Homework #6 due next Tuesday at 11:59PM
There will be a QUIZ this week in recitations on the material covered in lecture last week – you may use your formula sheet
Ammeter: device that measures current (amperes)

Two-terminal device
Insert into the circuit so that the current to be measured passes through the ammeter “in series”

Insert an additional device – a different circuit change currents and voltages in the rest of the circuit? resistance should be as LOW as possible

Single loop circuit: EXAMPLE: $E$ and $R$. Insert ammeter with resistance $r$. Current changes from $E/R$ to $E/(R+r)$. The smaller $r$ is, the less the current changes.
**Voltmeter:** device that measures potential difference (volts)

Two-terminal device
Connected between the two points between which you want to measure the potential difference
“in parallel”

Insert an additional device – a different circuit
change currents and voltages in the rest of the circuit?
resistance should be as HIGH as possible

Single loop circuit: \( E \) and two resistors \( R \). Connect voltmeter with resistance \( r \) across one of the resistors. \( V \) across the resistor in absence of the voltmeter is \( \frac{E}{R} \). With the voltmeter, \( r \) is in parallel and \( V' \) is \( E \left( \frac{rR}{r+R} \right) \left( \frac{R+rR}{R} \right) = E \left( \frac{r}{r+R} \right) \left( \frac{1+r/\left( r+R \right)}{} \right) = E \left( \frac{1/(1+R/r)}{(2+R/r)/(1+R/r)} \right) = E \left( \frac{1/(2+R/r)}{1+R/r} \right) \) so want \( r >> R \)
**Voltmeter:** device that measures potential difference (volts)

Two-terminal device  
Connected between the two points between which you want to measure the potential difference  
“in parallel”

Insert an additional device – a different circuit  
change currents and voltages in the rest of the circuit? resistance should be as HIGH as possible

Measures potential differences in a fixed range  
“full scale” = maximum deflection, top of the range  
Deflection of needle is proportional to the voltage difference
Introduction to time-varying circuits

Release the steady-current condition a little bit
Allow current to depend on time \( i(t) \)
charge on capacitor(s) to change with time \( Q(t) \)

The rules we learned for time-independent circuits are still true:
Take a snapshot at time \( t \)
The voltage change through each circuit element is computed the same way as before
Loop rule and junction rule hold at each time \( t \)
A single-loop circuit with a battery \( E \), a resistor \( R \) and capacitor \( C \)

**STEADY CURRENT CONDITION:**
No current flows \( i = 0 \)
Charge on capacitor \( Q = CE \)
a single-loop circuit with a battery $E$, a resistor $R$ and capacitor $C$

Charge on capacitor $Q(t)$
$V(t)$ across the capacitor is $Q(t)/C$
$V(t)$ across the resistor is $E - V(t)$
i(t) is $(E - V(t))/R$
a single-loop circuit with a battery $E$, a resistor $R$ and capacitor $C$

Charge on capacitor $Q(t)$
$V(t)$ across the capacitor is $Q(t)/C$
$V(t)$ across the resistor is $E - V(t)$
i(t) is $(E - V(t))/R$

One more important fact
$i(t) = dQ/dt$
In the circuit shown, $\mathcal{E}$ is 20 V and $Q(t)$ on the 100 nF capacitor is 1 $\mu$C at $t=2.0$ s. What is the current through the 5.0 $\Omega$ resistor at $t = 2.0$s?

(a) 20 A
(b) 3.0 A
(c) 2.0 A
(d) 1.0 A
(e) I have no idea how to do this
RC circuits

Switch closed to “a” position at t=0
Initial q = 0

\[ E - iR - \frac{q}{C} = 0. \]

\[ i = \frac{dq}{dt}. \]

\[ R \frac{dq}{dt} + \frac{q}{C} = E \]

\[ q = C E (1 - e^{-t/RC}) \]

\[ i = \frac{dq}{dt} = \left(\frac{E}{R}\right)e^{-t/RC} \]

Fig. 27-15 When switch S is closed on a, the capacitor is charged through the resistor. When the switch is afterward closed on b, the capacitor discharges through the resistor.

A capacitor that is being charged initially acts like ordinary connecting wire relative to the charging current. A long time later, it acts like a broken wire.
RC circuits

The time it takes for the current to decrease by a factor of $e$ is known as the "time constant".

$$\tau = RC$$

The time it takes for the current to decrease by a factor of 2 is given by $\ln 2 = \frac{1}{R} \ln \frac{\mathcal{E}}{Q}$.

Fig. 27-15 When switch $S$ is closed on $a$, the capacitor is charged through the resistor. When the switch is afterward closed on $b$, the capacitor discharges through the resistor.
Discharge a charged capacitor: $q(t=0) = q_0$

The time it takes for the current to decrease by a factor of $e$ “time constant” $\tau = RC$

$R \frac{dq}{dt} + \frac{q}{C} = 0$

$q = q_0 e^{-t/RC}$

$RC \ln 2 = \text{the time it takes for the current to decrease by a factor of 2}$

$i = \frac{dq}{dt} = -\left( \frac{q_0}{RC} \right) e^{-t/RC}$
Discharge the capacitor

\[ R \frac{dq}{dt} + \frac{q}{C} = 0 \]

\[ q = q_0 e^{-t/RC} \]

\[ i = \frac{dq}{dt} = -\left( \frac{q_0}{RC} \right) e^{-t/RC} \]

\[ \tau = RC \]

the time it takes for the current to decrease by a factor of e

“time constant”

RC ln 2 = the time it takes for the current to decrease by a factor of 2

What happened to the energy in the capacitor at \( t=0 \)?

\( i^2R \) in the resistor – dissipated as heat
Clicker (to be answered with the demo)

If I put a second identical capacitor in parallel with the original what will happen to the time it takes for the current to drop by a factor of 2?

(a) Doubles
(b) Stays the same
(c) Decreases by a factor of two
(d) None of the above
Clicker (to be answered with the demo)

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