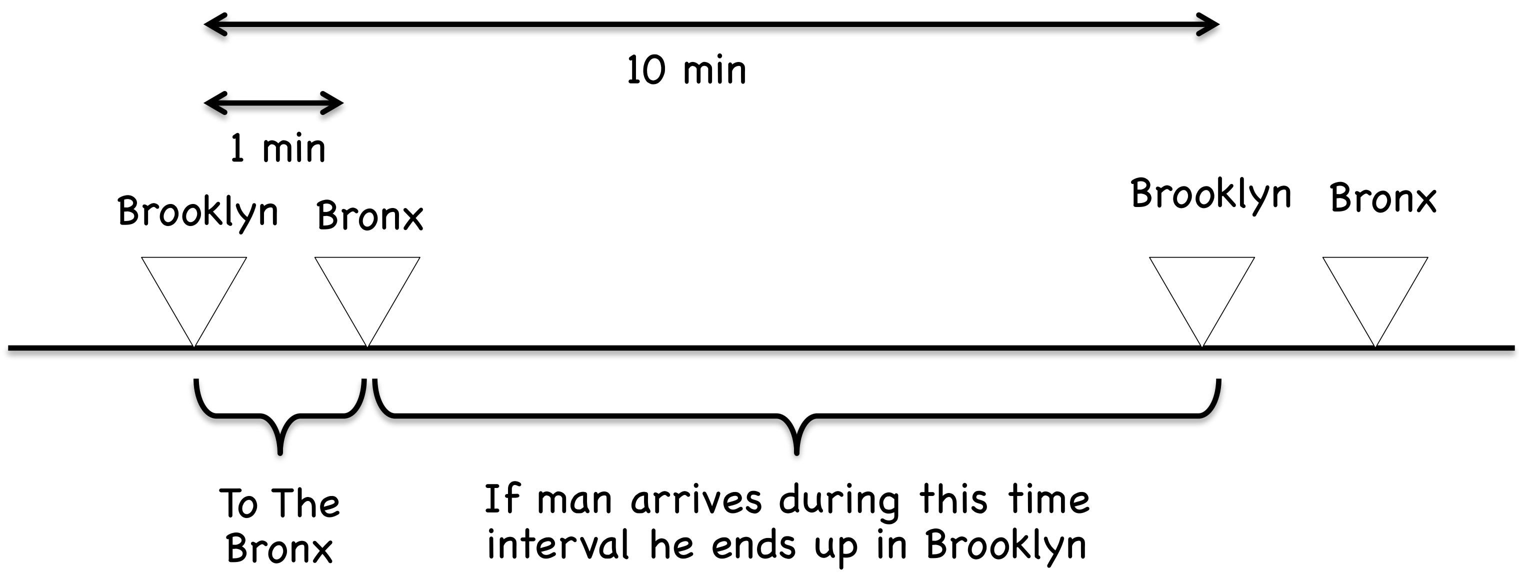
Puzzler

A young man lives in Manhattan near a subway express station. He has two girl friends, one in Brooklyn, one in the Bronx. To visit the girl in Brooklyn he takes a train on the downtown side of the platform; to visit the girl in The Bronx he takes a train on the uptown side of the same platform. Since he likes both girls equally well, he simply takes the first train that comes along. In this way he lets chance determine whether he rides to The Bronx or Brooklyn. The young man reaches the subway platform at a random moment each Saturday afternoon. Brooklyn and Bronx trains arrive at the station equally often – every 10 minutes. Yet for some obscure reason he finds himself spending most of his time with the girl in Brooklyn: in fact on the average he goes there nine times out of ten. Can you think of a good reason why the odds so heavily favor Brooklyn?

Solution: Because the Bronx train always arrives at the station one minute after the Brooklyn train.



If the man arrives at the train station at random times then 9 out of 10 times he will end up in Brooklyn.

Introduction to Audio and Music Engineering

Lecture 11

Topics:

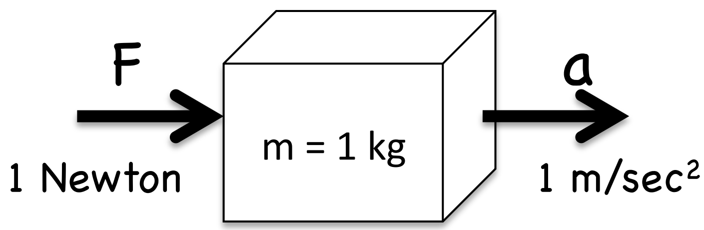
- Charge, Coulomb's Law
- Current
- Electric fields
- Voltage

Electric Charge

Coulomb's Law (1783)

