Phys1402-Fall2018 - Part 1 – Electrostatics and DC

Monday, October 15, 2018   8:44 PM

- Our course notes are now broken into 3 parts on OneDrive:
  - Part 1 - Electrostatics and DC Circuits:
    https://tamucc-my.sharepoint.com/:o:/g/personal/jeffery_spirko_tamucc_edu/EhkLJvTU1_pOkB5OmwRTR4IBMn97BZRqrI-ORgvtyty7Zg
  - Part 2 - Magnetism and AC Circuits:
    https://tamucc-my.sharepoint.com/:o:/g/personal/jeffery_spirko_tamucc_edu/EuR1xpOWEK5LqEaOjXrgoQkBZ7sy3B5pL6QA4wlUziZVxQ
  - Part 3 - Oscillations, Waves, and Light:
    https://tamucc-my.sharepoint.com/:o:/g/personal/jeffery_spirko_tamucc_edu/EnXylWa4gm5FhPXWNb-bb4kB_7YX7TQsxRdh7HcSKATncg
- Our course notes are also periodically exported to PDF in:
  http://faculty.tamucc.edu/jspirko/Phys1402/

- Professor: Dr. Jeff Spirko, jeffery.spirko@tamucc.edu, NRC-1111 (inside NRC-1100 suite)
- Office Hours: See Live Caledar http://faculty.tamucc.edu/jspirko/calendar.html
- Course Web Folder: http://faculty.tamucc.edu/jspirko/Phys1402/ - Lecture Notes, Web Links
- Course YouTube Playlist: Phys1402-Fall18
- SI Info: [TBD]
- Sessions: [TBD]
- Office Hour: [TBD]
- Lab Web Folder: http://physlab.tamucc.edu/ - Lab Policies, Practice Exercises, Lab Instructions, Auxiliary Files
- Textbook: Serway/Vuille, College Physics, 11th Edition (electronic version in WebAssign).
- Homework: Will appear on WebAssign.
- Lab Reports: Due 1 week after the lab, by midnight. Submit in the Lab Reports area in the Course Menu.

Why do we study E&M?

- Our society is electric
  - Energy: Heat, Light, Movement, Cooking
  - Information: Communication, Storage, Processing
- Fundamentals behind Light and Radio Waves.
- Basis of Chemistry (along with quantum mechanics)
- Used to measure and control experiments and processes.
- Math and Learning Practice.

Electrostatics

- All matter is made of atoms.
- Atoms are made of Protons, Neutrons, and Electrons.

The protons and neutrons are gathered in the nucleus.
The electrons "orbit" around it in a cloud.
Each proton always has the same positive charge.
Each electron always has the same negative charge.
Charge is a measurement of "how electric" something is.
Positive and negative charges cancel via addition.
Protons and electrons cannot be created or destroyed.
This means charge cannot be created or destroyed.
Generally, the protons stay in place. They are attached to the
nuclei. A few forms of proton movement:

- Nuclear reactions, particle physics beams.
- Chemical reactions.
- Material flow.

Otherwise, it's just the electrons that flow. This is the flow of
electricity in wires.

$q_p = +e$

$q_e = -e$

$e = 1.6 \times 10^{-19} \, C$

elementary charge

$\left\{ \text{In a battery.} \right.$
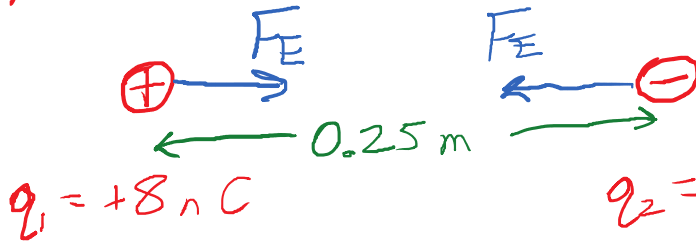
Electric Force

Most basic interaction of Physics I: Force
The electric force is called the Coulomb Force.
The easiest case is two small, far-apart charges.

$$e = 1.6 \times 10^{-19} \, C$$

Ex: Opposite Charges Attract

$q_1 = +8 \, nC$
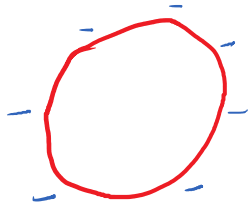
$q_2 = -5 \, nC \quad 10^{-9}$

0.25 m

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

$$k = 9 \times 10^9 \, Nm^2/C^2$$

$r = $ center-to-center distance

$$F_E = \frac{(9 \times 10^9 \, Nm^2/C^2)(8 \times 10^{-9} \, C)(5 \times 10^{-9} \, C)}{(0.25 \, m)^2} = 5.76 \times 10^{-6} \, N$$

$$= 5.76 \, \mu N$$

Charged Objects

Metal Ball
w/ extra electrons

Metal is a conductor, which means the electrons are free to roam around where they want.
Any balanced charges spread out throughout the metal.
Any extra charges repel and go to the edges.
The middle (called the "bulk") is neutral.

What if I have two charged metal spheres and bring them into contact?

wire provides "contact"

was $+8\,nC$ was $-5\,nC$
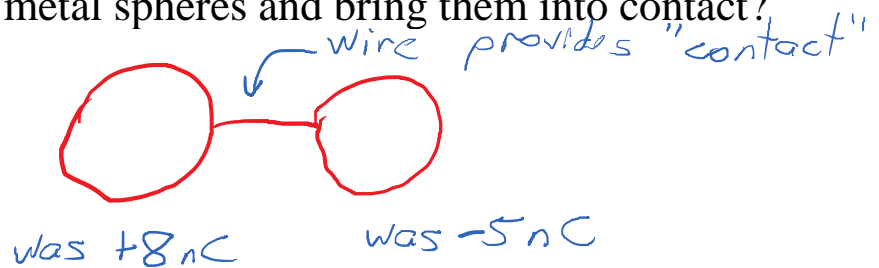
Both charges end up spreading out to both sides of the system.
If the objects are symmetric, so are the charges.

$$Q_T = +8 - 5 = +3\,nC$$

new $q_1 = +1.5\,nC$
new $q_2 = +1.5\,nC$

Coulomb Force Review

The electrostatic force depends on:
- Charge magnitude: "how electric" the objects are.
- Charge types: Like charges repel; opposites attract.
- Distance: Closer objects experience more force.

$$k = 9 \times 10^9 \ \frac{N\,m^2}{C^2}$$

Coulomb's Law

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

Restrictions/limitations: The charges must be
"small" compared to the distance between them.

A "neutral" object has $q = 0$ which makes
us think there should be no electric force, ever,
on a neutral object. But, actual objects are still
made of + and - charges. A "polarizable" object
allows its electrons to stretch away from the
nuclei just a little bit. This can cause an
attraction to any charged object.

Charge Distributions

Bunch of points:

$$Q = q_1 + q_2 + \cdots$$

Ex: A +1 nC charge has how many extra protons?

$$Q = q_1 + q_2 + \cdots$$
$$Q = Ne$$
$$(1\,nC) = N(1.6 \times 10^{-19}\,C)$$
$$N = \frac{1 \times 10^{-9}\,C}{1.6 \times 10^{-19}\,C} = 6.25 \times 10^{9}$$

This is usually done by stealing 6.25e9 electrons, not by adding protons.

