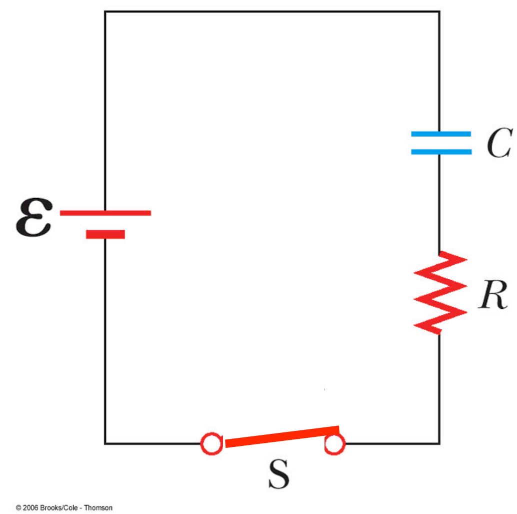
18.5 RC Circuits

Introduction to time-dependent currents and voltages.

Applications: timing circuits, clocks, computers, charging + discharging capacitors

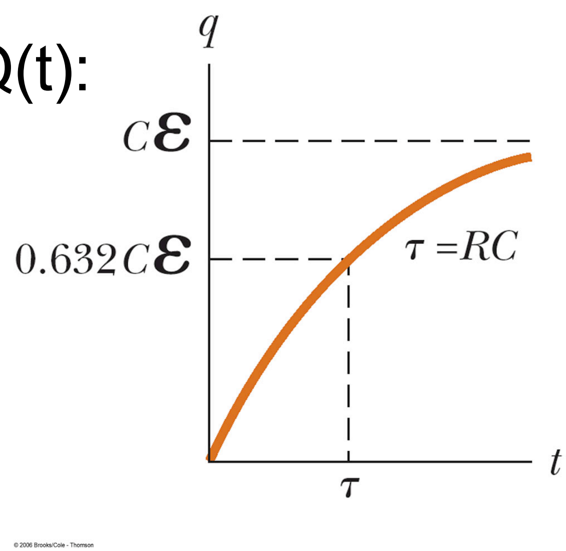
RC circuit: charging

At time t=0, close Switch

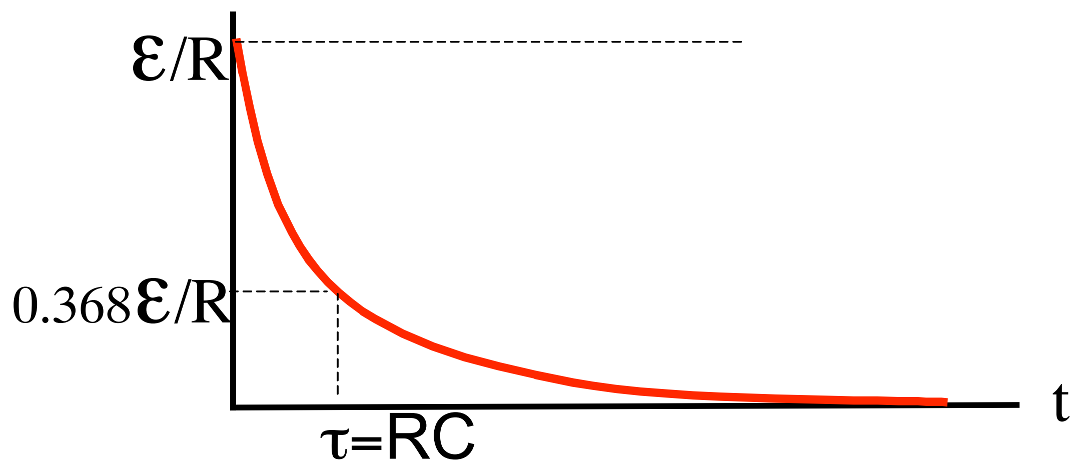


RC circuit: charging

Q(t):



I(t):



	t=0		$t \to \infty$
ΔV_C	0	$\varepsilon(1-e^{-(t/\tau)})$	ε
Q	0	$C\varepsilon(1-e^{-(t/\tau)})$	$C\varepsilon$
ΔV_R	ε	$\varepsilon(e^{-(t/\tau)})$	0
I	ε/R	$(\varepsilon/R)(e^{-(t/\tau)})$	0

Time constant τ = RC

RC is called the time constant: it's a measure of how fast the capacitor is charged up.

