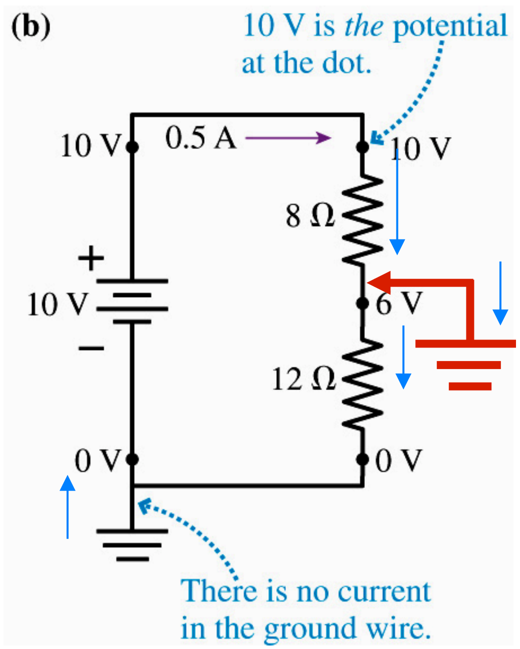
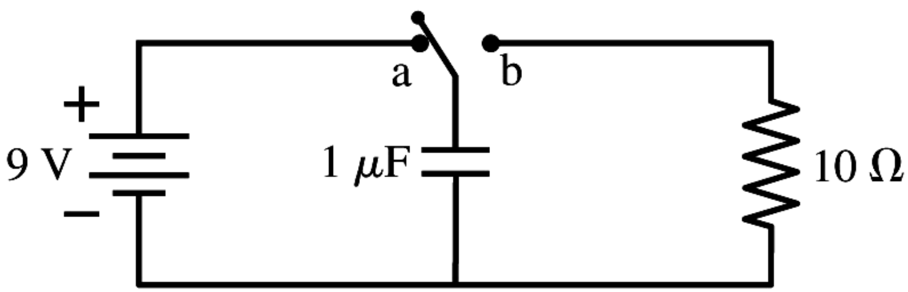
Physics 115

General Physics II



Session 25

Grounding and safety
RC Circuits
Oscilloscopes



- **R. J. Wilkes**
- Email: phy115a@u.washington.edu
- Home page: http://courses.washington.edu/phy115a/

Lecture Schedule

12-May	Mon	23	DC Circuits & Meters	21.5-21.8
13-May	Tues	24	DC Circuits	21.5-21.8
15-May	Thurs	25	RC circuits	21.6-21.7
16-May	Fri	26	Circuits - Neurons	
19-May	Mon	27	Magnetism	22.1
20-May	Tues	28	Magnetic Force	22.2-22.5
22-May	Thurs	29	Magnetic Fields	22.6-22.7
22-May	Fri	30	Induced EMF, Applications	23.1-23.3
26-May	***holiday***		NO CLASS	
27-May	Tues	31	Energy, RL circuits	23.4-23.8
29-May	Thurs	32	Transformer	23.9-23.10
30-May	**Fri**		**EXAM 3 - Chapters 21,22,23**	
2-Jun	Mon	33	AC circuits	24.1-24.3
3-Jun	Tues	34	AC circuits	24.4-24.5
5-Jun	Thurs	35	Resonance, Applications	24.6
6-Jun	Fri	36	Last class - review	
June 9	**FINAL EXAM**		**2:30-4:20 p.m.**	**Comprehensive**
	Mon		**Monday, June 9, 2014**	

Today

Grounding and GFI outlets

Electrical power wiring codes require a ground line – in North America it is the rounded 3rd prong of electrical plugs. The ground line is *supposed* to be connected directly to the Earth ($\mathbf{V}_{\mathbf{earth}}$=0).

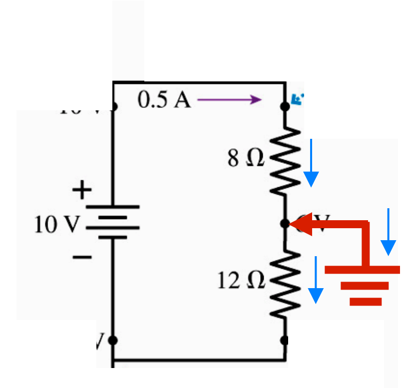
(Caution: houses wired before the 1960s may have no 3rd wire! Often homeowners replace old 2-prong outlets with 3-prong outlets...)

