Online Quiz Rules

- Leave the camera ON at all times
- UNMUTE the mic at all times → Do NOT MUTE! I will control.
- If you have questions, type into the zoom chat window to me
- POWER OFF your phone, iPADs and any other computing devices other than the computer you take test with
  - Turn off your pop-up blocker to Quest!
- Have your calculator, formula sheet and clean scrap sheets out
- Write down your answers on your scrap sheet!
  - Be sure to push the “Submit “ button when submitting your answer!
- If you haven’t already, please send me the photos of the front and back of your formula sheet within 15min of the end of the class!

PHYS 1444 – Section 002
Lecture #16

Monday, Apr. 6, 2020
Dr. Jaehoon Yu

CH 26
- RC Circuit

CH 27: Magnetism & Magnetic Field
- Electric Current and Magnetism
- Magnetic Field
- Magnetic Force on a Moving Charge

Today's homework is homework #10, due 11pm, Monday, Apr. 20!!

Announcements

- Reading Assignments: CH27.6, 27.8 and 27.9
- 2nd Non-comprehensive term exam in class Wednesday, Apr. 15
  - Do NOT miss the exam!
  - This is one of the two exams that will be chosen for the final grade!
  - Covers CH25.1 through what we finish Monday, Apr. 13
  - Online exam based on Quest but must join zoom class 12:55pm!
  - You can use your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
    - Turn off your phones!!
  - BYOF: You may prepare a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants
  - No derivations, word definitions or solutions of any problems!
  - Let's be fair to other students and not cheat!

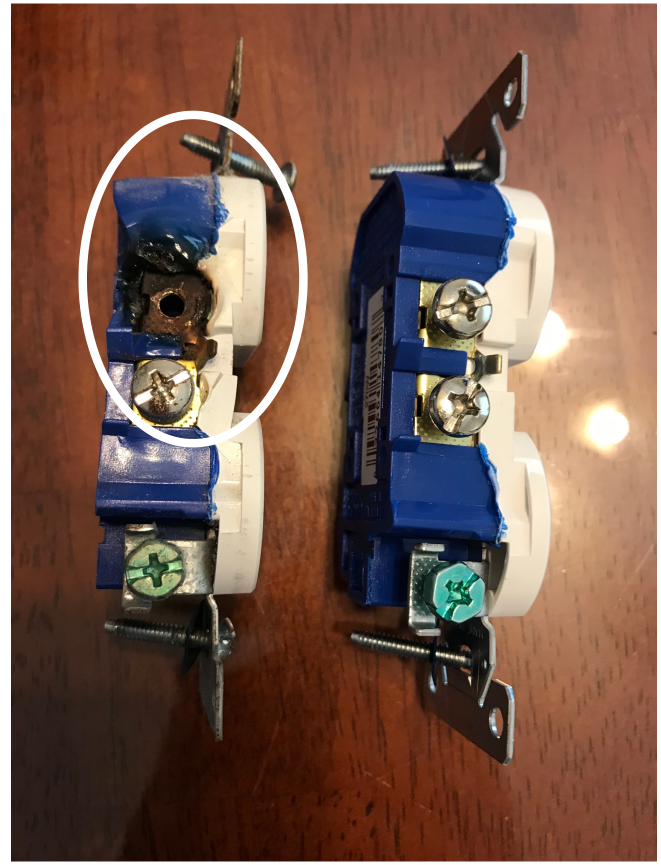
Reminder: Special Project #4

- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compile them in a table. (10 points total for the first 10 items and 0.5 points each additional item.)
- Estimate the cost of electricity for each of the items on the table using your own electric cost per kWh (if you don't find your own, use $0.12/kWh) and put them in the relevant column. (5 points total for the first 10 items and 0.2 points each additional items)
- Estimate the the total amount of energy in Joules and the total electricity cost per day, per month and per year for your home. (8 points)
- Due: Beginning of the class Monday, Apr. 13
  - Scan all pages of your special project into the pdf format
  - Save all pages into one file with the filename SP5-YourLastName-YourFirstName.pdf
  - Send me the file no later than 1pm Monday, Apr. 13
- Spreadsheet has been posted on the class web page. Download ASAP.

