PHYS 1441 – Section 002
Lecture #15

Wednesday, Oct. 31, 2018

Dr. Jaehoon Yu

- Chapter 26 – DC Circuit
  - EMFs in Series and Parallel
  - RC Circuits – Charging and Discharging
- Chapter 27: Magnetism & Magnetic Field
  - Electric Current and Magnetism
  - Magnetic Forces on Electric Current

Announcements

- Reading Assignments: CH26.5, 6 and 7
- Reminder: Quiz #3
  - At the beginning of the class Monday, Nov. 5
  - Covers CH25.5 to what we learn today (CH27.4?)
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants
  - No derivations, word definitions or solutions of any kind!
  - No additional formulae or values of constants will be provided!
- 2nd non-comprehensive term exam: Nov. 14
  - Covers CH25.5 to what we learn Monday, Nov. 12
  - BYOF
- Final exam date and time: 11am – 2:30pm, Wednesday, Dec. 12
- Colloquium today: Dr. D. Winklehner of MIT

Physics Department
The University of Texas at Arlington
<u>COLLOQUIUM</u>

Halloween Special: Developing High Intensity Ion Beams to Hunt Ghost particles

Dr. Daniel Winklehner
MIT

Wednesday October 31, 2018
4:00 p.m. Room 100 Science Hall

Abstract

In the field of the physics of particle beams we are constantly pushing the frontiers of highest energy, highest intensity, and best quality beams. These are strongly correlated parameters and often increasing one comes at the expense of reducing the others. However, through innovation and by leveraging physics (e.g. collective effects) we continuously reduce these tradeoffs. Recently, we have developed a very compact and cost-effective cyclotron-based driver to produce very high intensity beams. The system will be able to deliver continuous wave (cw) electrical beam currents of >10 mA of protons on target in the energy regime around 60 MeV. This is a factor 4 higher than the current state-of-the-art for cyclotrons. All areas of physics and energy science that call for high cw currents can greatly benefit from this result. In this colloquium, I will mainly focus on one example use of this accelerator for producing flavor-pure neutrino beams for IsoDAR (the Isotope Decay-At-Rest experiment), a proposed search for sterile neutrinos. I will present the beam physics challenges that we have addressed to bring us to the present state and outline the next steps that will boost the energy to 1 GeV and enable multi-megawatt cyclotrons for neutrino physics and Accelerator Driven Systems (ADS).

Refreshments will be served at 3:30 in physics lounge

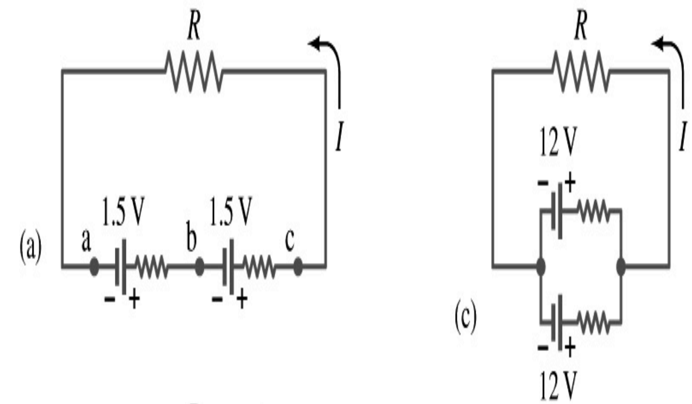
Reminder: Special Extra Credit #4

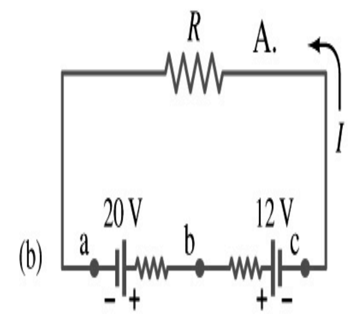
- **Election Participation Exercise**
- For those with legal voting rights: You can submit three “I Voted” stickers or the access code green sheet for 20 points total – one your own and two others who voted and the remainder 2 points each
- For those without legal voting rights: You can submit for the first four “I Voted” sticker or the access code green sheet for 20 points total and the remainder 2 points each
- Be sure to tape one side of the stickers on a sheet of paper with your name on it.
  - Write the precinct number the vote was cast, the full name of the person voted and the signature of the voter next to the relevant sticker
- None of the stickers can be from the same person on someone else’s extra credit or on your own. All of those with any of the identical persons on your extra credit sheet will get 0 credit.
- Deadline: Beginning of the class Wednesday, Nov. 7

These are acceptable!