Surface Charges: Charge spread out on a surface.

$$\sigma = \frac{Q}{A}$$

Surface Charge Density

Volume Charges: Charge spread out throughout a 3-D region.

$$\rho = \frac{Q}{V}$$

Volume Charge Density

Electric Field

How can we exert a particular force on a charge?

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

- Strong q_2, far away
- Weak q_2, nearby

$$F = \frac{k q_1 q_2}{r_2^2} + \frac{k q_1 q_3}{r_3^2}$$

- Multiple other charges.

We could rearrange this by dividing the q1 over to the other side.

$$\frac{F}{q_1} = \underbrace{\left(\frac{k q_2}{r_2^2} + \frac{k q_3}{r_3^2} + \cdots \right)}_{\text{Environment}} = E$$

The "test charge" q_1 doesn't care how E is created. All that matters in determining the force is q_1 and E.

Coulomb Force: $\vec{F} = q_o \vec{E}$

$\uparrow$ Electric Field of All other charges.

The electric force is:
- In the same direction as $\vec{E}$ for a ⊕ charge.
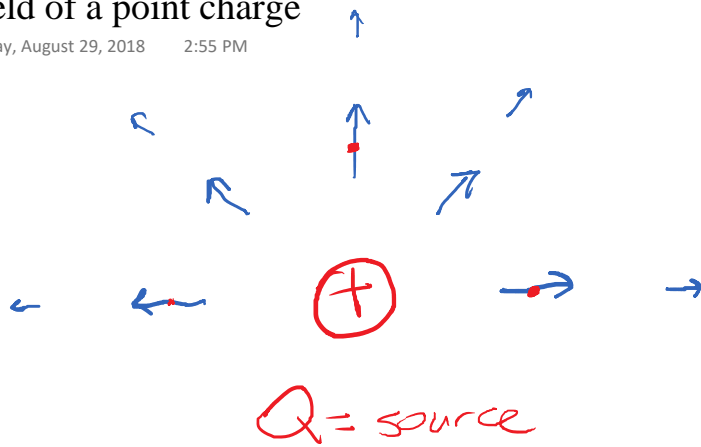- Opposite to $\vec{E}$ for a ⊖ charge.

The charges creating E are called "source charges".
The electric field E exerts forces on other "test charges".

The electric field acts as a conceptual middle-man between the source and test charges. But it exists whether there are test charges or not.

E-Field of a point charge

Imagine a ⊕ q_0 test charge at each dot, where would the force point?

$Q = source$

The electric field of a + source points away from the source.

$$E = \frac{F}{q_0} = \frac{1}{q_0}\left(k\frac{q_0 Q}{r^2}\right) = \frac{kQ}{r^2}$$

q_0 — Test Charge

If there are multiple sources, their electric fields add as vectors.

Where is $E = 0$?

$r_1 \rightarrow \leftarrow r_2$

⊕ .... • .... ⊕

$+2 nC$ $+2 nC$

Dots are candidates where fields are opposite.

$$E_1 = \frac{k(2nC)}{r_1^2} \qquad E_2 = \frac{k(2nC)}{r_2^2}$$

Since the charges are equal, the distances must be equal, and the point we are looking for is in the middle.

New Ex:

r_1 r_2

⊕ ..... • .... ⊕

$+1 nC$ $+4 nC$

Where is $E = 0$?

Intuitively, our point must be closer to the weaker charge.

$$E_1 = E_2$$

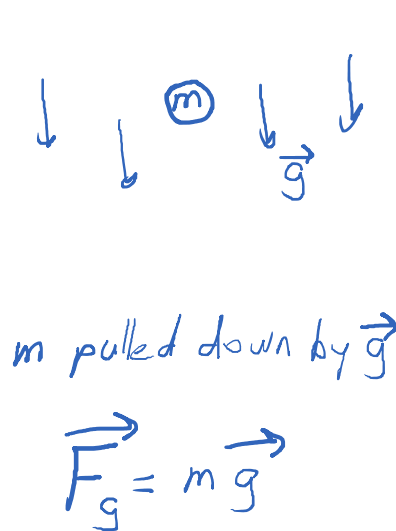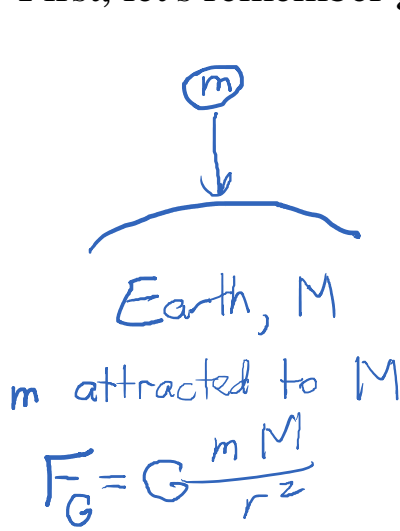$$\frac{kq_1}{r_1^2} = \frac{kq_2}{r_2^2} \qquad \frac{1}{r_1^2} = \frac{4}{r_2^2}$$
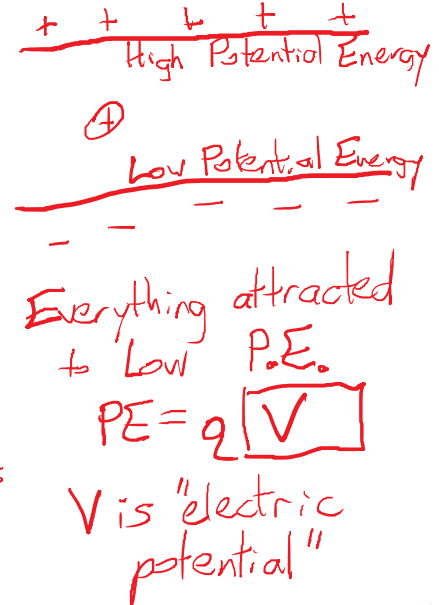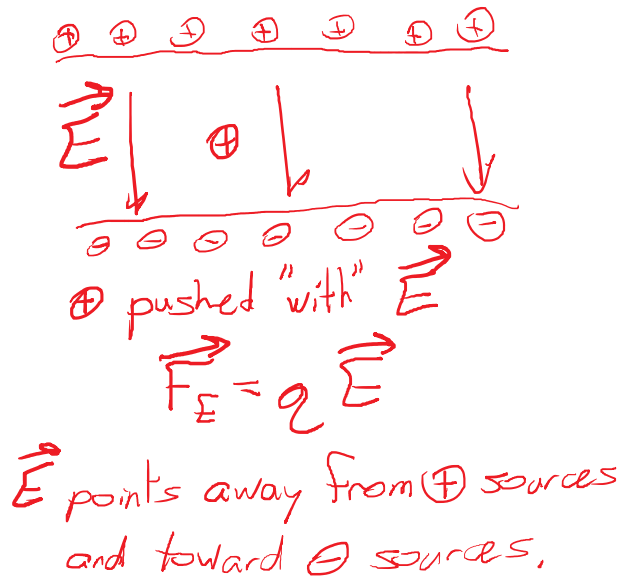
$$r_2^2 = 4r_1^2$$

$$r_2 = 2r_1$$

Lec 3, Labor Day, No Class

Monday, October 15, 2018   8:24 PM

From Electric Fields to Electric Potential

First, let's remember gravity.