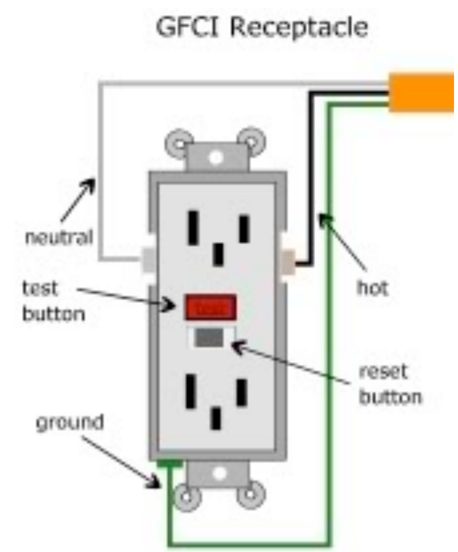
Circuit operation depends only on potential *differences*, so appliances etc should not be affected by the presence or absence of a ground connection.

Because the ground connection is connected at ***only one point***, *no current should flow through the ground connection.* **However**, if some part of a circuit is accidentally connected to ground another way (wire rubs on case?), current will flow through the ground line.

GFI (*ground fault interruption*) circuits, widely used, in bathroom wiring, detect current flow in the ground line and interrupt power automatically when it occurs. They prevent many accidental electrocutions.

CHECK your GFI outlets by pressing the 'TEST' button – power should go off; then RESET to restore protection.





Wiring conventions:
Black wire = "hot"
White = "neutral" (*should* be grounded)
Green = ground (*must* be grounded)

RC Exponential Decay

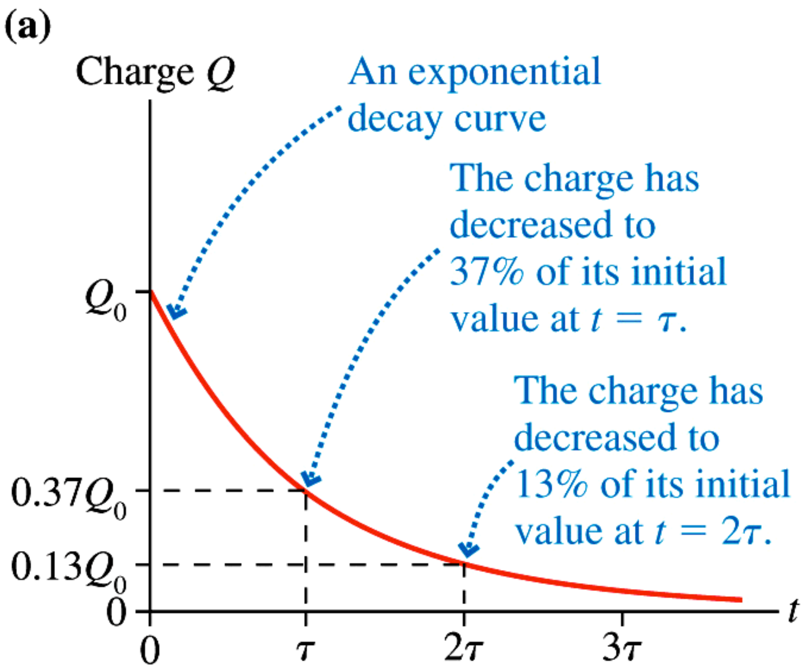
$$\boxed{Q(t) = Q_0 e^{-t/RC} = Q_0 e^{-t/\tau}}$$

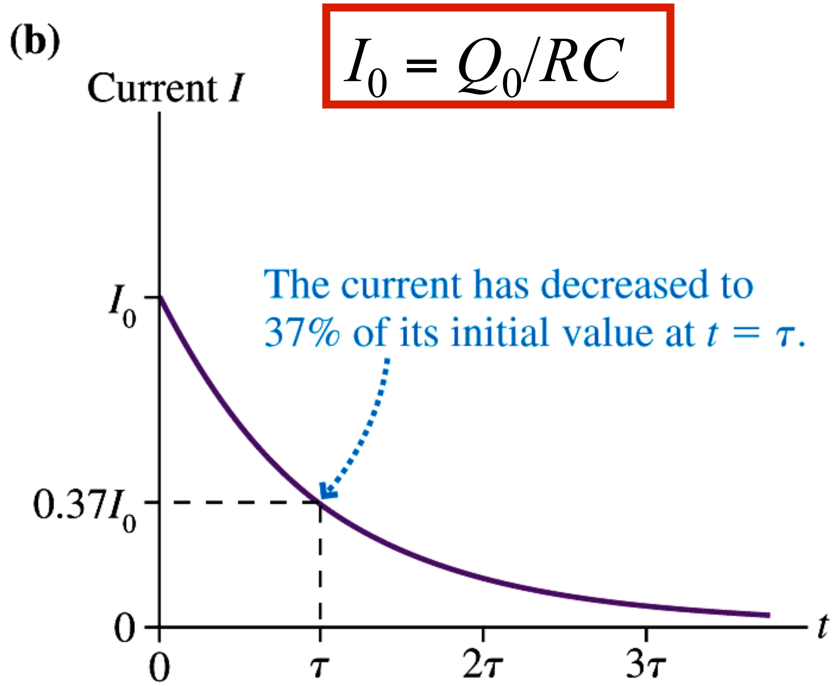
Define RC time constant: $\boxed{\tau \equiv RC}$