Item Name	Rated power (W)	Number of devices	Number of Hours per day	Daily Power Consumption (kWh)	Energy Cost per kWh (cents)	Daily Energy Consumption (J).	Daily Energy Cost ($)	Monthly Energy Consumption (J)	Monthly Energy Cost (S)	Yearly Energy Consumption (J)	Yearly Energy Cost ($)
Light Bulbs	30	4									
	40	6									
	60	15									
Heaters	1000	2									
	1500	1									
	2000	1									
Fans											
Air Conditioners											
Fridgers, Freezers											
Computers (desktop, laptop, ipad)											
Game consoles											
Total				0		0	0	0	0	0	0

The Bad Receptacle Story!

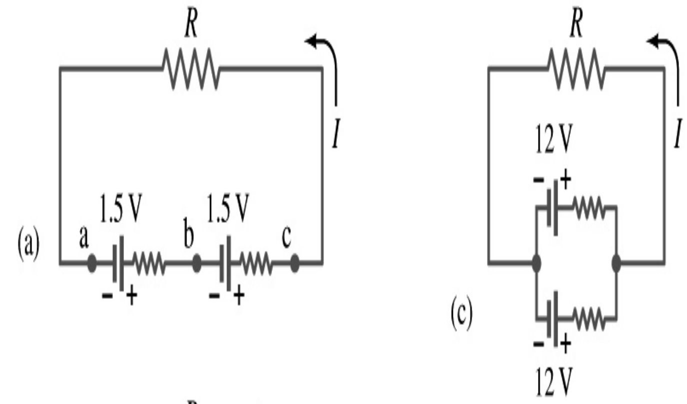
What do you see?

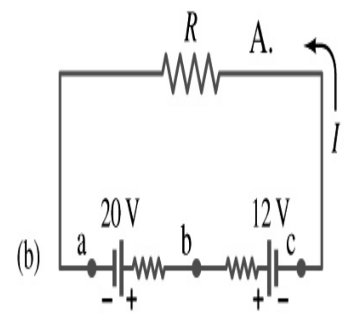


What's the big Q? Why did this connection burnt in the first place?

EMFs in Series and Parallel: Charging a Battery

- When two or more sources of emfs, such as batteries, are connected in series
  - The total voltage is the algebraic sum of their voltages, if their direction is the same
    - V_{ab}=1.5 + 1.5=3.0V in figure (a).
  - If the batteries are arranged in the opposite direction, the total voltage of the circuit is the difference between them
    - V_{ac}=20 – 12=8.0V in figure (b)
    - Connecting batteries in opposite direction is wasteful.
    - This, however, is the way a battery charger works.
    - Since the 20V battery is at a higher voltage, it forces charges into 12V battery
    - Some battery are rechargeable since their chemical reactions are reversible but most the batteries do not reverse their chemical reactions

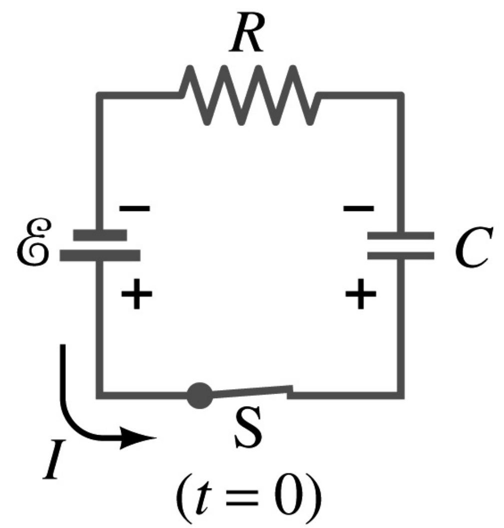




Parallel arrangements (c) are used only to increase currents. An example?