It has units of time:
RC = $(V/I)(q/V) = q/I = q / (q/t) = t$

At t = RC, Q(t) and $\Delta V_C(t)$ go to $1 - 1/e = 0.63$ of the final values

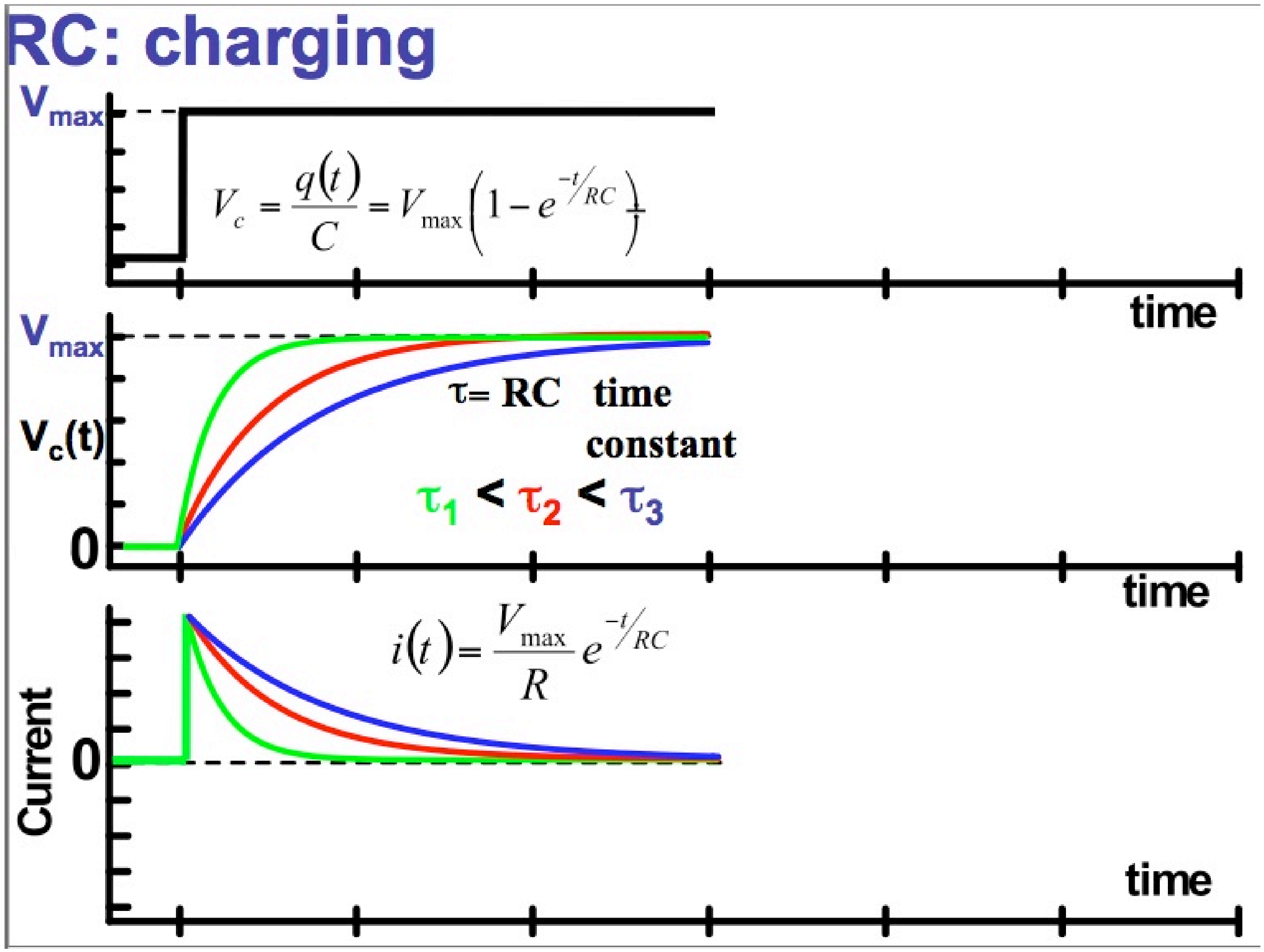
At t= RC, I(t) and $\Delta V_R(t)$ go to 1/e of the initial values

Time constant τ = RC

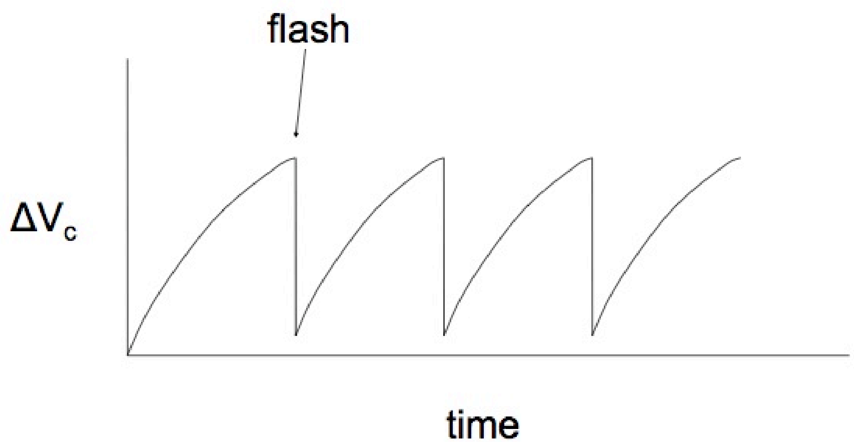
Think about why increasing R and/or C would increase the time to charge up the capacitor:

When charging up: τ will increase with C because the capacitor can store more charge.
Increases with R because the flow of current is lower.

Time constant τ = RC



You want to make a so-called flasher circuit that charges a capacitor through a resistor up to a voltage at which a neon bulb discharges once every 5.0 sec. If you have a 10 microfarad capacitor what resistor do you need?

