Physics 2B

Fall 2014
Lecture: MWF 11:30 am - 12:20 pm

Prof. Ignacio Mosqueira

Office Hours:

MWF: 10:30 - 11:30 am

Science 262

or by appointment

Ignacio.Mosqueira@sjsu.edu

Course Materials

Required Text:

College Physics, 9th Edition: Serway & Vuille.

Including Chapters 15- - 30 (Vol 2)

Lecture Slides

Made available on Canvas

Many online resources

MIT, OPEN courses, Wikipedia, Hyperphysics

Syllabus

Evaluation:

Students will receive a letter grade based upon the following:

1. Homework/Quizzes. 20% of grade.
2. Lab. 10% of grade.
3. Three midterm exams + final. 70% of grade.

A+: 95-100%   A: 90-95%   A-: 85-90%

B+: 80-85%   B: 75-80%   B-: 70-75%

C+: 65-70%   C: 60-65%   C-: 55-60%

F: Below 55%

Test Formats

Quizzes

Tricky problems, combination of solo work and group work

Midterms

Multiple Choice

Conceptual Questions and Quantitative Problems/Derivatives

Homework

Homework is given on a week long basis.

Homeworks include problems written by me, Conceptual questions from the book, and Quantitative problems from the book.

Start them early!!!

Don't Cheat!

- Only turn in your own work

Learning Objectives

Electric Force and Electric Fields
DC Electric Circuits
Magnetic Fields
Magnetic Induction
AC Electronic Circuits
Reflection and Refraction of Light
Lenses and Optical Instruments
Interference and Diffraction of Light Waves
Atomic Physics

Time to Jump into it

Any questions?

Chapter 15

- Charged Particles
- Insulators and Conductors
- Coulomb's Law
- Electric Fields (Lines)
- Electrostatic Equilibrium
- Gauss' Law (Electric Flux)

Charged Particles

Electrons and Protons

Convention:

electrons - negative

protons - positive

Each has a fundamental amount of charge:

$1.6*10^{-19}$ Coulombs

Total charge in a system is additive.

of e^- = # of p^+

neutral, zero charge

of e^- > # of p^+

negative net charge

of e^- < # of p^+

positive net charge

Atoms, what we interact with

Atoms:

Made of electrons, protons, and neutrons (no charge)

Electrons: mass = $9.11*10^{-31}$ kg

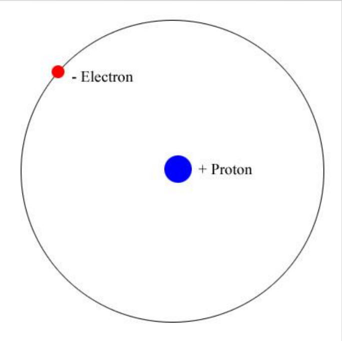
Protons: mass = $1.67*10^{-27}$ kg

Neutrons: $1.67*10^{-27}$ kg

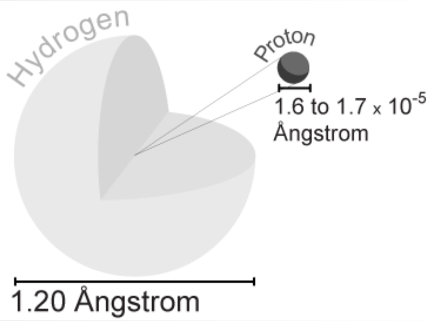
Protons and Neutrons make up the nucleus at the center, while electrons orbit around the nucleus.

There are exotic particles that go beyond the scope of this class that may get mentioned in the last week.

Simple Atom



Hydrogen - The most abundant atom in the universe. Simple Hydrogen is made of 1 proton and 1 el



What makes it hydrogen is that it only has 1 proton.

Add neutrons to make it heavier.

Steal the electron to make it positively charged.

Add electrons to make it negatively charged.

Larger Atoms

More protons in the nucleus.

  # of protons in nucleus = atomic number

Atomic Mass

  # of protons + # of neutrons (on average)

Isotopes

  different # of neutrons, changing the mass

Ionized Atoms

Not Ionized is neutral, # of e^- = # of p^+

Ionized atoms have a net charge.

Positive ions, or cations, are formed by the loss of electrons.

Negative ions, or anions, are formed by the gain of electrons.

Importance of Electrons

Electrons are shared

Electrons can leave an atom

Ionized atoms interact differently due to their charges

Bulk Distribution of Charges

Molecules are made up of many atoms.

Bulk materials can be made up of all the same type of atom, or normally different molecules.

The charge distribution in these materials depend on the molecules that make up the material, especially how charge moves in the material.

Conductivity

How easily charge moves through a material.

If charge moves easily it is a conductor.

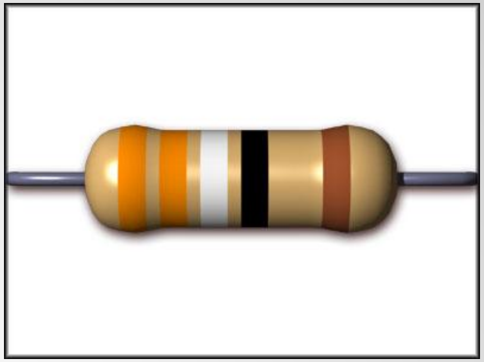
If charge stays in one place, it is called an insulator.

<u>Conductors:</u>
Copper, Silver, Gold, Aluminium, Platinum

<u>Insulators:</u>
Glass, Plastic, Rubber, Air, Wood

... shiny metals

Resistivity



Resistivity is the opposite of conductivity. Resistivity is how the material opposes movement of charge.

A perfect insulator would have infinite resistivity.

A perfect conductor would have zero resistivity.

A nice list of materials can be found on this Wikipedia Page:

http://en.wikipedia.

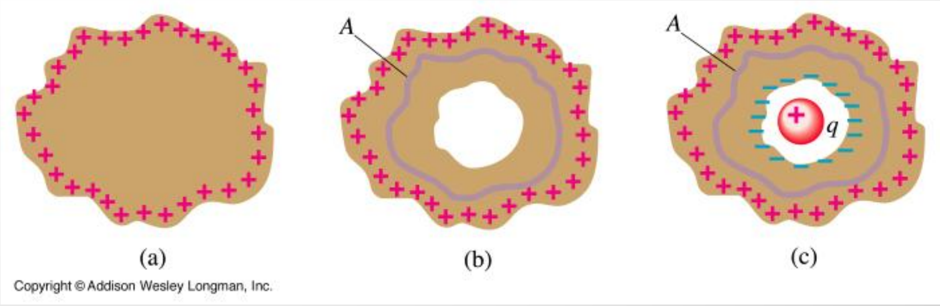
Charges on Conductors

Charges are free to move around on conductors

How the charges move depend on how charges interact with each other.

This is the focus for the next 2 weeks.

How to charges interact with each other and why? Not just on conductors but on insulators or loose from bulk materials.



The Basics

Opposites Attract while Sames Repel

Let's add some nouns:

Opposite charges attract each other such as an electron and a proton.

Like charges repel each other such as many electrons on the surface of a conductor.

Classic in Class Example

Glass Rod and Pelt

Or balloon example

What Happened to My Hair?

I placed a negative charge on your hair ...

... but how?

1. Electrons are stealable from atoms that make up the ground.
2. Rubber Insulator scrapes ground and steals some electrons, stored in charge clumps
3. When you touch it, you are an ok conductor, charge spreads over your surface area
4. Hair has large area and so lots of the charge.
5. Sames charged strands repel and spread

Why does My Hair Relax After?

You are surrounded by large conductive surfaces that can neutralize your charge.

On average spaces are normally neutral

Unless you are separated from your environment by insulators like rubber, latex and wood, you will conduct charge back and forth with your environment. Depending on whether you or the thing in more negatively charged.

