PHYS 1444 – Section 002
Lecture #16

Monday, Oct. 28, 2019

Dr. Jaehoon Yu

CH 26

- How to use Kirchhoff's rules
- RC Circuit

CH 27: Magnetism & Magnetic Field

- Electric Current and Magnetism

Homework #9 due extended to 11pm, Monday, Nov. 4!!

Today's Homework is #10 due 11pm, Friday, Nov. 8!!

Announcements

- Reading Assignments: CH26.5, 6 and 7
- Quiz #3
  - This Wednesday, Oct. 30, beginning of the class
  - Covers: CH25.5 through what we finish today (CH. 27.1?)
  - 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 for the quiz
  - No derivations, word definitions, set ups or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- 2nd non-comprehensive term exam: Nov. 11
  - Covers CH25.5 to what we learn Wednesday, Nov. 6
  - BYOF
- Final exam date and time: 1pm – 2:30pm, Wednesday, Dec. 4
- Remember the triple extra credit colloquia
  - This Wed. Oct. 30: Prof. Liantao Wang of U. of Chicago
  - Wed. Nov. 13: Prof Hitoshi Murayama of U.C. Berkeley

Reminder: Special Extra Credit #4

- **Civic Duty Participation Exercise**
- You can submit up to four “I Voted” stickers for 20 points total
  - If voted, they give 3 pieces of paper of which one has pricinct info.
- Be sure to tape one side of the stickers on a sheet of paper with your name on it along with the following info for each sticker
  - The number and the name of the precinct the vote was cast
  - The full name of the person voted next to the relevant sticker
  - The signature of the person voted next to the full name
- None of the stickers can be from the same person on someone else’s extra credit or yours
- Deadline: Beginning of the class next Wednesday, Nov. 6

2019-10-24 16:35
CAROLINA CALERO

Voter Ticket

11/05/2019
Center for Community Services Junior League of A
rlington

JAEHOON YU

Precinct: 2266
Ballot Style: 2266-013

Duo

2266-013

2019-10-24 16:35
CERT: 2102711
JAEHOON YU
BS: 2266-013 NP

ACCESS CODE

45478

10/24/2019 4:36 PM

EV-Junior League of Arlington

Pct: 2266-013

Reminder: Special Project #5

- 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)
- Spreadsheet: http://www-hep.uta.edu/%7Eyu/teaching/fall19-1444-002/sp5-spreadsheet.xlsx
- Due: Beginning of the class Monday, Nov. 11

PHYS1442-002, Fall 19, Special Project #5

Your Name						Electricity Rate					c/kWh
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									
Home Appliances (Fans, vacuum cleaners, hair dryers, pool pumps, etc)											
Air Conditioners											
Kitchen Appliances (Fridges, freeezers, cook tops, microwave ovens, toaster ovens, etc)											
Computing devices (desktop, laptop, ipad, mobile phones, printers, chargers, etc))											
Tools (power tools, electric mower, electric cutter, etc)											
Medical Devices (blood pressure machine, thermometer, etc)											
Transporations (electric cars, electric bicycles, electric motor cycles, etc											
Total											

