Electricity and Magnetism
DC Circuits
RC Circuits
Meters
Household Wiring

Lana Sheridan

De Anza College

Feb 13, 2018

Last time

- resistance-capacitance circuits

Overview

- resistance-capacitance circuits
- meters
- grounding a circuit
- household wiring

RC Circuits: Discharging Capacitor

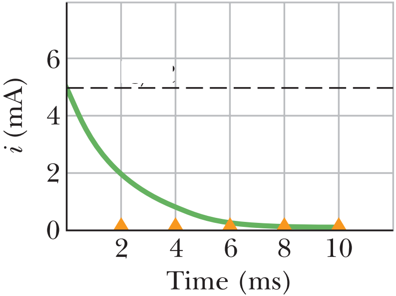
Charge:

$$q(t) = Q_i \, e^{-t/RC}$$

Current, with $I_i = \frac{Q_i}{RC}$:

$$i(t) = -I_i \, e^{-t/RC}$$

The negative sign means the current flows in the opposite direction through the resistor when discharging as compared with charging.



RC Circuits: Discharging Capacitor

Multiplying the current by the resistance R gives the potential difference across the resistor:

$$|\Delta V_R(t)| = (\Delta V)_i \, e^{-t/RC}$$

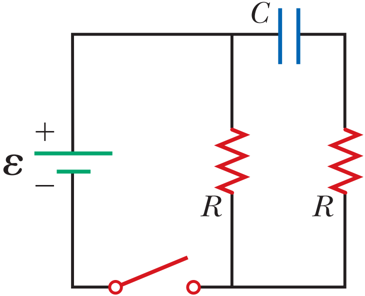
The same expression describes the potential difference across the capacitor!

$$|\Delta V_C(t)| = (\Delta V)_i \, e^{-t/RC}$$

where $(\Delta V)_i = I_i R = \frac{Q_i}{C}$.

RC Circuits Question

Quick Quiz 28.5: Consider the circuit shown and assume the battery has no internal resistance.

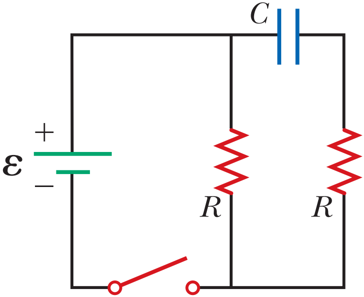


(i) Just after the switch is closed, what is the current in the battery?

(A) 0
(B) $\mathcal{E}/2R$
(C) $2\mathcal{E}/R$
(D) $\mathcal{E}/R$

RC Circuits Question

Quick Quiz 28.5: Consider the circuit shown and assume the battery has no internal resistance.

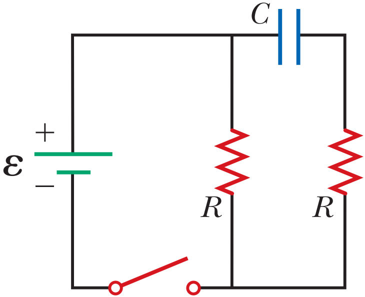


(i) Just after the switch is closed, what is the current in the battery?

(A) 0
(B) $\mathcal{E}/2R$
(C) $2\mathcal{E}/R$ ←
(D) $\mathcal{E}/R$

RC Circuits Question

Quick Quiz 28.5: Consider the circuit shown and assume the battery has no internal resistance.



(ii) After a very long time, what is the current in the battery?

(A) 0

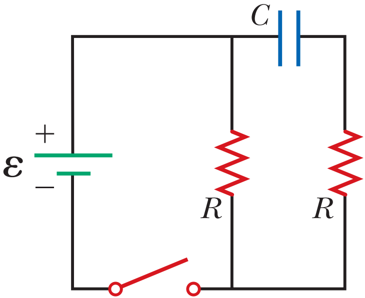
(B) $\mathcal{E}/2R$

(C) $2\mathcal{E}/R$

(D) $\mathcal{E}/R$

RC Circuits Question

Quick Quiz 28.5: Consider the circuit shown and assume the battery has no internal resistance.



(ii) After a very long time, what is the current in the battery?

(A) 0

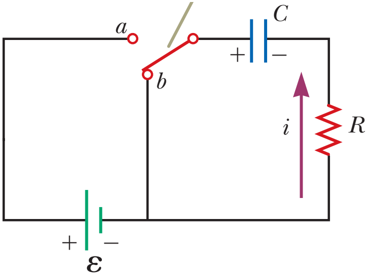
(B) $\mathcal{E}/2R$

(C) $2\mathcal{E}/R$

(D) $\mathcal{E}/R$ ←

RC Circuits Example 28.10

Consider a capacitor of capacitance C that is being discharged through a resistor of resistance R as shown in the figure.