- High mgh

- Low mgh

m pulled down by $\vec{g}$

m attracted to low mgh.

Earth, M

m attracted to M

$$F_G = G\frac{mM}{r^2}$$

$$\vec{F_g} = m\vec{g}$$

F

High Potential Energy

Low Potential Energy

$\oplus$ attracted to $\ominus$

$$F_E = k\frac{qQ}{r^2}$$

$\oplus$ pushed "with" $\vec{E}$

$$\vec{F_E} = q\vec{E}$$

Everything attracted to Low P.E.

$$PE = q\boxed{V}$$

$\vec{E}$ points away from $\oplus$ sources and toward $\ominus$ sources.

V is "electric potential"
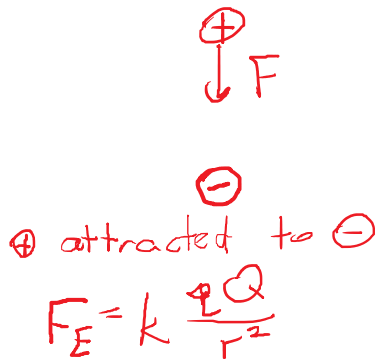
What is electric potential?

- Potential energy per unit test charge
- Positive test charges attracted toward lower (less positive or more negative) potential.
- Positive potentials generated by positive source charges. Negative potential generated by negative sources.
- We don't really know where "zero" is. Earth is generally at the same potential, so we use that.

What about negative test charges?

Sources $\Rightarrow$ Fields $\Rightarrow$ Test
Q   create   affect q

High $\oplus$ V

E F
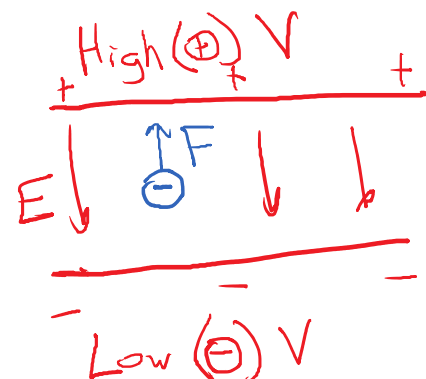
Low $\ominus$ V

that.

What about negative test charges?

- The sources don't change. The fields don't change. (E = electric field, V = potential field)
- The negative test charges are attracted the other way.

$$^-\text{Low} \ominus V$$

$$PE = q \, V$$

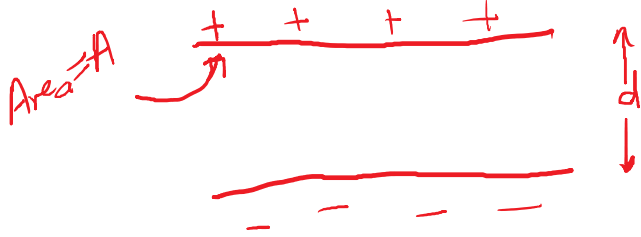opposite to V $\quad$ negative

Calculating Potentials

Point Source

FQ

$$V = \frac{kQ}{r}$$

Different From $E = \frac{kQ}{r^2}$:

- Different denominator
- V not a vector

Capacitor

Two parallel metal plates, charged opposite but with equal magnitudes.

Area $= A$

$+ \quad + \quad + \quad +$

$- \quad - \quad - \quad -$

d

Lower d = Easier to gather charges.

Bigger A = More room to spread out.

Capacitance: $C = \frac{K \varepsilon_0 A}{d}$

K = kappa = dielectric constant = 1 or larger

$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N m^2}$ ← coulombs

C = capacitance in farads (F)

Typical: $C = 25 \ \mu F = 25 \times 10^{-6} \ F$

Capacitance tells us how much voltage (V) it takes to put a certain amount of charge (Q) inside.

$$Q = CV$$

Ex: Hook 25 μF capacitor to a **3** V battery.

$V_B = 3 \ V$

⌐ volts = unit of V

$Q = (25 \times 10^{-6} F)(3.0 \ V)$
$= 75 \times 10^{-6} \ C$
$Q = 75 \ \mu C$

Other things a Capacitor does

$Q = CV$

Store Energy $\text{Energy} = \frac{1}{2}QV = \frac{1}{2}CV^2$

Recall, for a test charge $PE = qV$

Ex: $\text{Energy} = \frac{1}{2}(25 \times 10^{-6} F)(3.0 V)^2$

$= 112.5 \times 10^{-6} J = 112.5 \, \mu J$

Generate E-Field $E = \frac{V}{d}$

Ex: $25 \, \mu F$ with

$d = 20 \, nm, \quad 3.0 V$

$E = \frac{3.0 V}{20 \times 10^{-9} m} = 150000000 \, V/m$

$= 1.5 \times 10^8 \, V/m = 150 \, \frac{MV}{m}$

Note: E-field is force per unit test charge, in N/C.
Now, E-field can also be measured in V/m.
These are the exact same, equivalent units.

Electric potential is like:
- Height
- Pressure

+   +   +   +

Strong positive "pressure"

Strong negative "pressure"

- - - -

Lec 5 - DC and Ohm's Law

Monday, September 10, 2018   2:00 PM
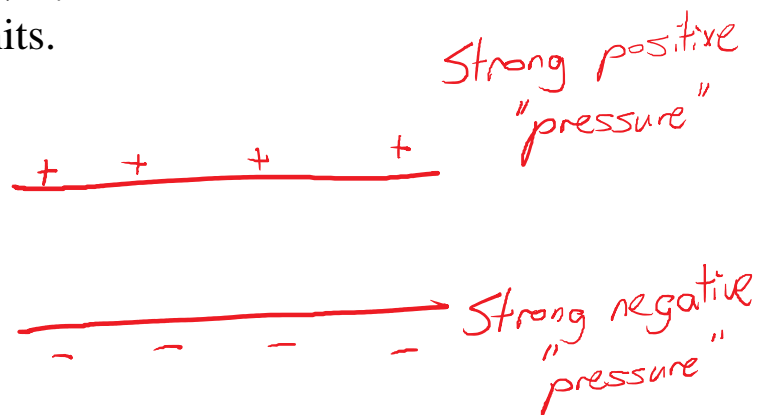
Electrostatics

High Voltages   (usually)

"Dead-end" containers

Charge builds up.

Tiny amounts of q.

DC Circuits

Low Voltages

Continuous paths

No buildup, just Flow.

Lots of flow, but no excess in any one place.

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

Current — Amount of moving charge / Time elapsed

Voltage: Motivation for current to flow. Need a voltage source for any current to flow.
Current: Rate of flow of charges.

How do we measure current?
- Current meter called an ammeter
- Intercept the flow of current and make it go through the meter.
- We want the measured value to be the same as what the current was before we intercepted it. The ammeter must allow current to flow easily.