Kirchhoff's Rules

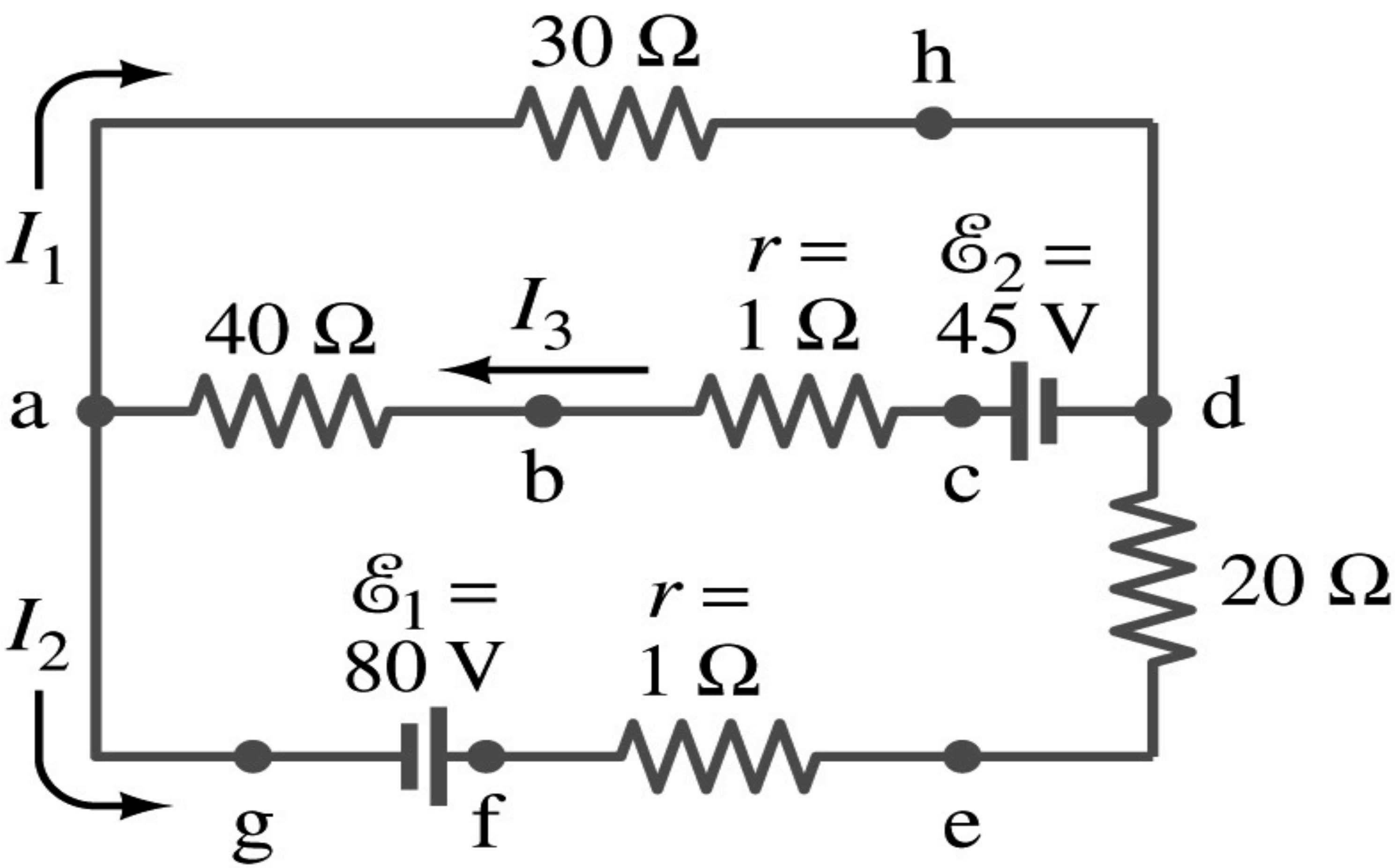
- Kirchoff's 1st rule: The junction rule uses **charge conservation**
  - At any junction point, the sum of all currents entering the junction must be equal to the sum of all currents leaving the junction.
- Kirchoff's 2nd rule: The loop rule uses **conservation of energy**.
  - The sum of the changes in potential in any closed path of a circuit must be zero.

How to use Kirchhoff's Rules??

