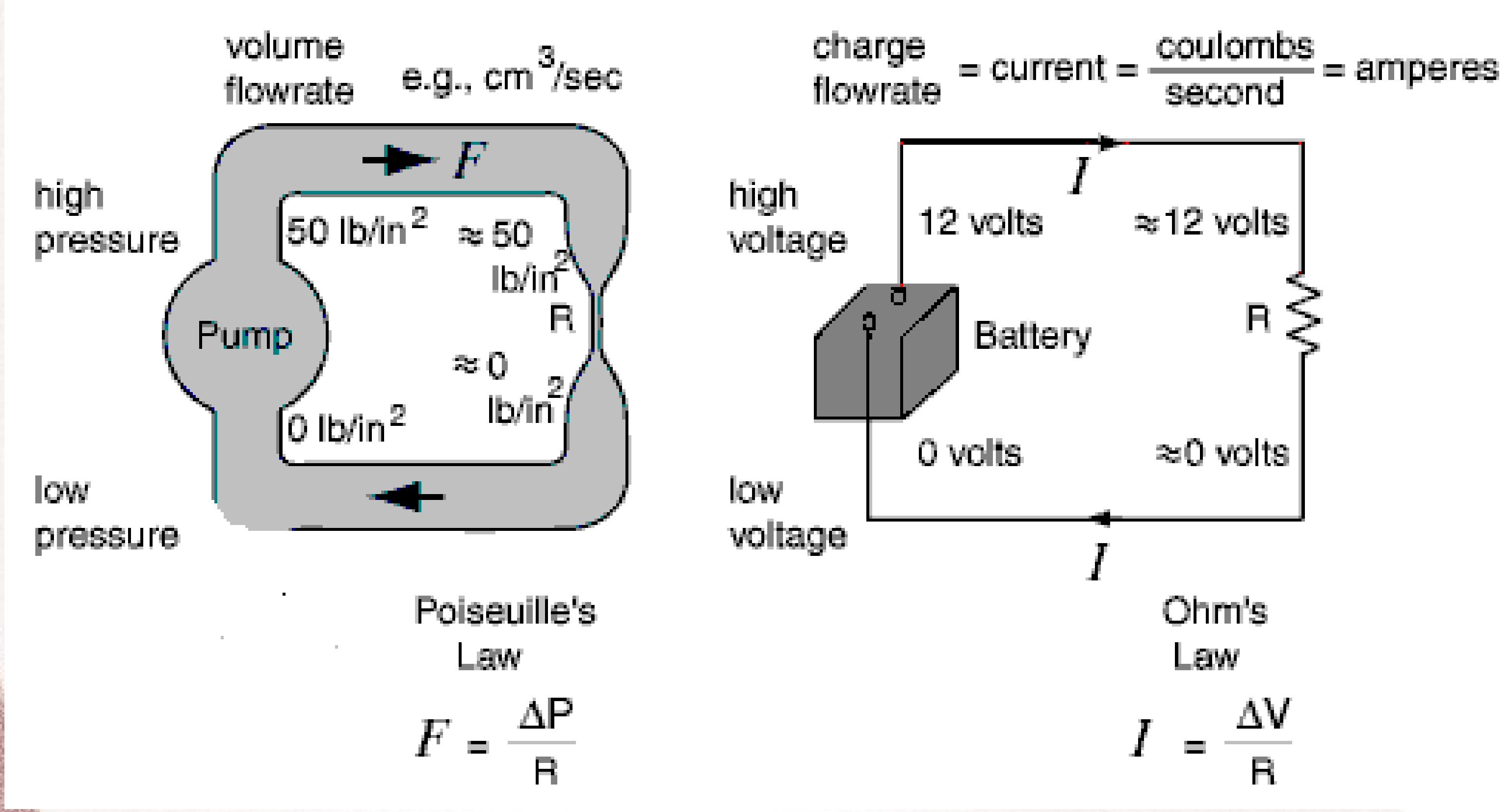
or

$$1\Omega=1V/A.$$

Log Ride Analogy



Water circuit analogy



Example problem

- How many amps of current would flow in a light bulb that has a resistance of 60Ω if it is connected to a 12 V battery.