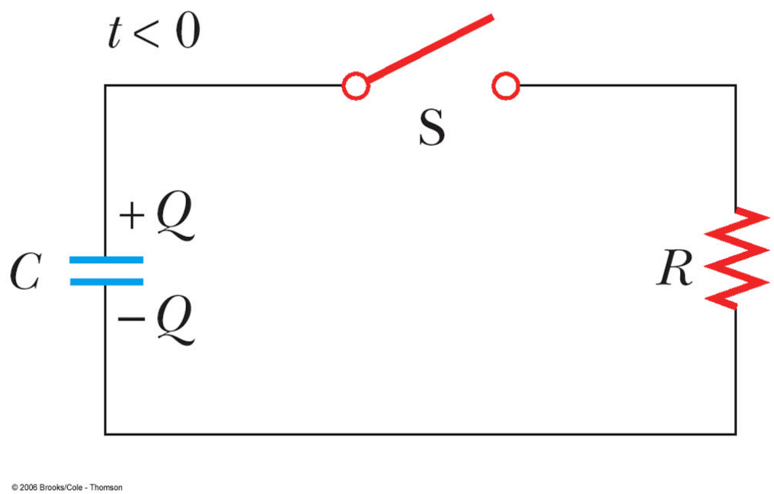


Solution: Have the flash point be equal to 0.63 $\Delta V_{C,max}$ (I.e., let $t=\tau$)

τ = RC $\rightarrow$ R = τ/C = 5s/10^{-6}F = 5 $\times 10^{5}$ Ohms

This is a very big resistance, but 5 seconds is pretty long in "circuit" time

Discharging an RC circuit:

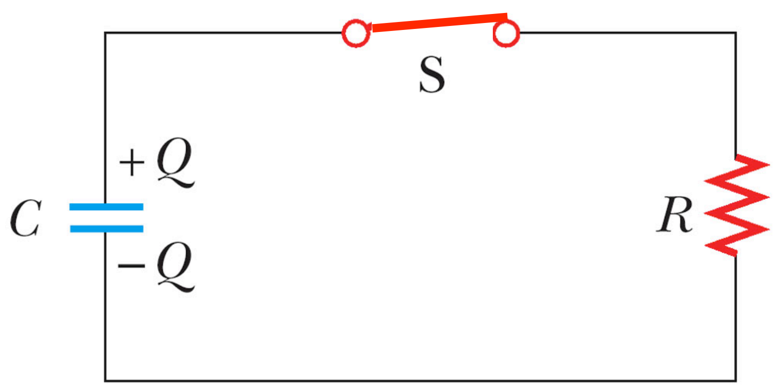


First, disconnect from EMF source.

Q is at maximum value, $Q_{max} = C\varepsilon$

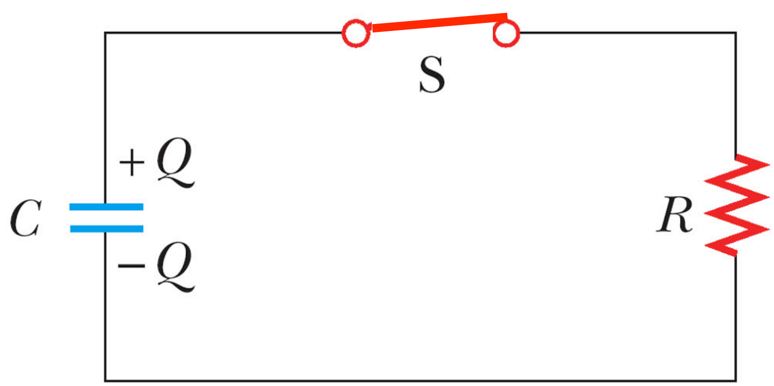
ΔV_C is at maximum value of $\Delta V_{C,max} = \varepsilon$

Discharging an RC circuit:



Then close switch at time t=0.

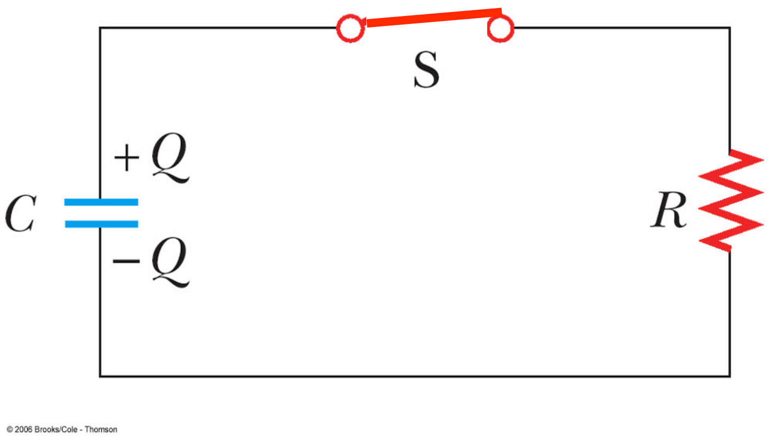
Discharging an RC circuit:



Circuit now has only R and C.

From loop rule: $-\Delta V_C - \Delta V_R = 0$

Discharging an RC circuit:



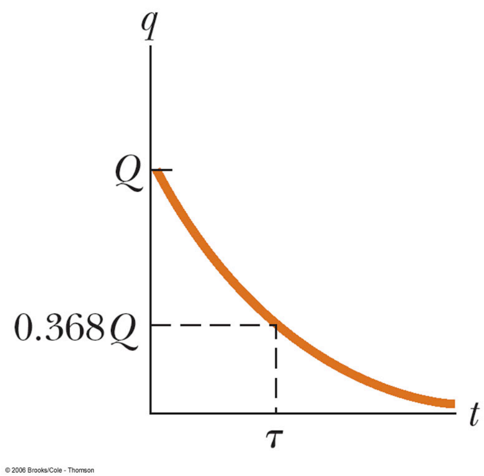
Circuit now has only R and C.

