Lecture 2

28 January, 2013

Announcements (1/28/13)

- 401B and 501B:
  - Laboratory Meeting Tues Jan 29, 4^{00}-5^{00} pm
- Electricity Test in 2 weeks (Feb 11)
- Fill out and hand in 3x5 cards to Lauritz

Foundations:

Basic Electricity
Basic Neurophysiology
Basic Neuroanatomy

Part I: Basic Electricity

- Prelude
- Atomic Stuff
- Voltage, Resistance, Current, Power, Energy
- DC Series Circuits
- DC Parallel Circuits
- AC Circuits in brief

Prelude: Scale of Measurement

- Deci = 10^{-1}
- Centi = 10^{-2}
- Milli = 10^{-3}
- Micro = 10^{-6}
- Nano = 10^{-9}
- Pico = 10^{-12}
- Fento = 10^{-15}
- Kilo = 10^{3}
- Mega = 10^{6}
- Giga = 10^{9}
- Tera = 10^{12}

Bits, Bytes, Mega, Giga, Tera (explained)
1 bit = a 1 or 0 (b)
4 bits = 1 nybble (?)
8 bits = 1 byte (B)
1024 bytes = 1 Kilobyte (KB)
1024 Kilobytes = 1 Megabyte (MB)
1024 Megabytes = 1 Gigabyte (GB)
1024 Gigabytes = 1 Terabyte (TB)

What’s a Trillion $ (Tera $)

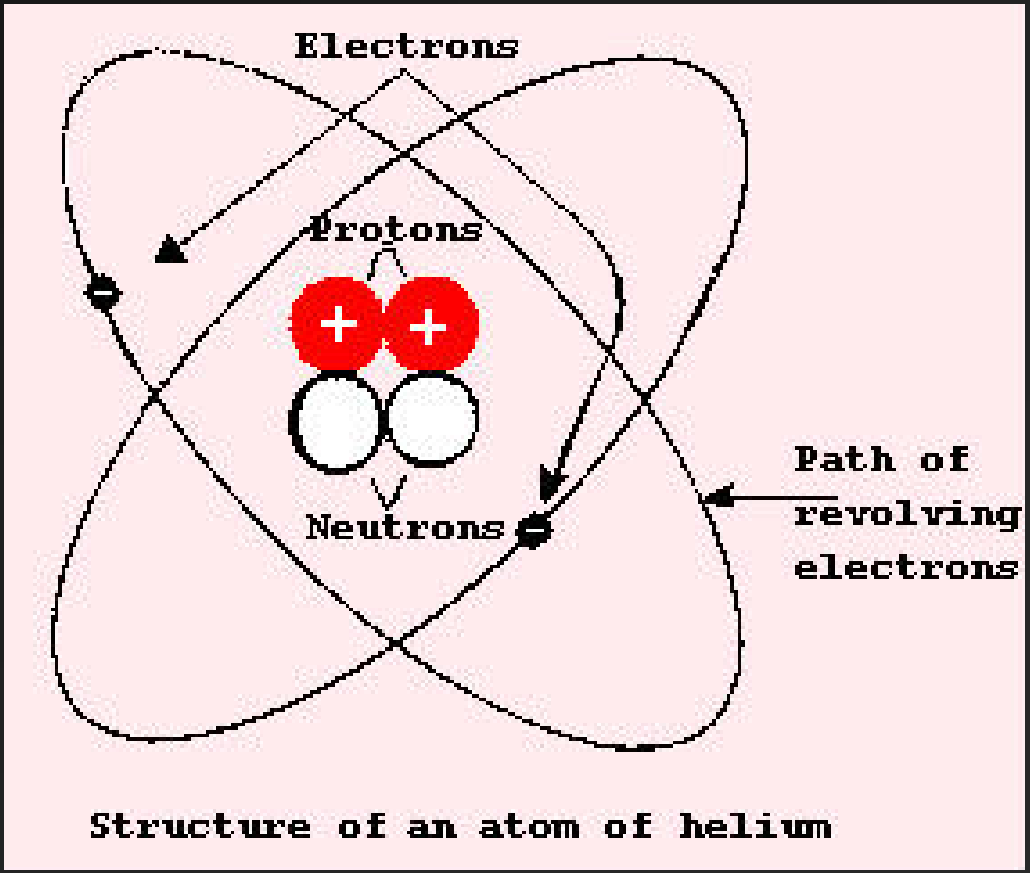
http://www.pagetutor.com/trillion/index.html

Prelude: 3 Great Forces

- Nuclear — Strong, very short (subatomic) distances …
- Electrostatic — Holds all kinds of stuff together in the everyday world
- Gravitational — Weakest, but impressive over very large distances and with large masses

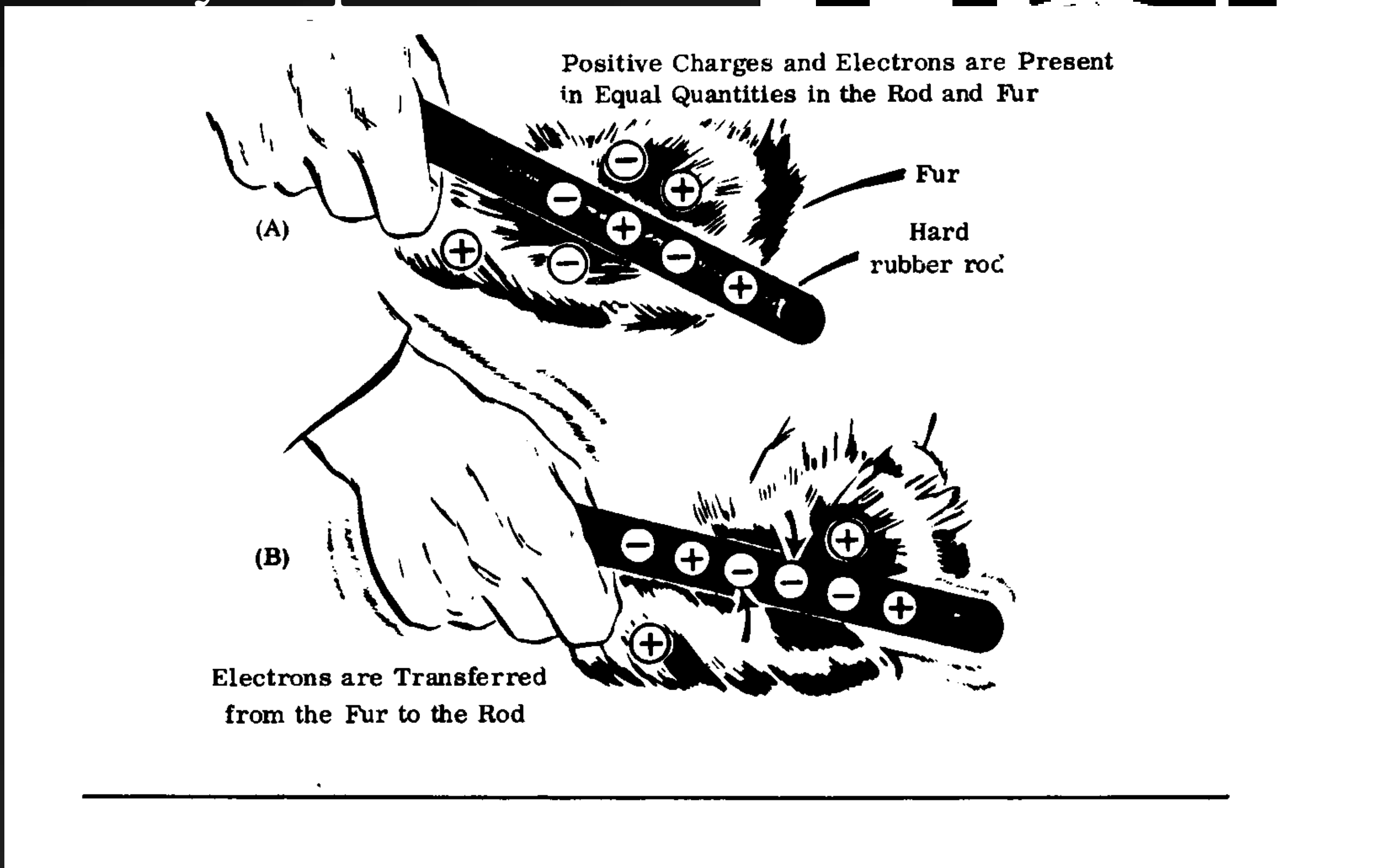
Electrostatic Forces

- Due to charged subatomic particles
  - Proton
  - Electron
  - but not Neutron
- The Law:
  - Unlike Charges Attract
  - Like Charges Repel