Neat Trick

What you need:

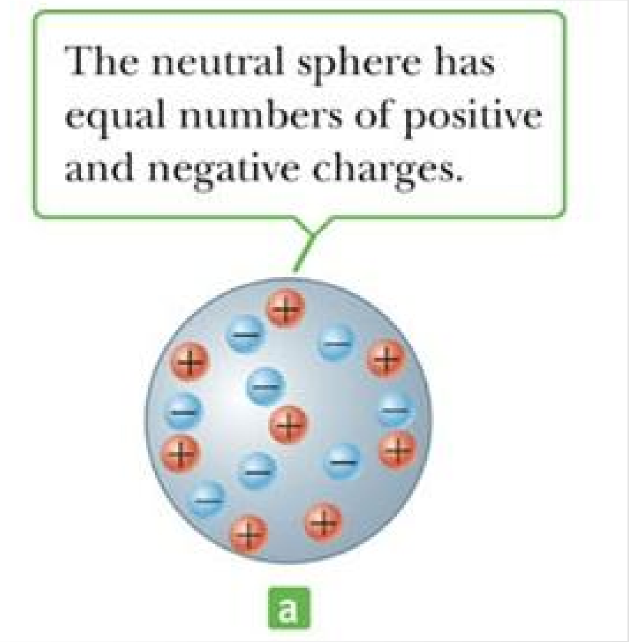
- Charged Rod (Insulator)
- Piece of Neutral Conductor
- Wire (Conductor)
- One very large Conductor ("Ground")

Neat Trick

Step 1

Place Neutral Conductor on a Neutral Insulator surface

(dry wood table)



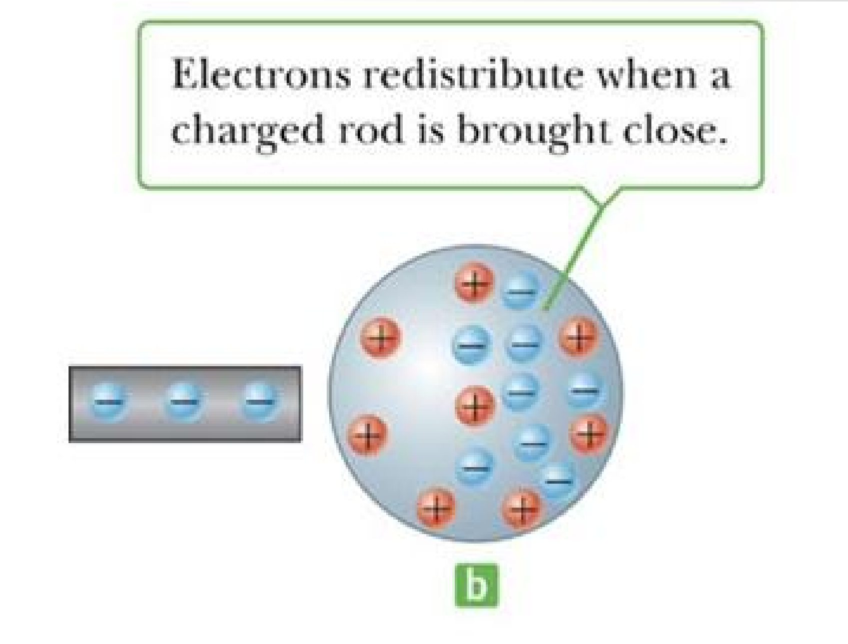
Notice number and distribution of charge

Neat Trick

Step 2

Take Charged Insulator and place it near Conductor

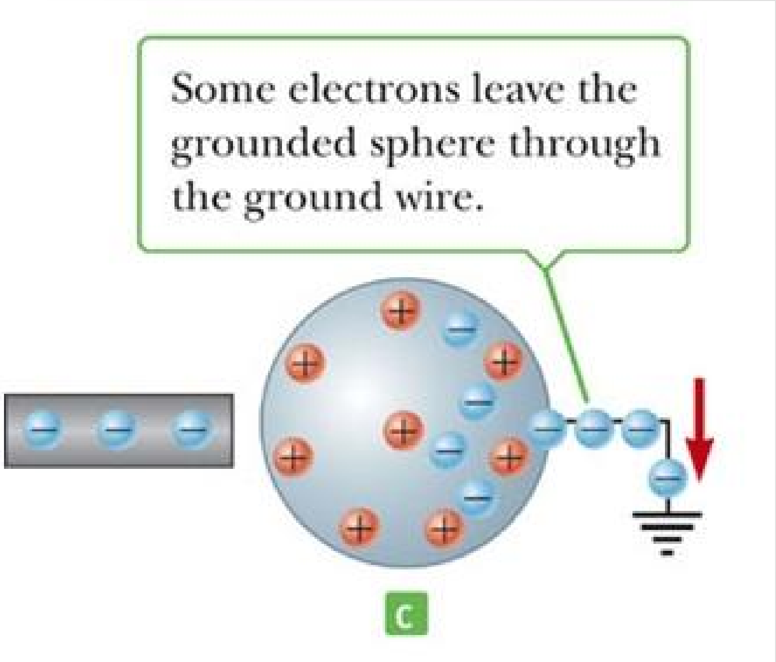
This induces an Electric Field (Next Lecture)



Neat Trick

Step 3

Use Wire to attach Negative end of Conductor to Ground



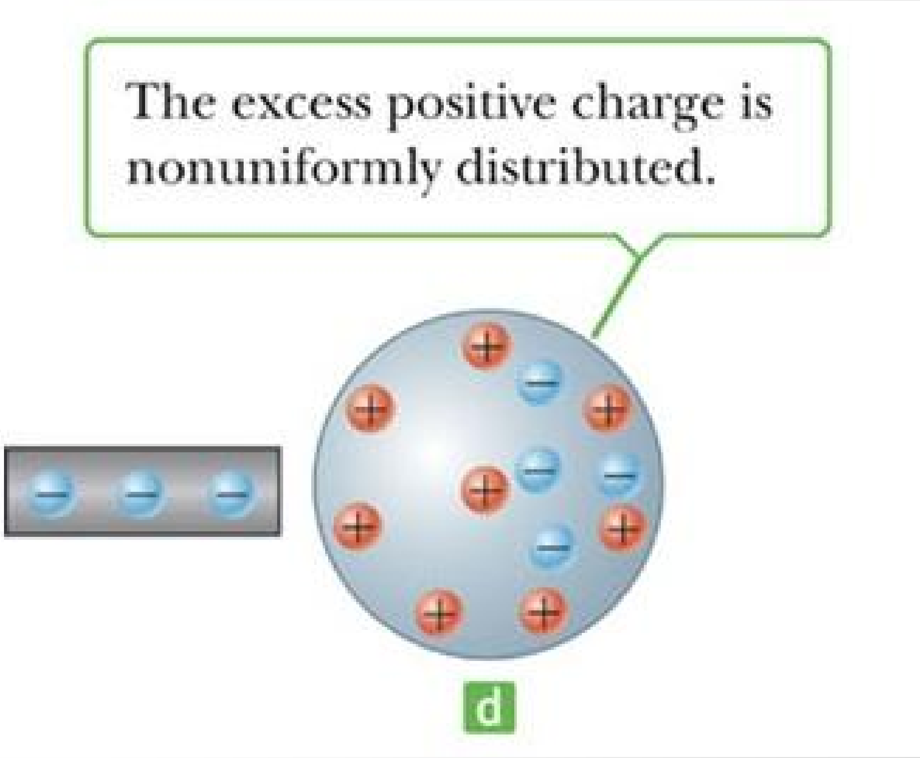
This is like when you touch the charged bit of balloon and charge spread over you