$$I = V / R$$

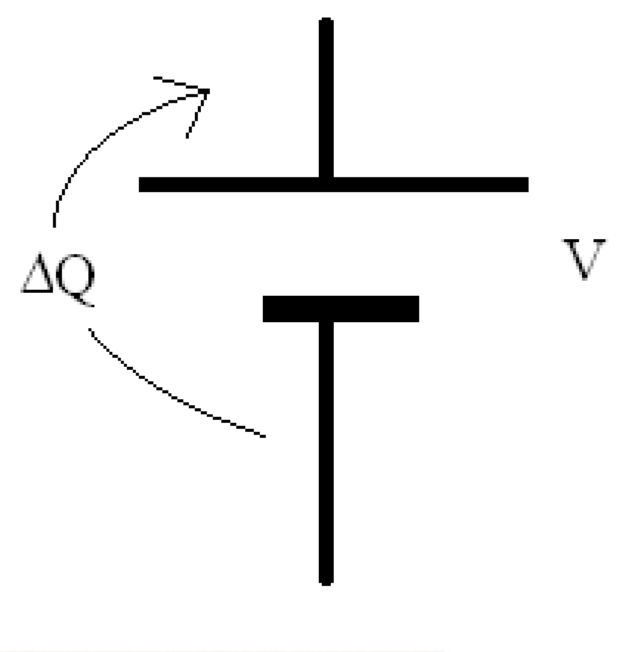
$$I = \frac{12V}{60\Omega} = 0.2\,A$$

Power in a circuit

- When Charge ΔQ passes through the battery it gains an amount of energy

  $E=(\Delta Q)V$

(This is the amount of work the battery does on the charge.)



- If the charge takes an amount of time Δt to pass through the battery, the battery supplies a power of (does work at a rate of)

$$P = \frac{E}{\Delta t} = \frac{\Delta Q}{\Delta t} V$$

$$But$$

$$\frac{\Delta Q}{\Delta t} = I$$

$$Thus$$

$$P = IV$$

- The power supplied by the battery must be dissipated in the resistor.
- We also know the V=IR.
- Power dissipated in resistor

$$P = IV = I(IR)$$

$$P = I^2 R$$

Example Calculation

What is the resistance and how much current flows through a 100 W bulb?

Note: The wattage on a bulb is its power output and assumes that you will use it in the US where the voltage in 110 V.