Free Electrons

- Some electrons can be easily displaced

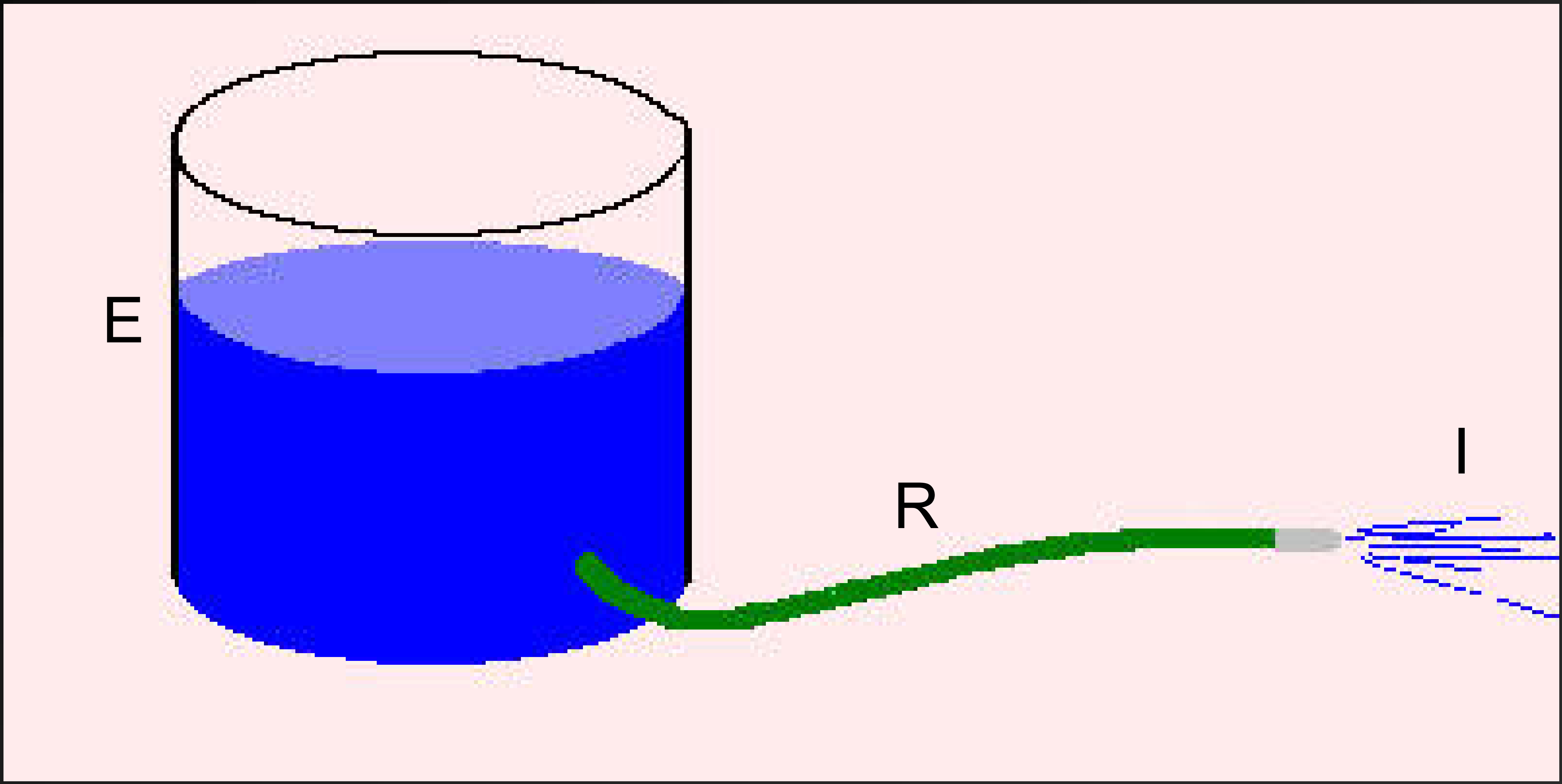


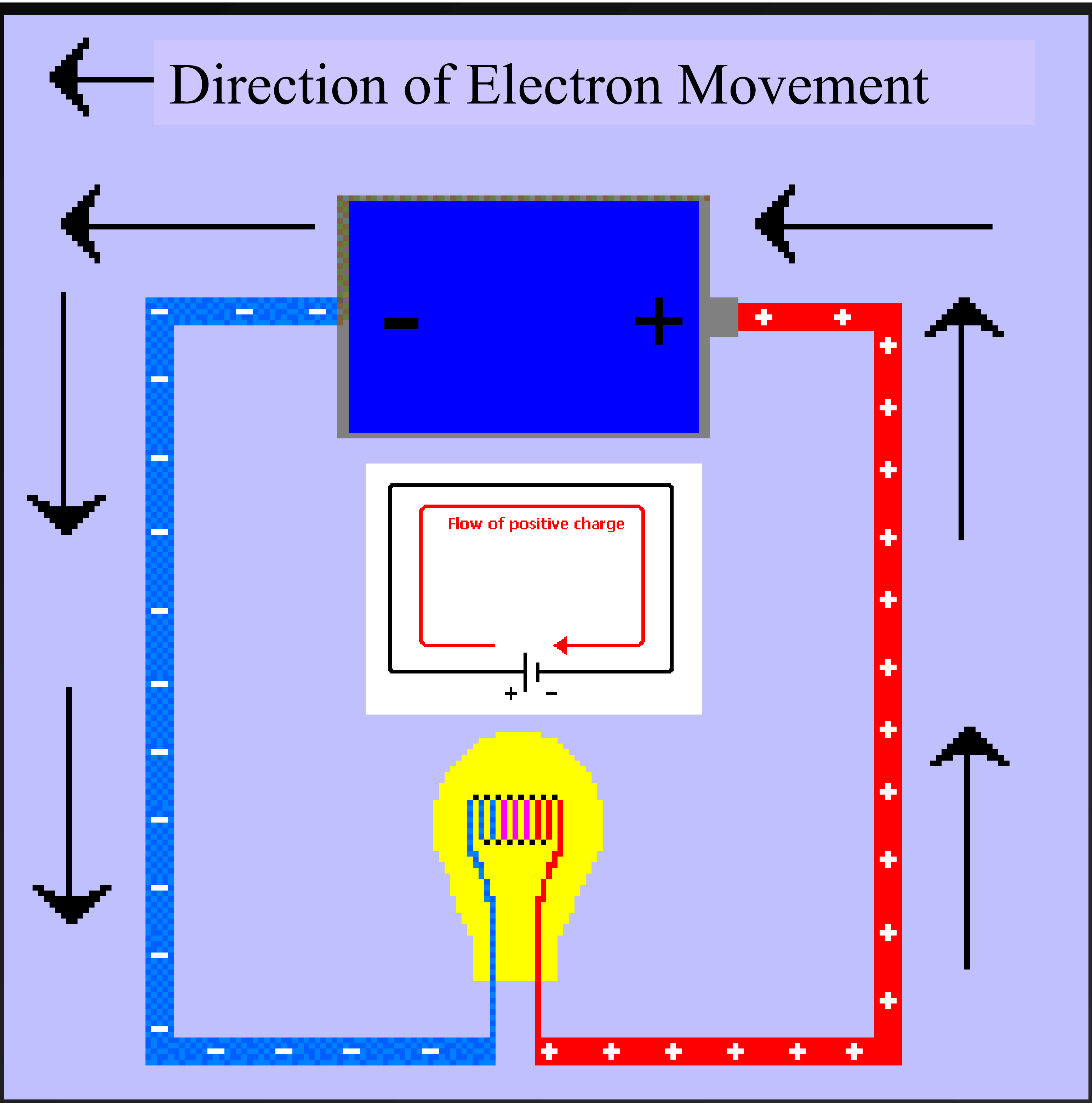
Demo

Static Electricity

- Friction with Poor Conductors
- Electrons displaced from one substance to the other (e.g Hair to comb, carpet to body)
- Leads to voltage potential (i.e., difference)

Basic Electricity by Analogy





DC
Anyway!

Details Details

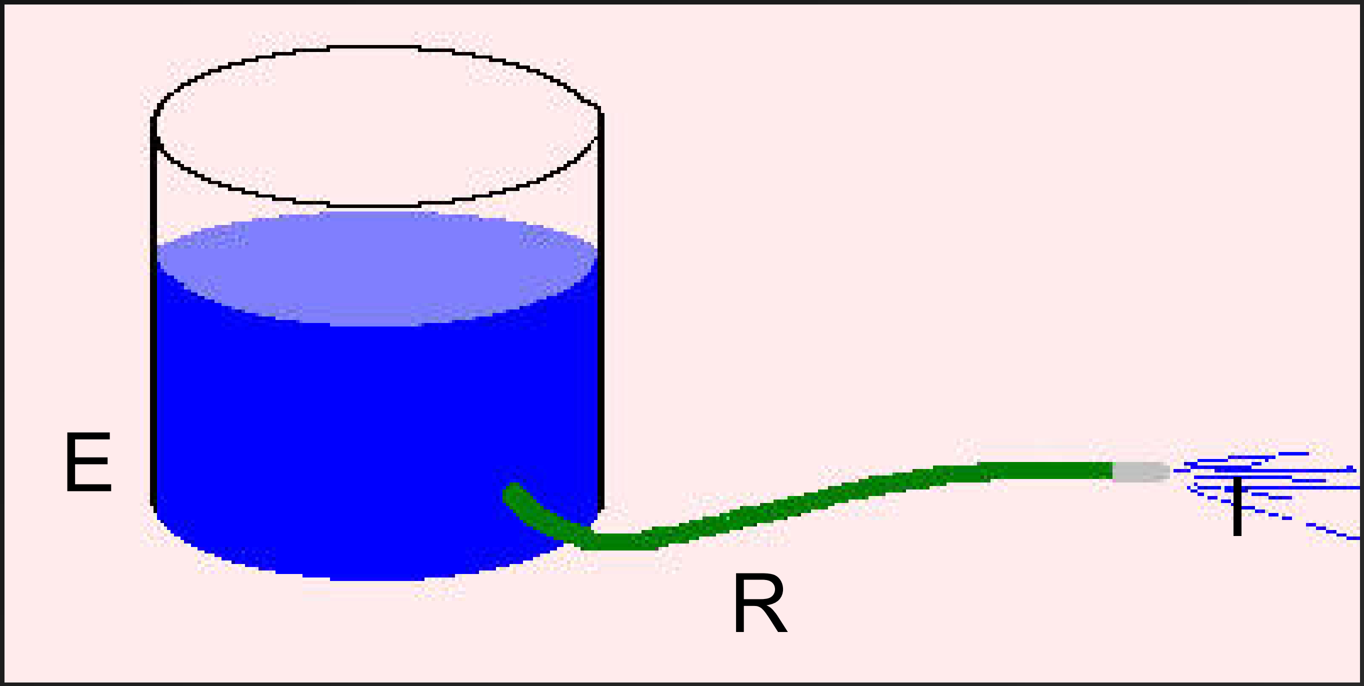
Symbol	Term	aka	Unit
E	Voltage	Electromotive Force	Volts (V)
I	Current	Rate of Flow	Amperes (A)
R	Resistance	--	Ohm (Ω)
P	Power	Rate of work	Watt (w)
W	Energy	Ability to do work	Watt-Second (Joule)