Neat Trick

Step 4

Detach Ground

Note the imbalance of charge on the conductor in number and distribution

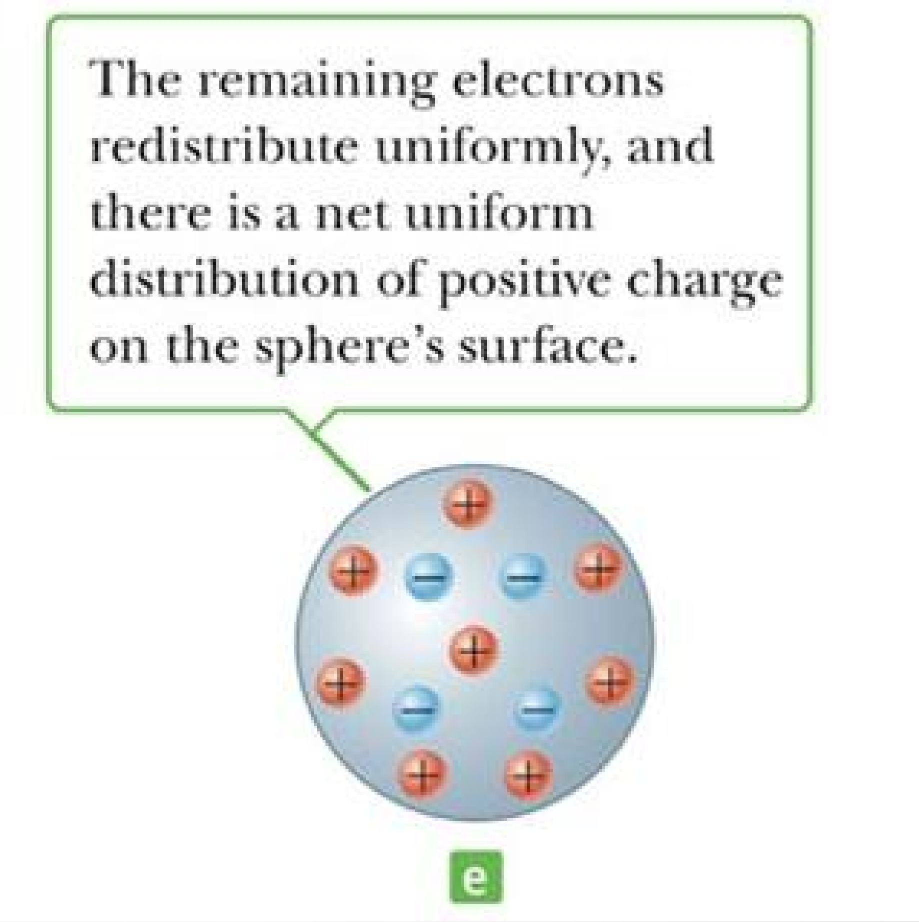


Neat Trick

Step 5

Remove Charge
Insulator

To reveal a charged
Conductor



How Charge Moves

Conduction

Charge moving because something touches the charged region

Induction

Charge moving without two objects touching.

Both are due to the force of one charge on another which we have only covered in the most simple terms.

Coulomb's Law

F : Force on on one charge from the other

k : a constant of nature

8.99*10^9 $Nm^{2/}C^2$

q_1 : charge 1

q_2 : charge 2

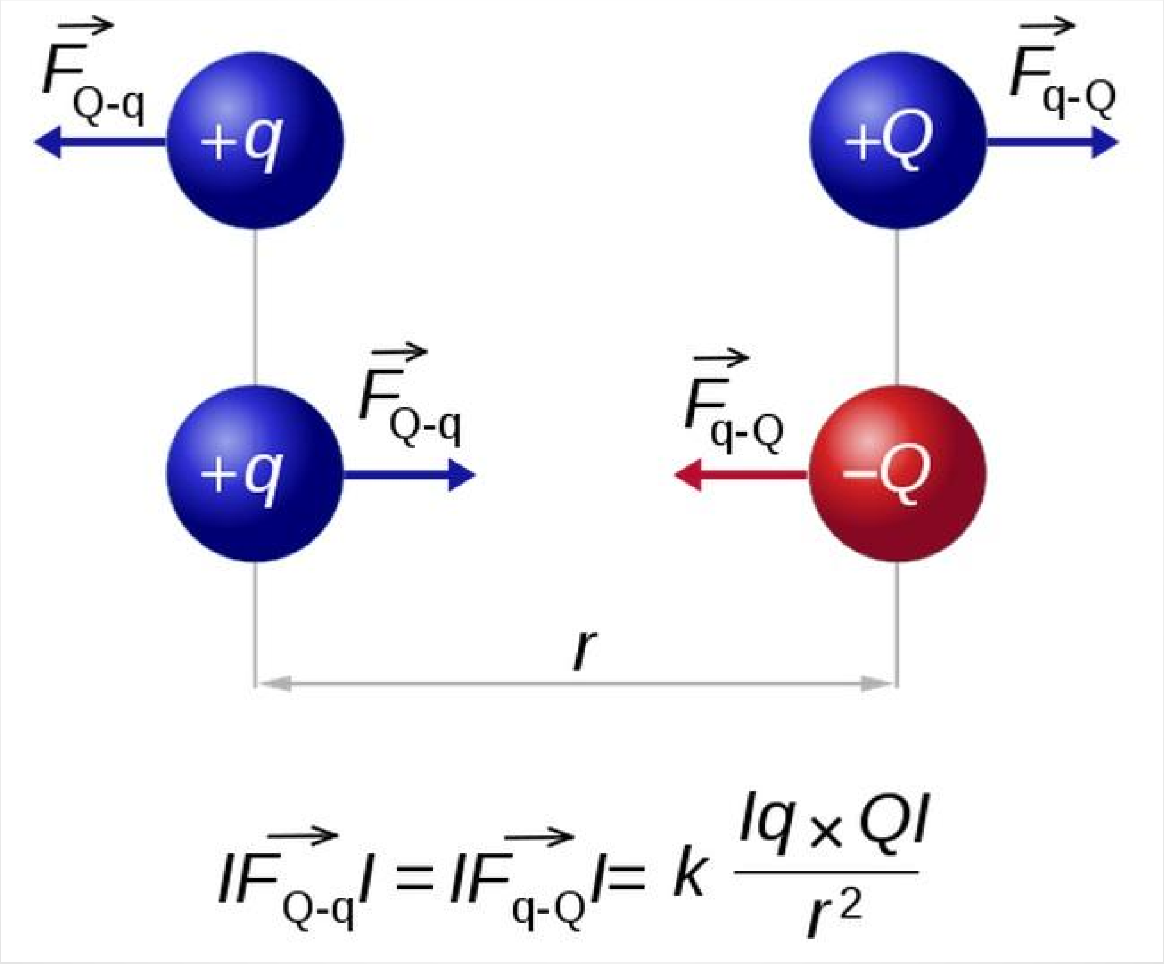
r : radial distance

$\hat{r}$ tween the charges

: direction or radius

$$\vec{F} = \frac{kq_1q_2}{r^2}\ \hat{r}$$

Does this Confirm what we already know about charges?



Coulomb's Law vs. Newton's Law of Universal Gravitation?

1. Charge can be negative or positive
2. Electric Forces can repel or attract
3. Net charge of universe is about neutral

1. There is only positive mass
2. Gravitational is always attractive
3. Net mass of the universe is positive

But which one is stronger?

Hydrogen Atom (Gravity vs Electro.)

What is a hydrogen atom?

What do we need to know about electrons and protons?

Notice that they are both $1/r^2$ laws.

We can now look at the ratio of the two forces.

(Work done on board and in book.)

$F_E > F_G$!!

Why don't electric forces dominate the earth's orbit instead of gravity?