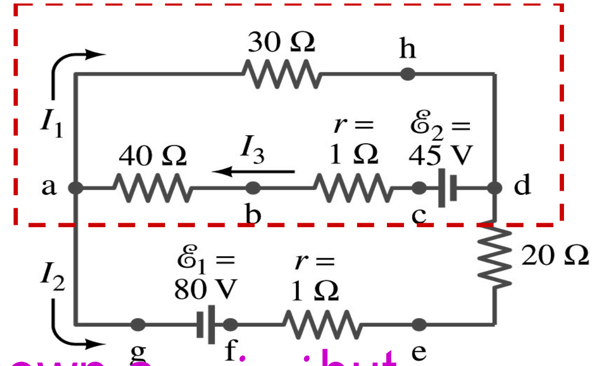
1. Determine the flow of currents at the junctions and label each and everyone of the indepent currents.
   - It does not matter which direction, you decide but keep it!
     - You cannot have all current coming in or going out of a junction, though!
   - If the value of the current after completing the calculations are negative, you just need to flip the direction of the current flow.
2. Write down the current equation based on Kirchhoff's 1st rule at various junctions.
   - Be sure to see if any of them are the same.
3. Choose closed loops in the circuit
4. Write down the potential in each interval of the junctions, keeping the proper signs as you decided in step 1 above.
5. Write down the potential equations for each loop.
6. Solve the equations for unknowns.

Example 26 – 9

Use Kirchhoff's rules. Calculate the currents I_1, I_2 and I_3 in each of the branches of the circuit in the figure.



Example 26 – 9



Use Kirchhoff's rules. Calculate the currents I_1, I_2 and I_3 in each of the branches of the circuit in the figure.

The directions of the current through the circuit is not known a *priori* but since the current tends to move away from the positive terminal of a battery, we arbitrarily choose the direction of the currents as shown.

We have three unknowns so we need three equations.

Using Kirchhoff's junction rule at point *a*, we obtain $I_3 = I_1 + I_2$

This is the same for junction *d* as well, so no additional information.

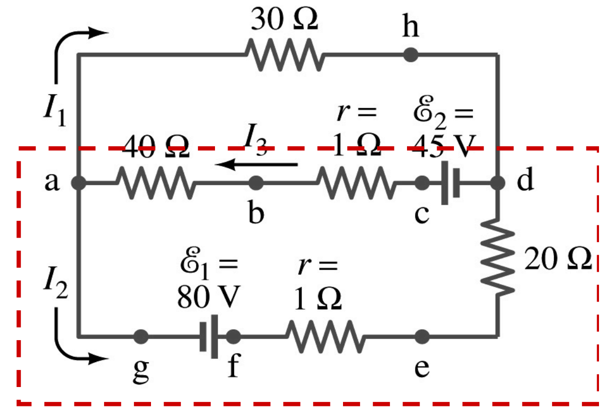
Now the second rule on the loop *ahdcba*.

$$V_{ah} = -I_1 30 \qquad V_{hd} = 0 \qquad V_{dc} = +45 \qquad V_{cb} = -I_3 \qquad V_{ba} = -40I_3$$

The total voltage change in the loop *ahdcba* is.

$$V_{ahdcba} = -30I_1 + 45 - 1 \cdot I_3 - 40I_3 = 45 - 30I_1 - 41I_3 = 0$$

Example 26 – 9, cnt'd



Now the second rule on the other loop *agfedcba*.

$V_{ag} = 0 \quad V_{gf} = +80 \quad V_{fe} = -I_2 \cdot 1 \quad V_{ed} = -I_2 \cdot 20$

$V_{dc} = +45 \quad V_{cb} = -I_3 \cdot 1 \quad V_{ba} = -40 \cdot I_3$

The total voltage change in loop *agfedcba* is. $V_{agfedcba} = -21I_2 + 125 - 41I_3 = 0$