Ohm's Law

$$I = \frac{E}{R}$$

$$E = IR$$

$$R = \frac{E}{I}$$



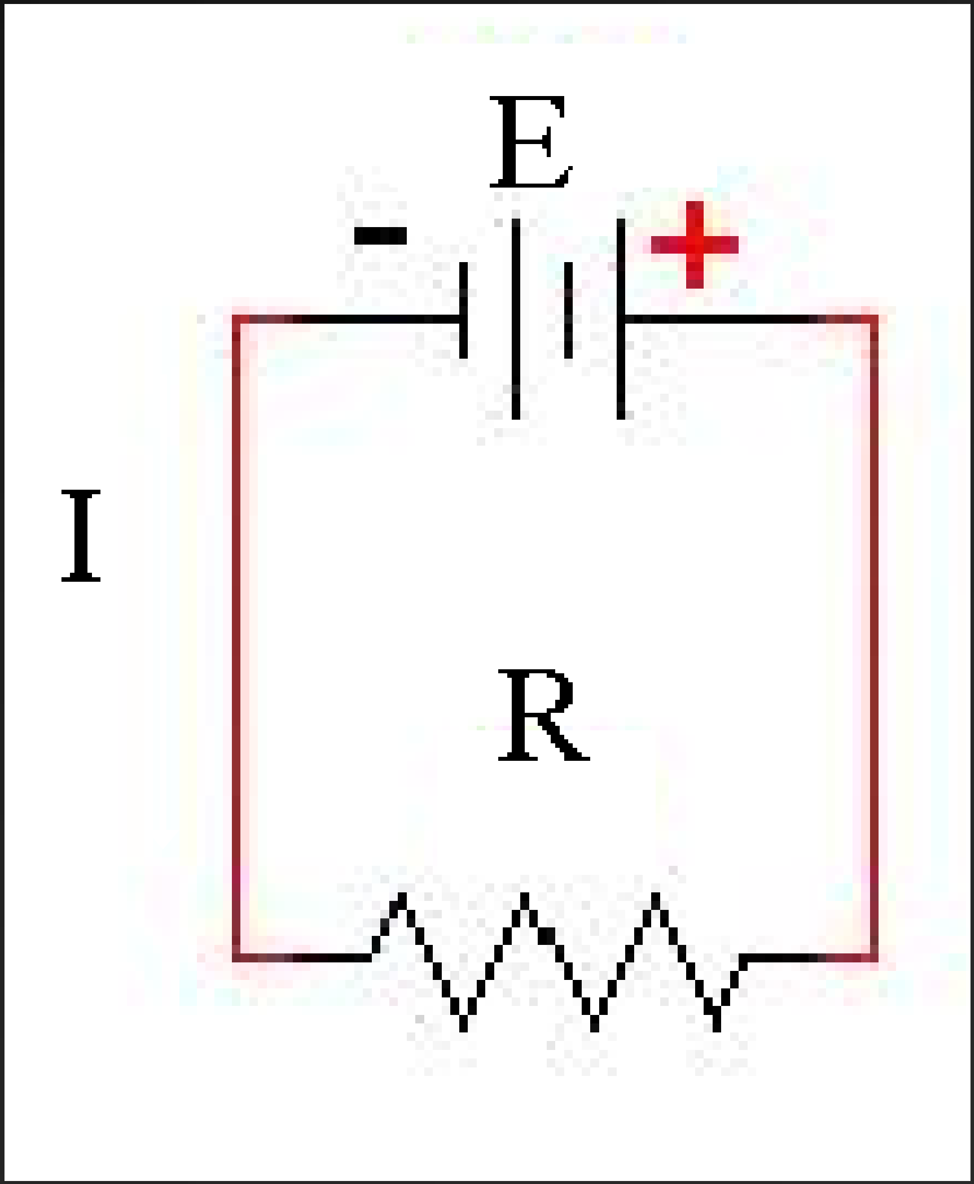
See also: http://www.falstad.com/circuit/e-ohms.html