Is gravity an important element of how an atom works?

Superposition

Sum of the Forces on an object is equal to the mass multiplied by the acceleration of an object.

This is just like vector addition of forces from 2A.

Determine all the forces that act on the particle.

Break them into x and y components.

Superposition, 3 charges

- Draw example
- Determine Force directions and components
- Calculate Force Magnitudes
- Add Together
- Determine Total Force Magnitude and Direction

(Work done on board and in book.)

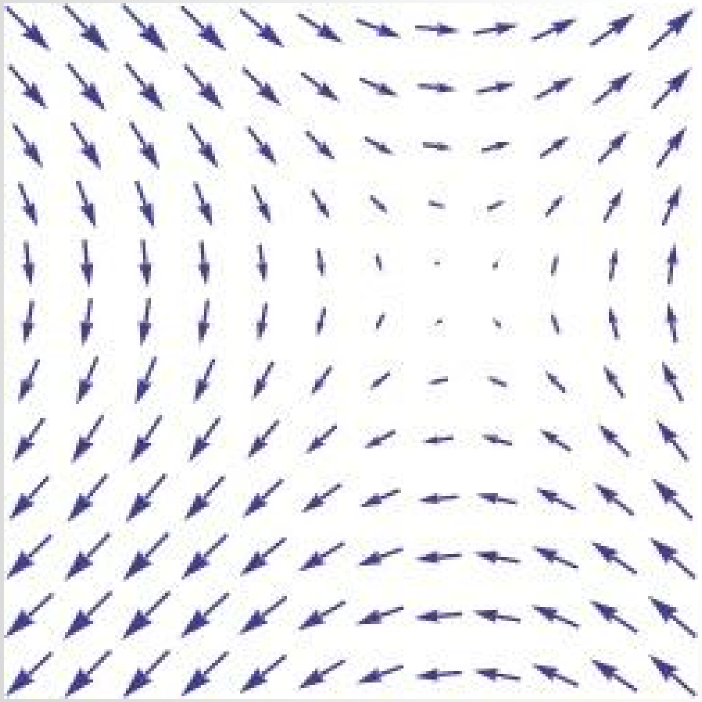
What is a vector field?

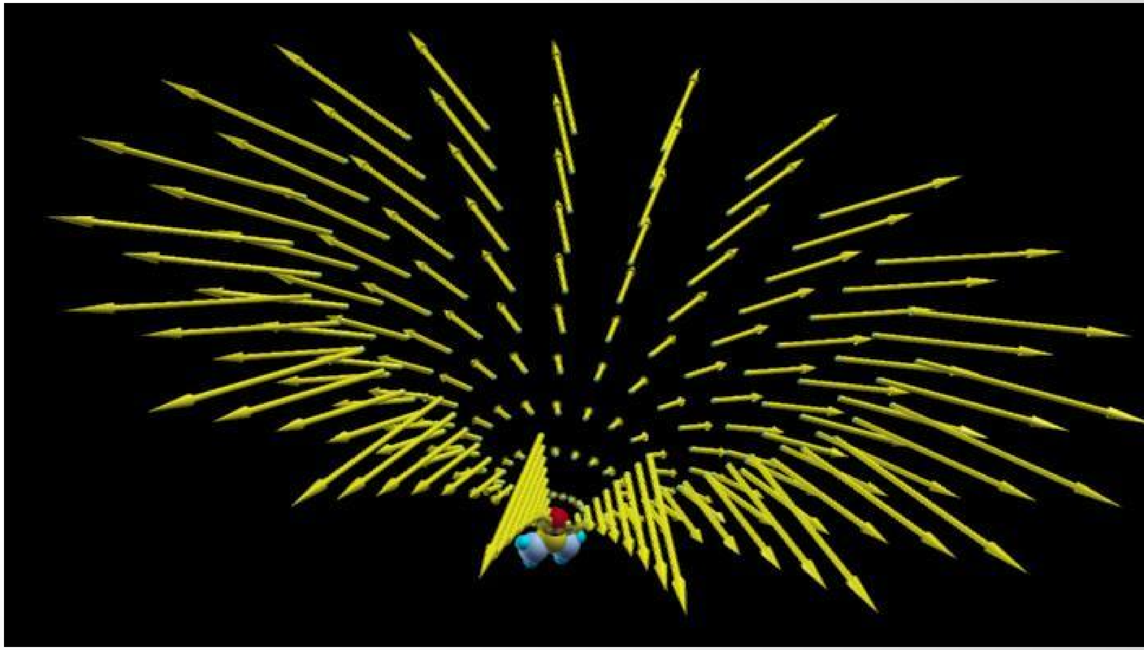
A vector field shows a vector property at many spots.

In the grass field, you can see the direction of the wind.

2D or 3D

It can be a 2D or a 3D field



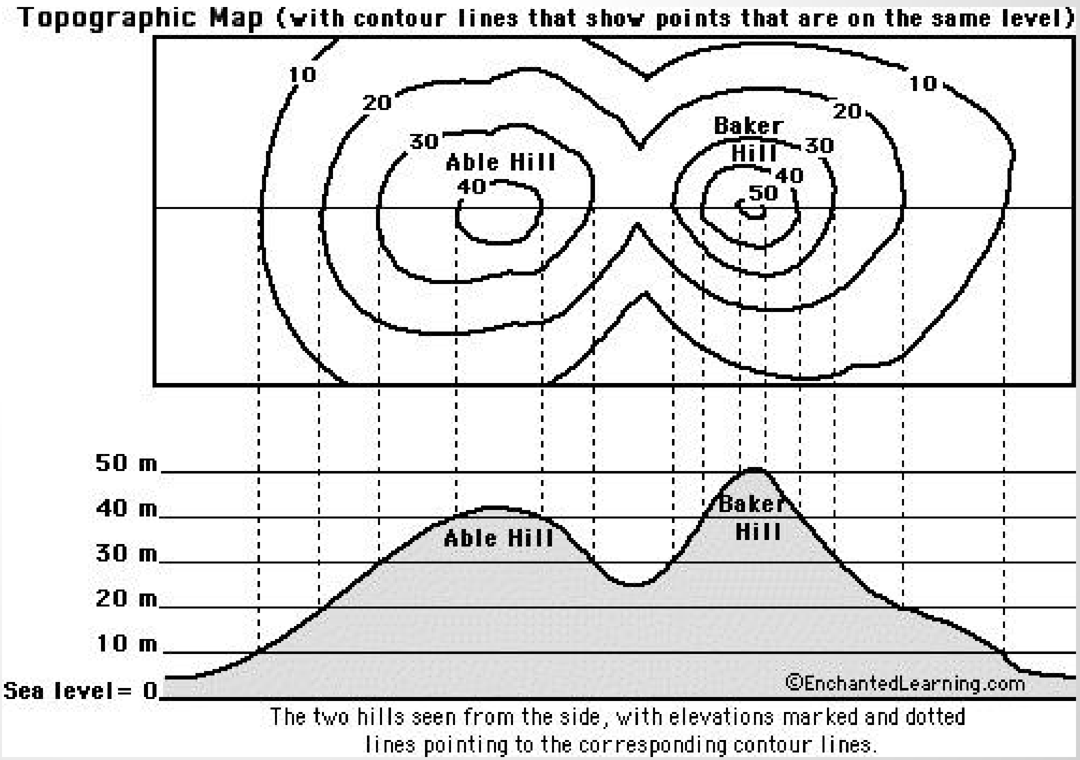


As you can see, it helps in visualizing information.

How is this different from a map?

A map shows scalar quantities at each position.
(in higher math there is vector mapping, but that is beyond what I want to cover here)

Each position has a scalar value associated with it.



Keep this in mind

Whether the thing in question is a vector or a scalar is very important.