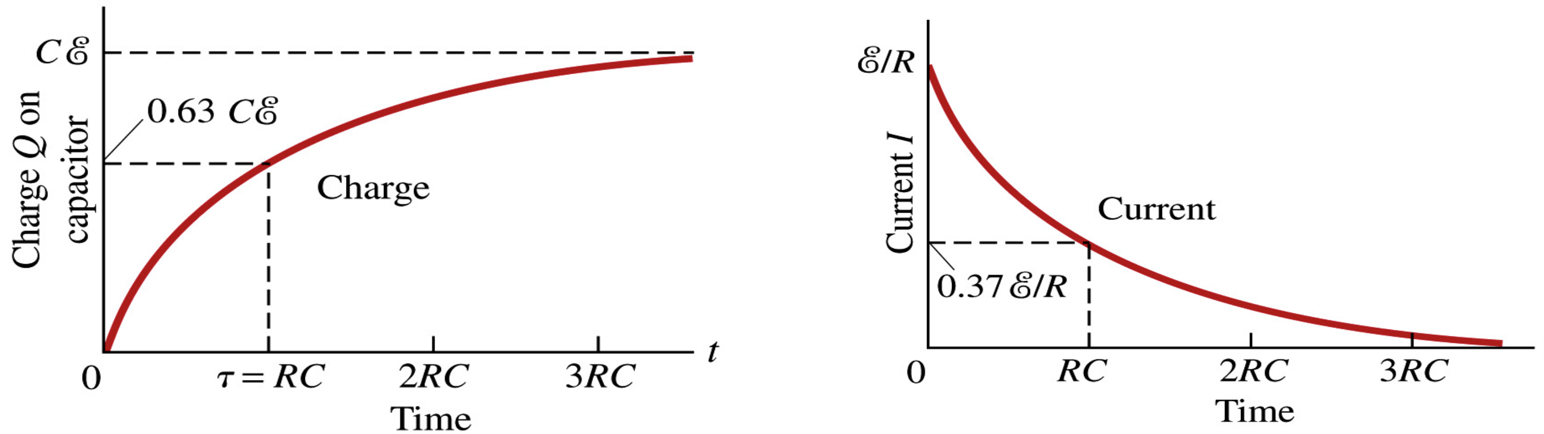
RC Circuits

- Circuits containing both resisters and capacitors
  - RC circuits are used commonly in everyday life
    - Control windshield wiper timer
    - Timing of traffic light from one color to another
    - Camera flashes and heart pacemakers
- How does an RC circuit look?
  - There should be a source of emf, capacitors and resisters
- What happens when the switch S is closed?
  - Current immediately starts flowing through the circuit.
  - Electrons flow out of negative terminal of the emf source, through the resister R and accumulates on the upper plate of the capacitor.
  - The electrons from the bottom plate of the capacitor will flow into the positive terminal of the battery, leaving only positive charge on the bottom plate.
  - As the charge accumulates on the capacitor, the potential difference across it increases
  - The current reduces gradually to 0 till the voltage across the capacitor is the same as emf.
  - The charge on the capacitor increases until it reaches to its maximum $C\mathscr{E}$.



RC Circuits

- How does all this look like in graphs?
  - The charge and the current on the capacitor as a function of time