$$1/e = 1/2.71828 = 0.367879$$

$$\boxed{I(t) = \frac{dQ(t)}{dt} = \frac{Q_0}{RC} e^{-\frac{t}{RC}} = I_0 e^{-t/RC} = I_0 e^{-t/\tau}}$$

$$\boxed{I_0 = Q_0/RC}$$

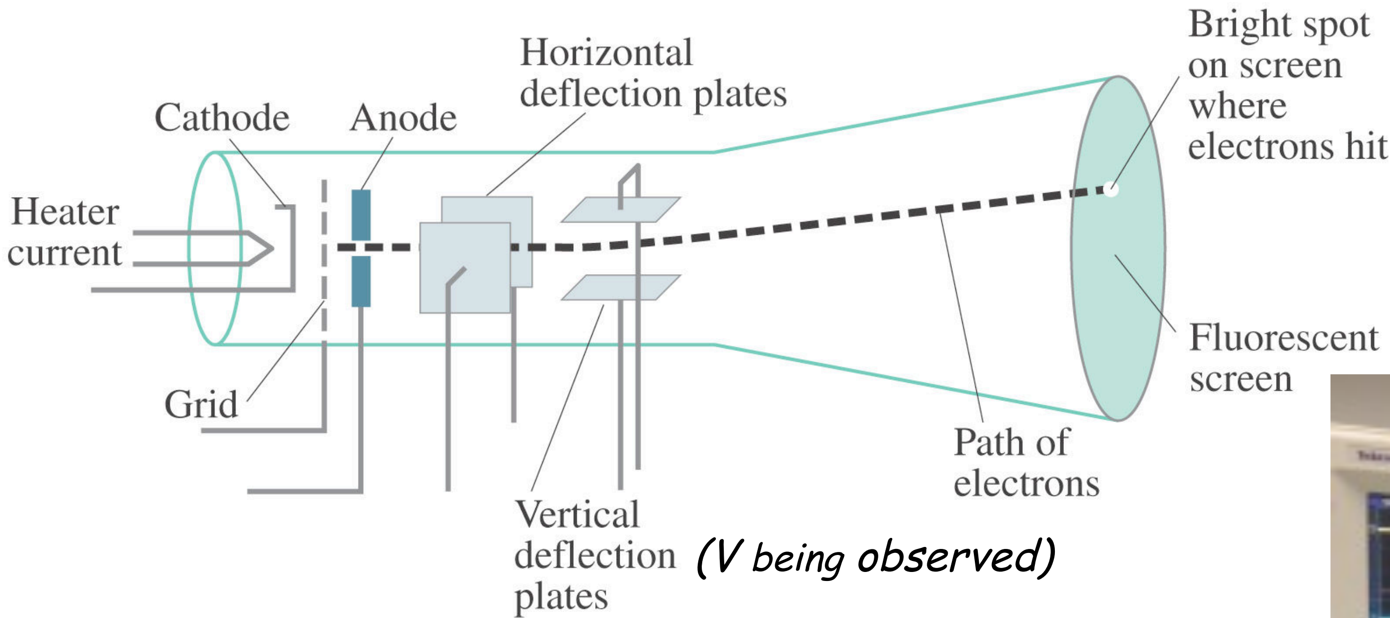




Watching RC behavior with an oscilloscope

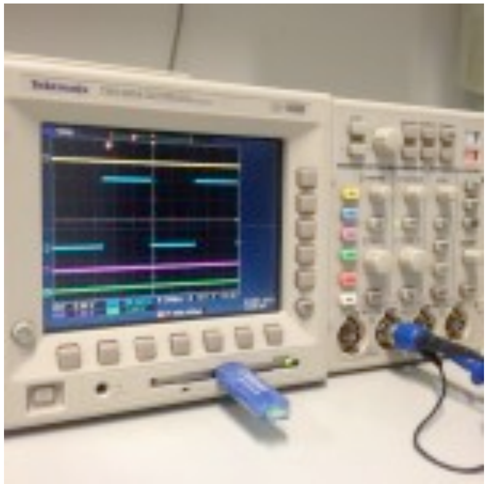
Oscilloscope = basic science research tool: makes plots of voltage vs time, with precision down to nanosec and microvolts.