Using maps and fields can help visualize not just their distinction, but how they interact.

What do we already know?

Scalar Quantities

Vector Quantities

Important connections

Gravitational fields:

Electric and magnetic fields

Gravitational and spring potential energy:

Electric potential energy

Mass/gravity superposition:

Charge/electric field superposition

Remember conservation laws as well

Electric Fields

What? $$E = \frac{F}{q} = \frac{kQ_{source}q}{qr^2} = \frac{kQ_{source}}{r^2}$$ in the radial direction

Why?

The electric field is independent of the charge put into the system.

How?

Add together the field from all sources to find the electric field at the prefered point.

No really why?

The direction of the force changes depending on the charge placed in the system, while the electric field doesn't depend on the test charge.

It is useful in determining voltages, current, and advanced optical properties of materials.

The flux of the electric field has a really cool property.

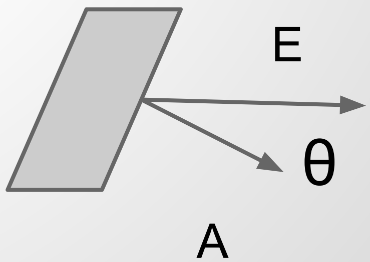
...well I think so.

Wait, What... Flux?

Flux is the the amount of a property that goes through an area. But it has to be in the same direction as the area vector.

Terminology is normally flux into or out of a surface.

Electric Flux = Φ = E A cos (θ)



Area points perpendicular to the surface

Help Visualize this with Field Lines

An electric field line is a continuous line that goes from a positive charge to a negative charge.

There should be a consistent ratio between the charge of a source charge and the number of electric field lines entering or leaving a source.

Let's see some distinctions at this website:

http://www.physicsclassroom.com/class/estatics/u8l4c.cfm

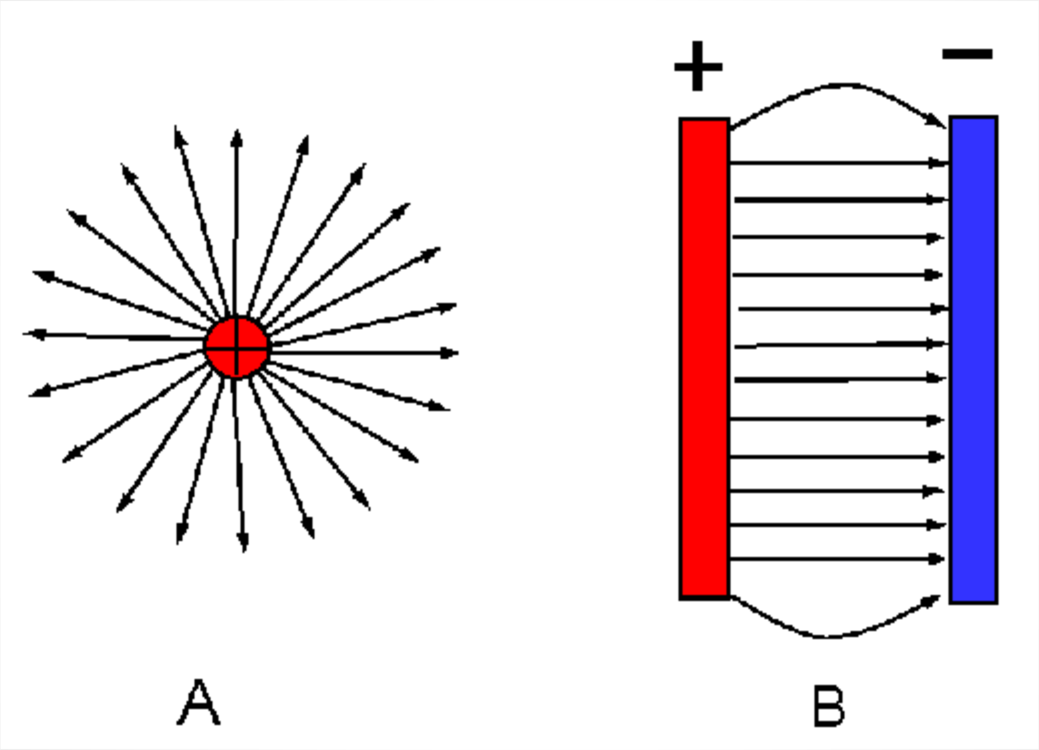
What does the E Field line Mean?

The Electric field line is the path a charged particle would take if it was released stationary into the electric field.

In lab 2 you will be looking at the connection between electric field lines and electric potential, we will get to that soon.

The density of lines tells you about magnitude while the path tells you about direction.

Field lines point perpendicular to charged surfaces



We will discuss a ring after we finish discussing electric flux.

Electric Flux around charges

We are considering the total surface as a whole that encompass a charge. (closed surfaces)

If a line goes in one side and out another, it cancels out and has no effect on the total flux.

For that reason, only charged sources inside the surface have an effect on the flux.

Flux around a point charge, Gauss's Law (simple derivation)

Define the surface: a sphere of radius R centered on the charge.

$\Phi = E\,A\cos(\theta)$ ... E and A are both radial

θ is 0 or 180° assume positive E so θ is 0.

$E = kQ_{enc}/R^2$ $\quad A = 4\pi R^2$ $\quad k = 1/4\pi\epsilon_0$

$\Phi = (1/4\pi\epsilon_0)*(Q_{enc}/R^2)*(4\pi R^2)$

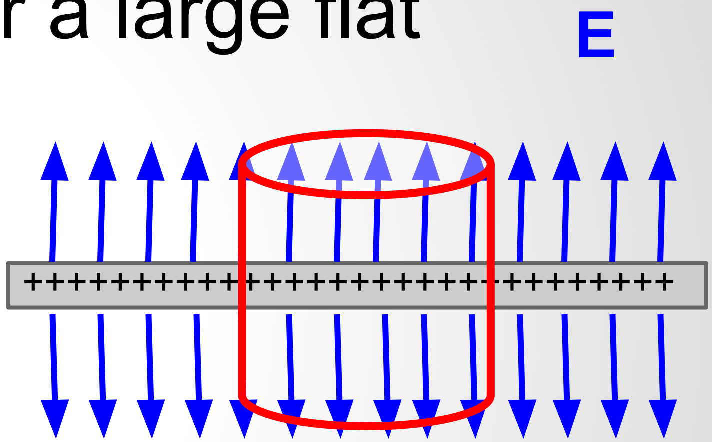
$\Phi = Q_{enc}/\epsilon_0$

And this is true in general for any closed surface since you see the independence of position!

The Flux can be used as a tool!

What is the Electric field near a large flat charged conductive plate?

$\Phi = E\ A \cos(\theta) = Q_{enc}/\epsilon_0$



Closed surface is best as a cylinder.

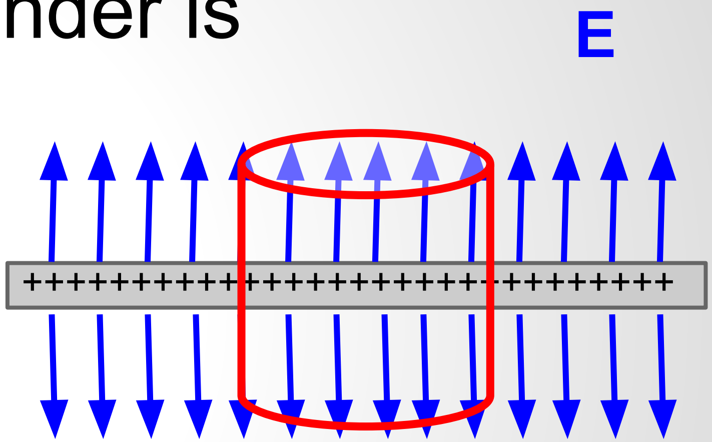
To determine total flux, the flux through each part of the surface must be considered.