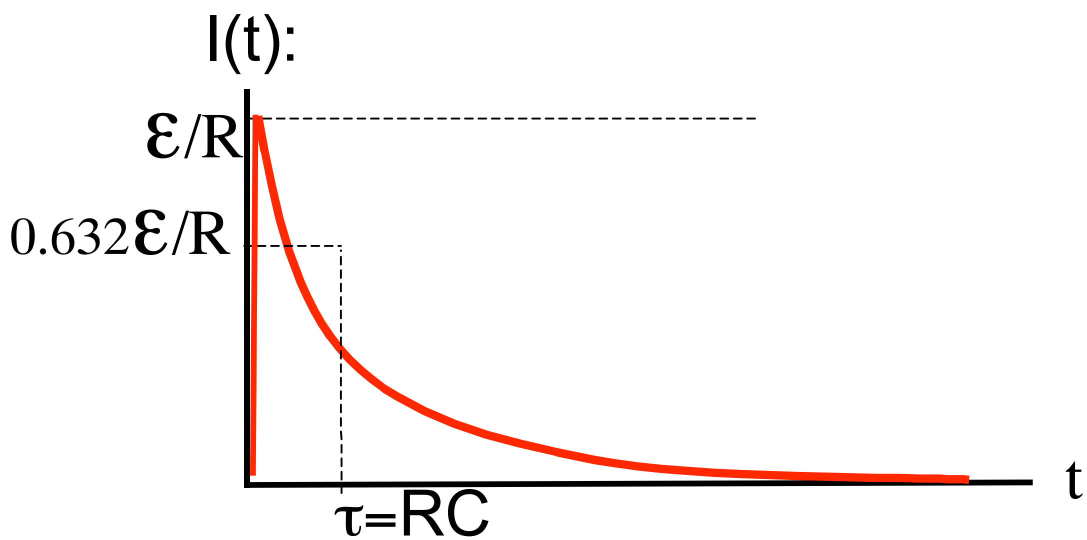
From loop rule: $-\Delta V_C - \Delta V_R = 0$

As capacitor discharges, Q and ΔV_C decrease with time.

ΔV_R will track ΔV_C

So $I = \Delta V_R/R$ will jump from 0 to ε/R at t=0, then exponentially decay





	t=0		$t \to \infty$
ΔV_C	ε	$\varepsilon(e^{-(t/\tau)})$	0
Q	$Q_{max}=C\varepsilon$	$C\varepsilon(e^{-(t/\tau)})$	0
ΔV_R	ε	$\varepsilon(e^{-(t/\tau)})$	0
I	ε/R	$\varepsilon/R(e^{-(t/\tau)})$	0

Think about why increasing R and/or C would increase the time to discharge the capacitor:

τ will increase with C because there is more stored charge in the capacitor to unload. τ increases with R because the flow of current is lower.

Given a 12 μF capacitor being discharged through a 2000 Ω resistor. How long does it take for the voltage drop across the resistor to reach 5% of the initial voltage?

Solution:

First, calculate τ: $\tau = 2000\Omega * 12\text{x}10^{-6}$ F = 24 ms

Then: $V = V_0 \exp(-t/\tau)$

$V / V_0 = \exp(-t/\tau)$

Take ln of both sides: $\ln(V/V_0) = -t/\tau$

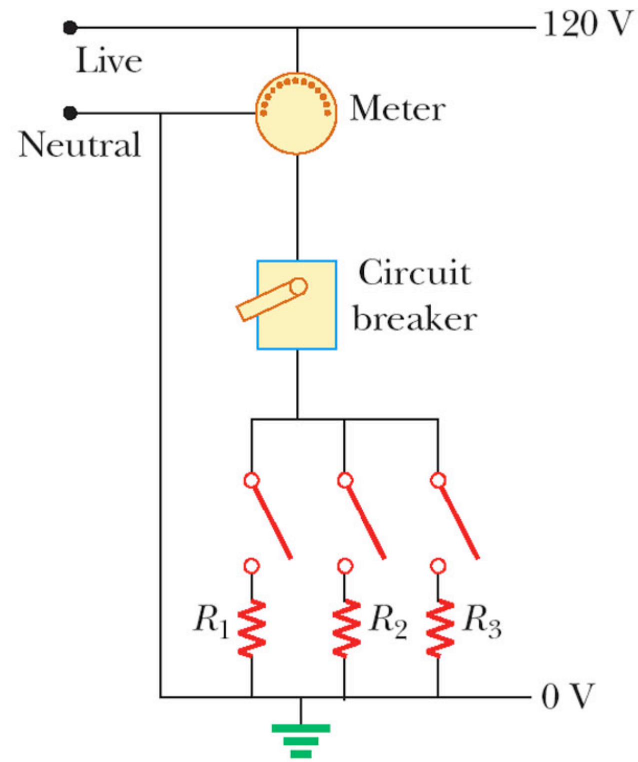
Solve for t: $t = -\tau * \ln(V/V_0) = -0.024 \text{ s} (\ln(0.05)) = 0.072$ sec

Household circuits

Circuits are in parallel. All devices have same potential. If one device fails, others will continue to work at required potential.