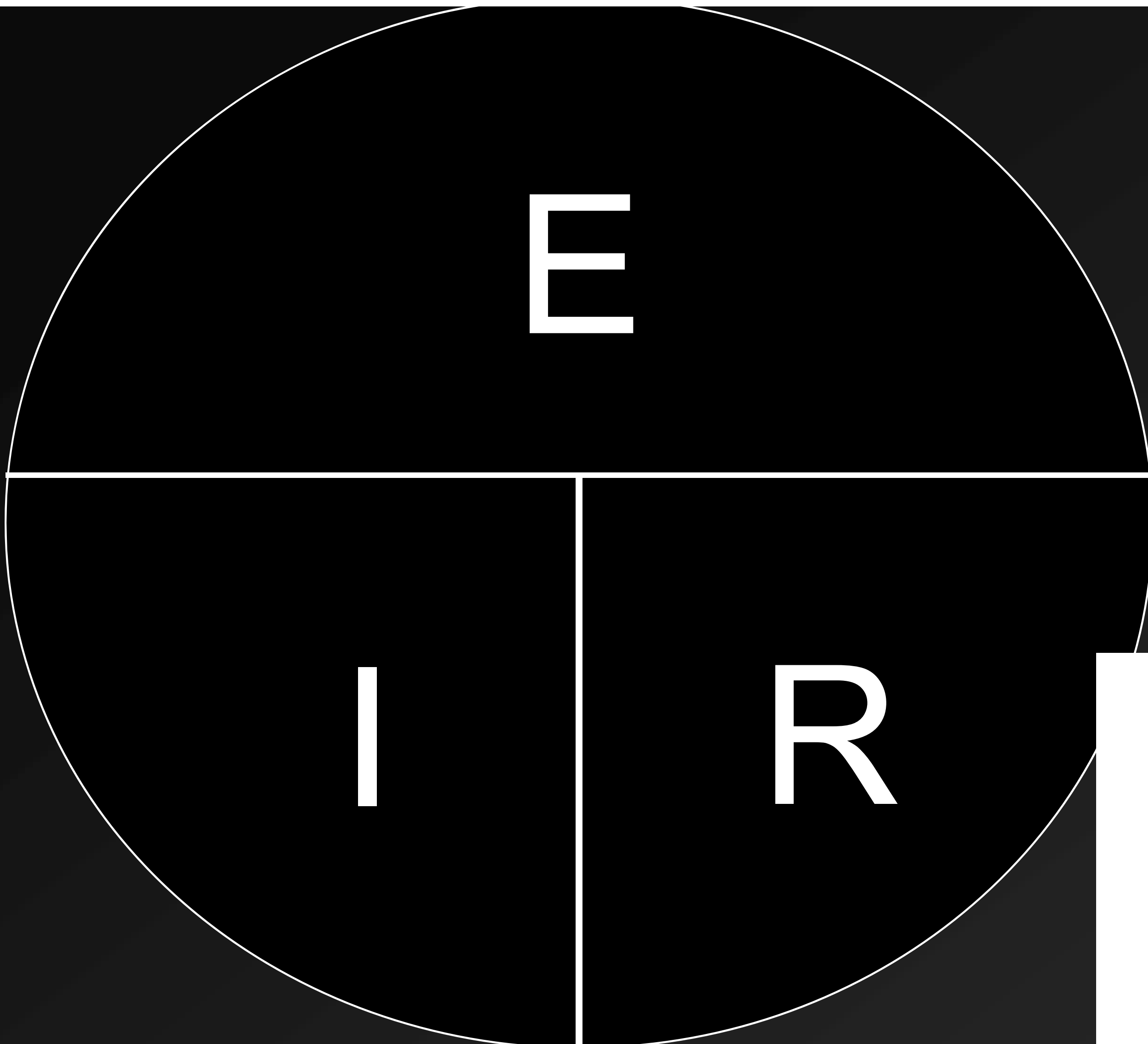
Ohm's Law

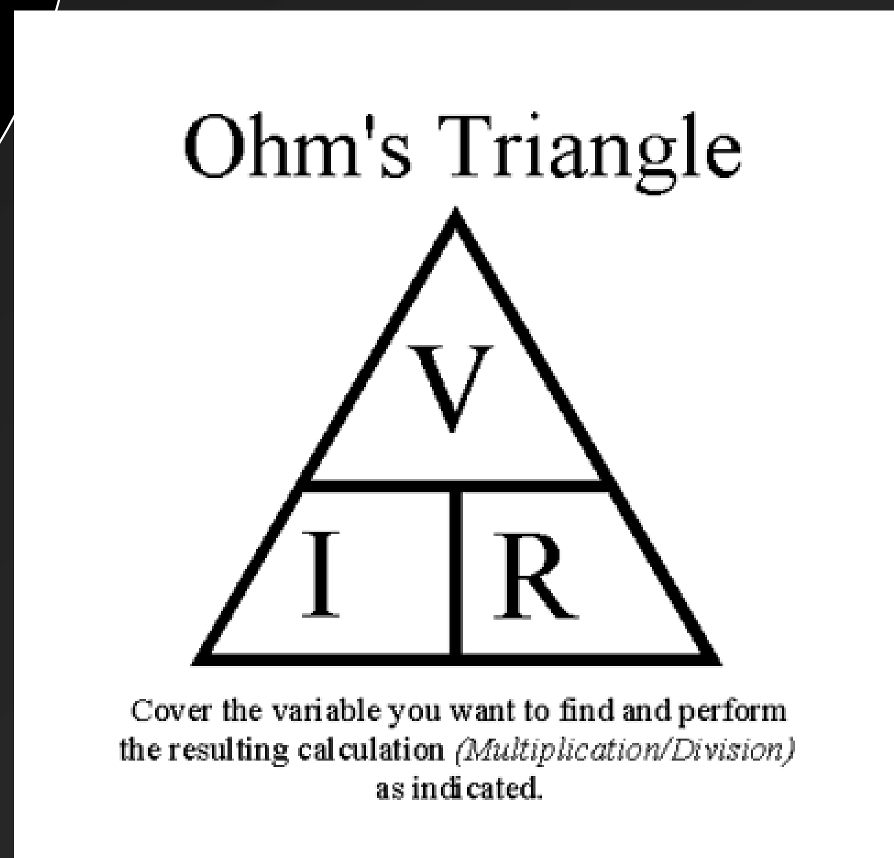
$$I = \frac{E}{R}$$

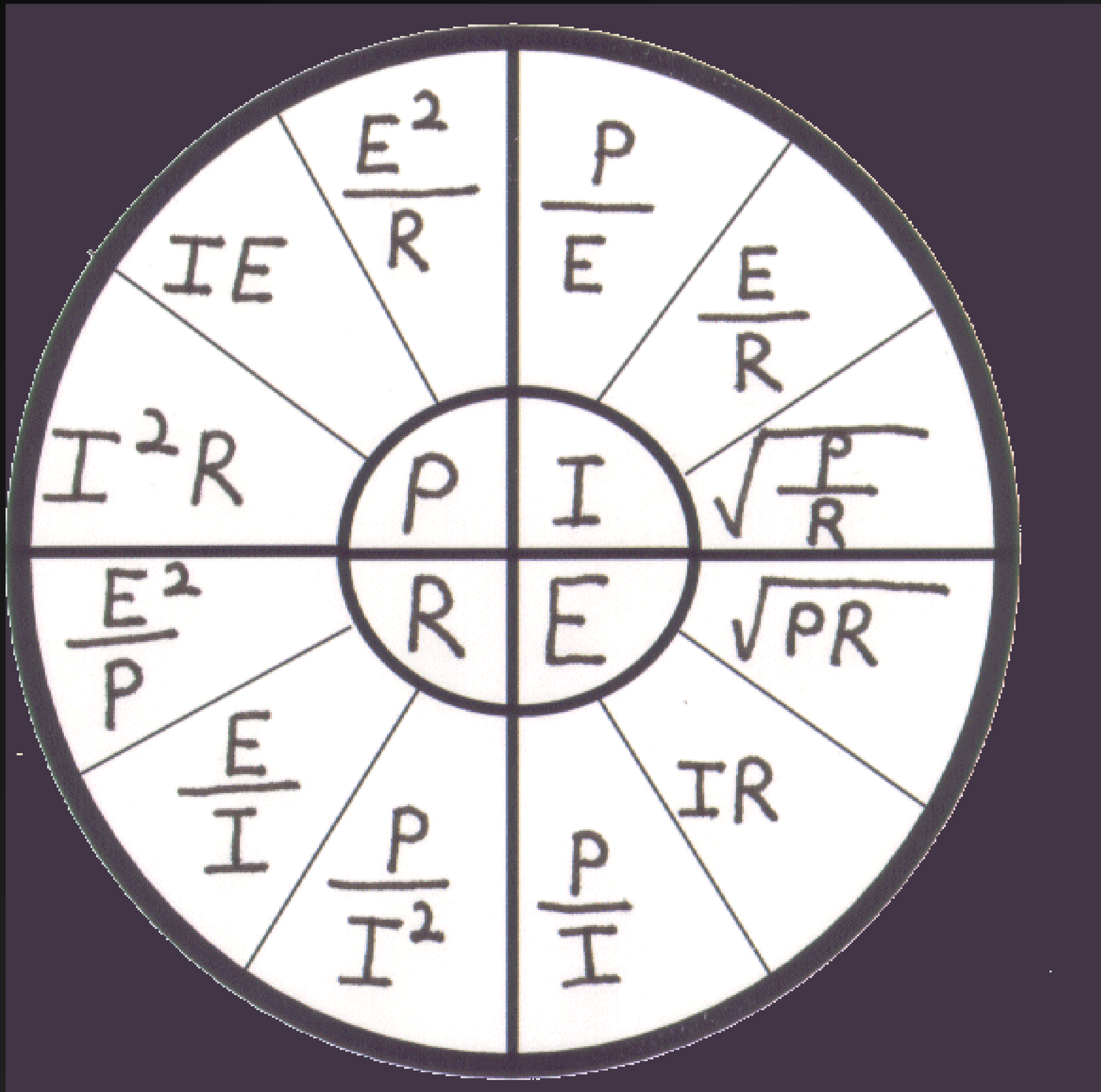
$$E = IR$$

$$R = \frac{E}{I}$$



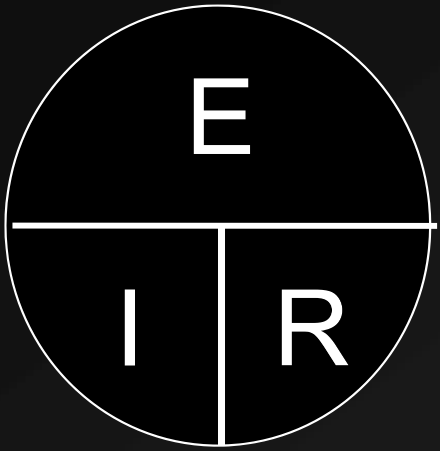

E
I
R

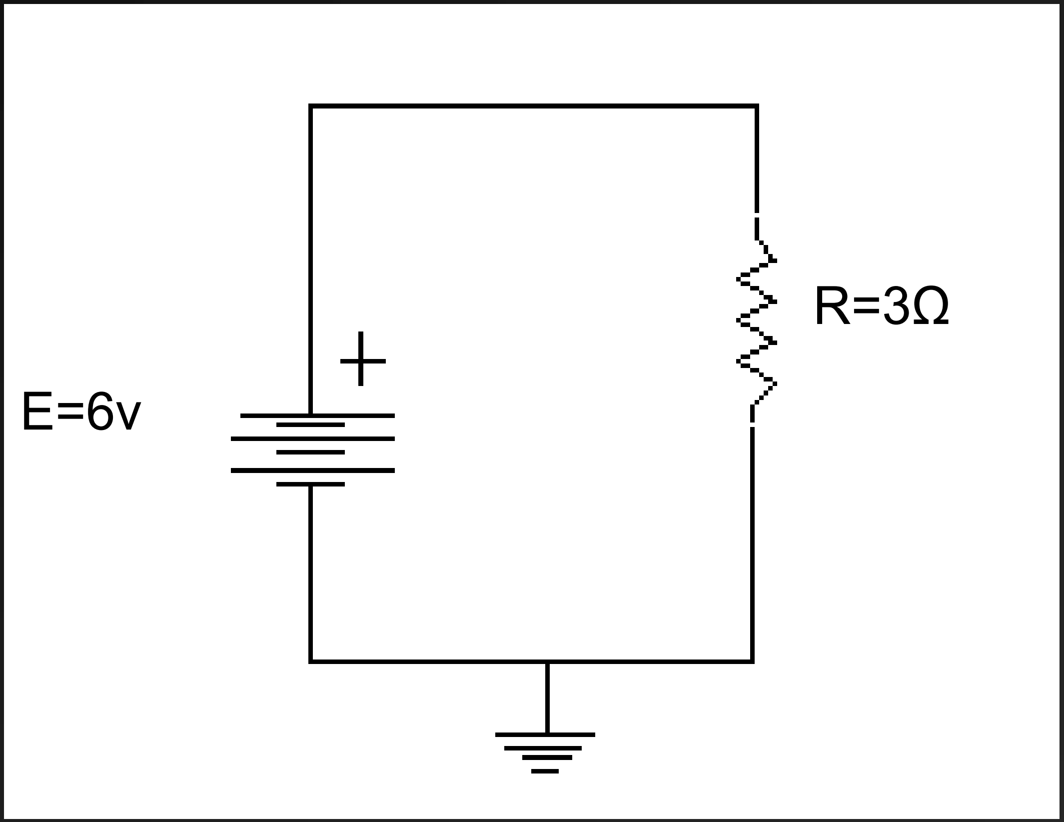

Ohm's Triangle
V
I
R
Cover the variable you want to find and perform the resulting calculation *(Multiplication/Division)* as indicated.



P
I
R
E
$\frac{E^2}{R}$
IE
I^2R
$\frac{E^2}{P}$
$\frac{E}{I}$
$\frac{P}{I^2}$
$\frac{P}{I}$
IR
$\sqrt{PR}$
$\sqrt{\frac{P}{R}}$
$\frac{E}{R}$
$\frac{P}{E}$

Basic Circuit

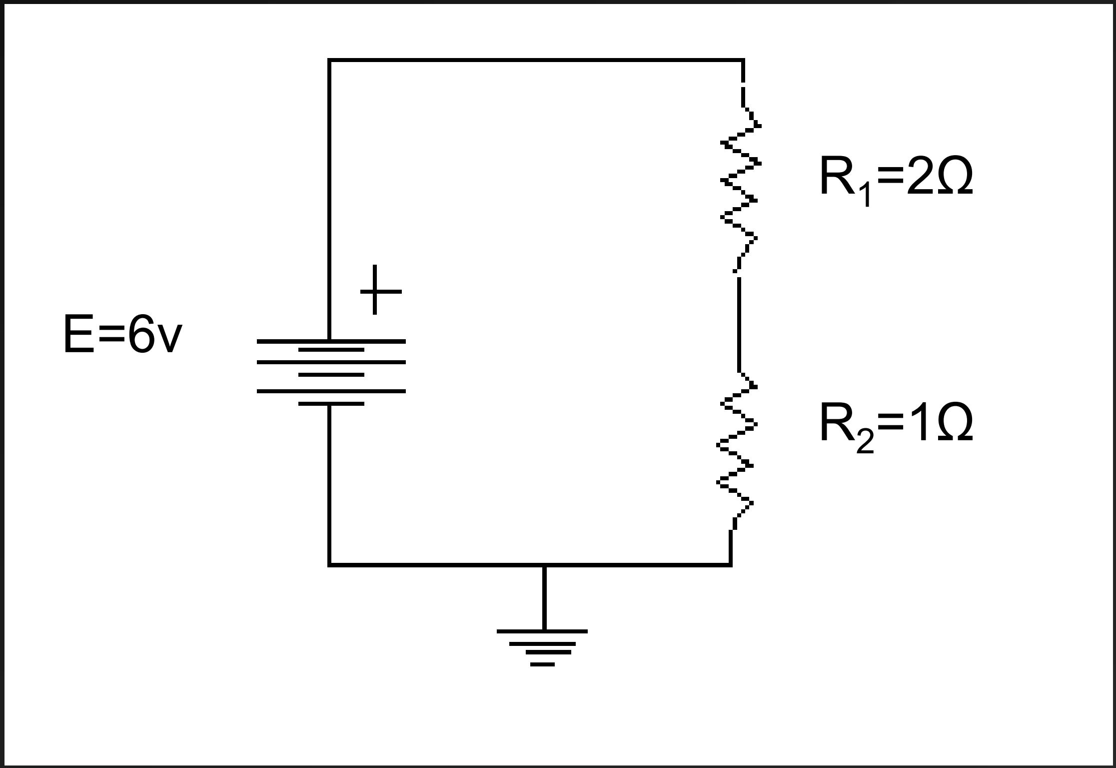




I = ?