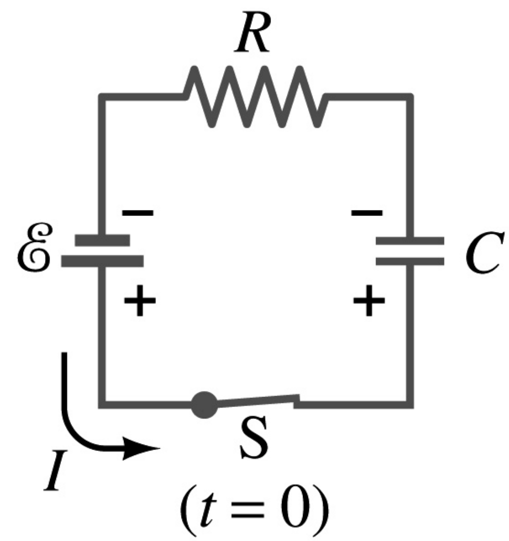
  - From energy conservation (Kirchhoff's 2nd rule), the emf $\mathscr{E}$ must be equal to the voltage drop across the capacitor and the resister
    - $\mathscr{E} = IR + Q/C$
    - R includes all resistance in the circuit, including the internal resistance of the battery, I is the current in the circuit at any instance, and Q is the charge of the capacitor at that same instance.

Analysis of RC Circuits

- In an RC circuit $Q = C\varepsilon\left(1 - e^{-t/RC}\right)$ and $V_C = \varepsilon\left(1 - e^{-t/RC}\right)$
- What can we see from the above equations?
  - Q and V_C increase from 0 at t=0 to the maximum value $Q_{max}=C\mathcal{E}$ and $V_C=\mathcal{E}$.
- In how much time?
  - The quantity RC is called the **time constant** of the circuit, τ
    - τ=RC, What is the unit? Sec.
  - What is the physical meaning?
    - The time required for a capacitor to reach $(1 - e^{-1})=0.63$ or 63% of the full charge
- The current is $I = \frac{dQ}{dt} = \frac{\varepsilon}{R}e^{-t/RC} = I_0 e^{-t/RC}$

Example 26 – 12

RC circuit, with emf. The capacitance in the circuit of the figure is C=0.30μF, the total resistance is 20kΩ, and the battery emf is 12V. Determine (a) the time constant, (b) the maximum charge the capacitor could acquire, (c) the time it takes for the charge to reach 99% of this value, (d) the current I when the charge Q is half its maximum value, (e) the maximum current, and (f) the charge Q when, the current I is 0.20 its maximum value.



(a) Since $\tau = RC$ We obtain $\tau = 20\times10^{3}\cdot0.30\times10^{-6} = 6.0\times10^{-3}\ \mathrm{sec}$

(b) Maximum charge is $Q_{\max} = C\varepsilon = 0.30\times10^{-6}\cdot12 = 3.6\times10^{-6}\,C$

(c) Since $Q = C\varepsilon\left(1-e^{-t/RC}\right)$ For 99% we obtain $0.99C\varepsilon = C\varepsilon\left(1-e^{-t/RC}\right)$

$$e^{-t/RC} = 0.01;\quad -t/RC = -2\ln10;\quad t = RC\cdot2\ln10 = 4.6RC = 28\times10^{-3}\ \mathrm{sec}$$

(d) Since $\varepsilon = IR + Q/C$ We obtain $I = \left(\varepsilon - Q/C\right)/R$

The current when Q is $0.5Q_{max}$ $I = \left(12-1.8\times10^{-6}/0.30\times10^{-6}\right)/20\times10^{3} = 3\times10^{-4}\,A$

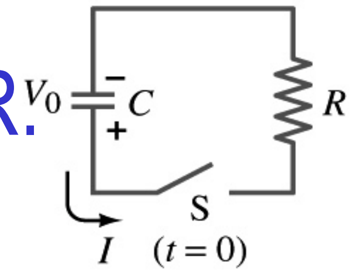
(e) When is I maximum? when Q=0: $I = 12/20\times10^{3} = 6\times10^{-4}\,A$

(f) What is Q when I=120mA? $Q = C\left(\varepsilon - IR\right) =$

$$= 0.30\times10^{-6}\left(12-1.2\times10^{-4}\cdot2\times10^{4}\right) = 2.9\times10^{-6}\,C$$

Discharging an RC Circuit

- When a capacitor is already charged, it is allowed to discharge through the resistance R.