ΔV is 120 V above ground potential

Heavy-duty appliances (electric ranges, clothes dryers) require 240 V. Power co. supplies a line which is 120V BELOW ground potential so TOTAL potential drop is 240 V

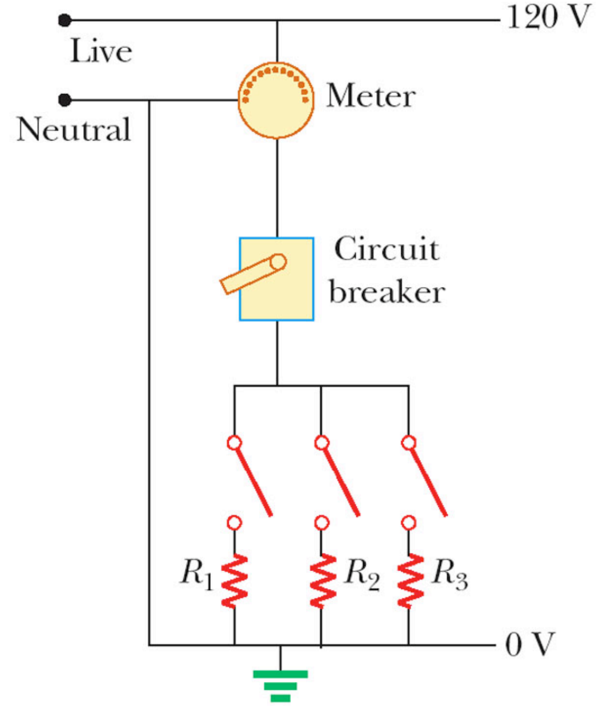


Circuit breakers or fuses are connected in series.

Fuses: melt when I gets too high, opening the circuit

Circuit breakers: opens circuit without melting. So they can be reset.

Many circuit breakers use electromagnets, to be discussed in future chapters



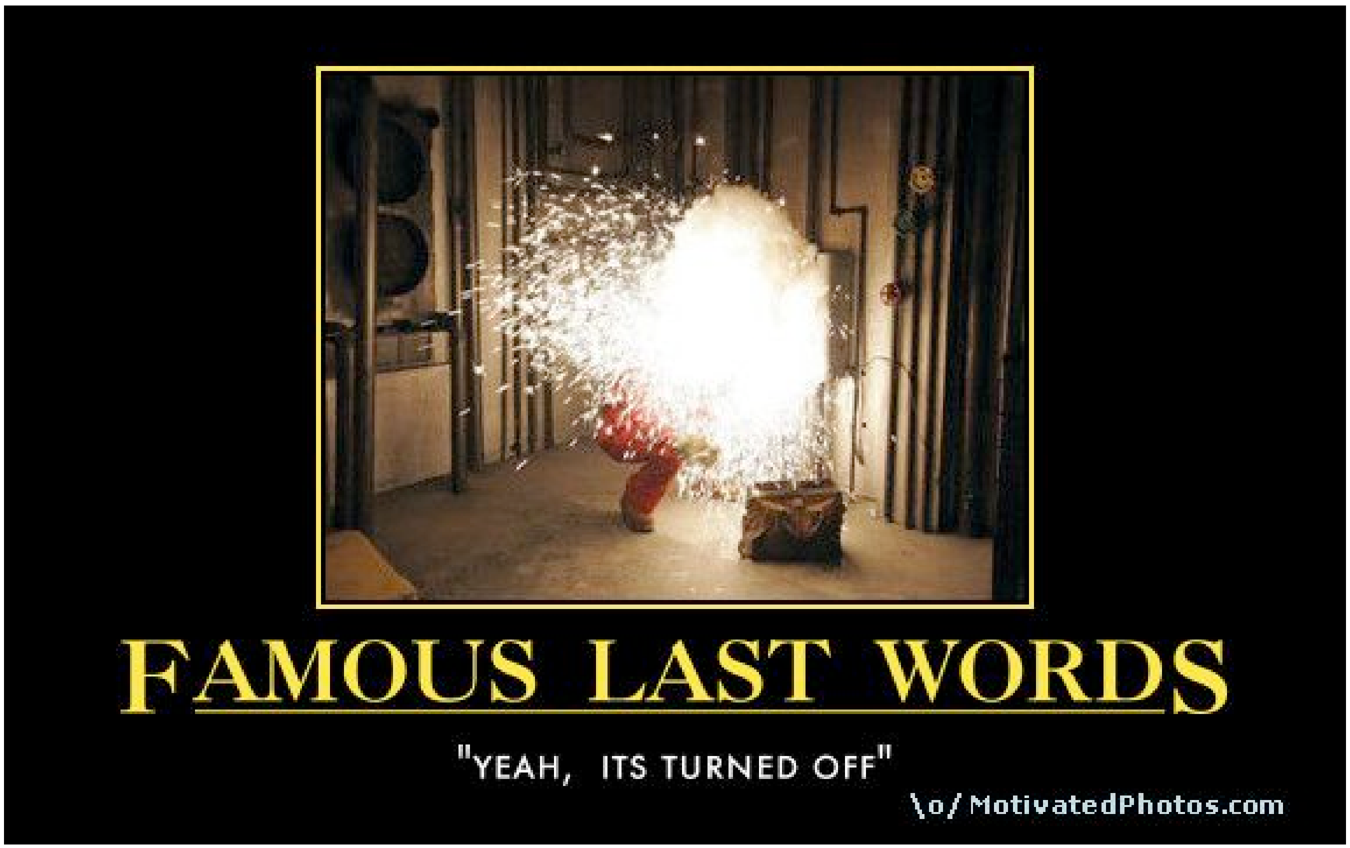
Example: Consider a microwave oven, a toaster, and a space heater, all operating at 120 V:

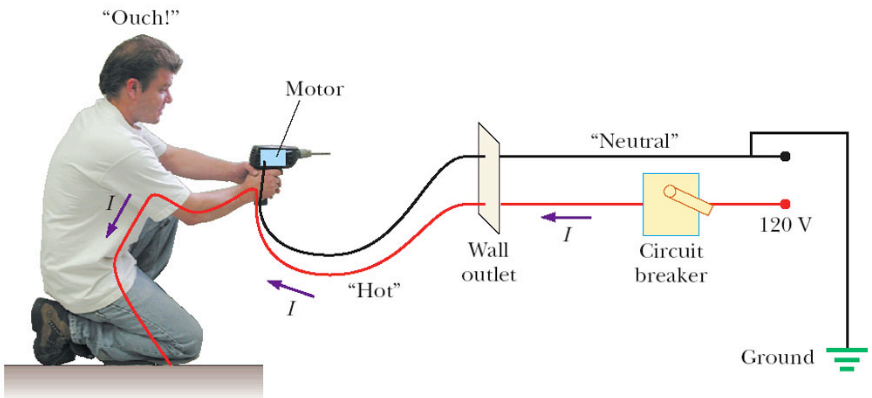
Toaster: 1000 W
Microwave: 800 W
Heater: 1300 W

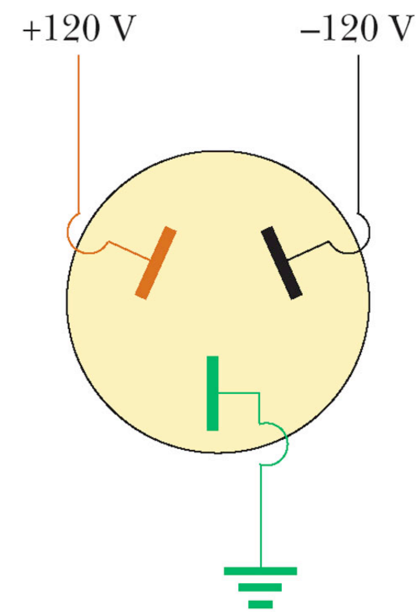
How much current does each draw? $I = P/\Delta V$
Toaster: $I = 1000W/120V = 8.33A$
Micro: $I = 800W/120V = 6.67A$
Heater: $I = 1300W/120V = 10.8\ A$

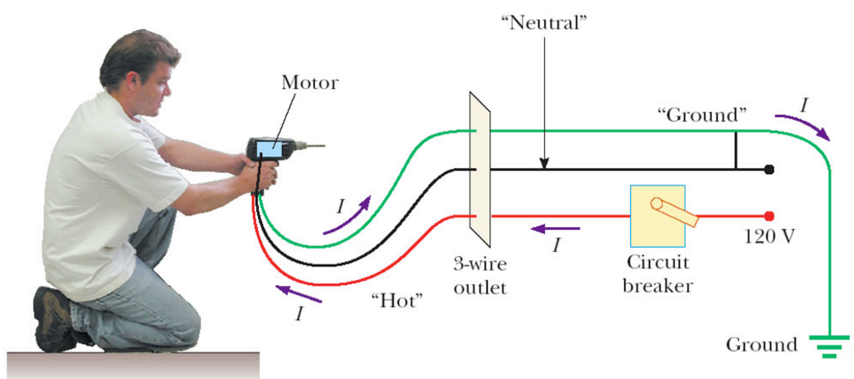
Total current (if all operated simultaneously)= 25.8 A
(So the breaker should be able to handle this level of current, otherwise it'll trip)

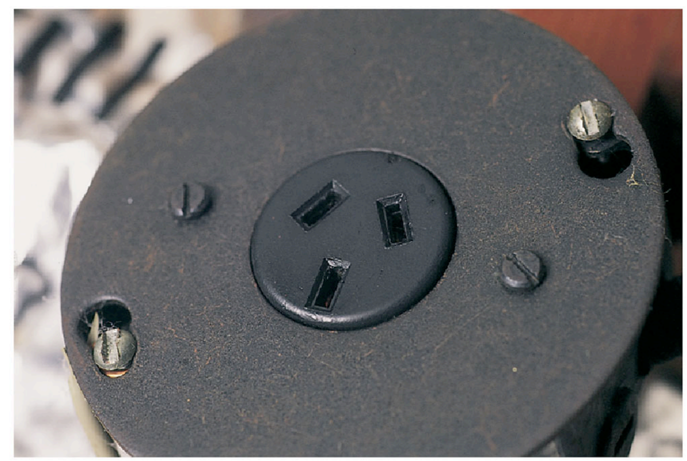
Electrical Safety




"Ouch!"
Motor
"Neutral"
I
I
120 V
I
"Hot"
Wall
outlet
Circuit
breaker
Ground


+120 V
–120 V


"Neutral"
Motor
"Ground"
I
I
I
120 V
3-wire
outlet
Circuit
breaker
I
"Hot"
Ground



$R_{skin(dry)} \sim 10^5\ \Omega$

TABLE 28-1 *Effects of Externally Applied Current on the Human Organism*

CURRENT RANGE	EFFECT
0.5–2 mA	Threshold of sensation
10–15 mA	Involuntary muscle contractions; can't let go
15–100 mA	Severe shock; muscle control lost; breathing difficult
100–200 mA	Fibrillation of heart; death within minutes
>200 mA	Cardiac arrest; breathing stops; severe burns

So for ΔV = 10,000V:

$I = \Delta V/R = 10{,}000\text{V}/10^5\ \Omega = 0.1$ A = dangerous.