$$I = P / V$$

$$I = {100W}/{110V} = 0.91\,A$$

$$R = V / I$$

$$R = {110V}/{0.91\,A} = 121\,\Omega$$

- Redo the calculations for a 60 W bulb

$$I = P / V$$

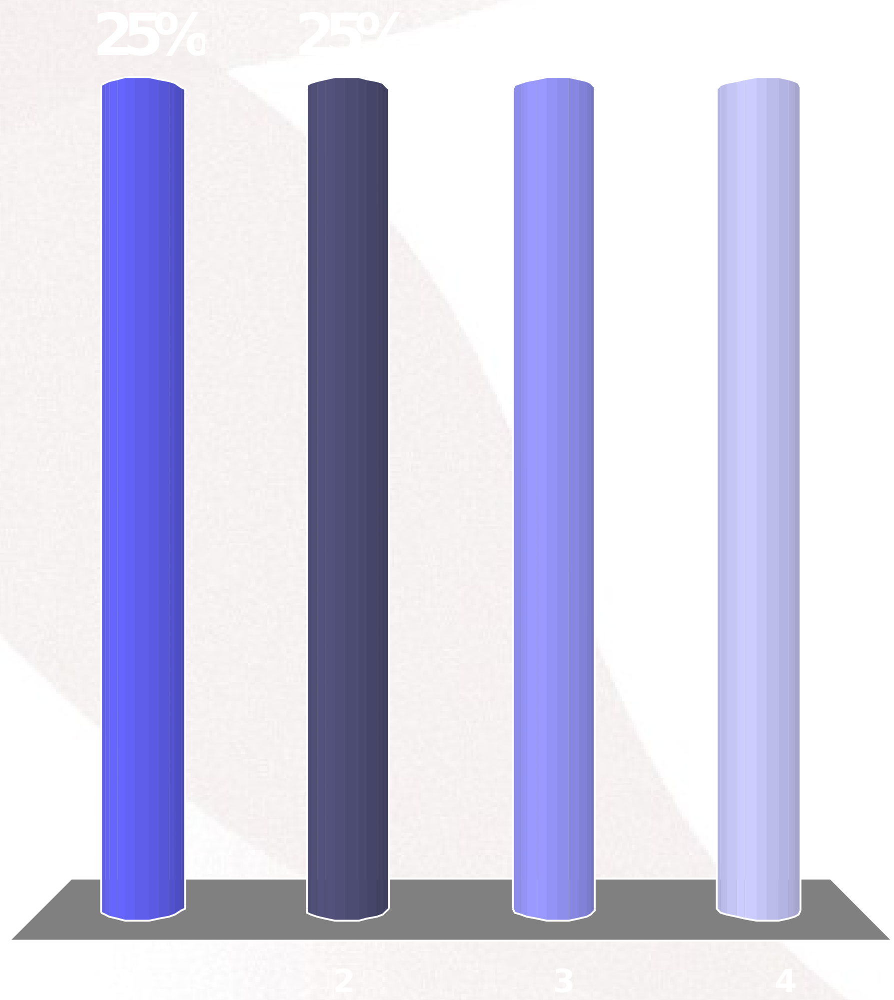
$$I = {}^{60W}\!\big/_{110V} = 0.55 A$$

$$R = V / I$$

$$R = {}^{110V}\!\big/_{0.55A} = 200\,\Omega$$

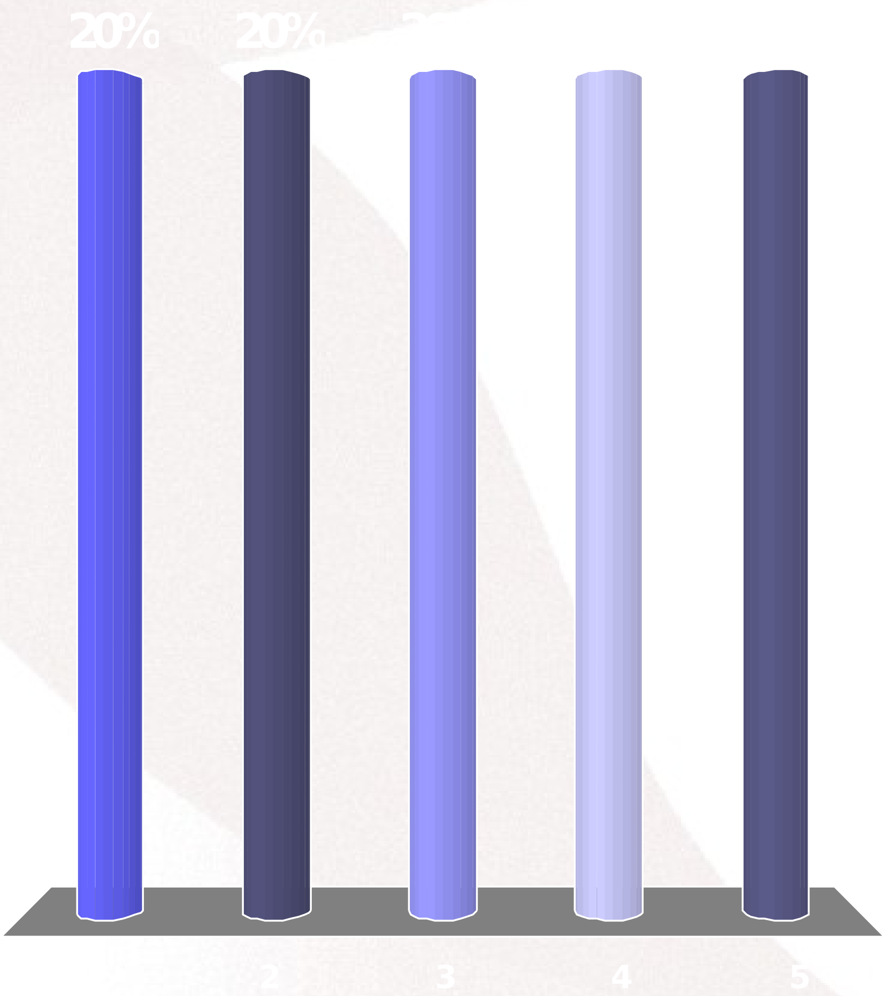
If a positive and a negative charge are sitting next to each other, which of the following is true?

1. The charges will attract each other.
2. The charges will repel each other.
3. The charges will neither attract or repel each other.
4. None of the above.