Volt-Ohm Meter Demo

Series Circuit



$$R_T = R_1 + R_2$$

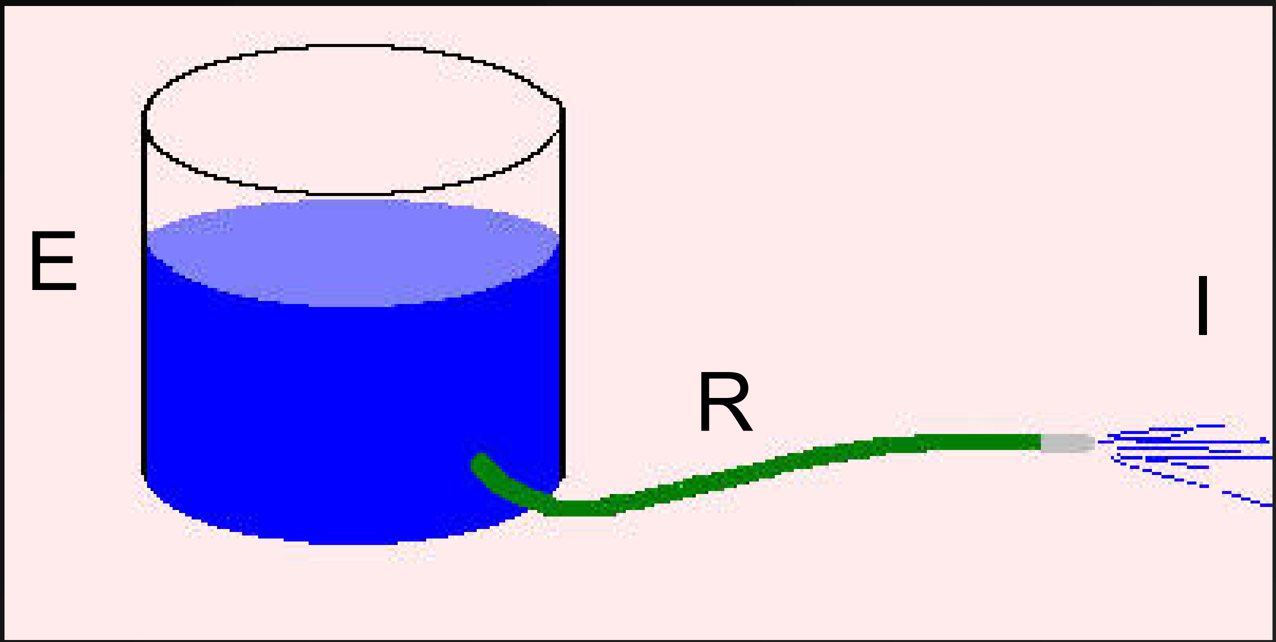
I = ?

E_{R1}=?

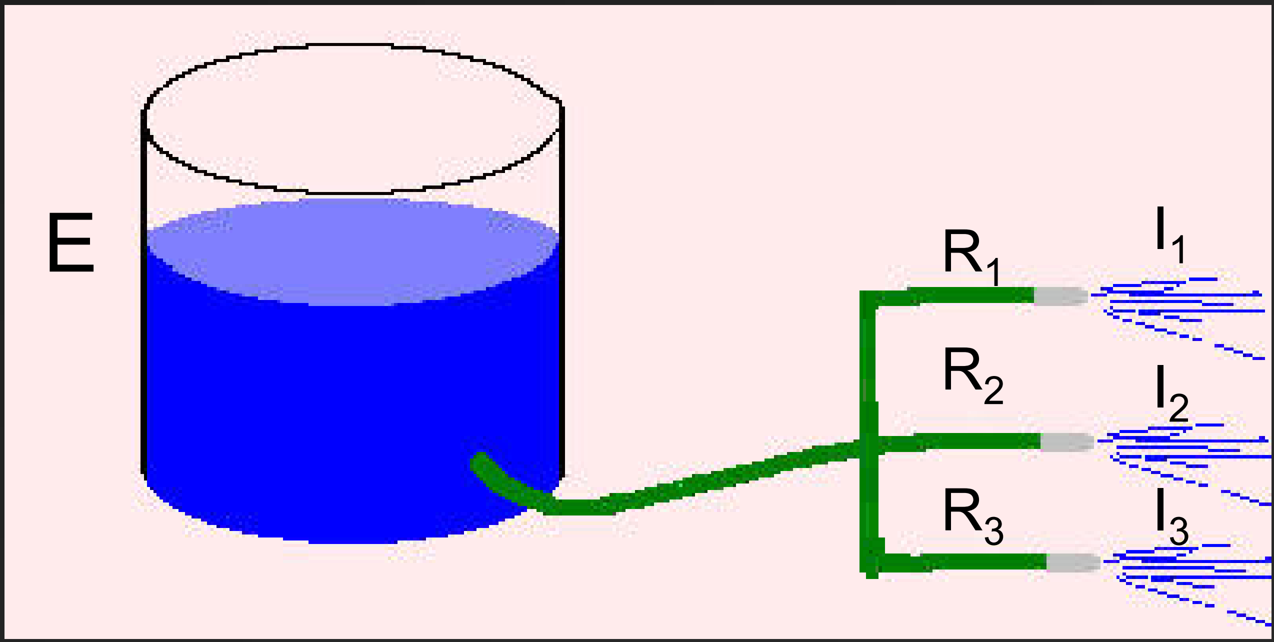
E_{R2}=?