Old-fashioned 'cathode ray tube' (CRT) oscilloscope
Electron beam is moved across phosphorescent screen, and deflected in proportion to V being observed: makes x-y plot of V vs time



(V being observed)

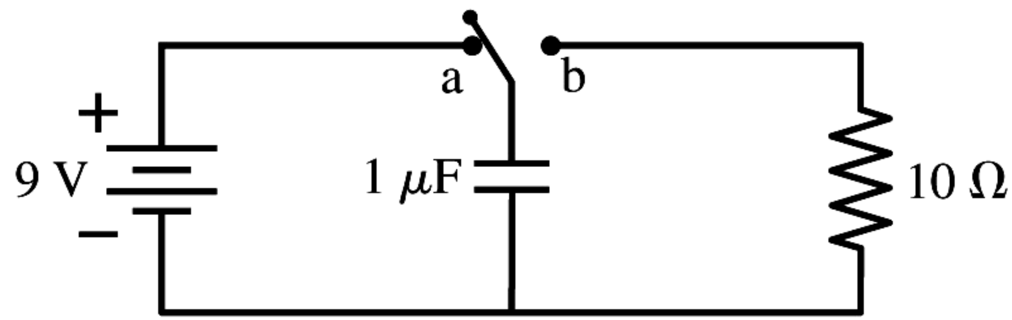
Modern digital oscilloscope: computer + display,
(But controls are made like those of CRT scopes because people are used to them)



Example: Exponential Decay of current in RC Circuit

The switch has been in position **a** for a long time. It is changed to position **b** at t=0.

What are the charge on the capacitor and the current through the resistor at t=5.0 μs?



$$\tau = RC = (10\ \Omega)(1.0\times10^{-6}\ \text{F}) = 10\ \mu\text{s}$$

$$Q_0 = C\Delta V_C = (1.0\times10^{-6}\ \text{F})(9.0\ \text{V}) = 9.0\times10^{-6}\ \text{C}$$

$$Q(5\ \mu\text{s}) = Q_0 e^{-t/RC} = (9.0\times10^{-6}\ \text{C})\exp(-.5) = 5.5\ \mu\text{C}$$

$$I_0 = \frac{Q_0}{RC} = \frac{(9.0\times10^{-6}\ \text{C})}{(10\ \mu\text{s})} = 0.90\ \text{A} \qquad I(5\ \mu\text{s}) = I_0 e^{-t/RC} = (0.90\ \text{A})\exp(-.5) = 0.55\ \text{A}$$

Reverse process: Charging a Capacitor

Using the Loop Law: $\mathcal{E} - R\dfrac{\Delta Q}{\Delta t} - \dfrac{1}{C}Q = 0$

Calculus tells us solution is: $Q(t) = a + be^{-\frac{t}{RC}}$,

for which $\dfrac{\Delta Q}{\Delta t} = -\left(\dfrac{b}{RC}\right)e^{-\frac{t}{RC}}$