Befor measuring:

Battery $\pm$ ε R I

While measuring

ε (A) R I

Ohm's Law

Monday, September 10, 2018   2:27 PM

More voltage leads to more current.
Ideally, they are proportional.

$$V = I R \qquad \text{(Ohm's Law)}$$

Voltage (V)   Current (A)   Resistance (Ω)
in ohms

Ex: Flashlight with a 3.0 V battery that wants 0.2 A to flow.

$$(3.0 \text{ v}) = (0.2 \text{ A}) R$$

$$\frac{3.0 \text{ v}}{0.2 \text{A}} = 15\Omega = R$$

Voltage was introduced as energy per charge.

$$\left(\frac{Energy}{Charge}\right)\left(\frac{Charge}{Time}\right) = \frac{Energy}{Time} = Power$$

$$V \qquad I \qquad = P$$

Same flashlight - what is its power?

$$P = (3.0 \text{ v})(0.2 \text{ A}) = 0.6 \text{ W}$$

Cost of Energy

Electric Rate: $0.12/kWh

$$\text{Power} = \frac{\Delta \text{Energy}}{\Delta t} \Rightarrow \Delta \text{Energy} = P \Delta t$$

SI Units: $1 J = (1 W)(1 s)$

On invoice: $1 kWh = (1000 W)(3600 s) = 3600000 \text{ W·s}$
$$= 3.6 \times 10^6 \text{ J}$$

What if we leave a 1 W device operating for a whole month?

$$\text{Energy} = P \Delta t = (1.0 W)(30 \text{ days})\left(\frac{24 \text{ hours}}{1 \text{ day}}\right)\left(\frac{1 kW}{1000 W}\right)$$
$$= 0.72 \text{ kW}$$

$$\text{Cost} = (0.72 \text{ kW})\left(\frac{\$0.12}{kW}\right) = \$0.086$$
$$\text{Cost} = (\text{Amount})(\text{Rate})$$

Let's say I leave the porch light on all of the time.

Incandescent: 75 W   ~ $6.50 per month
LED   10 W   ~ $0.86 per month

Measuring Voltage

Car A/C system
(freon Flow)

Condenser

Pump

Evaporator
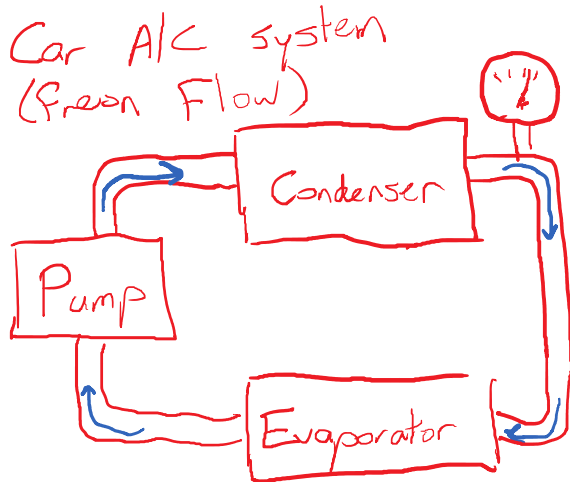
Pressure gauge is a
"dead-end" path.

It measures the pressure difference
between the freon pipe and the
atmosphere.

Circuit

R_1

+

V

R_2
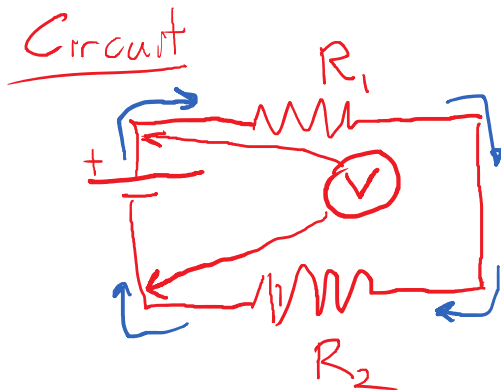
- Just like the pressure gauge, the voltmeter is a dead-end path. No current flows through it.
- The voltmeter needs to measure a voltage difference. The voltmeter is connected to 2 points in a circuit.
- The voltmeter to the left is connected "across the battery".
- The current is unaffected by the voltmeter.

Measuring Resistance and Power

Defined by $V = I R$

- Place a known V across a resistor.
- Measure the current I that flows.
- Divide to calculate the resistance.

An ohmmeter does all of these things for us.
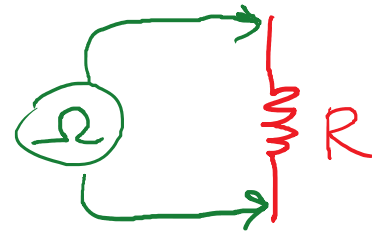
Note that there must not be another voltage source in the circuit. That would confuse the ohmmeter and yield garbage results (at best) or cause damage (at worst).

How about measuring power?   Defined by $P = V I$

Must measure both voltage (V) and current (I) while the circuit is operating as designed (i.e. with another voltage source).

Power Meter
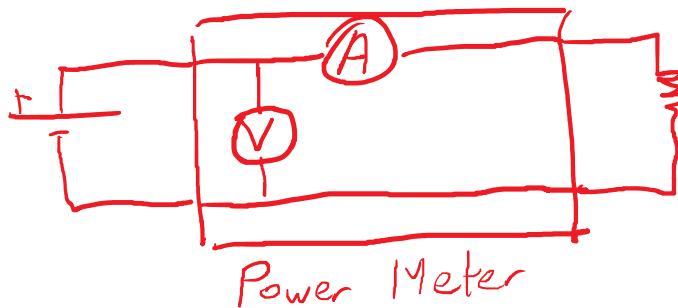
Lec 6 - Series and Parallel - Series Circuit Components

Simple Circuit:

$\mathcal{E} = 3.0V$ $R = 15\Omega$

$$V = IR$$
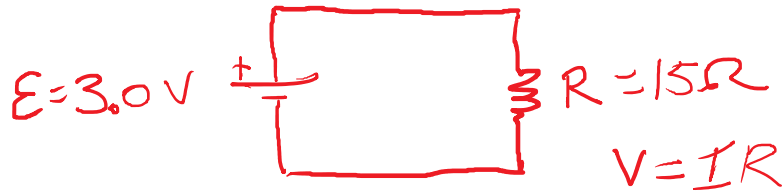
Current: $I = \dfrac{V}{R} = \dfrac{3.0V}{15\Omega} = 0.2A$

When we measure current, we place the meter **in series** so that the current must go through the meter.

When two components are in series, they have the same current. Recognize this by a connection between them with no branches.

Series Resistors

$\mathcal{E} = 3.0V$ $R_1 = 15\Omega$

$R_2 = 5\Omega$
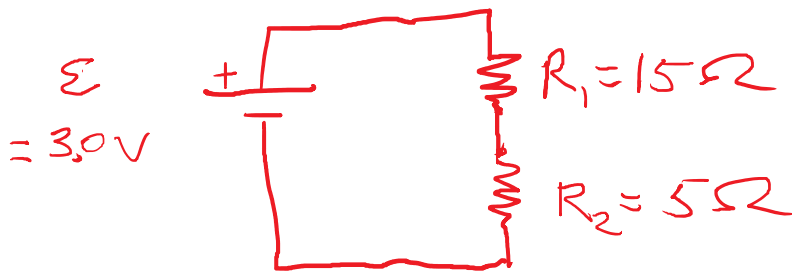
R_1 and R_2 have the same current.

$$I_1 = I_2 \quad (\text{In series})$$

Voltage is energy per charge.