Total Flux

Area vector out the side of cylinder is perpendicular to E.

So flux outside is zero.

There are 2 identical sides, top and bottom.



$\Phi = 2 * EA_{top} = Q_{enc}/\epsilon_0$

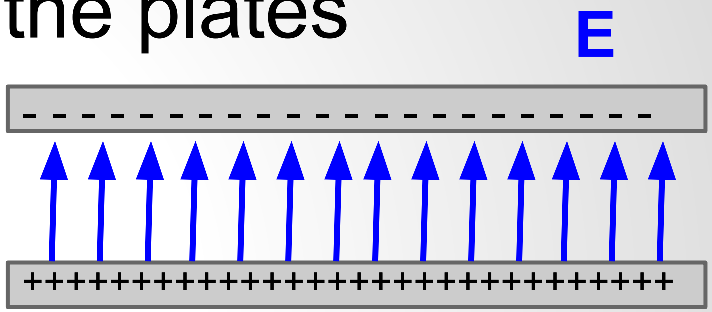
$E = Q_{enc}/A_{top}2\epsilon_0$

But, Q_{enc}/A_{top} is charge surface density, σ

Outside a flat conductor $E = \sigma/2\epsilon_0$ outwards

What about a Capacitor?

In a capacitor the charge on the plates is equal and opposite, so they have the same charge density.



The E field from the negative plate points towards it, while the positive plate points away from it, which means the two fields superimpose to double what it is from a single plate.

Gaussian Surface

The closed surface that defines the total electric flux.

They should be chosen to take advantage of the symmetry of the charge distribution.

Surface of a conductor is an ideal Gaussian Surface

Conductors in Electrostatic Equilibrium

Unbalanced charge is pushed to the surface.

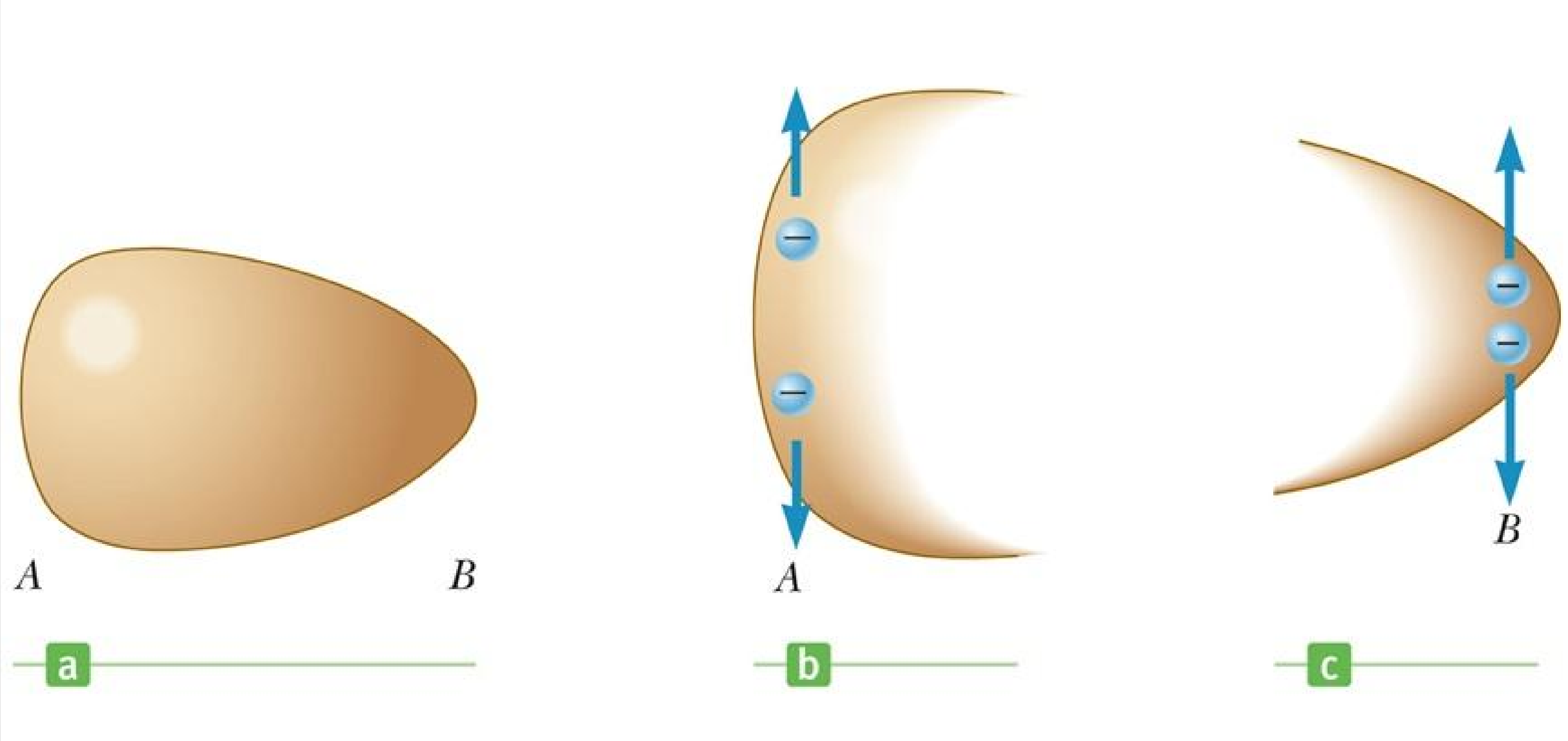
Since the net charge inside a conductor is zero, the flux and electric field inside the conductor when stationary is zero.

The electric field leaves the conductor perpendicular to the surface.

What about with weird shapes?

Why more charge density at the tip?

Charges on the surface are pushed around according to Coulomb's Law.



Topics Covered So Far Include:

- Charge Carriers
- Conductors and Insulators
- Conduction and Induction
- Coulomb's Law
- Electric Fields
- Electric Field Lines
- Electric Flux and Gauss's Law
- Conductors in Electrostatic Equilibrium

Let's do some example problems!

Before we move on: Charge Distributions

- Individual charges: q
- Charge per length: λ L: length
- Charge per unit area: σ A: area
- Charge per unit volume: ρ V: volume

$$Q_{TOT} = \Sigma q \text{ or } \lambda L \text{ or } \sigma A \text{ or } \rho V$$

Expect quiz and midterm questions on total charge given a certain charge density in a volume.

Chapter 16

Electric Potential Energy and Electric Potential (They are different things)

Equipotentials and Electric Field Lines/Surfaces

Capacitance

Capacitor Circuit

Combinations of Capacitors

Energy Stored in a Capacitor

Dielectrics

Electric Potential Energy

$U = \Delta PE = -$ Work to assemble charges

Work $= W = F^*\Delta r \cos(\theta) = F^*\Delta x$

Where x and F are in the same direction

For Electric Forces, $F = qE$

$\Delta PE = - qE_x{}^*\Delta x$ (x could be any direction)

Or between 2 charges

$PE = kq_1q_2/r$

You can use this in conservation of energy problems.

Electric Potential (also called Voltage)

$V = PE/q$

Voltage Difference

$\Delta V = - E_x * \Delta x$ or $E = - \Delta V/\Delta x$

Electric Field is the negative slope of Voltage

Voltage Near a charge is

$V = kq/r$

Voltage differences can be measured with a voltmeter as you will do in Lab 2*... and throughout semester

Relationship Between E and V

E is the negative 3 dimensional slope of V

Lines and surfaces of constant voltage (equipotential or isopotential lines) are perpendicular to Electric Field lines

Electric field lines point from high to low potential much like they point from positive to negative charges.