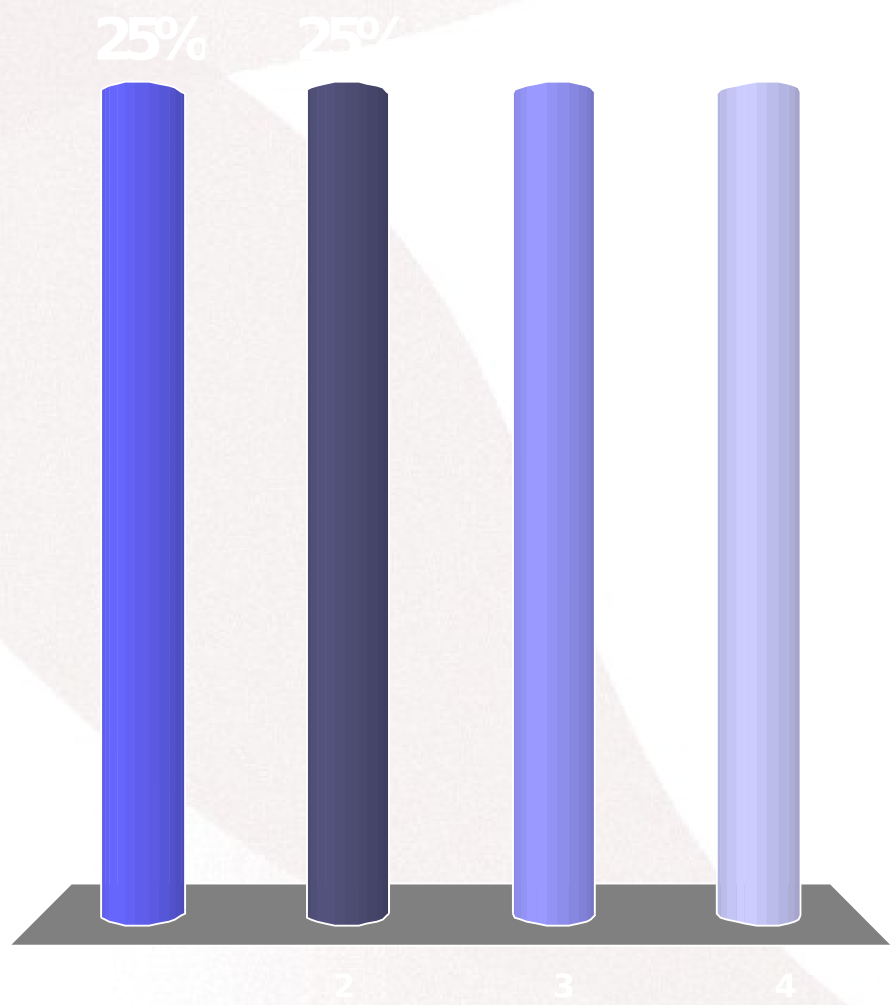
A material in which charges are free to move is called a(n)

1. Insulator
2. Conductor
3. Semiconductor
4. Convector
5. Radiator



The Mercury 2 solar car run on a 100 V battery pack. If the motor is drawing 10 A of current, How much power is the pack supplying?

1. 10 W
2. 100W
3. 1000W
4. 10000W



$$V = IR$$

$$P = IV$$

$$P = I^2 R$$

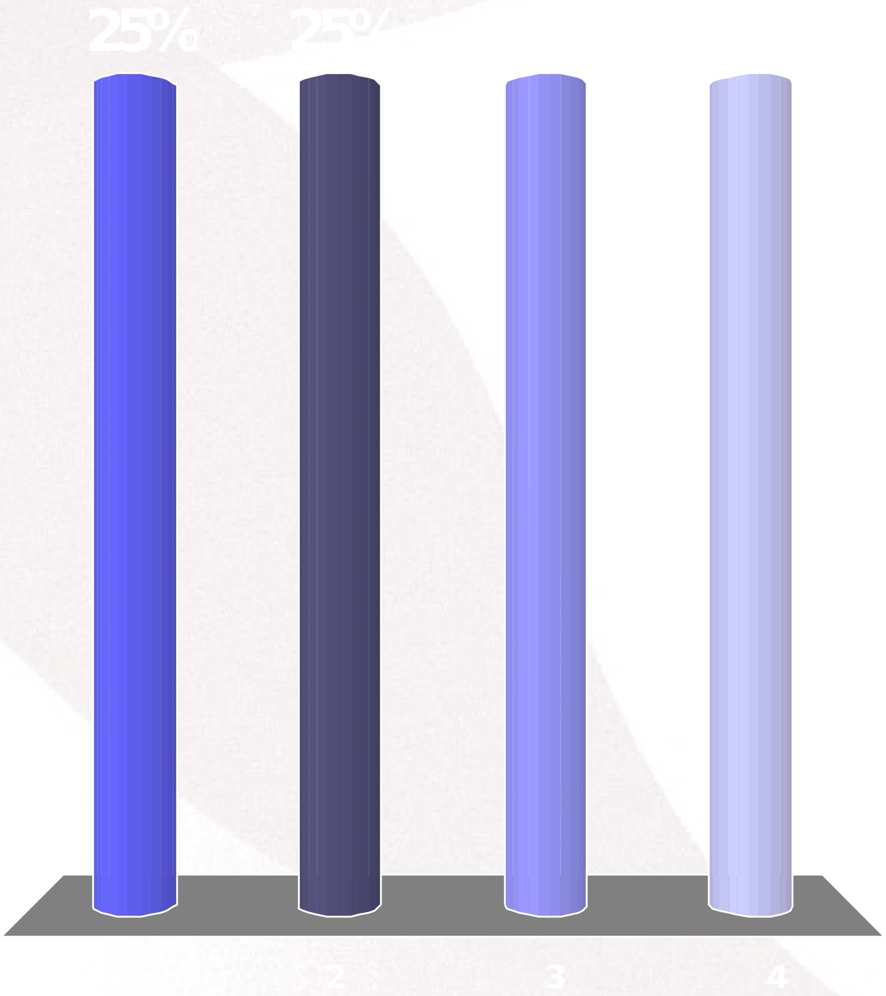
The Mercury 2 solar car run on a 100 V battery pack. If the motor is drawing 10 A of current, What is the resistance of the motor?