(a)

  - When the switch S is closed, the voltage across the resistor at any instant equals that across the capacitor. Thus IR=Q/C.
  - The rate at which the charge leaves the capacitor equals the negative of the current flows through the resistor
    - I= - dQ/dt
    - Negative since the current is leaving the capacitor
  - Thus the voltage equation becomes a differential equation

$$-\frac{dQ}{dt}R = \frac{Q}{C}$$

Rearrange terms

$$\frac{dQ}{Q} = -\frac{dt}{RC}$$

Discharging an RC Circuit

- Now, let's integrate from t=0 when the charge is Q_0 to t when the charge is Q $\int_{Q_0}^{Q}\frac{dQ}{Q}=-\int_0^t\frac{dt}{RC}$
- The result is $\ln Q\Big|_{Q_0}^{Q}=\ln\frac{Q}{Q_0}=-\frac{t}{RC}$
- Thus, we obtain

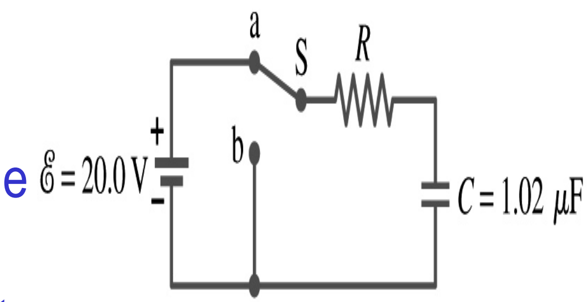
$$Q(t)=Q_0e^{-t/RC}$$

- What does this tell you about the charge on the capacitor?
  - It decreases exponentially w/ time at the time constant RC
  - Just like the case of charging
- The current is: $I=-\frac{dQ}{dt}=\frac{Q_0}{RC}e^{-t/RC}$ $\quad I(t)=I_0e^{-t/RC}$

  What is this?

  - The current also decreases exponentially w/ time w/ the constant RC

Example 26 – 13



Discharging RC circuit. In the RC circuit shown in the figure the battery has fully charged the capacitor, so $Q_0 = C\mathscr{E}$. Then at t=0, the switch is thrown from position a to b. The battery emf is 20.0V, and the capacitance C=1.02μF. The current I is observed to decrease to 0.50 of its initial value in 40μs. (a) what is the value of R? (b) What is the value of Q, the charge on the capacitor, at t=0? (c) What is Q at t=60μs?

(a) Since the current reaches to 0.5 of its initial value in 40μs, we can obtain

$$I(t) = I_0 e^{-t/RC}$$

For $0.5I_0$ →

$$0.5I_0 = I_0 e^{-t/RC}$$

Rearrange terms →

$$-t/RC = \ln 0.5 = -\ln 2$$

Solve for R →

$$R = t/(C\ln 2) = 40\times10^{-6}/\left(1.02\times10^{-6}\cdot\ln 2\right) = 56.6\Omega$$

(b) The value of Q at t=0 is

$$Q_0 = Q_{max} = C\varepsilon = 1.02\times10^{-6}\cdot 20.0 = 20.4\mu C$$

(c) What do we need to know first for the value of Q at t=60μs?

The RC time $\tau = RC = 56.6\cdot 1.02\times10^{-6} = 57.7\mu s$

Thus $Q(t = 60\mu s) = Q_0 e^{-t/RC} = 20.4\times10^{-6}\cdot e^{-60\mu s/57.7\mu s} = 7.2\mu C$

Application of the RC Circuit

- What do you think the charging and discharging characteristics of RC circuits can be used for?
  - To produce voltage pulses at a regular frequency
  - How?
    - The capacitor charges up to a particular voltage and discharges
    - A simple way of doing this is to use breakdown of voltage in a gas filled tube
      - The discharge occurs when the voltage breaks down at V_0
      - After the completion of discharge, the tube no longer conducts
      - Then the voltage is at V_0' and it starts charging up
      - How do you think the voltage as a function of time look?
        - » A sawtooth shape
    - Pacemaker, intermittent windshield wiper, etc