$P_{Batt} = \mathcal{E}I$
Gen by batt.

$P_1 = IV_1$
Used by R_1

$P_2 = IV_2$
Used by R_2

$$P_{batt} = P_1 + P_2$$
$$\mathcal{E}I = V_1 I + V_2 I$$
$$\mathcal{E} = V_1 + V_2$$

Voltages add in series.

$R_1 = 15\Omega$ Measured $V_1 = 2.25V$ ✓
$R_2 = 5\Omega$ Measured $V_2 = 0.75V$

Notes:
$V_1 + V_2 = 3.0V$ ✓
$V_1 \quad 2.25$ 15Ω ✓

$$R_2 = 5\,\Omega \qquad \text{Measured } \dot{V}_2 = 0.75\,V \qquad \begin{array}{c} V_1 + V_2 = 3.0\,V \\ \dfrac{V_1}{V_2} = \dfrac{2.25}{0.75} = 3 = \dfrac{15\,\Omega}{5\,\Omega} \checkmark \end{array}$$

$$I = \frac{V_1}{R_1} = \frac{2.25\,v}{15\,\Omega} = 0.15\,A$$

In series, the bigger R gets a larger share of the voltage.

From the battery's perspective:

$I = 0.15\,A$

$\varepsilon = 3.0\,V$

R_{eq}
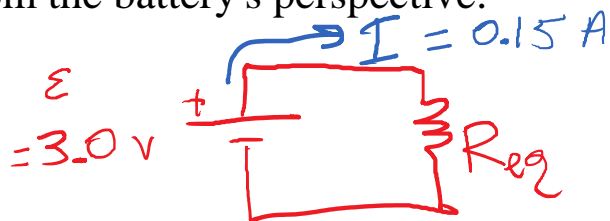
$$V = I\,R_{eq}$$
$$(3.0v) = (0.15A)\,R_{eq}$$
$$\frac{3.0v}{0.15A} = 20\,\Omega = R_{eq}$$

Series resistors act like a single equivalent
resistance, where:

$$R_{eq} = (R_1 + R_2 + \cdots)$$

Important example: Internal Resistance of a Battery

R_{int} ε R_1

$$\varepsilon = I R_1 + I R_{int}$$
$$\varepsilon = V_{terminal} + I R_{int}$$

Parallel Circuits

Parallel Resistors
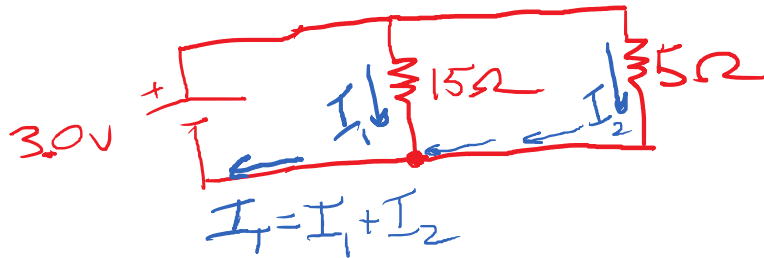
$I_T = I_1 + I_2$

- Parallel means attached at both ends.

- Current adds in parallel

Power: $\varepsilon I_T = V_1 I_1 + V_2 I_2$

Only way for this to work is:

$$\varepsilon = V_1 = V_2$$

- Voltages are the same in parallel.

Parallel Equivalent Resistance

$I = 0.8 A$

3.0v R_{eq}
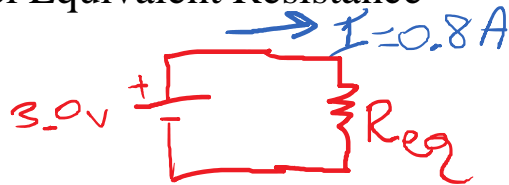
$I_1 = \dfrac{3.0}{15} = 0.2 A$

$I_2 = \dfrac{3.0}{5} = 0.6 A$

$I_T = I_1 + I_2 = 0.8 A$

$$R_{eq} = \frac{3.0v}{0.8A} = 3.75 \Omega$$

Direct calculation? $I_T = I_1 + I_2$

$$\frac{\varepsilon}{R_{eq}} = \frac{\varepsilon}{R_1} + \frac{\varepsilon}{R_2}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

$$R_{eq}^{-1} = R_1^{-1} + R_2^{-1}$$

$$R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots \right)^{-1}$$

$(1/15 + 1/5)^{\wedge}(-1) = 3.75$

Easy-to-do Calculations:

$R_1 = R_2$

In Series: $R_{eq} = R_1 + R_1 = 2 R_1$

In Parallel: $\left(\frac{1}{1} + \frac{1}{1} \right)^{-1}$

In Parallel: $R_{eq} = \left(\dfrac{1}{R_1} + \dfrac{1}{R_1} \right)^{-1}$

$$= \left(\frac{2}{R_1} \right)^{-1} = \frac{R_1}{2}$$

Combination Circuits

$R_1 = 5\Omega$

$R_2 \; 4\Omega$

$R_3 \; 12\Omega$

$R_4 = 8\Omega$

$24V$

	V	I	R
R_1	7.5v	1.5A	5Ω •
R_2	4.5v	1.125	4Ω
R_3	4.5v	0.375	12Ω
R_4	12v	1.5A	8Ω •
Tot	24V	1.5A	16Ω
R_{23}	(4.5v)	1.5A	3Ω •

$R_2 \| R_3$

$$R_{23} = \left(\frac{1}{4} + \frac{1}{12}\right)^{-1} = 3\Omega$$

R_1

R_{23}

R_4

$$I = \frac{24V}{16\Omega} = 1.5A = I_1 = I_{23} = I_4$$

For a looping path

$$\Sigma \varepsilon = \Sigma V_{used}$$

How could we add up voltages to get 24 V?
We could add V1 + V2 + V4 = 7.5 + 4.5 + 12 = 24
Or we could: V1 + V3 + V4 = 7.5 + 4.5 + 12 = 24

Lec 7 - More Circuits - Kirchoff's Laws

- **Current:** Total in = Total out

6.0 A → ● → 4.0 A

$I_3 = ?$

$(6.0A) = (4.0A) + I_3$

$2.0A = I_3$

Consequences: In series, each current is the same.

$R_1 \; I_1 \quad I_3 \; R_2$

$I_1 = I_2$

In parallel, currents add.

$I_{tot} → \quad → I_2$

$I_1 ↓ \; R_1 \qquad R_2$
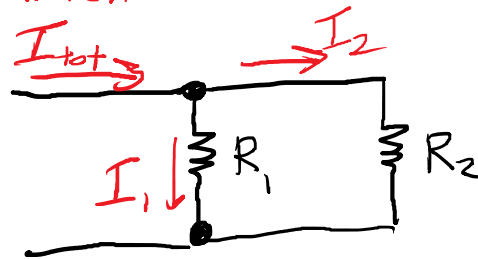
$I_{Tot} = I_1 + I_2$

- **Voltage Law:** If you add up the voltages in any loop, the total is zero.