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 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

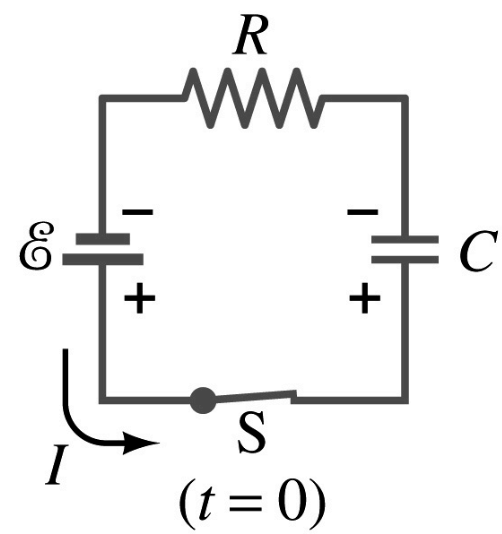




Parallel arrangements (c) are used only to increase currents. An example?

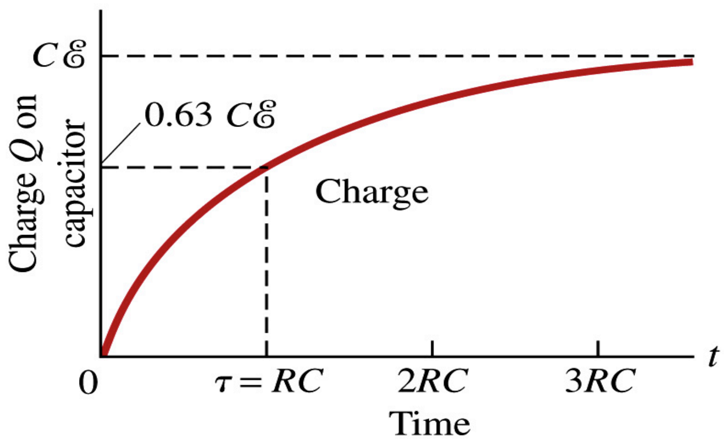
RC Circuits

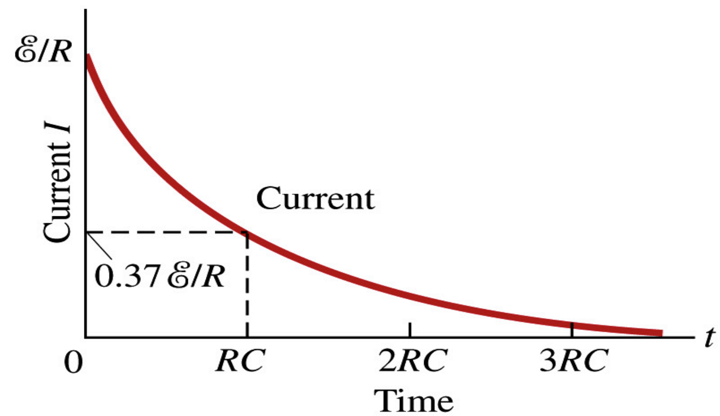
- Circuits containing both resisters and capacitors
  - RC circuits are used commonly in everyday life
    - Control windshield wiper timer
    - Timing of the traffic light
    - Camera flashes and heart pacemakers
- How does an RC circuit look?
  - There should be a source of emf, capacitors and resisters
- 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 till it reaches to its maximum $C\mathcal{E}$.