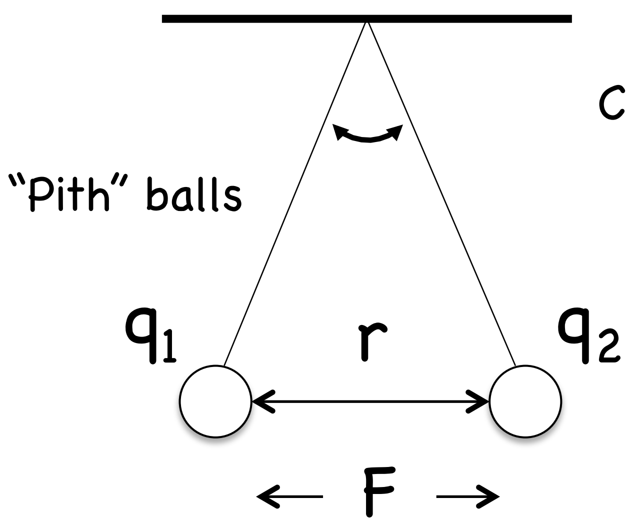
$$F = k\frac{q_1 q_2}{r^2} \text{ Newtons} \qquad k = 8.988 \times 10^9 \text{ Nt-m}^2/\text{Coul}^2$$

1 Newton is the force required to accelerate 1 kg by 1 m/sec^2



Newton's 2nd Law

$$F = ma$$



Charge can be + or −
- Like charges repel
- Opposite charges attract

For:
- $q_1 = q_2 = 1$ Coul
- r = 1 meter
- F = 8.988×10^9 Nt

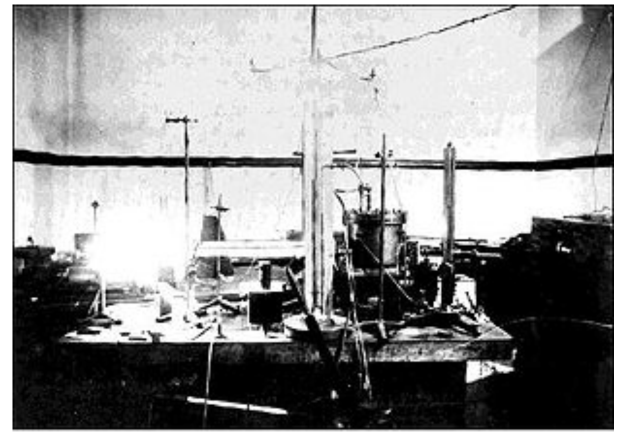
That's a huge Force!

Enough to levitate about 5000, 200 ton locomotives!

1 Coulomb is a lot of charge!

1897 – J.J. Thompson discovered that charge comes in "corpuscles" – electrons

1908 - Millikan measured the charge of a single electron

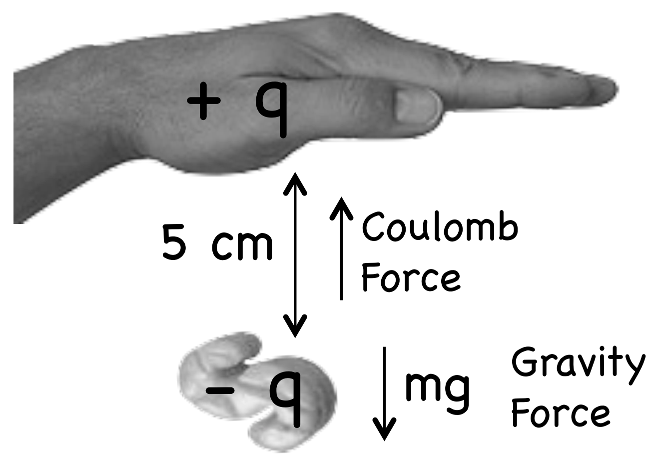


1 electron = 1.602×10^{-19} Coulomb

1 Coulomb = 6.242×10^{18} electrons

Problem: Coulomb's Law

When you are unpacking objects packed in styrofoam "peanuts" the peanuts usually stick to everything! How many electrons would there need to be on a styrofoam peanut of size 1 cm^3 to be picked up by your hand from a distance of 5 cm? Assume that the styrofoam peanut and your hand both have the same amount of charge on them, but with opposite signs. (the density of styrofoam is about 0.035 $gram/cm^3$ and the Earth's gravitational acceleration is $g = 9.8\ m/sec^2$.



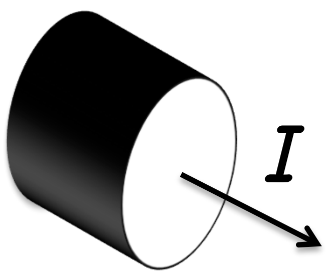
Answer: 6.1×10^{13} electrons

Electrical Current

For our purposes it's not important that charge is made up of discrete particles – we will treat charge like a fluid that is infinitesimally divisible.