After how many time constants is the charge on the capacitor one-fourth its initial value?

RC Circuits Example 28.10

After how many time constants is the charge on the capacitor one-fourth its initial value?

$$q(t) = Q_i\, e^{-t/RC}$$

Let T be the time when the charge is $1/4$ of the initial charge.

$$\begin{aligned} \frac{q(T)}{Q_i} &= \frac{1}{4} \\ e^{-T/\tau} &= \frac{1}{4} \\ \frac{T}{\tau} &= \ln 4 \end{aligned}$$

RC Circuits Example 28.10

After how many time constants is the charge on the capacitor one-fourth its initial value?

$$q(t) = Q_i \, e^{-t/RC}$$

Let T be the time when the charge is $1/4$ of the initial charge.

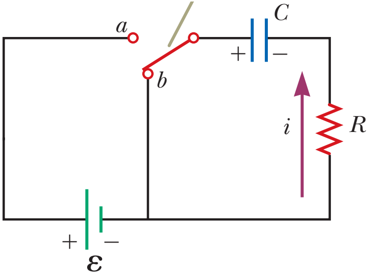
$$\begin{aligned} \frac{q(T)}{Q_i} &= \frac{1}{4} \\ e^{-T/\tau} &= \frac{1}{4} \\ \frac{T}{\tau} &= \ln 4 \end{aligned}$$

So,

$$T = (\ln 4)\tau = 1.39\tau$$

RC Circuits Example 28.10

Consider a capacitor of capacitance C that is being discharged through a resistor of resistance R as shown in the figure.



The energy stored in the capacitor decreases with time as the capacitor discharges. After how many time constants is this stored energy one-fourth its initial value?

RC Circuits Example 28.10

After how many time constants is this stored energy one-fourth its initial value?

$$U = \frac{q^2}{2C}$$

Now let T be the time when the energy stored is $1/4$ of the initial energy.

$$\begin{aligned} \frac{U(T)}{U_i} &= \frac{1}{4} \\ \frac{q(T)^2}{Q_i^2} &= \frac{1}{4} \\ e^{-T/\tau} &= \frac{1}{2} \end{aligned}$$

RC Circuits Example 28.10

After how many time constants is this stored energy one-fourth its initial value?

$$U = \frac{q^2}{2C}$$

Now let T be the time when the energy stored is $1/4$ of the initial energy.

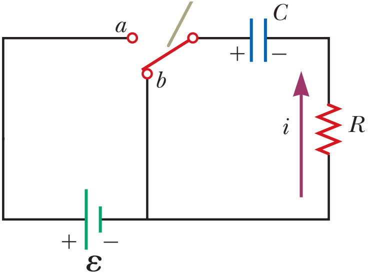
$$\begin{aligned} \frac{U(T)}{U_i} &= \frac{1}{4} \\ \frac{q(T)^2}{Q_i^2} &= \frac{1}{4} \\ e^{-T/\tau} &= \frac{1}{2} \end{aligned}$$

So,

$$T = (\ln 2)\tau = 0.693\tau$$

RC Circuits Example 28.11: Energy delivered

A 5.00 μF capacitor is charged to a potential difference of 800 V and then discharged through a resistor. How much energy is delivered to the resistor in the time interval required to fully discharge the capacitor?



RC Circuits Example 28.11: Energy delivered

$C = 5.00\ \mu\text{F}$, $\Delta V = 800$ V. How much energy is delivered to the resistor in the time interval required to fully discharge the capacitor?

Two ways: (1) Energy conservation. (2) “sum up” the power delivered over the time.

RC Circuits Example 28.11: Energy delivered

Way (1): Energy not stored in the resistor must have been delivered to the resistor.

$$\Delta U_C + \Delta E_R = 0$$

$$\Delta E_R = U_{C,i} - U_{C,f}$$

RC Circuits Example 28.11: Energy delivered

Way (1): Energy not stored in the resistor must have been delivered to the resistor.

$$\Delta U_C + \Delta E_R = 0$$

$$\begin{aligned} \Delta E_R &= U_{C,i} - U_{C,f} \\ &= \frac{Q_i^2}{2C} - 0 \\ &= \frac{(C\ \Delta V)^2}{2C} - 0 \\ &= \frac{C\ (\Delta V)^2}{2} \end{aligned}$$

$$\Delta E_R = 1.60\ \text{J}$$

RC Circuits Example 28.11: Energy delivered

Way (2): integrate the power delivered over the time

$$P = \frac{\mathrm{dW}}{\mathrm{dt}}$$

$$\begin{aligned} \Delta E_R &= \int P \, \mathrm{dt} \\ &= \int i^2 R \, \mathrm{dt} \\ &= R \int_0^\infty I_i^2 e^{-2t/RC} \, \mathrm{dt} \end{aligned}$$