1. 1 ohm
2. 10 ohm
3. 100 ohm
4. 1000 ohm

$$V=IR$$

$$P=IV$$

$$P=I^2 R$$

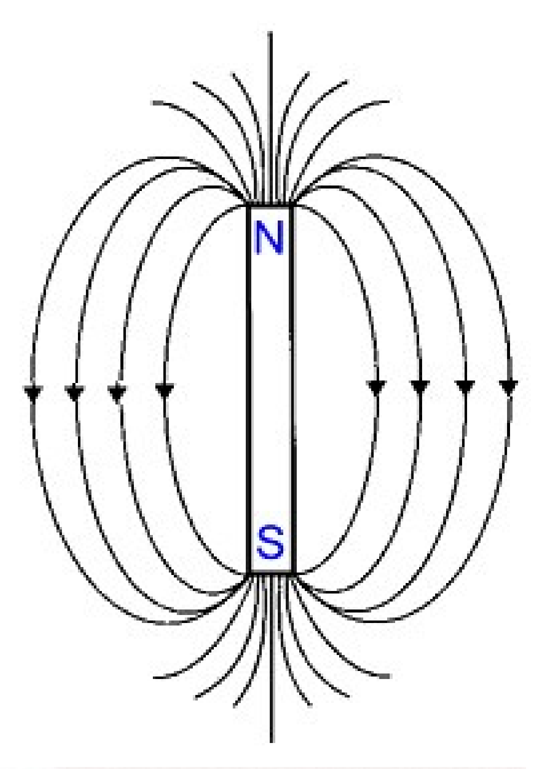


Electricity

Part 3: Magnetic fields, Faradays Law, Electrical Generation

Magnetic Fields

- Somewhat similar to electric fields, but also differences.
- 2-poles called North and South
  - Similar to +/- charges
  - Different in that N/S always come as a pair. You will never find a monopole.



- Like poles repel and unlike poles attract each other.

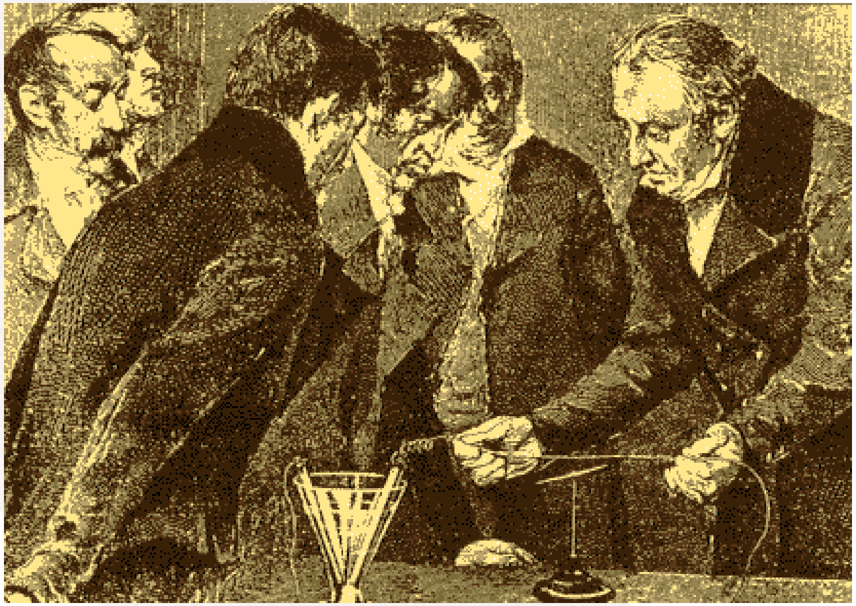
    Similar to like charge attract, unlike charges repel