Total $\Delta V = 0$

Total Source ΔV = Total Used ΔV

$$\Sigma \varepsilon = \Sigma (IR)$$

$\varepsilon = 12v$ \quad $I →$ \quad $R = 3\Omega$
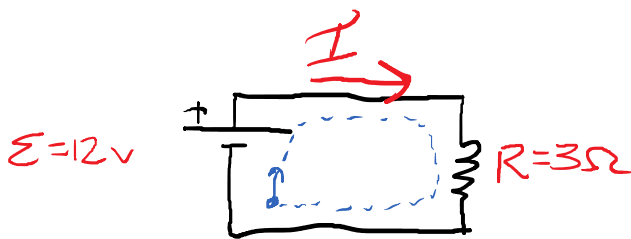
$12v = I(3\Omega)$

$\frac{12}{3} = 4.0A = I$

Series:

$\varepsilon = 6v$ \quad $I →$ \quad 2Ω \quad 3Ω
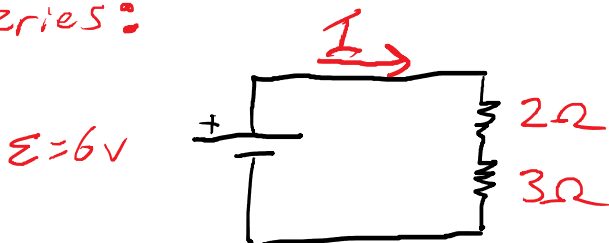
$6v = I(2\Omega) + I(3\Omega)$

Series voltages Add

$\frac{6}{5} = (1.2A) = I$ \qquad $6v = I(2\Omega + 3\Omega)$

Parallel:

$\mathcal{E} = 3v$
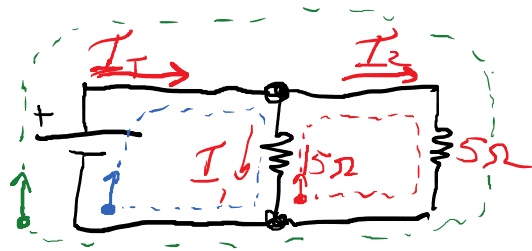
$I_T = I_1 + I_2$

- $3v = I_1(15\Omega)$
- $3v = I_2(5\Omega)$

What about the "right loop"?

This only "works" if one is negative.
Rule to fix this: If your loop goes "backwards"
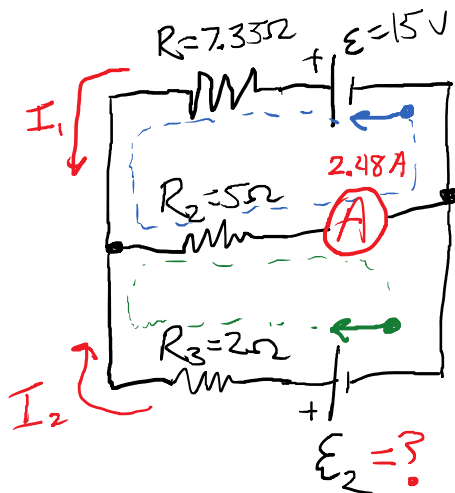across a resistor, add a minus sign.

- $0 = I_1(15\Omega) + I_2(5\Omega)$
    (Broken!)

$0 = -I_1(15\Omega) + I_2(5\Omega)$
    (Fixed)

Algebra $\Rightarrow$ $I_1(15\Omega) = I_2(5\Omega)$

Gives parallel voltage rule: $V_1 = V_2$

Application of Kirchoff's Laws

Current Law: $I_1 + I_2 = (2.48\,A)$

Bottom Loop: $\mathcal{E}_2 = I_2(2\,\Omega) + (2.48\,A)(5\,\Omega)$

Top Loop: $(+15\,v) = I_1(7.35\,\Omega) + (2.48\,A)(5\,\Omega)$

Algebra:

$$15 = 7.35\,I_1 + 12.4$$

$$2.6 = 7.35\,I_1$$

$$I_1 = \frac{2.6}{2.35} = 0.354\,A$$

$$0.354 + I_2 = 2.48 \Rightarrow I_2 = 2.126\,A$$

$$\mathcal{E}_2 = (2.126)(2\,\Omega) + (2.48)(5\,\Omega) = 16.7\,v$$

Outer Loop Kirchoff's Voltage Law:

Start @ top-right, counter-CW

$$(15\,v) - (16.7v) = I_1(2.35) - I_2(2)$$

We went backwards across EMF2.

$$15 - 16.7 = 2.6 - 4.252$$

$$-1.7 = -1.65 \quad \checkmark \; (\text{Roundoff Error})$$

RC Circuits

A capacitor can store voltage and energy, and provide current, much like a battery.

Battery Circuit

$\mathcal{E}$ R
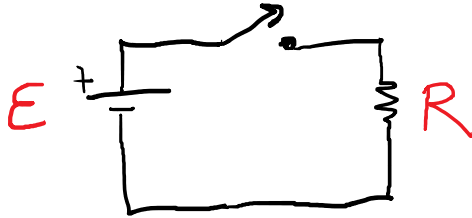
$V_{batt} = \mathcal{E} = const$

Capacitor Circuit

C   R

$V_0 = given$
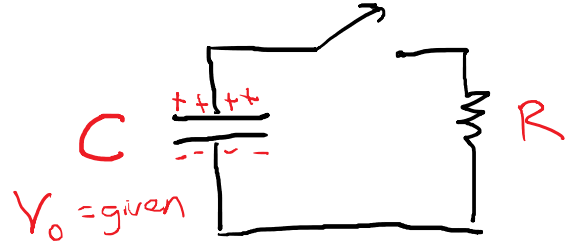
$Q = CV$

$V_c = \dfrac{Q}{C}$

$C = capacitance \ (F)$
$Q = charge \ (C)$

If Vbatt = Vc, these circuits behave the same … at first.
But the battery can maintain its voltage continuously.
The capacitor starts becoming "drained" immediately.
Since the capacitor voltage is proportional to its charge, both
start decreasing immediately. The resistor will feel the
lower voltage and draw less current.

The voltage decreases exponentially.

$V = V_i \, e^{-t/\tau}$
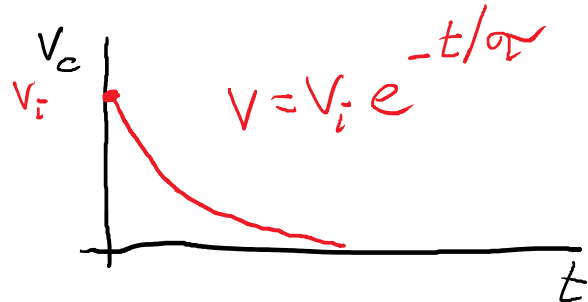
Wednesday, September 19, 2018   1:56 PM

Consider the circuit shown below. (Assume $\mathcal{E}$ = 9.00 V, R_1 = 1.50 Ω, R_2 = 4.30 Ω, R_3 = 5.50 Ω, and R_4 = 11.0 Ω.)