RC Circuits

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





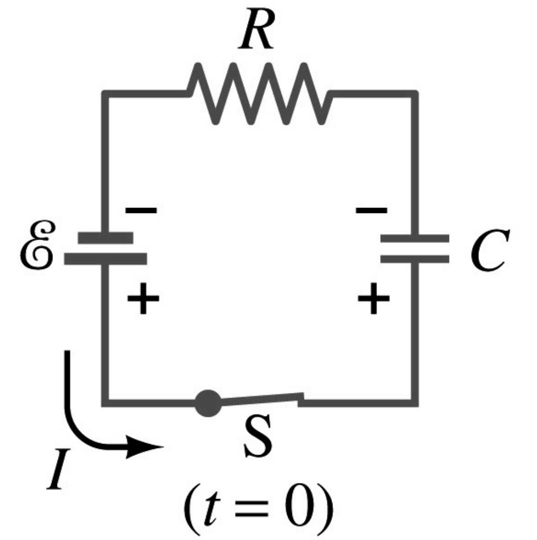
  - From energy conservation (Kirchhoff's 2nd rule), the emf $\mathscr{E}$ must be equal to the voltage drop across the capacitor and the resister
    - $\mathscr{E} = IR + Q/C$
    - R includes all resistance in the circuit, including the internal resistance of the battery, I is the current in the circuit 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 $Q_{max}=C\mathscr{E}$ and $V_C=\mathscr{E}$.
- 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 $I = \dfrac{dQ}{dt} = \dfrac{\varepsilon}{R} e^{-t/RC}$

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 $\tau = 20\times10^{3}\cdot 0.30\times10^{-6} = 6.0\times10^{-3}\ \mathrm{sec}$

(b) Maximum charge is $Q_{\max} = C\varepsilon = 0.30\times10^{-6}\cdot 12 = 3.6\times10^{-6}\,C$

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

$$e^{-t/RC} = 0.01;\quad -t/RC = -2\ln 10;\quad t = RC\cdot 2\ln 10 = 4.6RC = 28\times10^{-3}\ \mathrm{sec}$$

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

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

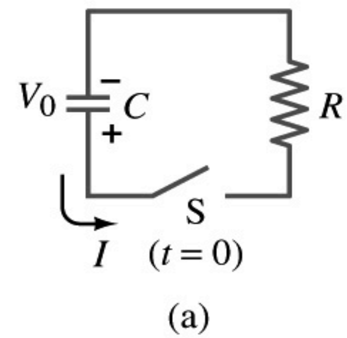
(e) When is I maximum? when Q=0: $I = 12/20\times10^{3} = 6\times10^{-4}\,A$

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

$$= 0.30\times10^{-6}\left(12 - 1.2\times10^{-4}\cdot 2\times10^{4}\right) = 2.9\times10^{-6}\,C$$

Discharging RC Circuits

- When a capacitor is already charged, it is allowed to discharge through a resistance R.
  - 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 through the resistor
    - I= - dQ/dt
    - This is because the current is leaving the capacitor
  - Thus the voltage equation becomes a differential equation



$$-\frac{dQ}{dt}R = \frac{Q}{C} \quad \xrightarrow{\text{Rearrange terms}} \quad \frac{dQ}{Q} = -\frac{dt}{RC}$$

Discharging RC Circuits

– 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 $$\boxed{Q(t)=Q_0e^{-t/RC}}$$

– What does this tell you about the charge on the capacitor?

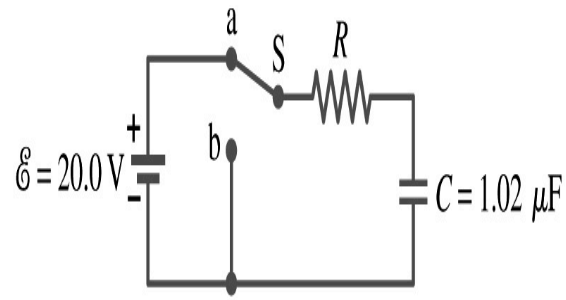
- It decreases exponentially w/ time at the time constant RC
- Just like the case of charging

What is this?

– The current is: $$I=-\frac{dQ}{dt}=\frac{Q_0}{RC}e^{-t/RC}$$ $$\boxed{I(t)=I_0e^{-t/RC}}$$

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

$$I(t)=I_0e^{-t/RC}$$

For $0.5I_0$

$$0.5I_0=I_0e^{-t/RC}$$

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

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

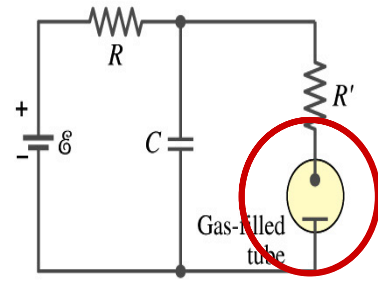
(c) What do we need to know first for the value of Q at t=60μs?