Show/Use all these in Lab 2*

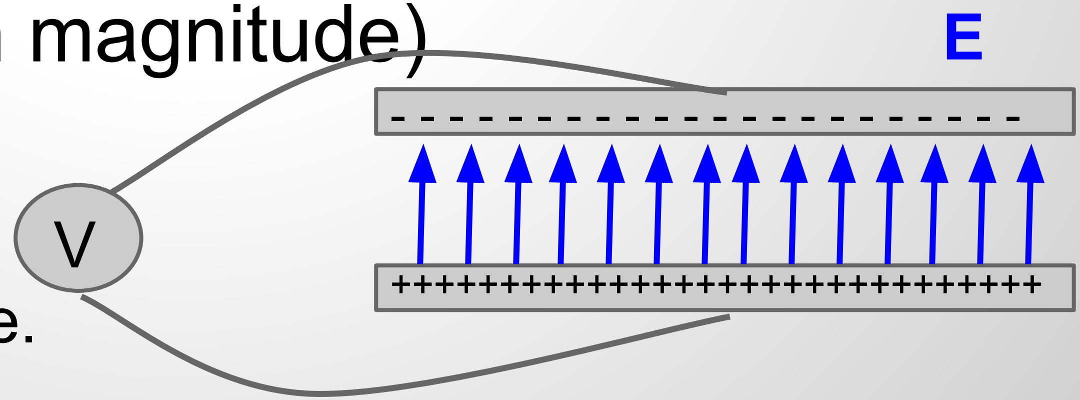
Consider a Capacitor

We know the Electric field in a capacitor given the charge density: $E = \sigma/\epsilon_0$

The voltage measured across the capacitor is measured across the separation distance of the capacitor: $\Delta x = d$

so $\Delta V = \sigma d/\epsilon_0$ (in magnitude)

Note, this does not tell you the voltage at each plate, just the difference.



What about Potential Energy?

$PE = q\Delta V$ ... but what q?

What is the bit of charge

that moves through a circuit?

Electrons!

This is why, in electronics and Quantum mechanics, energy is commonly referred to in eV (Electron Volts) instead of J (Joules).

Note 1 eV = $1.60 * 10^{-19}$J

What does this mean in a Circuit

Kirchhoff Laws

Loop Law

$\Delta V = 0$ over closed loop

Junction Rule ... once we learn about current

When Measuring, direction matters.

$\Delta V_{bat} + \Delta V_C = 0$

So how does this relate to the charge on the capacitor?

Charge on a Capacitor

Capacitance is how much charge the capacitor can hold when a specific voltage difference is applied: $C = Q/\Delta V$

Usually written $\Delta V = Q/C$

This voltage is used when a capacitor is in a circuit and Kirchhoff's Loop Law is being used.

Defining Capacitance

$C = Q / \Delta V$

$= Q /(\sigma d/\epsilon_0) = Q\epsilon_0 / \sigma d$

But $\sigma = Q/A$ or $Q/\sigma = A$

$= A\epsilon_0 / d$

the permittivity of free space

$\epsilon_0 = 8.85*10^{-12}\ C^2/Nm^2$

Permittivity is how well a space responds to an electric field. Dielectric materials have different permittivities.

Dielectric Capacitors

$C = A\epsilon / d$ where $\epsilon = \kappa\epsilon_0$

Where κ is a value 1 or larger called the dielectric constant.

Most values are between 1 and 100, in extreme cases can be in the thousands.

See pg 575 in book, or Wikipedia for a good list of values.

These dielectrics result in capacitors that can hold more charge.

Why Dielectric Hold More Charge

Insulating, non-conductive, no region of constant voltage.

The medium adds additional Electric field to separate more charges.

Other Dielectric Applications

Some Dielectric Crystals have different dielectric constants depending on direction, foundation of Electro-optics and the cutting edge of information technology...

more on this when we cover optics

Also, Dielectrics greatly advance battery and capacitor possibilities.

Multi Capacitor Circuits

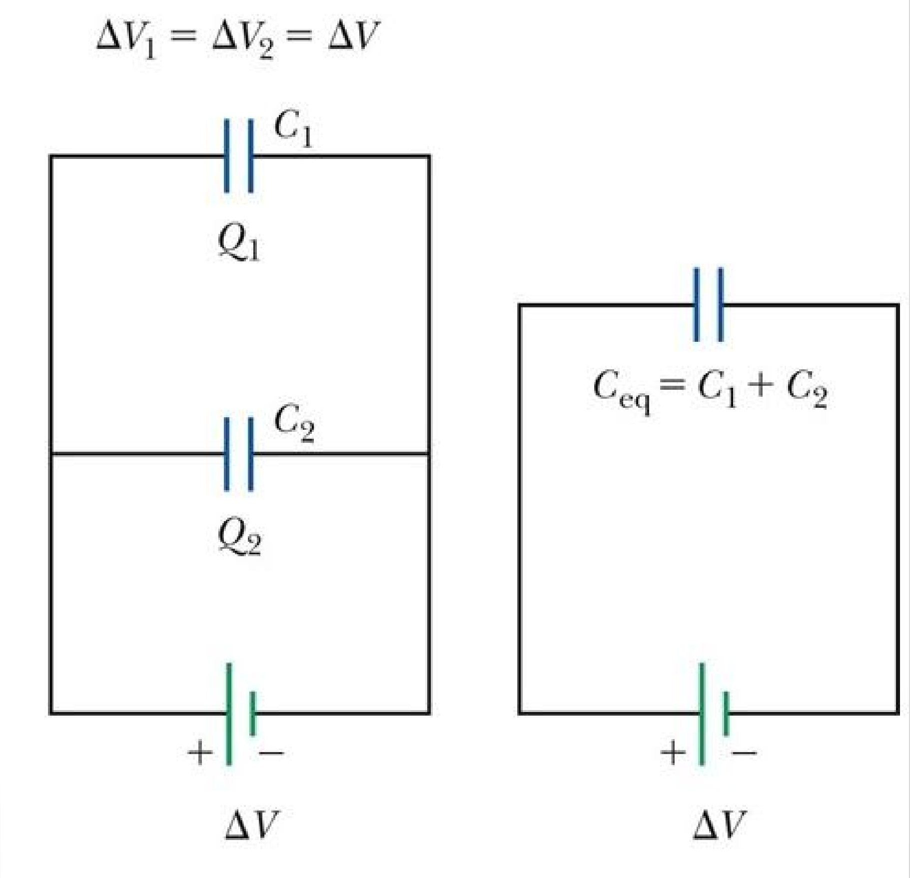
<u>Capacitors in Parallel</u>

-Parallel components have 2 common wires

-It helps to know what the total Capacitance of the Circuit is

C_{eq} is the Equivalent Capacitance

$C_{eq} = C_1 + C_2 + C_3 + ...$



Derivation?

We need to learn a new law in order to derive the equivalent capacitance equation.

Kirchhoff's Junction Law

It is a variation on conservation of charge. Charge cannot be created or disappear, it can only be neutralized. So when current flows in a circuit, as much current as flows into a junction must flow out of that junction.

$$Q_{in} = Q_{out}$$

Derivation

Q_{in} is the equivalent charge that the battery has to supply. Q_{out} is the charge spread out over all the capacitors. In a parallel circuit that is additive.

Qeq = Q1 + Q2 + Q3 ...

Remember Q = C/V

Remember Kirchhoff's Loop Law,

Vbat = V1=V2=V3 ...