So the three equations become

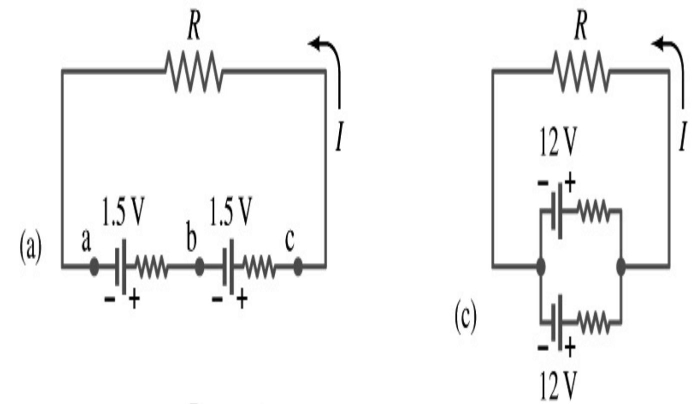
$$I_3 = I_1 + I_2$$
$$45 - 30I_1 - 41I_3 = 0$$
$$125 - 21I_2 - 41I_3 = 0$$

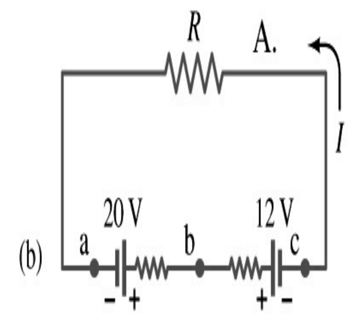
We can obtain the three current by solving these equations for I_1, I_2 and I_3.

Do this yourselves!!

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 an 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

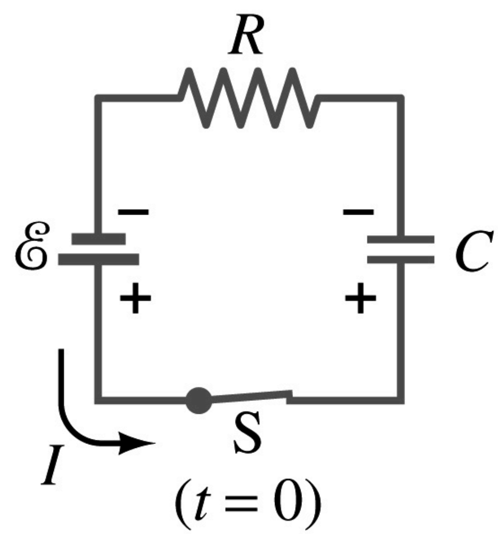




Parallel arrangements (c) are used only to increase currents. An example?

RC Circuits

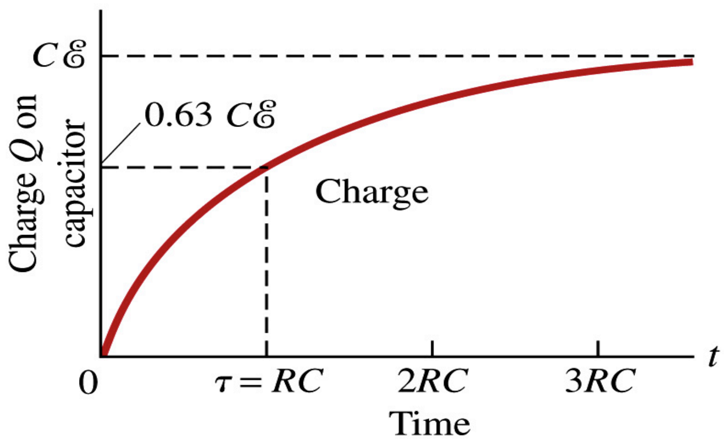
- Circuits containing both resisters and capacitors
  - RC circuits are used commonly in everyday life
    - Control windshield wiper timer
    - Timing of traffic light from one color to another
    - Camera flashes and heart pacemakers
- How does an RC circuit look?
  - There should be a source of emf, capacitors and resisters