$-q \rightarrow$ surplus of electrons

$+q \rightarrow$ deficit of electrons



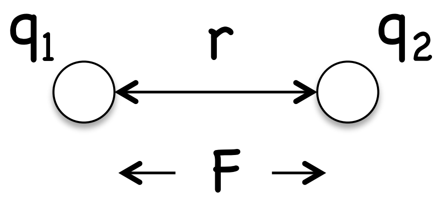
1 Ampere = 1 Coulomb/sec

+ current corresponds to positive charge moving in the direction indicated by arrow

Positive direction $\longrightarrow$

$\xrightarrow{+q}$	Positive current	$\xleftarrow{+q}$	Negative current
$\xrightarrow{-q}$	Negative current	$\xleftarrow{-q}$	Positive current

Another look at Coulomb's Law …

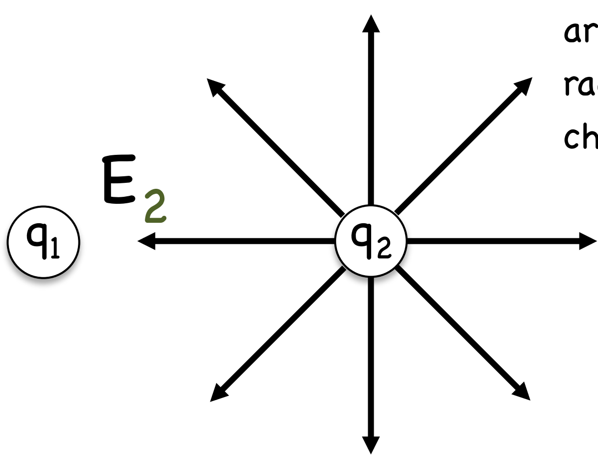


$$F = k\frac{q_1 q_2}{r^2}$$

Electric Field: E

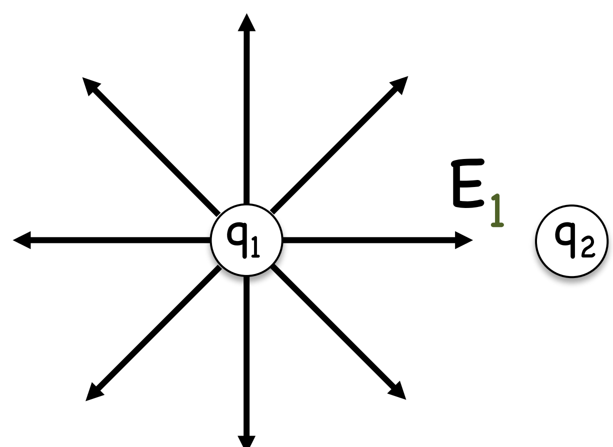
$$F = q_1\left(k\frac{q_2}{r^2}\right) = q_1 E_2$$

where $\quad E_2 = k\frac{q_2}{r^2}$



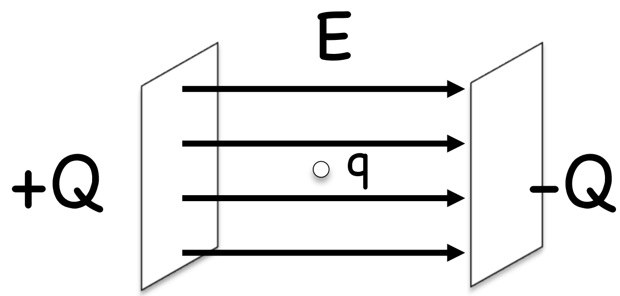
$F = q_1E_2$

Electric field lines are directed radially from the charge q_2



$$F = q_2\left(k\frac{q_1}{r^2}\right) = q_2 E_1$$

Electric Field between two charged plates



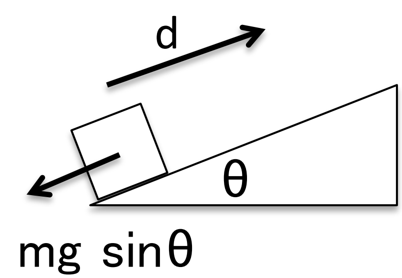
$F = qE$

Electric field points from +Q to -Q

To move the charge against the electric field force requires that we do <u>work</u>.