This circuit is easier.

$$V_2 = V_3 = V_4 = V_{234}$$
$$I_2 + I_3 + I_4 = I_{234} \quad \text{(Not usually easy to apply.)}$$

A typical hair dryer consumes 1.60×10^3 W of electrical power. If the hair dryer runs for 14.4 minutes, determine the following.

    (a) the amount of energy consumed
    (c) the cost of this energy, assuming the electrical power company charges $0.120 per kWh

$$P = \frac{\Delta Energy}{\Delta t} \qquad \Delta Energy = P \Delta t$$

$$(\text{Total Cost}) = (\text{Unit Cost})(\text{Amount})$$

$$1 J = (1 W)(1 s)$$
$$1 kWh = (1 kW)(1 \text{ hour})$$
$$= (1000 W)(3600 s)$$
$$= 3.6 \times 10^6 \ J$$

Capitacitors in DC Circuits

- All charges generate voltage. $V = \dfrac{kq}{r}$

- Isolated charges make huge V w/ little q.

- V is
  - Energy per unit charge
  - Difficulty of moving more charges.

- Capacitors make it easy to gather Lots of q w/ little V.

charges → $+ + \; | \; + +$ ← Plates
          $- - \; | \; - -$

$$Q = CV$$

Q = charge on one plate in coulombs (C)

C = capacitance in farads (F)

V = voltage in volts (V)

Inside, 2 things happen:

$$\text{Elec Field} = E = \frac{V}{d} \leftarrow \text{distance between plates}$$
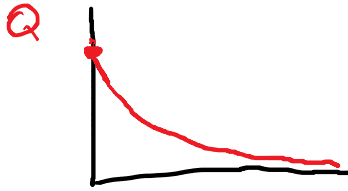
$$\text{Energy} = \frac{1}{2} \left(\frac{\text{Energy}}{\text{Charge}} \right) (\text{Charge}) = \frac{1}{2} VQ$$

RC Circuits - The process of charging and discharging.

Discharging

$$Q = Q_o e^{-t/\tau} \qquad V = V_o e^{-t/\tau} \qquad I = I_o e^{-t/\tau}$$

All are exponential decay.

For discharging, exp(-t/tau) is the fraction of charge remaining.

t/τ	$e^{-t/\tau}$	
0	1.0	100%
1.0	0.37	37%
2.0	0.14	14%
3.0		5%
4.0		2%
5.0		1%

(0.37)(0.37)

After 5τ, we're 99% done.

How much time does it take to get to 50% of the original charge?

$$Q = (0.5)Q_o$$
$$Q = Q_o e^{-t/\tau}$$

$$0.5 = e^{-t/\tau}$$
$$\ln(0.5) = \frac{-t}{\tau}$$
$$-0.693 = -t/\tau$$
$$0.693\,\tau = t$$
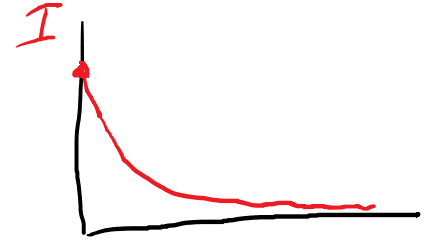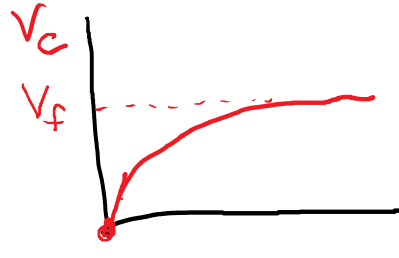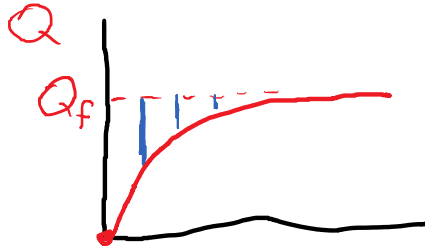
ln x finds y value to solve

$$x = e^y$$
$$\ln x = y$$

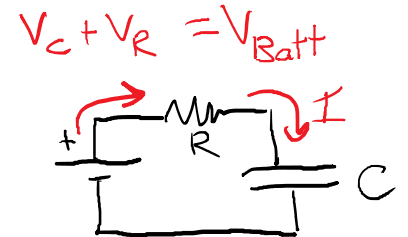The time constant (tau) depends on the

resistance and capacitance.
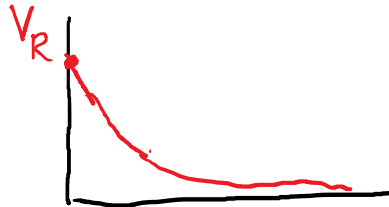- Bigger capacitors take more time to drain.
- Bigger resistors make the draining slower.

$$\tau = RC$$

Charging

Q

Q_f

V_c

V_f

I

$$Q_f - Q = Q_f e^{-t/\tau}$$
$$Q = Q_f(1 - e^{-t/\tau})$$

V_R

$$V_c + V_R = V_{Batt}$$

Exponentially approaching a final value.
It takes 5 time constants to be 99% complete.
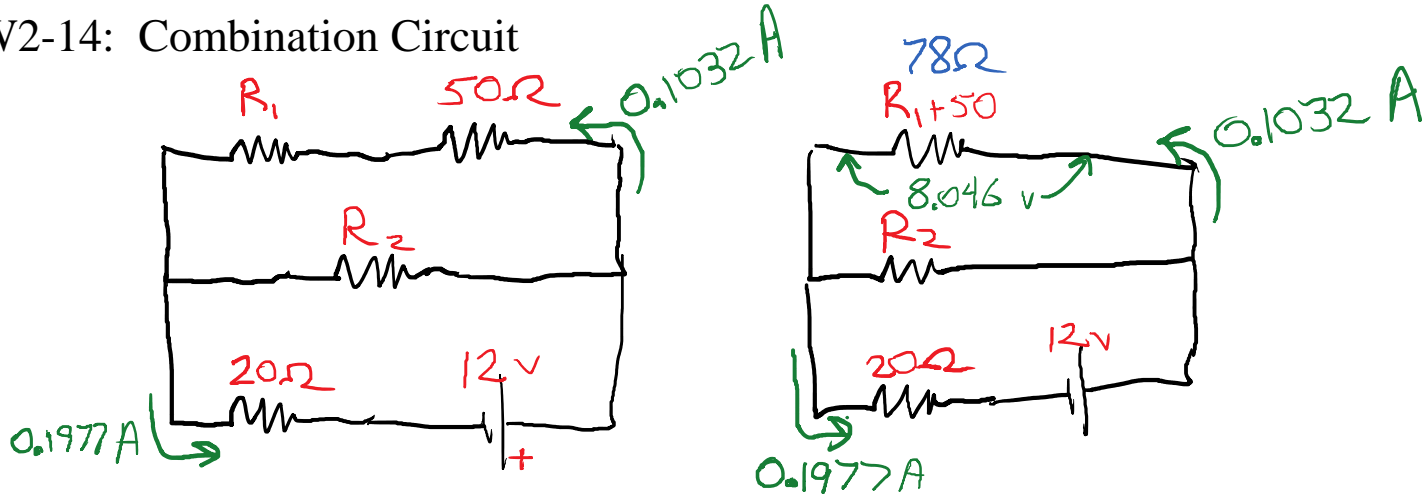
$\ln(0.01) = -4.605170185988091$
≈ -5

Focus on understanding exponential decay
(discharging) for the exam.