    Demos: small magnets

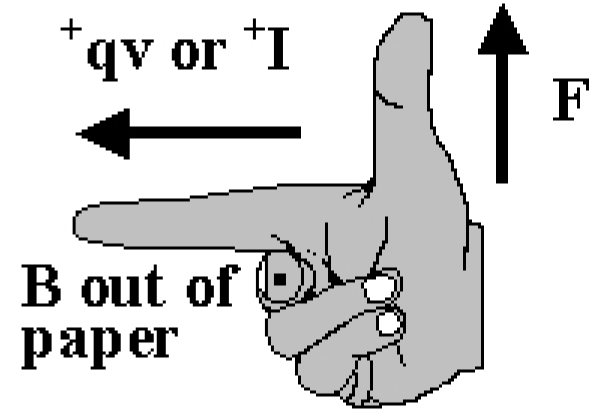
Notation: We usually use the symbol B to represent magnetic fields

Hans Oersted

- Until 1820, Electricity and Magnetism were considered to be separate phenomena.
- Oersted discovered that a current carrying wire (moving charges) deflected a compass needle, i.e. currents create magnetic fields



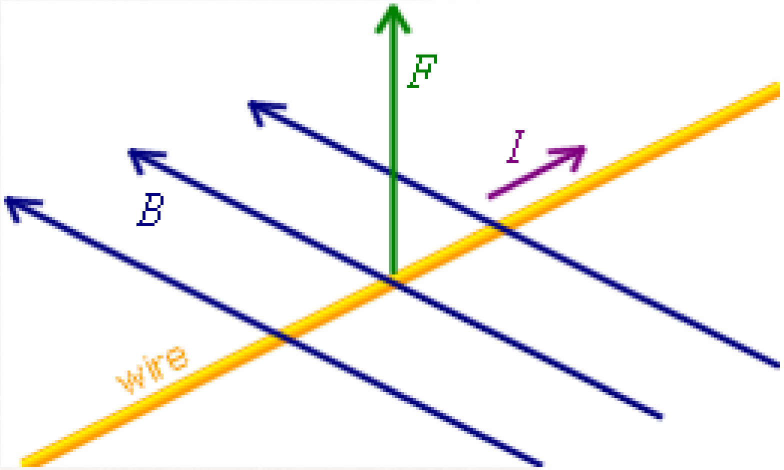
- Magnitude of the force is $F=qv_{\perp}B$
- $v_{\perp}$ is the part of the velocity $\perp$ to the B field.
- Use Right Hand Rule to find the Direction of the force.



You don't have to be able to reproduce the math on magnetic fields, but you do need to be able to qualitatively discuss magnetic fields and their role in electricity generation.

Magnetic Force on Wires

- Since a current in a wire is moving charges, they also experience magnetic forces.
- If the wire is ⊥ B then the magnitude of the force is



$$F = IlB$$

$$l = \text{length of wire}$$

Units of B

- Use force on wire equation:

