PHYS 1444 – Section 003
Lecture #14

Wednesday, Oct. 19, 2005

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- RC circuit example
- Discharging RC circuits
- Application of RC circuits
- Magnets
- Magnetic field
- Earth's magnetic field
- Magnetic field by electric current
- Magnetic force on electric current

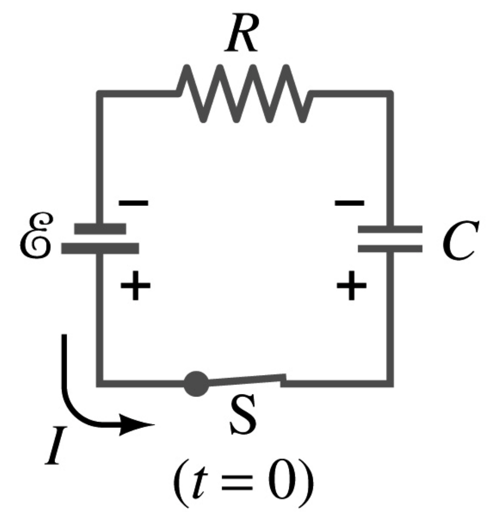
Announcements

- There is a colloquium at 4pm in SH103
  - All Physics faculty will introduce their own research
  - An extra credit opportunity
- Extra credit opportunity was announced on Sept. 14th:
  - 15 point extra credit for presenting a professionally prepared 3 page presentation on any one of the exhibits at the UC gallery (till 9/16) and the subsequent themed displays at the central library.
    - Must include what it does, how it works and where it is used. Possibly how it can be made to perform better.
    - Due: Oct. 19, 2005

Analysis of RC Circuits

- Since $Q = C\varepsilon\left(1 - e^{-t/RC}\right)$ 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 ε and V_C= ε.
- In how much time?
  - The quantity RC is called the time constant, τ, of the circuit
    - τ=RC, What is the unit? Sec.
  - What is the physical meaning?
    - The time required for the capacitor to reach $(1-e^{-1})=0.63$ or 63% of the full charge
- The current is $I = \frac{dQ}{dt} = \frac{\varepsilon}{R} e^{-t/RC}$

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

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

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

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

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

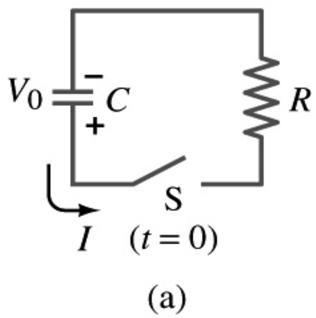
(e) When is I maximum? when Q=0: $I = 12/20\times10^{3} = 6\times10^{-4}\,A$

(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 the current flows through the resistor
    - I=-dQ/dt.   Why 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 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

$$Q(t) = Q_0 e^{-t/RC}$$

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

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

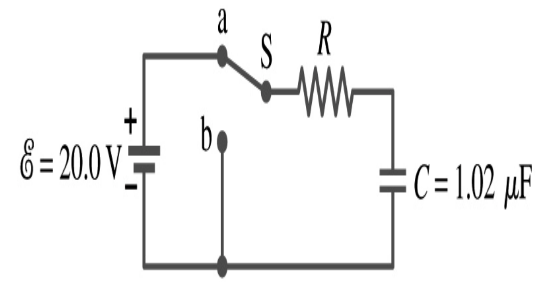
What is this?

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

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

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

Example 26 – 13



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

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

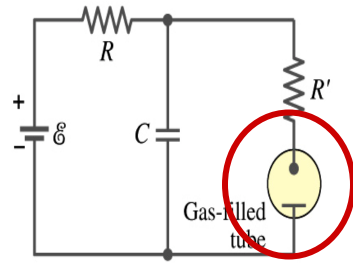
(c) What do we need to know first for the value of Q at t=60μs?

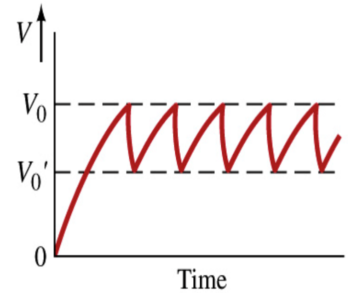
The RC time $\tau = RC = 56.6\cdot 1.02\times10^{-6} = 57.7\mu s$

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

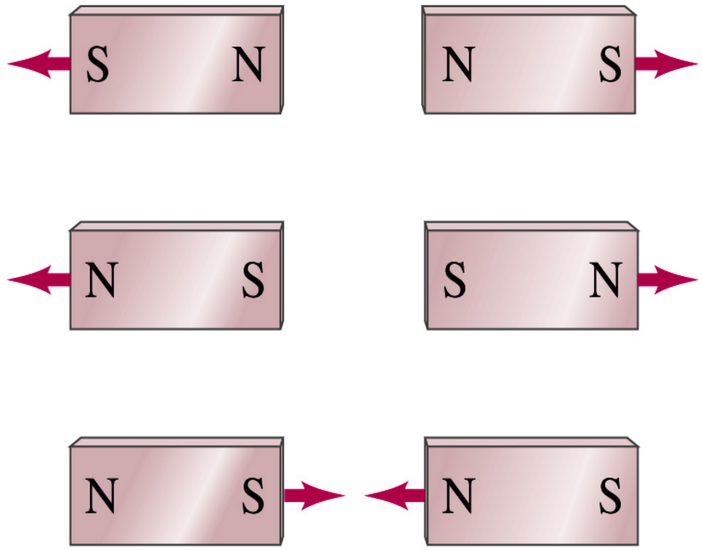
- What do you think the charging and discharging characteristics of RC circuits can be used for?
  - To produce voltage pulses at a regular frequency
  - How?
    - The capacitor charges up to a particular voltage and discharges
    - A simple way of doing this is to use breakdown of voltage in a gas filled tube
      - The discharge occurs when the voltage breaks down at V0
      - After the completion of discharge, the tube no longer conducts
      - Then the voltage is at V0' 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





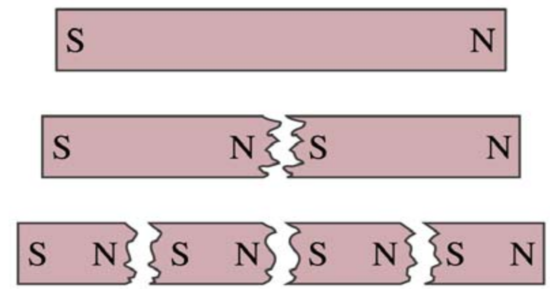
Magnetism

- What are magnets?
  - Objects with two poles, north and south poles
    - The pole that points to 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 magnet poles are the same as the electric charge?
  - No. Why not?
  - While the electric charges (positive and negative) can be isolated the magnet 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