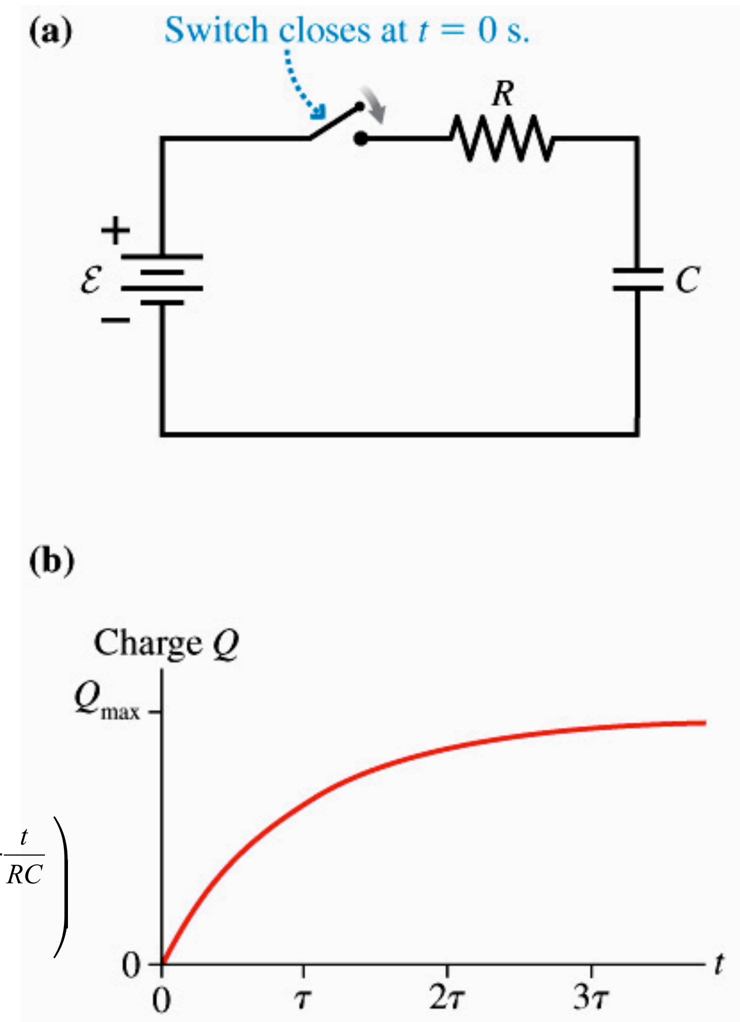
At $t = 0,\ I = \dfrac{\Delta Q}{\Delta t} = \dfrac{\mathcal{E}}{R} = -\dfrac{b}{RC} \Rightarrow b = -\mathcal{E}C$

At $t = \infty,\ I = 0 \Rightarrow V = \mathcal{E} \quad and \quad Q = a$

$\Rightarrow VC = a = \mathcal{E}C$

So $Q(t) = \mathcal{E}C - \mathcal{E}C\, e^{-\frac{t}{RC}} = \mathcal{E}C\left(1 - e^{-\frac{t}{RC}}\right) = Q_{\max}\left(1 - e^{-\frac{t}{RC}}\right)$

RC = time constant for RC circuit (units = seconds)



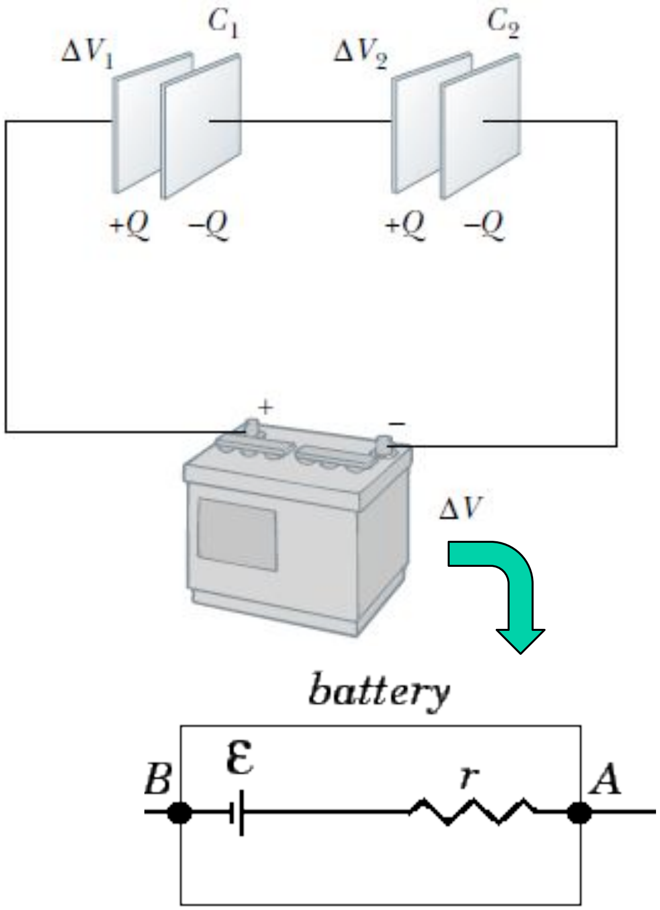
Exponentially approaches max Q

Example: battery and 2 capacitors in series

A battery (internal resistance r=2 ohms, open-circuit emf = 10V) is connected at t=0 to two capacitors in series: C_1 = 2 μf, C_2 = 3 μf.

What is the time constant for this circuit?

What is the charge on the capacitors at t=5.0 μs?