Lec 9 - Review for Exam 1

Test is Wed 9/26.
Covers Electrostatics and DC Circuits (including RC)
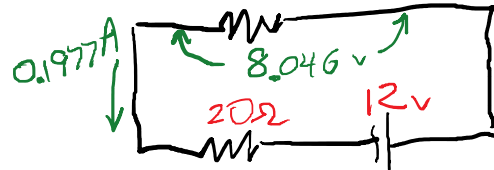Chap 15-18, HW1 and HW2, Labs 1-4.

HW2-14: Combination Circuit

Ex: $R_1 = 28\Omega$ $R_1 + 50 = 78\Omega$ $(R_1 + 50) \| R_2 = 40.7\Omega$

$R_2 = 85\Omega$

$(R_1 + 50) \| R_2 = \left(\frac{1}{78} + \frac{1}{85} \right)^{-1} = 40.7$

$$I = 12 / 60.7 = 0.1977$$

$V\_40.7 = IR = (0.1977) * (40.7) = 8.0464$
$I\_(R1+50) = V/R = 8.0464 / 78 = 0.1032$

$P\_50 = V*I = (IR)*I = I^2 * R = (0.1032)^2 * 50 = 0.5325$ W

Equivalent Circuits:
- Redraw, combining series or parallel resistors into an equivalent.
- Keep simplifying until a pure series or pure parallel circuit is found.
- Transfer values back up through the previous iterations.
  - Parts of the circuit that didn't change get the same currents and voltages.
  - Series equivalents have the same current as their components.
  - Parallel equivalents have the same voltage as their components.

Electrostatics Review

Electric Field
- Generated by charges. Points away from + and toward -.
  - Point charges make a diverging (or converging) field.

$$E = \frac{kQ}{R^2}$$

- Proportional to Q
- Weaker with distance

$$C = \frac{\varepsilon_o A}{d}$$

  - Capacitors make a uniform field.

$$E = \frac{V}{d} = \frac{Q}{Cd} = \frac{Qd}{\varepsilon_o A \, d}$$

$$Q = CV$$
$$\hookrightarrow V = \frac{Q}{C}$$

- Proportional to Q
- Same strength everywhere inside capacitor.

- Electric field causes forces on other charges.
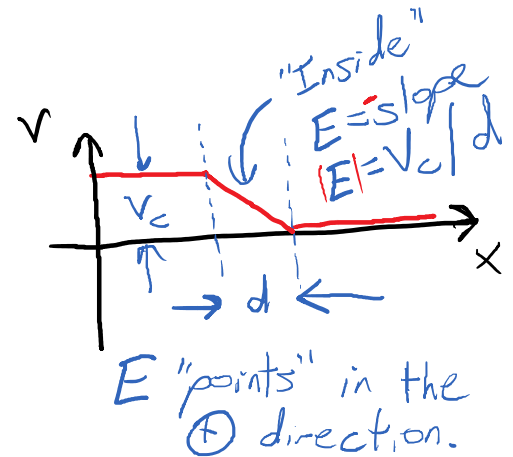
$$\vec{F_E} = q\vec{E}$$

q = "test charge"

  - If the test charge is negative, F_E is opposite to E.
  - We use test charges to measure E.
- Electric field is closely related to voltage.

$$E = -\frac{\Delta V}{\Delta x} = -\frac{\text{Voltage Change}}{\text{Displacement}}$$

"Inside"
E = slope
|E| = V_c / d

E "points" in the ⊕ direction.

  - Electric field points "downhill"

A 5 micro-F capacitor has 20 V across it. The capacitor's plate separation is 0.1 mm.
- Electric field inside?

$$E = \frac{V}{d} = \frac{20 \text{ V}}{0.1 \times 10^{-3} \text{ m}} = 200\,000 \text{ V/m}$$

- Force on a loose electron between plates?

$$F = qE = (1.6 \times 10^{-19} \text{ C})(200000 \text{ N/C})$$
$$= 3.2 \times 10^{-14} \text{ N}$$

- Acceleration of loose electron between

- Acceleration of loose electron between plates? (no other forces)

$$= 3.2 \times 10^{-14} \, N$$

$$F_{net} = ma \qquad a = \frac{F}{m} = \frac{3.2 \times 10^{-14} \, N}{9.11 \times 10^{-31} \, kg}$$

3.2e-14 / 9.11e-31 = 3.51E16 $= 3.51 \times 10^{16} \, m/s^2$

- Speed if accelerated from one plate to the other? Release from rest

$$v_f^2 = \cancel{v_i^2} + 2a\Delta x \qquad d = 0.01 \, mm$$

$$v_f^2 = 2(3.51 \times 10^{16})(0.1 \times 10^{-3})$$

2*3.51e16*0.1e-3 = 7.02E12 $= 7 \times 10^{12} \, m^2/s^2$

Already squared!

- Kinetic energy of electron when it hits the other side?

$$KE = \tfrac{1}{2}mv^2 = \tfrac{1}{2}(9.11 \times 10^{-31})(7 \times 10^{12})$$

$= 0.5 * 9.11e-31 * 7e12 = 3.2e-18 \, J$

- Energy per unit charge?

$$\frac{KE}{e} = \frac{3.2 \times 10^{-18}}{1.6 \times 10^{-19}} = 20 = \text{original voltage}$$

Where is the electric field zero?

$$E = \frac{kQ}{R^2}$$

$E_1 = \longleftarrow$

$E_2 = \longrightarrow$

$E_1 = \longrightarrow$

$E_2 = \longrightarrow$

$d = 5\,mm$

$q_1 = +4\,nC$

$E_1 + E_2 \neq 0$

$q_2 = -1\,nC$

$E_1 = \longrightarrow$

$E_2 = \longleftarrow$

$E_1 + E_2 = 0$?

Check strengths
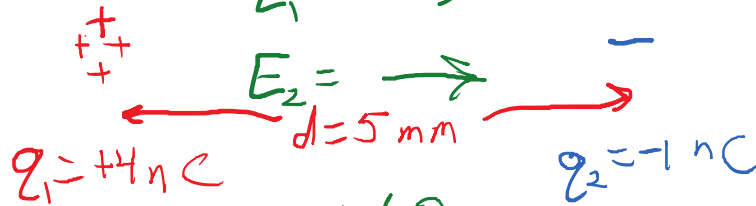
E_1 definitely stronger.

q_1 stronger

R_1 is more

$$|E_1| = |E_2|$$

$$\frac{kq_1}{R_1^2} = \frac{kq_2}{R_2^2}$$

$$\frac{q_1}{q_2} = \left(\frac{R_1}{R_2}\right)^2$$

$$2 = \sqrt{\frac{4}{1}} = \sqrt{\frac{q_1}{q_2}} = \frac{R_1}{R_2}$$

$$R_1 = R_2 + (5mm)$$

The logic is different if we're looking for a place
where V = 0 (instead of E = 0).

Lec 10 - Exam 1 - No notes

Monday, October 15, 2018   9:04 PM