RC Circuits Example 28.11: Energy delivered

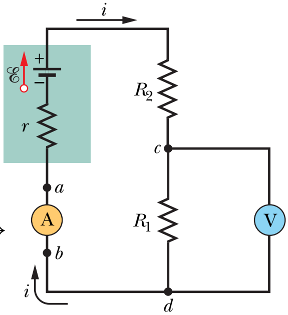
Way (2): integrate the power delivered over the time

$$P = \frac{\mathrm{dW}}{\mathrm{dt}}$$

$$\begin{aligned} \Delta E_R &= \int P \, \mathrm{dt} \\ &= \int i^2 R \, \mathrm{dt} \\ &= R \int_0^\infty I_i^2 e^{-2t/RC} \, \mathrm{dt} \\ &= I_i^2 R \left[-\frac{RC}{2} e^{-2t/RC} \right]_0^\infty \\ &= \left(\frac{\Delta V}{R} \right)^2 \frac{R^2 C}{2} \\ &= \frac{C(\Delta V)^2}{2} \end{aligned}$$

Same! $\Delta E_R = 1.60 \text{ J}$

Ammeters and Voltmeters



ammeter →

← voltmeter

Ammeter

A device for measuring **current** through a component in a circuit.

Voltmeter

A device for measuring **potential difference** across a component of a circuit.

Ammeter

For an ammeter to work, the same current that you want to measure must go through the ammeter.

Therefore, it must be connected in series in the part of the circuit where you want to test the current.

Ammeter

For an ammeter to work, the same current that you want to measure must go through the ammeter.

Therefore, it must be connected in series in the part of the circuit where you want to test the current.

Any resistance from the ammeter (r_A) will decrease the current in that part of the circuit.

$$I = \frac{\Delta V}{R + r_A}$$

If $r_A = 0$ the current through that part of the circuit is unchanged.

The current cannot actually be zero, but it needs to be as small as possible for an accurate measurement:

$$r_A << R$$

Voltmeter

For an voltmeter to work, the same potential difference must be across the voltmeter as the part of the circuit to be measured.

This means he voltmeter must be connected in parallel across the component where you wish to measure the potential drop.

Voltmeter

For an voltmeter to work, the same potential difference must be across the voltmeter as the part of the circuit to be measured.

This means he voltmeter must be connected in parallel across the component where you wish to measure the potential drop.

Because this creates another path for the current, the resistance of the voltmeter affects the effective resistance of that part of the circuit:

$$\Delta V = I R_{\text{eq}} = I \left(\frac{R}{R/r_V + 1} \right)$$

If r_V is infinite, the potential difference in that part of the circuit is unchanged.

It cannot actually be infinite, but we need

$$r_V >> R$$

Meters

Some meters can be used either as ammeters or voltmeters with different settings.

These are called **multimeters**.

You (may?) have used three different ones already in lab:

- Hewlitt Packard digital multimeter (HP-DMM)
- Extech digital multimeter (hand-held DMM)
- Simpson Volt-Ohm meter (Simpson VOM)

Meters

Some meters can be used either as ammeters or voltmeters with different settings.

These are called **multimeters**.

You (may?) have used three different ones already in lab:

- Hewlitt Packard digital multimeter (HP-DMM)
- Extech digital multimeter (hand-held DMM)
- Simpson Volt-Ohm meter (Simpson VOM)

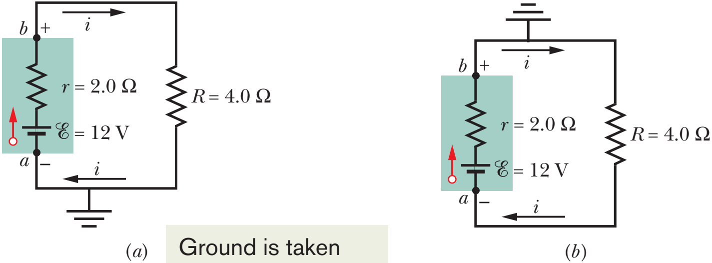
Since the internal resistance must be very much less for an ammeter than a voltmeter it is important to use the meters in the correct mode.

If a meter is in ammeter mode and put in parallel as if it is a voltmeter a very large current may flow through it. This can damage the device. Usually meters are fused in ammeter mode.

Grounding a circuit

A circuit can be "grounded", that is, connected to the Earth. This should drain any built-up charge off of that part of the circuit.

By convention, we label the potential at this point $V = 0$. This gives us an absolute scale for potential, rather that simply speaking of potential differences.