Equivalent C:

$$C_{EQ} = \frac{1}{1/C_1 + 1/C_2} = \frac{C_1 C_2}{C_1 + C_2} = \frac{(2\mu F)(3\mu F)}{(2\mu F)+(3\mu F)} = 1.2\mu F$$

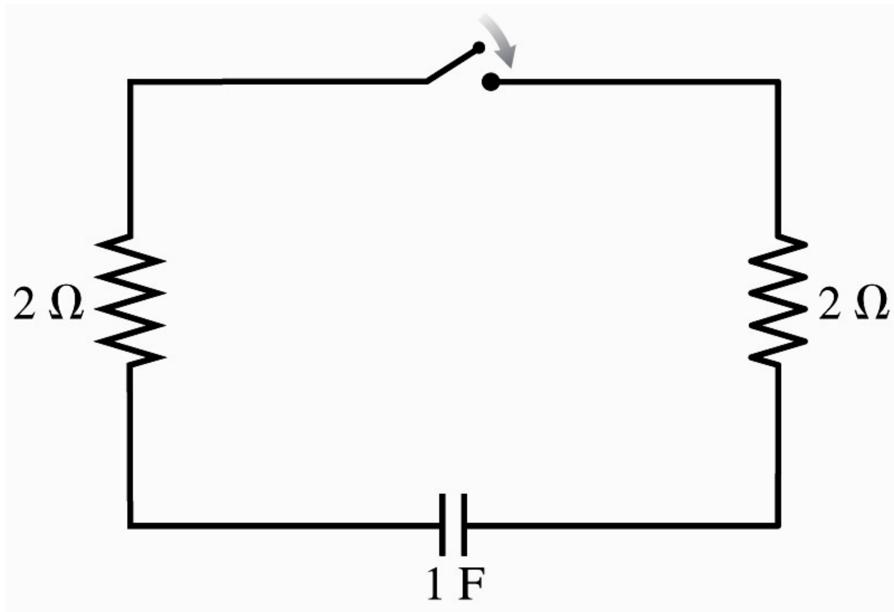
$$\text{time constant } \tau = RC = (2\Omega)(1.2\mu F) = 2.4\mu s$$

$$\text{At } \; t = \infty, \;\; I = 0 \Rightarrow V_C = \mathcal{E} \quad \textit{and} \quad Q_{MAX} = V_C C = \mathcal{E} C_{EQ}$$

$$Q_{MAX} = 10V(1.2\mu F) = 12\mu C$$

$$Q(t) = Q_{\max}\left(1 - e^{-\frac{t}{RC}}\right) = Q_{\max}\left(1 - e^{-\frac{5\mu s}{2.4\mu s}}\right) = Q_{\max}\left(1 - \exp(-2.08)\right) = 12\mu C(0.875) = 10.5\mu C$$

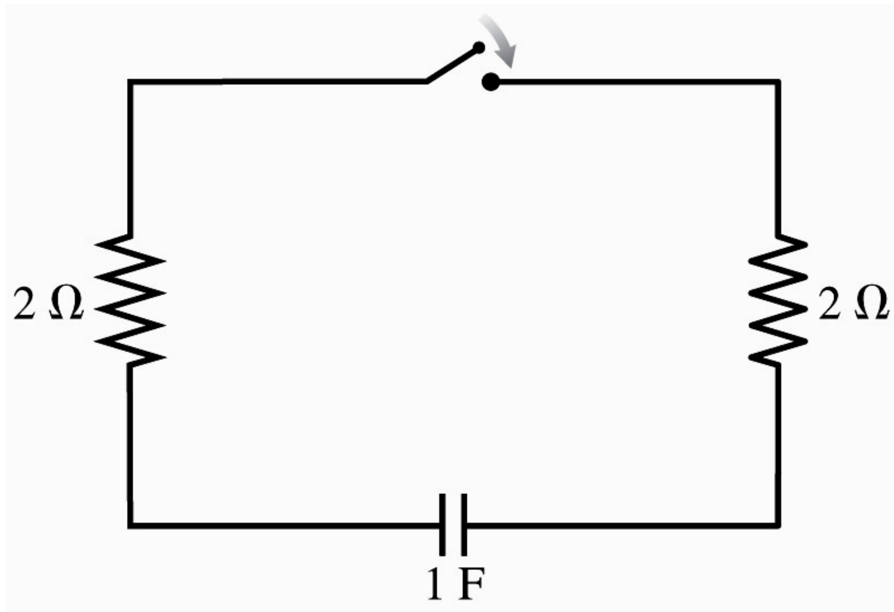
Clicker Question 1



The 1F capacitor is initially charged with 1 C.
The time constant for the discharge of this capacitor is:

(a) 5 s; (b) 4 s; (c) 2 s; (d) 1 s; (e) the capacitor does not discharge because the resistors cancel.