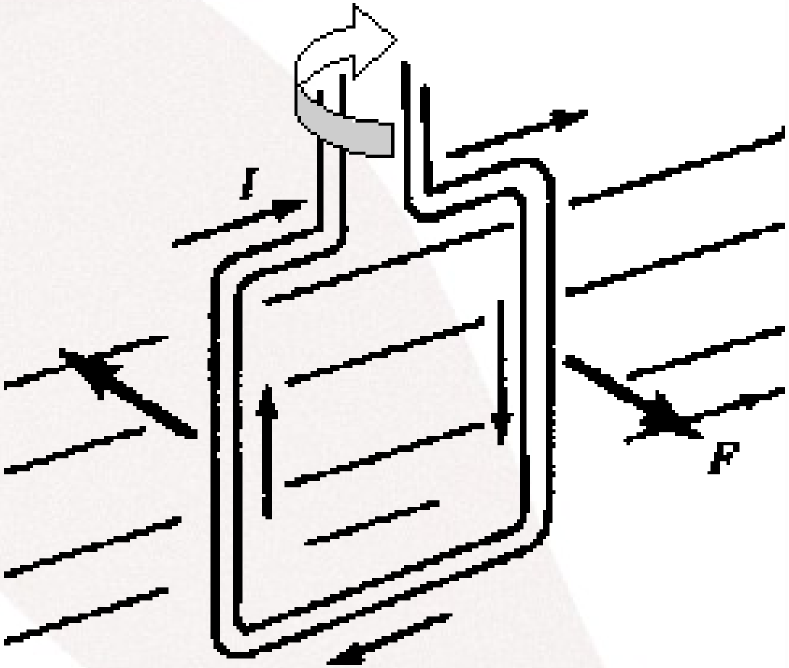
$$B = \frac{F}{Il}\left(\frac{N}{A \cdot m}\right)$$

By definition

$$1\,Tesla = 1\mathrm{T} = 1\,\frac{N}{A \cdot m}$$

Application: Motors

- Current flow in each side of the wire loop produces a force in opposite directions
- Causes loop to rotate.



Motional Potential

- When a wire "cuts" across a B-field the electrons in the wire see themselves a moving in the B-field.
- Results in a magnetic forc on the charge of F=qvB
- In diagram, electrons will all try to move down, this leaves + charges behind and creates an E-field along the wire.

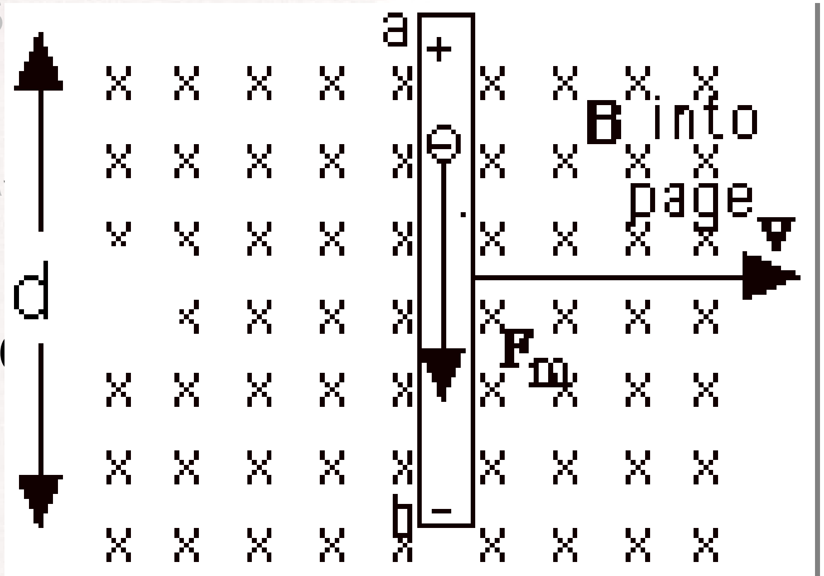


Fig. 5

- Process continues until the electric force and the magnetic force balance each other.