But $R_{skin(wet)}$ is much, much lower, $\sim 10^3 \Omega$:

So in this case, when ΔV = 120V, I is also ~ 0.1 A = dangerous

18.8: Conduction of electrical signals by neutrons

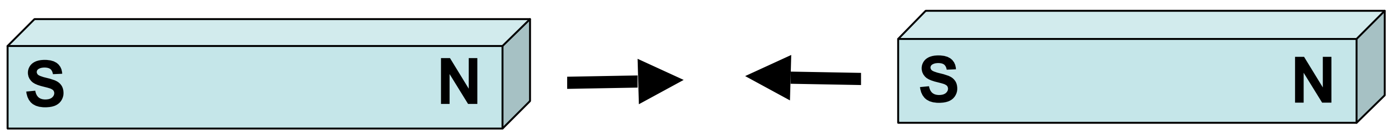
Ch. 19: Magnetism

Bar magnets.
Planetary magnetic fields.
Forces on moving charges.
Electrical motors (electrical energy →mechanical energy)
Generators (mechanical → electrical energy)
Magnetic data storage: magnetic tapes, computer drives
MRI (magnetic resonance imaging)

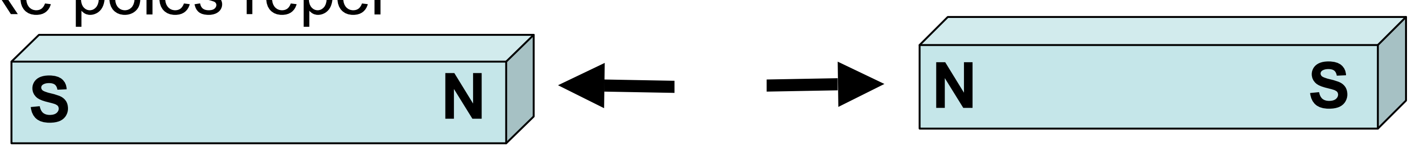
A magnet has two poles (magnetic dipole)

North–South

Opposite poles attract



Like poles repel



stable

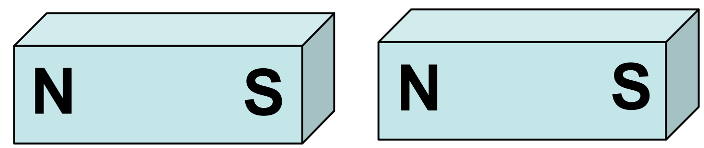
unstable

No magnetic monopoles

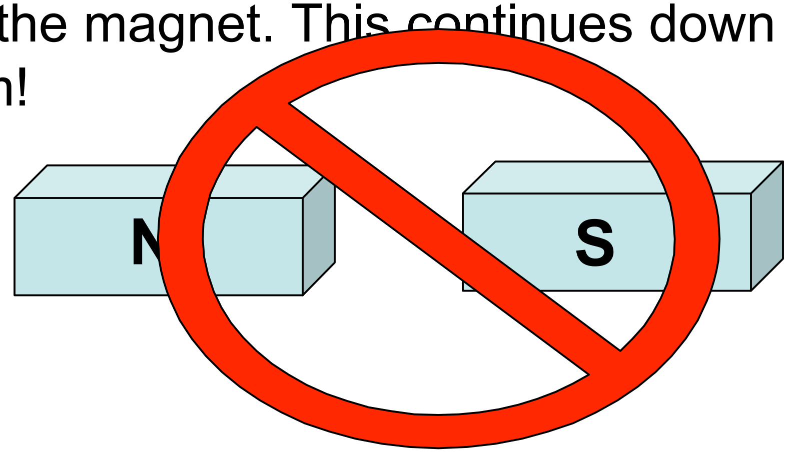
No *magnetic monopoles* are found (i.e. there is no magnetic equivalent of charge).

If you cut a magnetic bar in two….

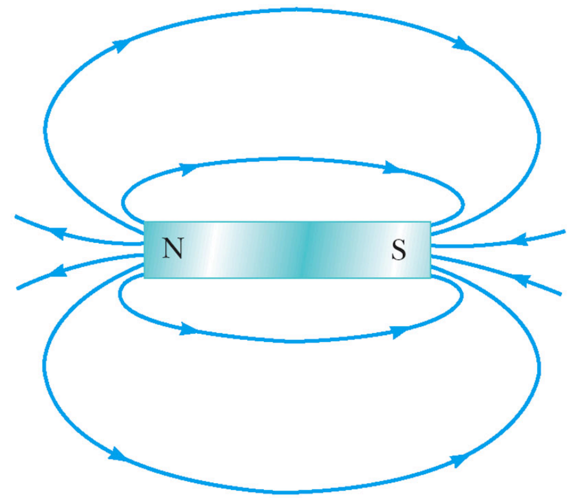
You get two smaller magnets:



You do not get separate N & S magnetic charges -- no matter how small the magnet. This continues down to the scale of a single atom!