Java Demo

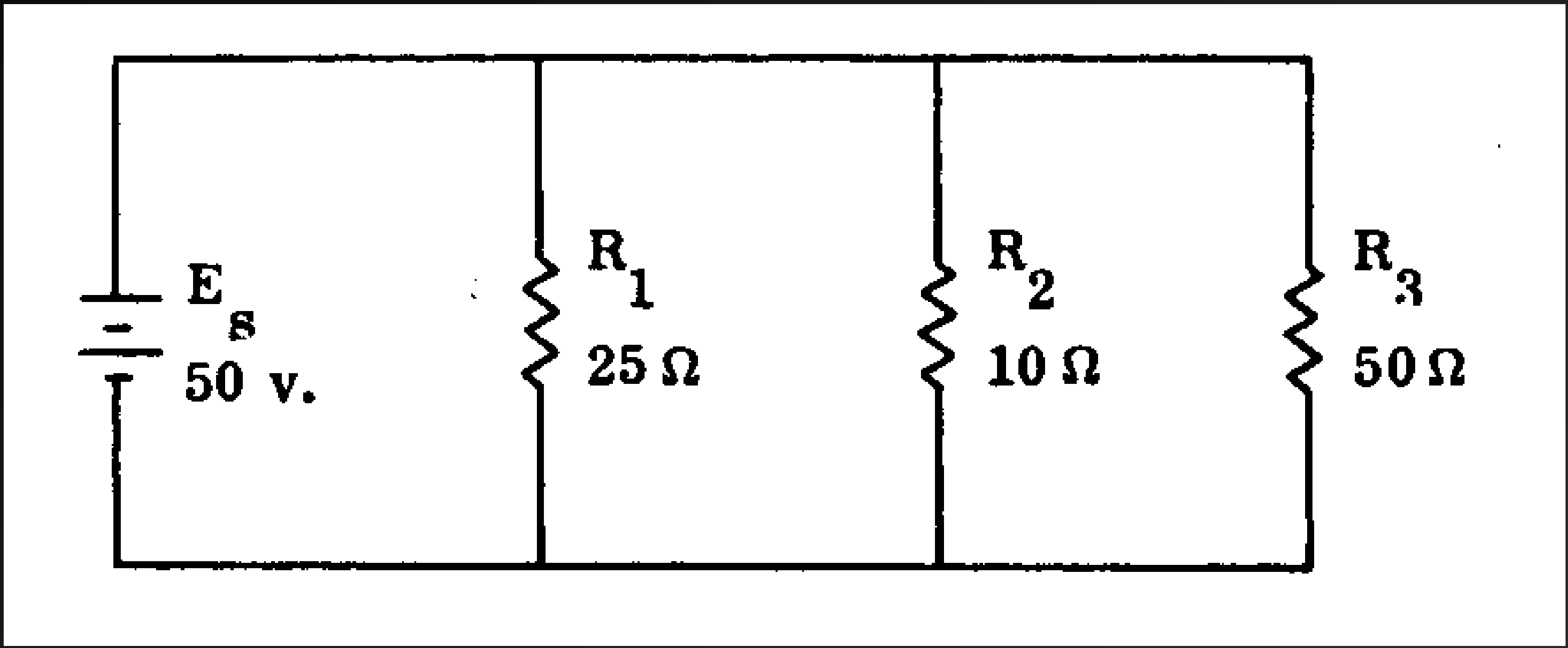
By Analogy: Series Vs Parallel



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



Parallel Circuit



$R_T = ?$

$I_T=?$

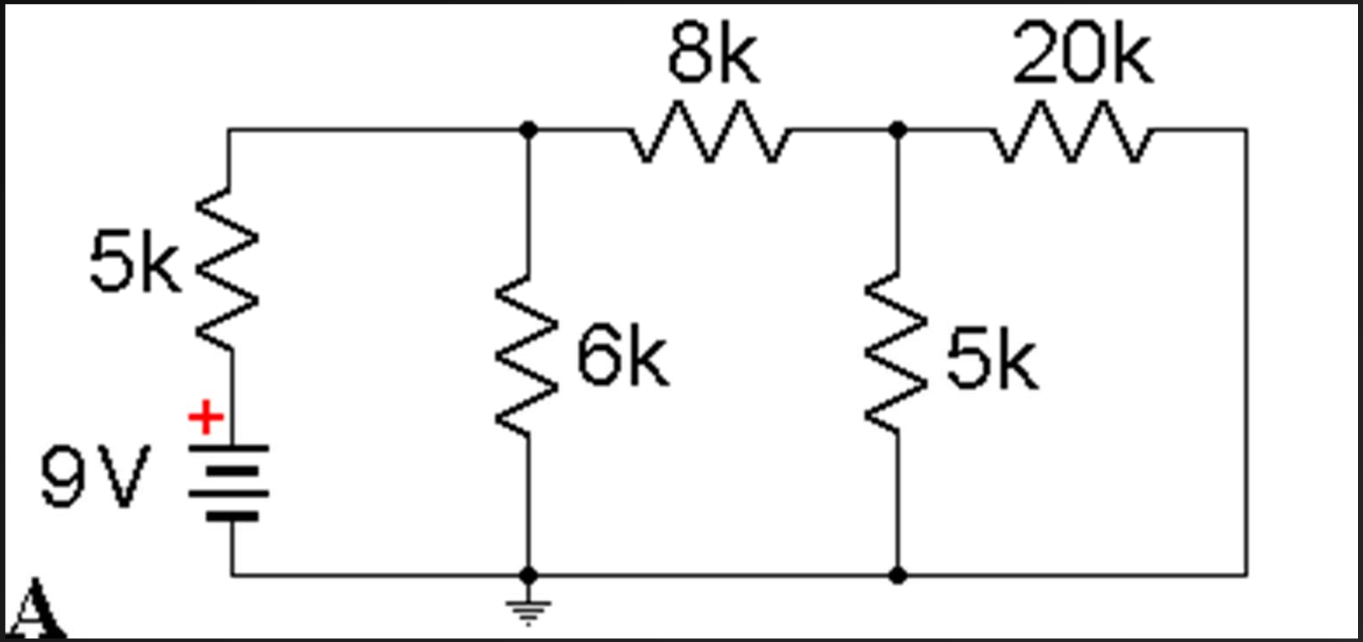
$I_1=?$

$I_2=?$

$I_3=?$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Complex Circuits

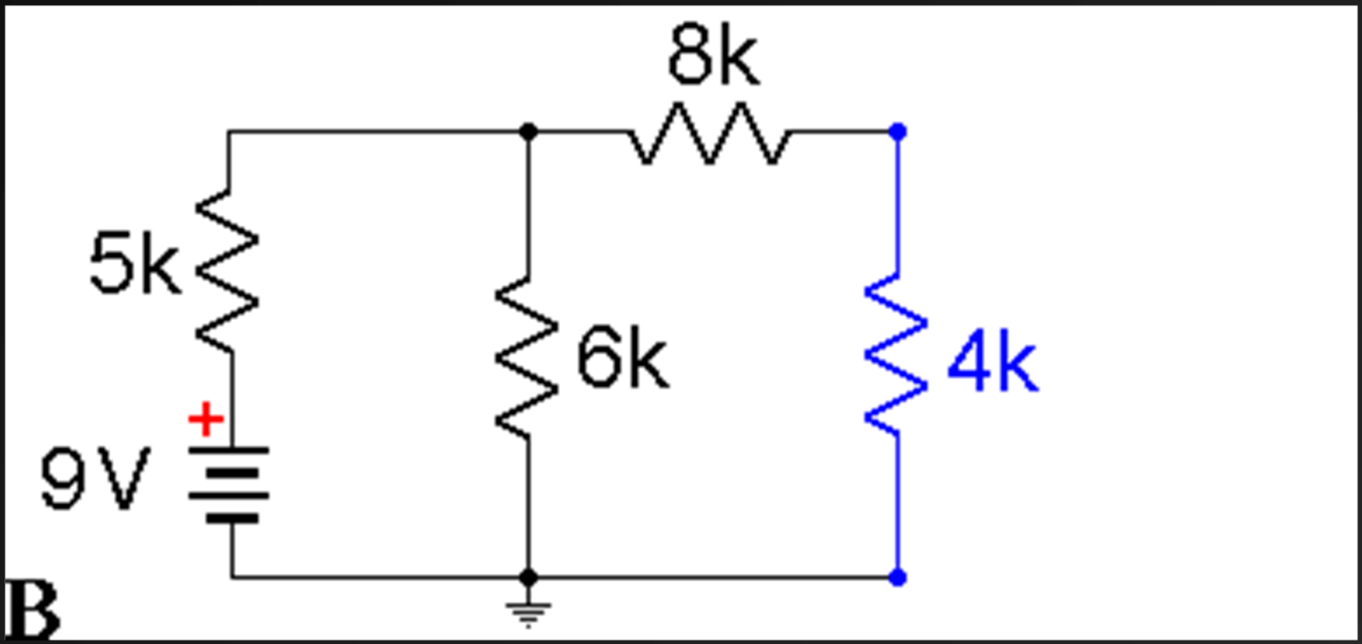


Find the current flowing in the circuit, and the voltage drops.

YIKES! Need to reduce. Start at the parallel combination of 20k and 5k resistors; it is replaced with its effective resistance of 4k
$[1/R_{equiv} = 1/20 + 1/5 = 1/20 + 4/20 = 5/20 = 1/4]$.

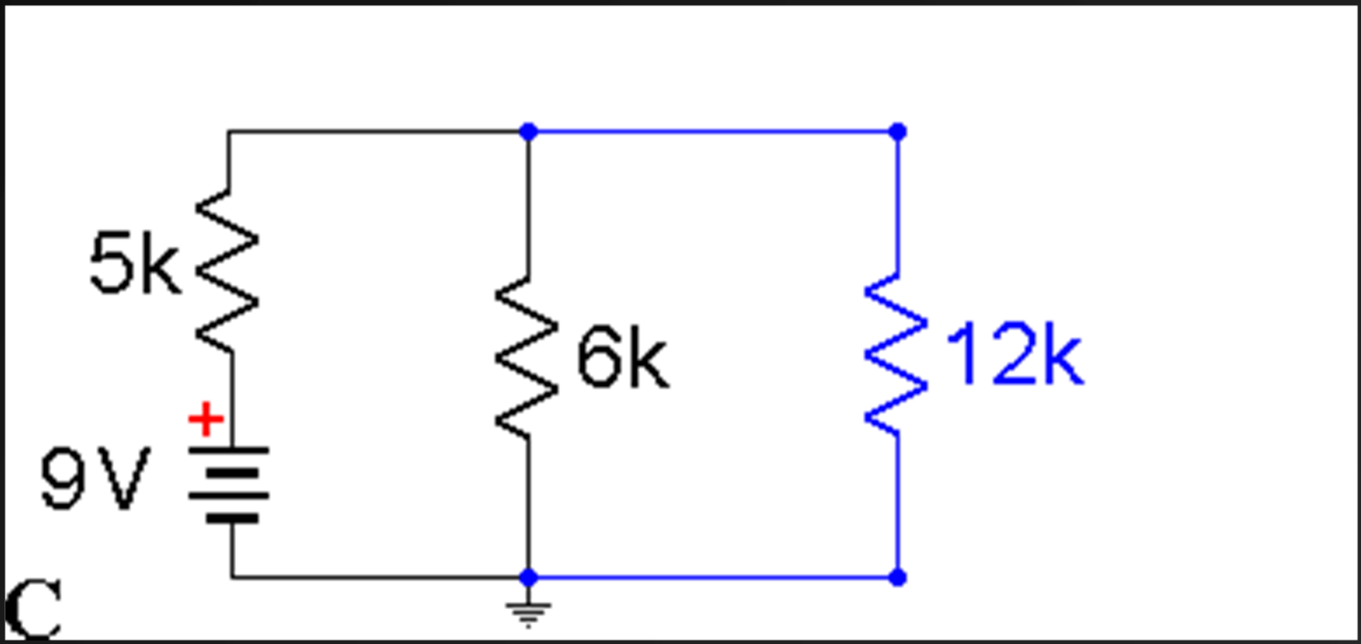
This and subsequent slides on this circuit adapted from:
"http://www.physics.udel.edu/~watson/phys345/examples/effective-circuit.html"

Slightly less Complex Circuit



Looking Better. The effective resistance of 4k is in series with the actual resistance of 8k, leading to replacement by its effective resistance of 12k. [R_{equiv} = 4k + 8k]

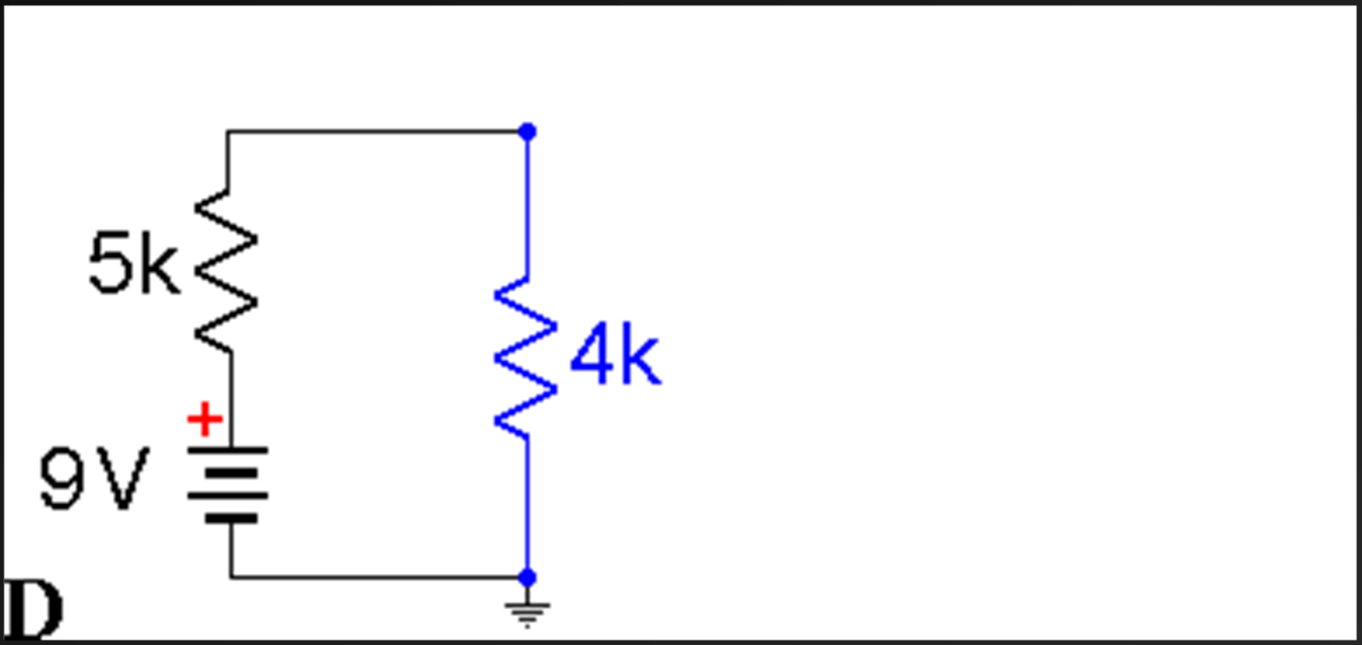
Less Complex Still



Better Still. Now there is a parallel combination of 12k and 6k resistors; it is replaced with its effective resistance of 4k