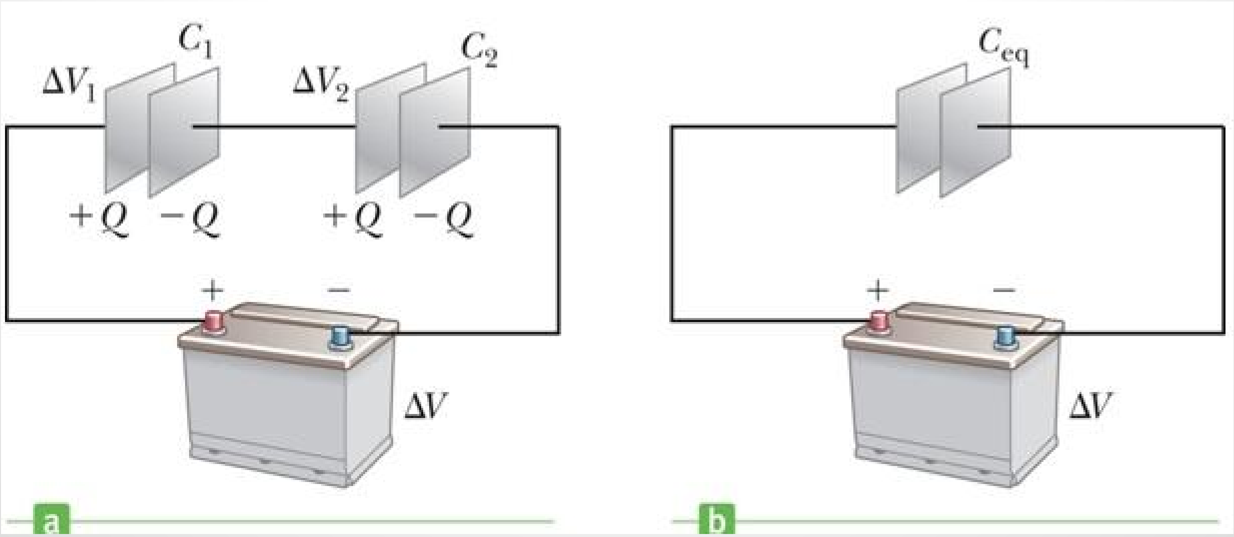
Plug both in, algebra ... $C_{eq} = C_1 + C_2 + C_3 +$ ...!!

Capacitors in Series

Components in series share ONE common wire.

$$1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3 \ldots$$

$$\text{if only 2... } C_{eq} = C_1C_2/(C_1+C_2)$$



Derivation

Since they are all on the path without a junction, then the charge on each is the same. (KJL)

$Q_{EQ} = Q_1 = Q_2 = Q_3$ ... Q

For the same reason the equivalent voltage is additive. (KLL)

$V_{EQ} = V_{tot} = V_1 + V_2 + V_3$ ...

Remember $V = Q/C$

$Q/C_{EQ} = Q/C_1 + Q/C_2 + Q/C_3$ ... giving...

$1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3$ ...

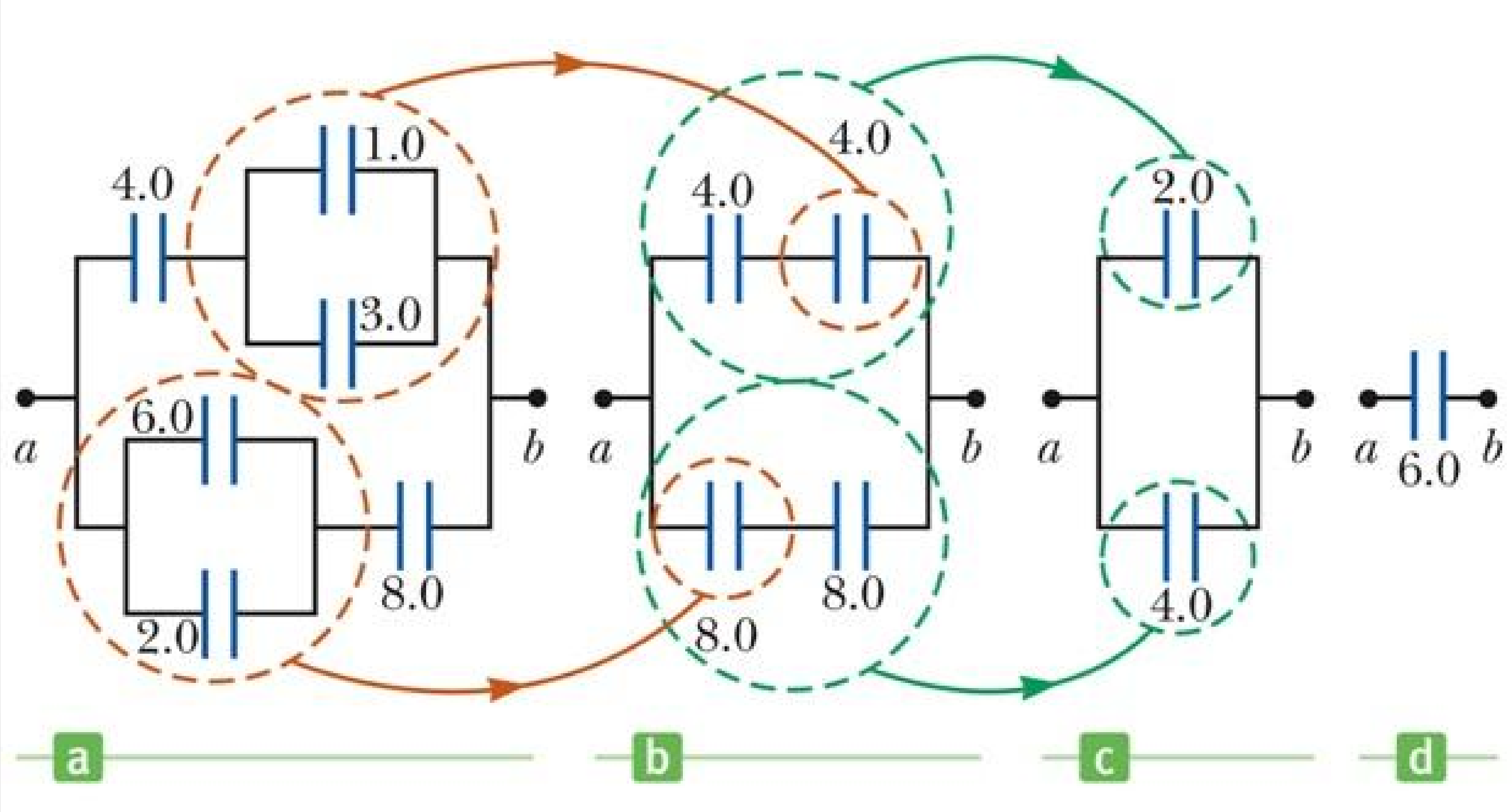
What About Combination?

Circuits are rarely simple series or parallel circuits, normally a combination of the two.

We already have the tools to break these down, simplify each step but there will be more steps.

This will require much relabelling, and redrawing at times, but after practise you start to see patterns and they get easier.

Example Combo Circuit



Note Units: Capacitance has units of Farads.
Is 1 Farad a lot?

Capacitor's Stored Potential Energy

$PE = QV_P$

Here, Q is all of the electrons that are being brought in from infinity. V_P is the voltage from one plate, since the first was free to assemble.

$V_P = V_C/2$ ... $PE = QV_C/2$

... but both V_C and Q change as the Capacitor charges up, and $V_C = Q/C$, $Q = V_C C$.

So we have 2 more way to write it

$$PE = V_C^2C/2 \quad \text{or} \quad Q^2/2C \quad \text{or} \quad QV_C/2$$

You have a lot of tools now

Kirchhoff's Loop Law

Kirchhoff's Junction Law

PE near a charge

V near a charge

Capacitance w/ and w/out a Dielectric

Equivalent Capacitance in Series

Equivalent Capacitance in Parallel

Combo Circuit Technique