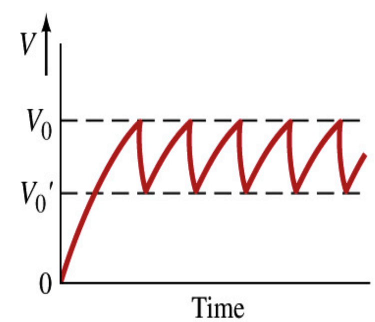
The RC time $\tau=RC=56.6\cdot1.02\times10^{-6}=57.7\mu s$

Thus $Q(t=60\mu s)=Q_0e^{-t/RC}=20.4\times10^{-6}\cdot e^{-60\mu s/57.7\mu s}=7.2\mu C$

Application of RC Circuits

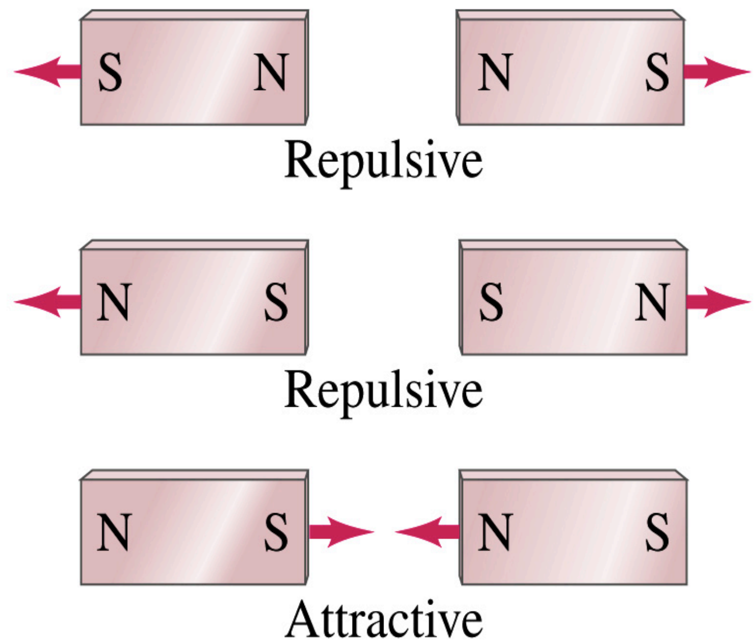
- What do you think the charging and discharging characteristics of RC circuits can be used for?
  - To produce voltage pulses at a regular frequency
  - How?
    - The capacitor charges up to a particular voltage and discharges
    - A simple way of doing this is to use breakdown of voltage in a gas 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
    - Pace maker, intermittent windshield wiper, etc





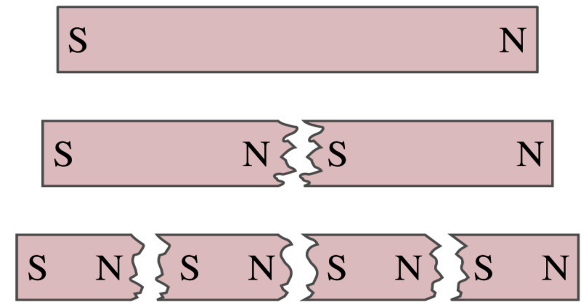
Magnetism

- What are magnets?
  - Objects with two poles, North and South poles
    - The pole that points to the geographical North is the North pole and the other is the South pole
      - Principle of compass
  - These are called magnets due to the name of the region, Magnesia, where rocks that attract each other were found
- What happens when two magnets are brought to each other?
  - They exert force onto each other
  - What kind?
  - Both repulsive and attractive forces depending on the configurations
    - Like poles repel each other while the unlike poles attract



Magnetism

- So the magnetic poles are the same as the electric charge?
  - No. Why not?
  - While the electric charges (positive and negative) can be isolated, the magnetic poles cannot be isolated.
  - So what happens when a magnet is cut?
    - If a magnet is cut, two magnets are made.
    - The more they get cut, the more magnets are made



  - Single pole magnets are called the monopole but it has not been seen yet
- Ferromagnetic materials: Materials that show strong magnetic effects
  - Iron, cobalt, nickel, gadolinium and certain alloys
- Other materials show very weak magnetic effects