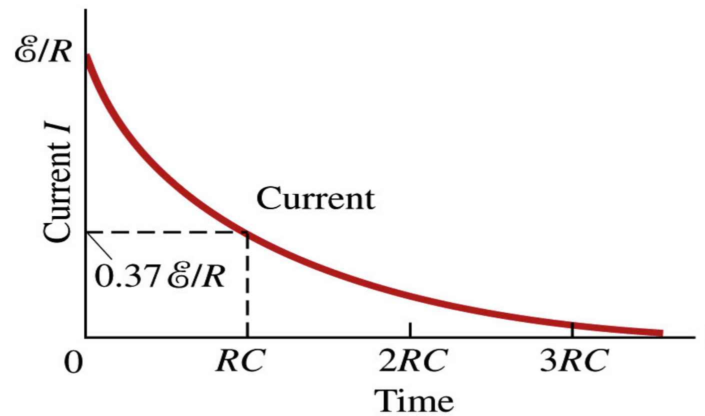


- What happens when the switch S is closed?
  - Current immediately starts flowing through the circuit.
  - Electrons flow out of negative terminal of the emf source, through the resister R and accumulates on the upper plate of the capacitor.
  - The electrons from the bottom plate of the capacitor will 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





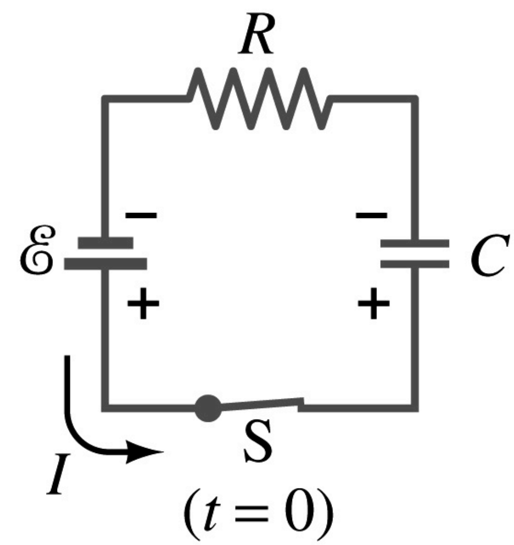
  - From energy conservation (Kirchhoff's 2nd rule), the emf $\mathcal{E}$ must be equal to the voltage drop across the capacitor and the resister
    - $\mathcal{E} = IR + Q/C$
    - R includes all resistance in the circuit, including the internal resistance of the battery, I is the current in the circuit 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 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? $\boxed{\text{Sec.}}$
  - 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 $\tau = 20\times10^{3}\cdot 0.30\times10^{-6} = 6.0\times10^{-3}\ \text{sec}$

(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 $0.99C\varepsilon = C\varepsilon\left(1 - e^{-t/RC}\right)$

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

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

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

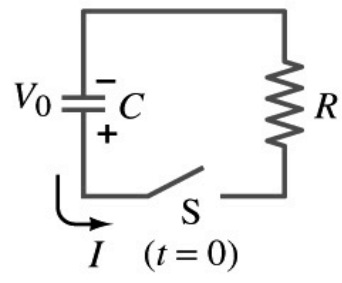
(e) When is I maximum? when Q=0: $I = 12/20\times10^{3} = 6\times10^{-4}\,A$

(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 an RC Circuit

- 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 the current flows through the resistor
    - I= - dQ/dt
    - Since the current is leaving the capacitor
  - Thus the voltage equation becomes a differential equation



(a)

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

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

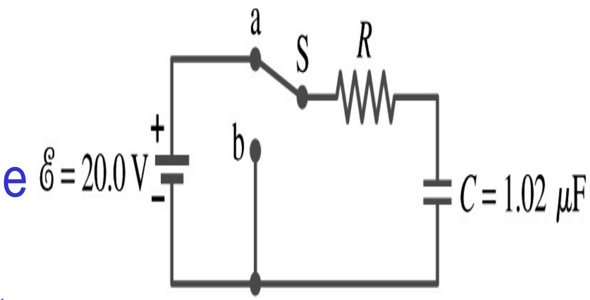
$$\boxed{Q(t)=Q_0e^{-t/RC}}$$

- 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 constant RC

Example 26 – 13



Discharging RC circuit. In the RC circuit shown in the figure the battery has fully charged the capacitor, so $Q_0 = C\mathcal{E}$. 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 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