$$qE = qvB$$

$$E = vB$$

- The Voltage change along the wire is

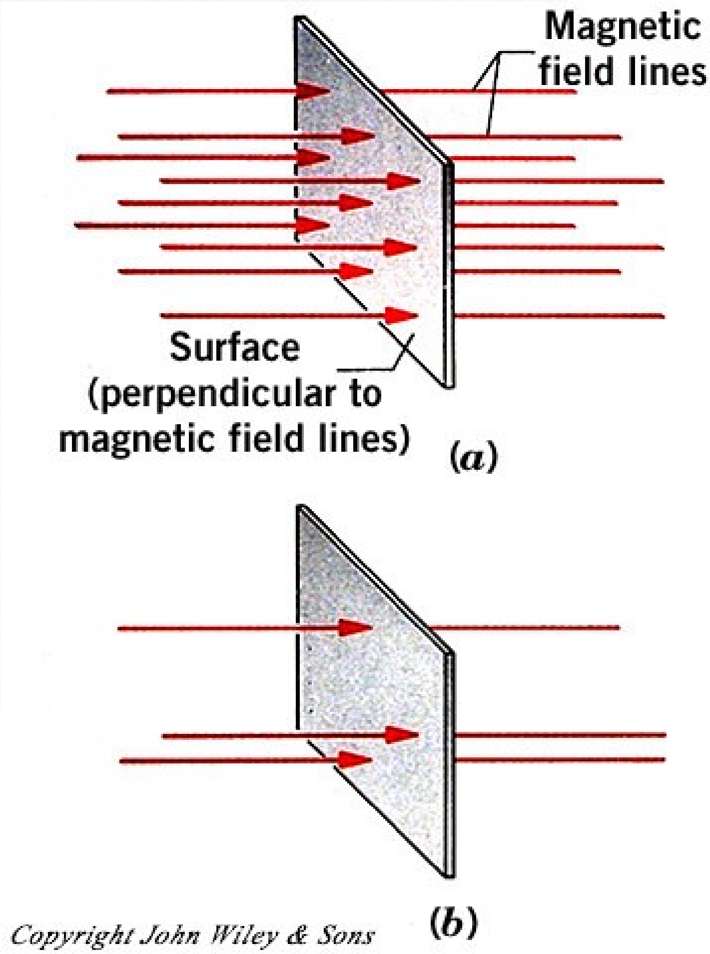
$$V = Ed$$

Or

$$V = vBd$$

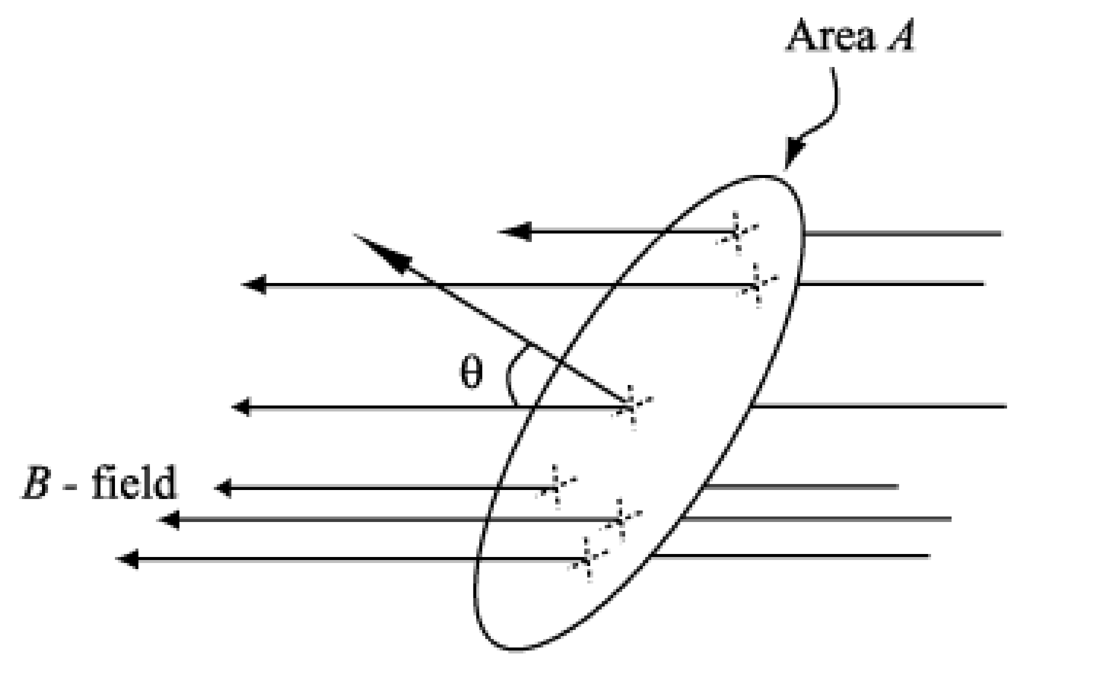
Magnetic Flux

- Flux is a measure of how much magnetic field passes through a surface
- $\Phi = BA$
- Actually only want part of B that is Perpendicular to the area.



- More generally

- $\Phi = BA\cos\theta$



Faraday's Law

- You can induce a voltage in a loop of wire by changing the magnetic flux through the loop.
- Three way to change the flux

1. Change A (usually not practical.)
2. Change B (important for a lot of uses)
3. Change θ (This is how we usually do it for power generation.)

Generators

- Basically a “backwards” motor.
- Instead of running current through the loop to get the shaft to rotate, rotate the shaft to get electrical current.
- This is what is done in essentially all power plants. You run a heat engine/water wheel/wind mill to turn the shaft.