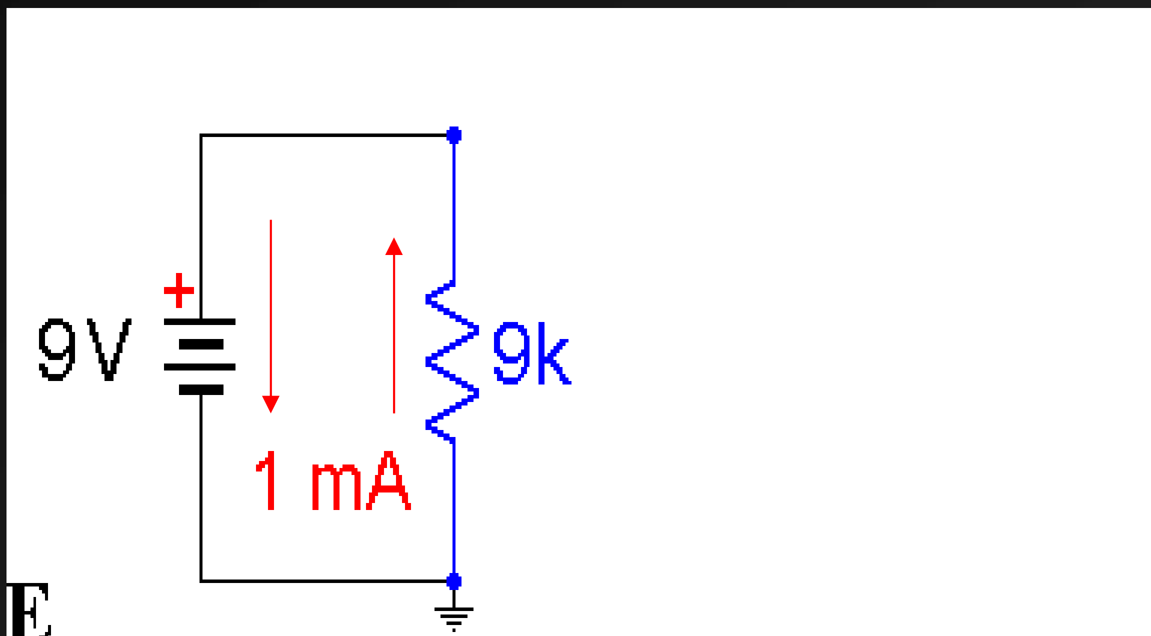
[$1/R_{equiv}$ = 1/12 + 1/6 = 1/12 + 2/12 = 3/12 = 1/4].

Now Series: Almost Simple



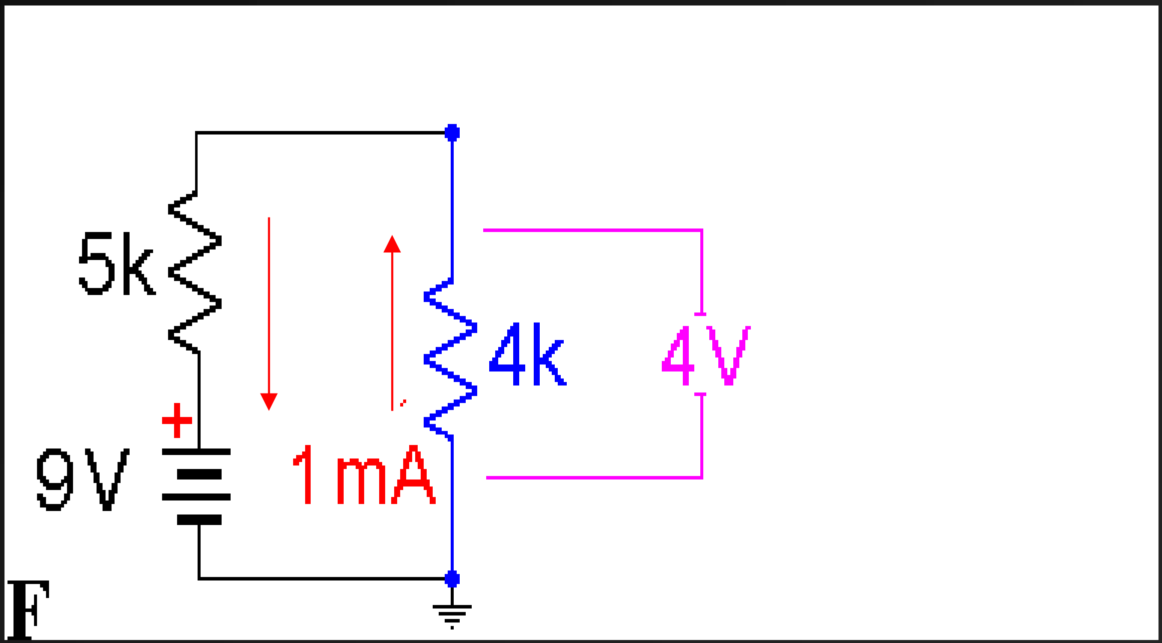
Now we have a simple series circuit!
Finally, the equivalent resistance for the entire circuit is 9k.
[R_{equiv} = 4k + 5k].

Now Series: Almost Simple



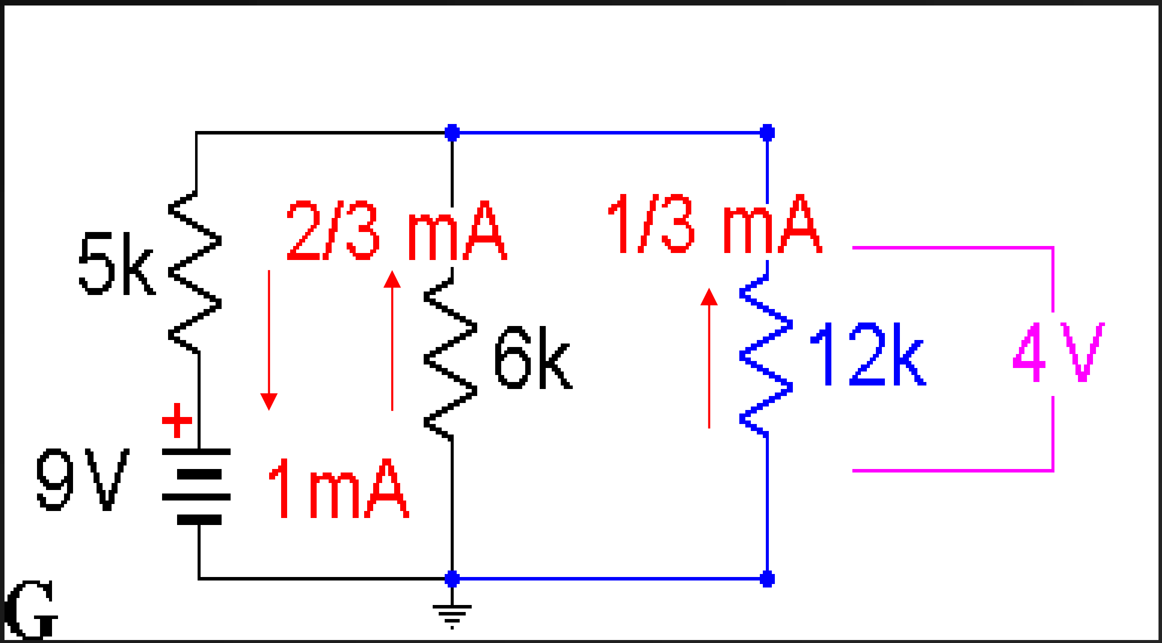
I = ?
[I = E/R = 9 V/9 k = 1 mA]

Working Back: Voltage Drops and Current



The real 5k resistor and the effective 4k resistance each have 1 mA of current since they are in series. Thus the 4k resistance has 4V of voltage difference across it (by Ohm's law).

Working Back: Voltage Drops and Current

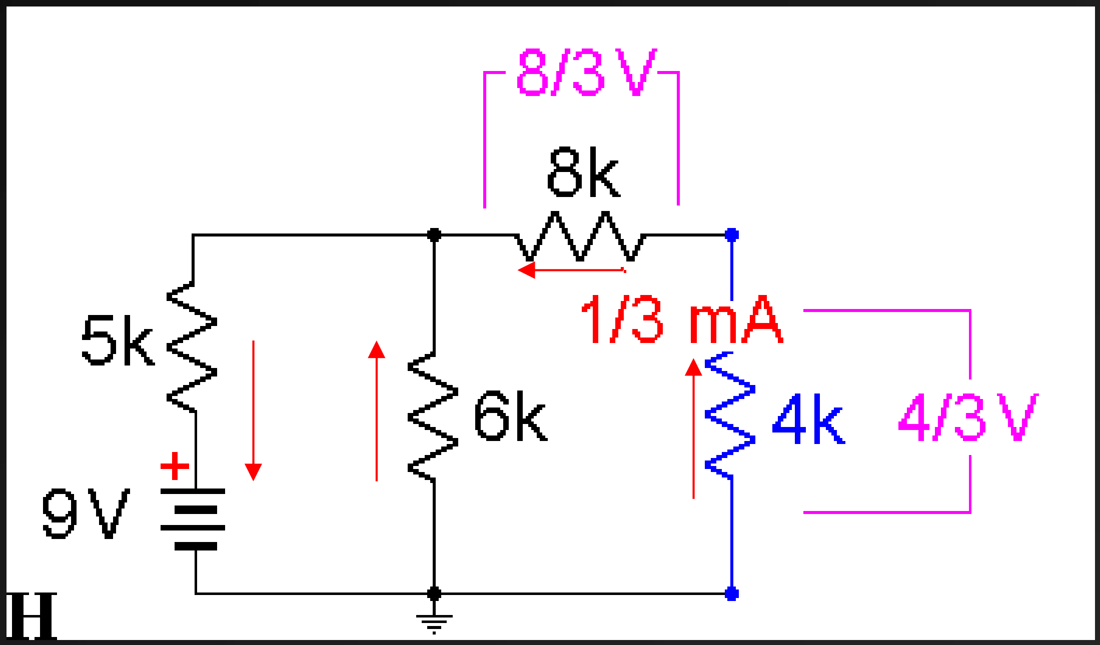


Breaking the 4k resistance into its component parts (in parallel), we find that 2/3 mA of current flows in the 6k resistor and 1/3 mA flows in the effective resistance of 12k.