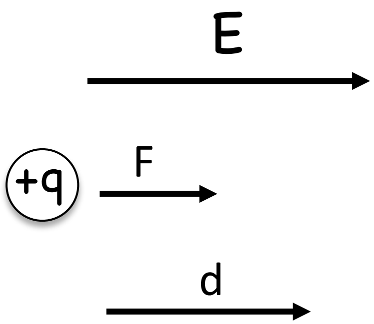
$W = F \times d$

Work "Energy"   Force   Distance



$W = mg\sin\theta \times d$

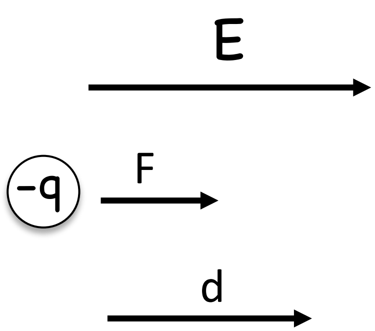
Force, Work and Energy



W = qE x d

= positive

→ so work is done by the electric field on the charge (energy is added)

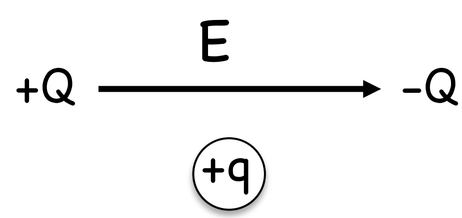


W = -qE x d

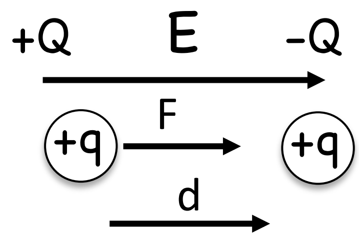
= negative

→ so work must be done to move the charge

Remember: opposite charges attract.



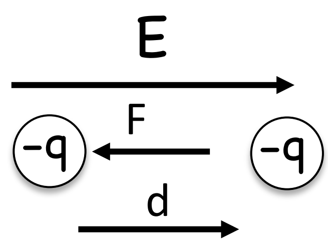
Electric Potential (Voltage)



The charge is moving in the direction of the E-field force.

→The E field does work on the charge (adds energy).

→ So we say that the charge moves from a higher to a lower electric potential.

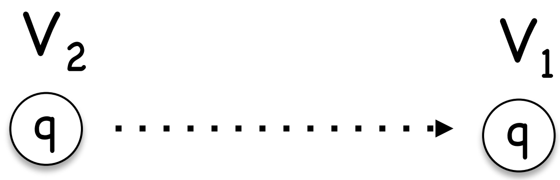


The charge is moving against the direction of the E-field force.

→Work must be done to move the charge against the force (spend energy).

→ So we say that the charge moves from a lower to a higher electric potential.

Electric Potential (Voltage)

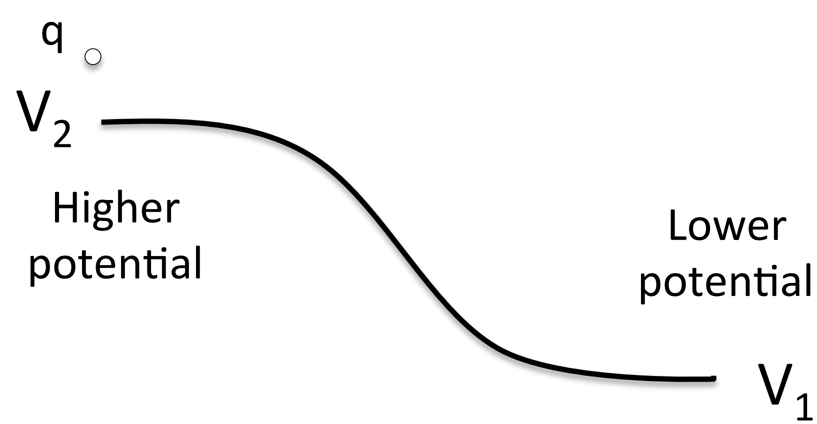


$$\Delta V = V_2 - V_1$$

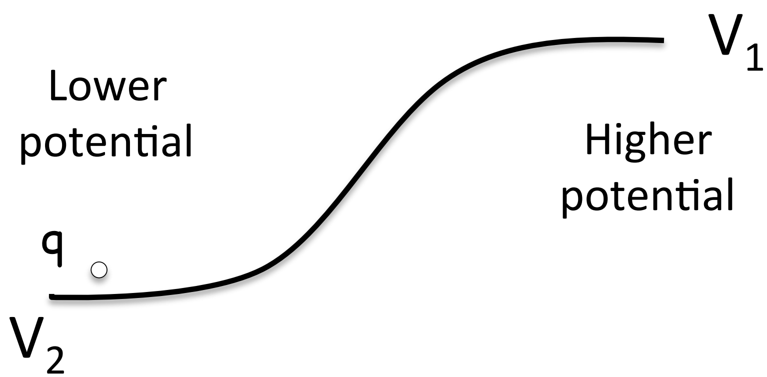
Work done by the Electric field to bring a charge from potential V_2 to V_1

$$W = q\Delta V = q(V_2 - V_1)$$

So, if q is positive and $V_2 > V_1$ the field does work (adds energy) to the charge.



If q is positive and $V_2 < V_1$ we have to do work to move the charge.



Only the difference in potential matters – we can set the zero of voltage any place we wish.

So rather than writing ΔV we just use V for the voltage (potential) difference between two points.