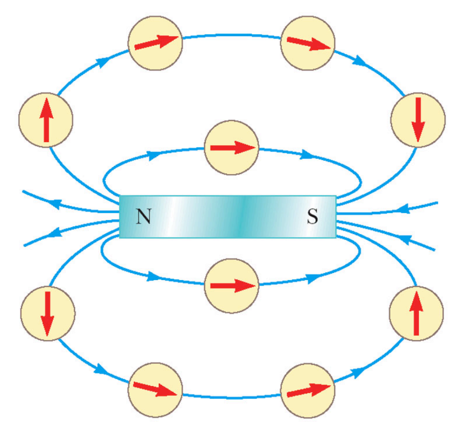


Magnetic Field Lines



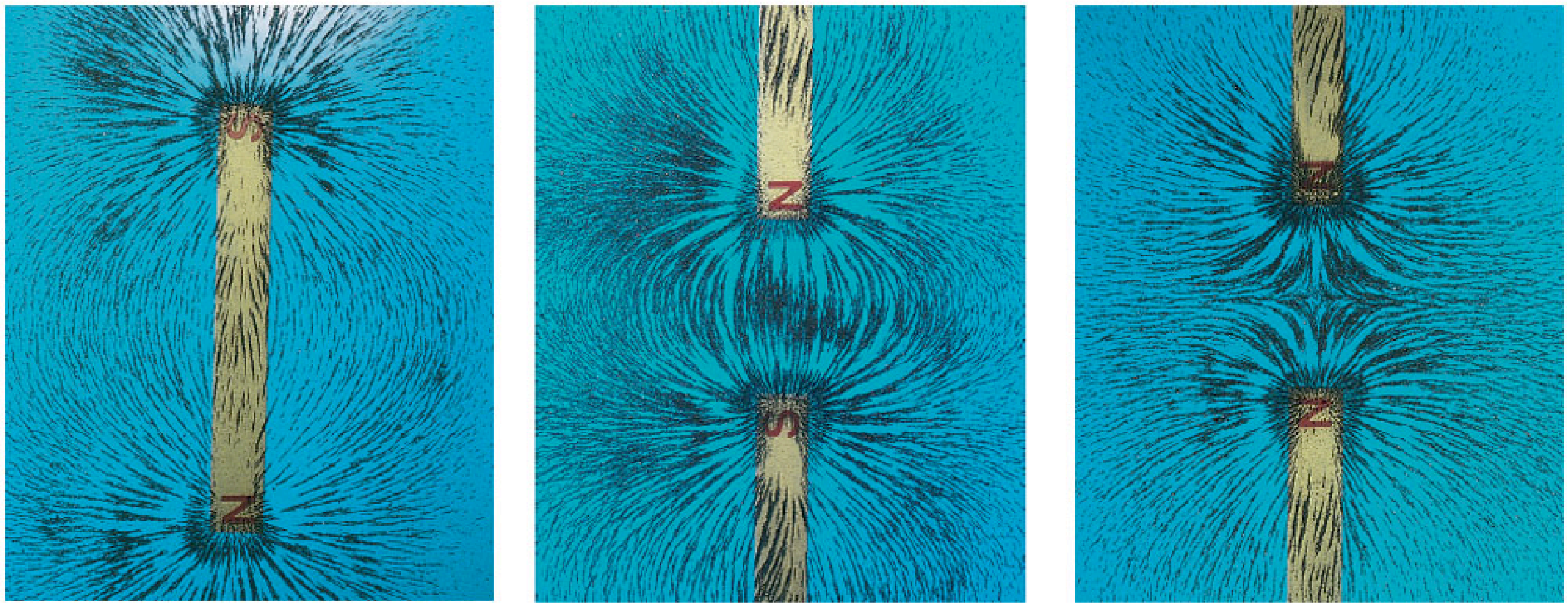
B-field lines flow from N to S pole.

Can be traced out using a compass



When placed in external magnetic fields, magnetic dipoles (e.g., compass needle) orient themselves parallel to B-field lines.

Magnetic Field Lines



Can also be traced out with Fe filings

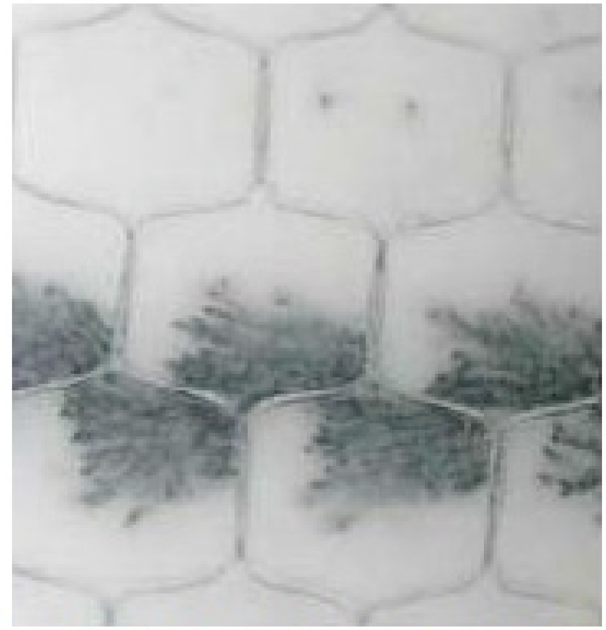
Soft/Hard Magnetic materials

Soft magnetic materials (e.g., Fe): Easily magnetized, but can lose magnetization easily

Hard materials more difficult to magnetize, but retain magnetism for a long time ("permanent magnet")
Ex.: metal alloys such as Alnico (Aluminum, Nickel, Cobalt)

Ferromagnetic materials: materials which can become magnetized and can be attracted to other magnets

Magna-doodle



Close-up of the honeycombed structure of the display

The tip of the magnetic pen

Ferromagnetic fluids

“Leaping ferrofluid demonstration:”
http://www.youtube.com/watch?v=Rg9xSLdXKXk

Sachiko Kodama, Yasushi Miyajima "Morpho Towers -- Two Stand”:
http://www.youtube.com/watch?v=me5Zzm2TXh4
(see also sachikokodama.com)

Ferrofluid: how it works:
http://www.youtube.com/watch?v=PvtUt02zVAs

Ferrofluid on the track of a Magnetized Meatgrinder
http://www.youtube.com/watch?v=OE2pB1pyZN0