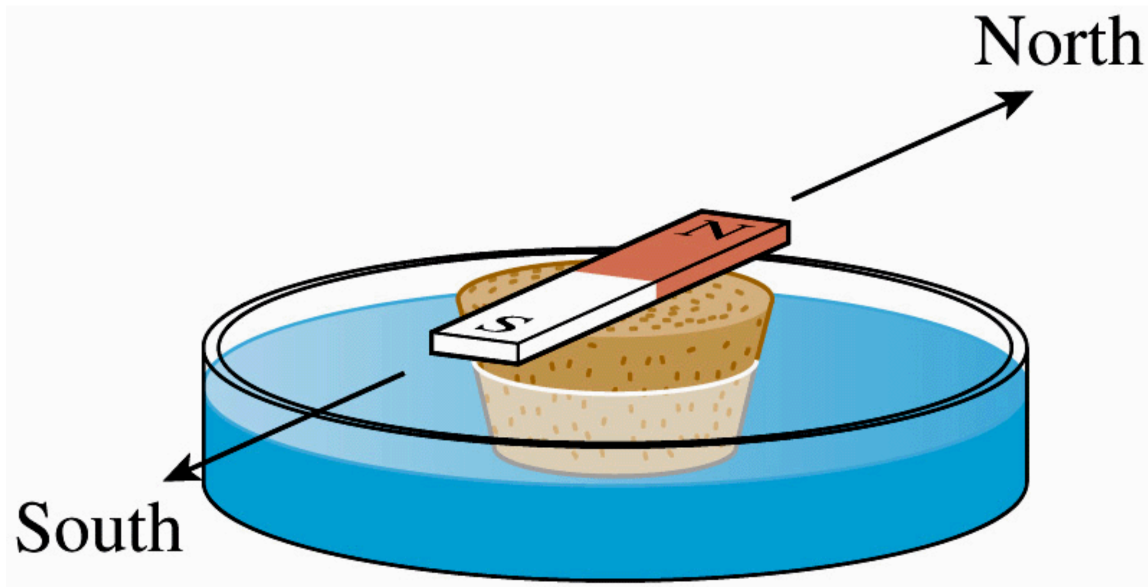
Clicker Question



The 1F capacitor is initially charged with 2 C.
The time constant for the discharge of this capacitor is:

(a) 5 s; (b) 4 s; (c) 2 s; (d) 1 s; (e) the capacitor does not discharge because the resistors cancel.

Magnetism: definitions of poles

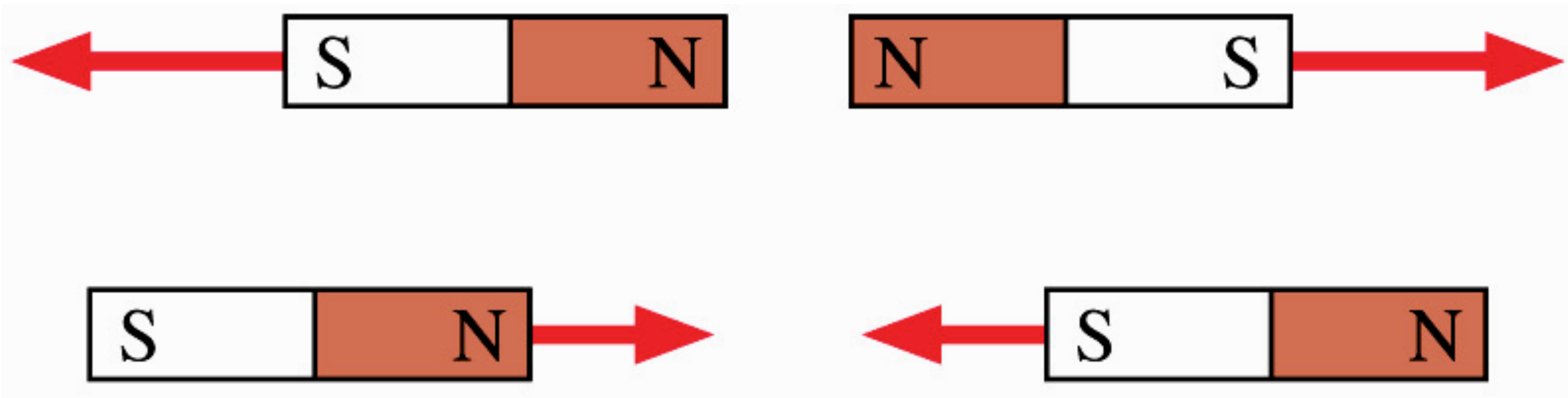


Put bar magnet on a cork and float it in a dish of water.

The magnet turns and aligns itself with the north-south direction.