(a) (b)

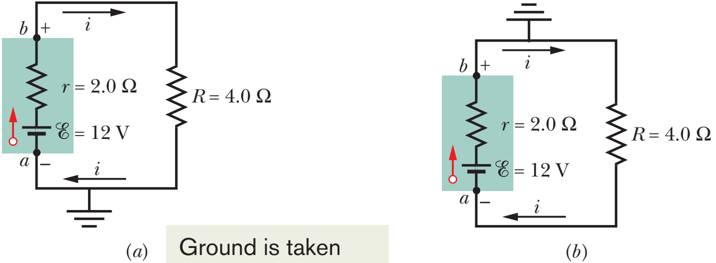
Ground is taken to be zero potential.

Grounding a circuit is represented with a three-line symbol.

Grounding a circuit and changes in potential

What is happening to the surface charges in the circuit?

Grounding a circuit



Ground is taken
to be zero potential.

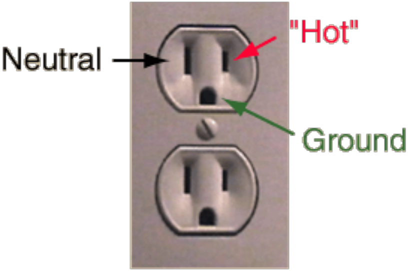
In (a), the potential at a, $V_a = 0$ V and at b, $V_b = 8$ V.

In (b), the potential at b, $V_b = 0$ V and at a, $V_a = -8$ V.

Household Wiring

Electricity is delivered to your house in two line or “live” wires, each at 120V (rms), but with different polarities.

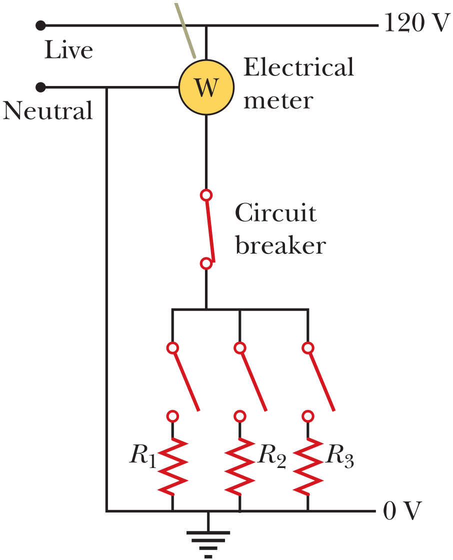
These wires are then split and power runs to sockets with one line wire and one neutral wire.



The neutral wire is supposed to be at 0V, but in practice charge can build up.

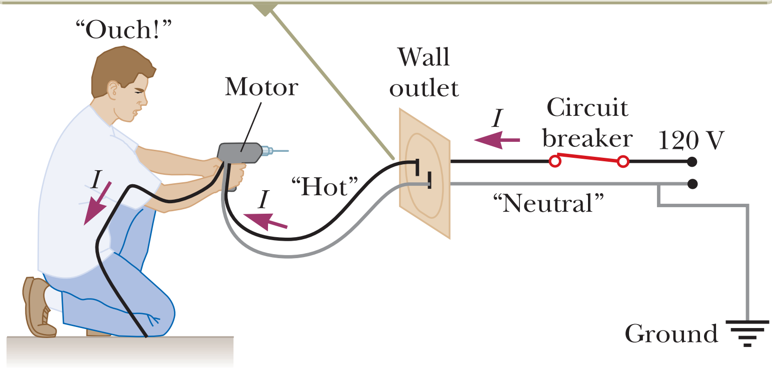
It is best to treat is as also “live”.

Household Wiring



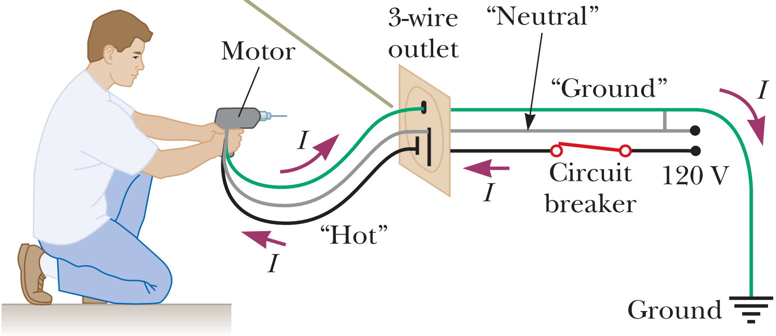
Safety and Grounding

In the situation shown, the live wire has come into contact with the drill case. As a result, the person holding the drill acts as a current path to ground and receives an electric shock.



Safety and Grounding

In this situation, the drill case remains at ground potential and no current exists in the person.



Summary

- RC circuits
- meters
- grounding a circuit
- household wiring

Next Test on Feb 15.

Homework

Serway & Jewett:

- PREVIOUS: Ch 28, onward from page 857. CQs: 7; Problems: 37, 41, 43, 45, 65, 71
- NEW: Ch 28. OQs: 12; CQs: 3; Problems: 25, 29, 47, 55