The end of the magnet that points north is called the magnet's ***north-seeking pole***, or simply its ***north pole***. The other end is called the ***south-seeking***, *or just the* ***south pole***.

Magnetism: properties of poles



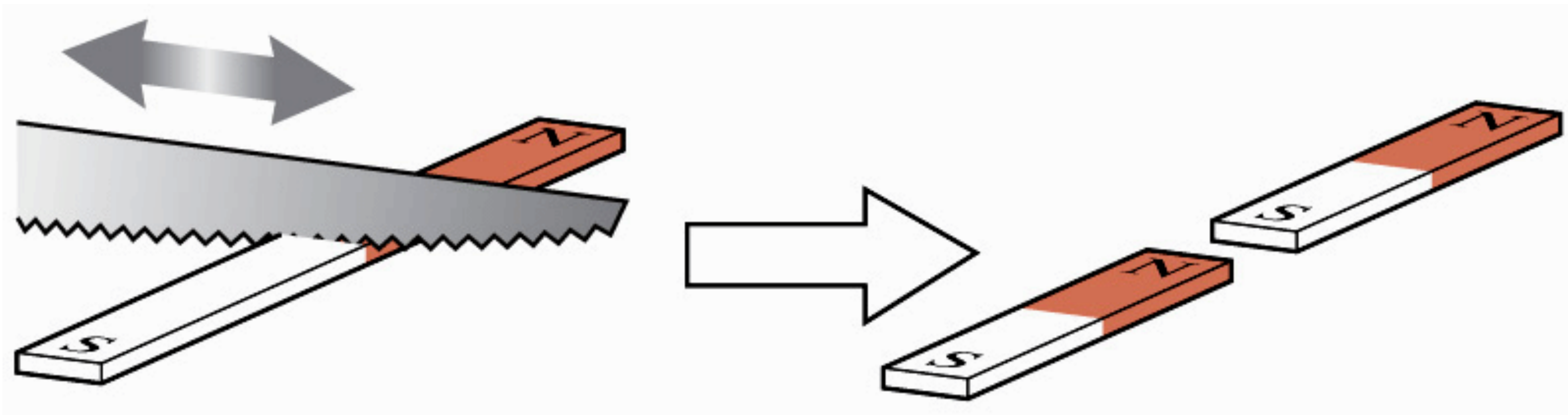
Bring the north poles of two bar magnets near to each other. Then bring the north pole of one magnet near the south pole of another magnet.

When the two north poles are brought near, a repulsive force between them is observed. When the a north and a south pole are brought near, an attractive force between them is observed.

Sounds familiar! Same as for electric charges: **like repel, unlike attract.**

Bar magnet is like an electric **dipole** (+ and – charge pair)

Magnetism: dipoles – monopoles?

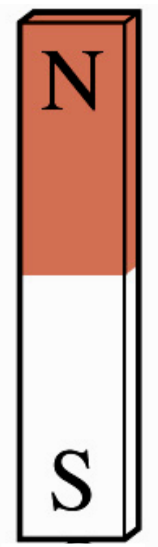


Cut a bar magnet in half. Can you isolate the north pole and the south pole on separate pieces?

No. When the bar is cut in half, **two** complete (but weaker) bar magnets are formed, each with a north pole and a south pole.

The same result would be found, even if the magnet was sub-divided down to the microscopic level.

Magnetism: only some materials are magnetic



Experiment: Bring a bar magnet near an assortment of objects.

Some objects, e.g. steel paper clips, iron ore, nickel coins, certain ceramics, will be attracted to the magnet.

Other objects, e.g., glass beads, aluminum foil, copper tacks, will be unaffected. No simple connection between magnetism and type of material (conductor, insulator, metal, non-metal)

Also: objects that are attracted to the magnet are **equally** attracted by the north and south poles of the bar magnet.

Conclusions from this collection of facts:

1. Like electricity, magnetism is a ***long range force***. The compass needle responds to the bar magnet from some distance away.
2. Magnetism is ***not*** the same as electricity. Magnetic poles are similar to charges but have ***important differences***.
3. Magnets have ***two poles***, "north" (N) and "south" (S). Like poles repel and opposite poles attract.
4. Poles of a magnet can be identified with a ***compass***. A north magnetic pole (N) attracts the south-seeking end of the compass needle (which is a south pole).
5. Some materials (e.g., iron) stick to magnets and others do not. The materials that are attracted are called ***magnetic materials***.
6. Magnetic materials are attracted by ***either pole*** of a magnet. This is similar in some ways to the attraction of neutral objects by an electrically charged rod by induced polarization.