I = E/R = 4/6K = 2/3 mA

I = E/R = 4/12K = 1/3 mA

Working Back: Voltage Drops and Current

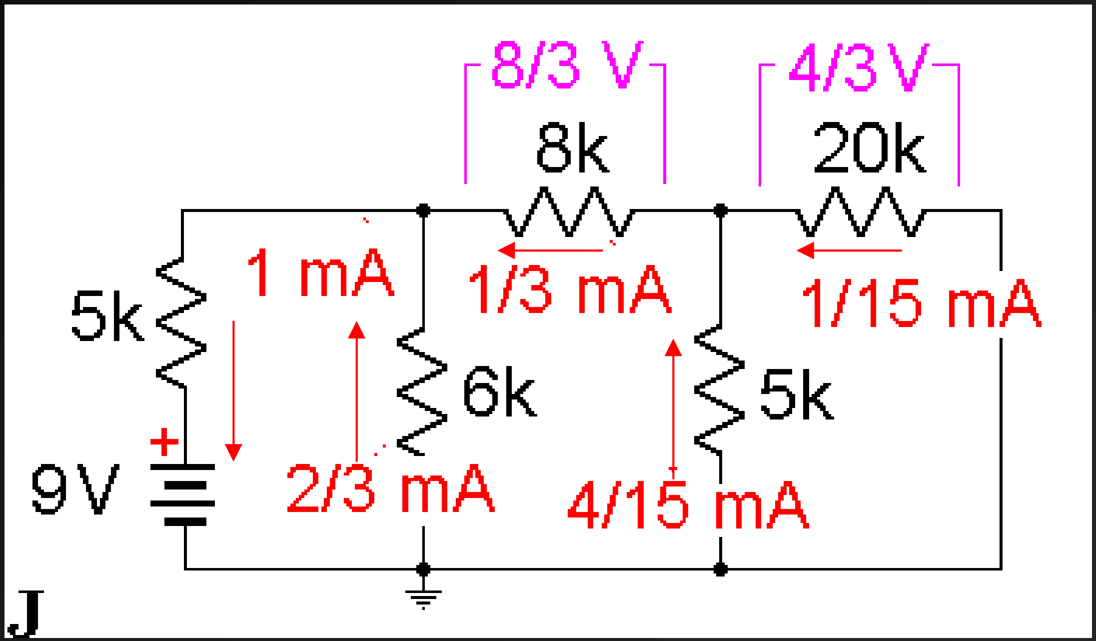


Breaking the 12k resistance into its component parts (in series), we find that there is 8/3 V across the 8k resistor and 4/3 V across the effective resistance of 4k.

E = IR = 4KΩ * 1/3 mA = 4/3 V

E = IR = 8KΩ * 1/3 mA= 8/3 V

Working Back: Voltage Drops and Current

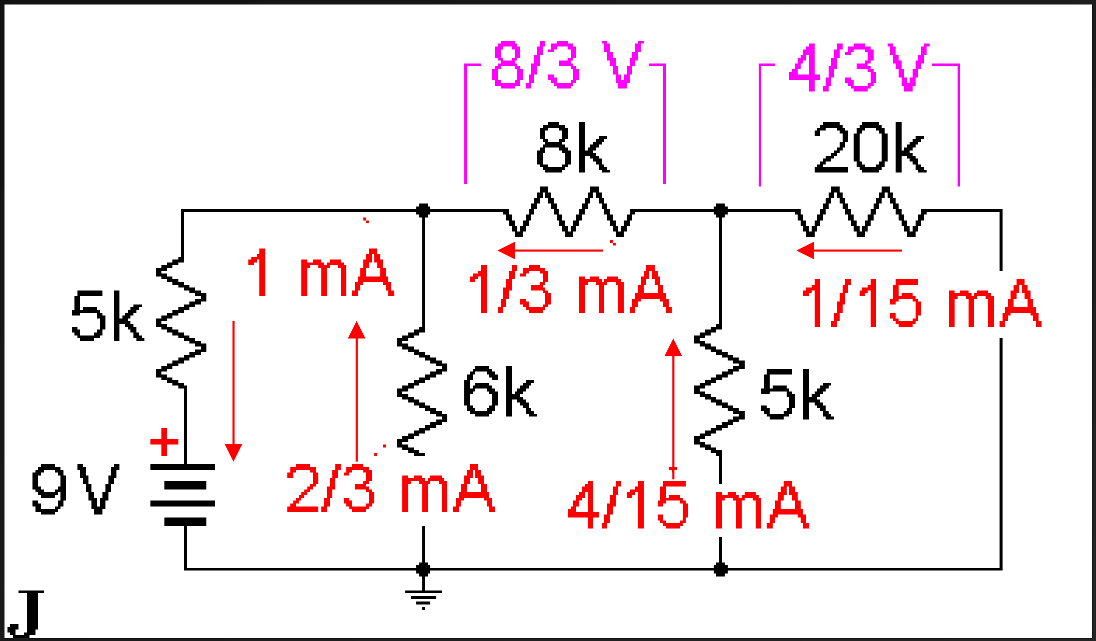


Finally, breaking the 4k resistance into its component parts (in parallel), we find that 1/15 mA of current flows in the 20k resistor and 4/15 mA flows in the 5k resistor.

I = E/R = (4/3V)/20KΩ = 4/60 mA = 1/15 mA

I = E/R = (4/3V)/5KΩ = 4/15 mA

Working Back: Voltage Drops and Current

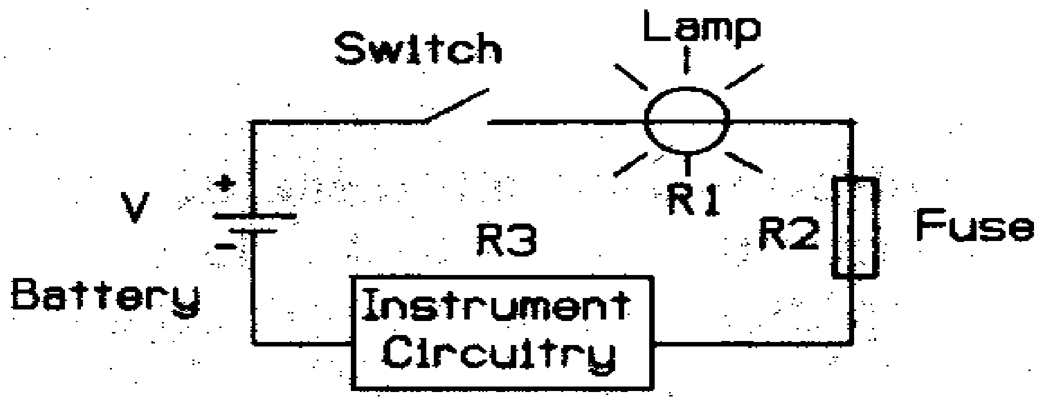


Summarizing:

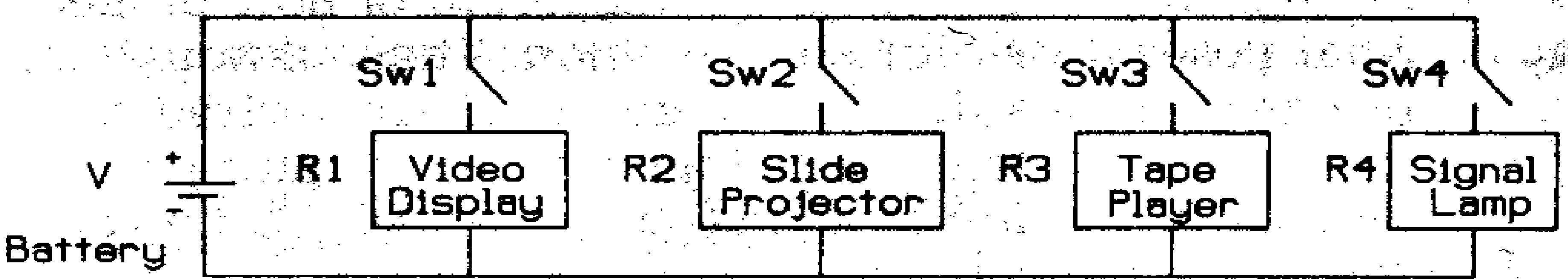
1. Current through the battery? 1 mA
2. Current through the 8k resistor? 1/3 mA
3. Voltage difference across the 20k resistor? 4/3 V

In Real Life…

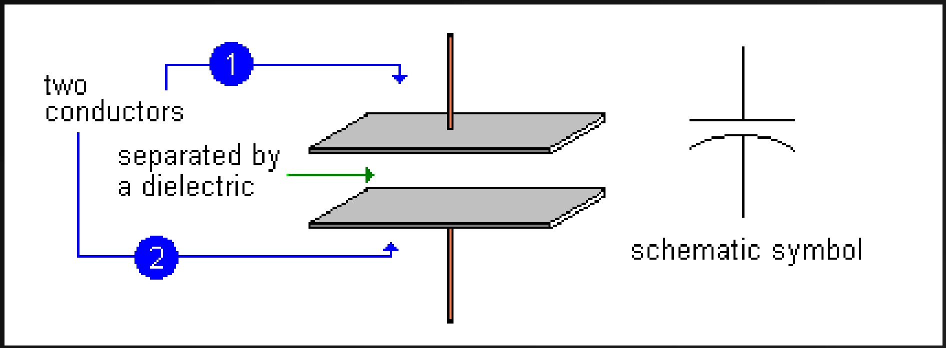
a) Series Circuit

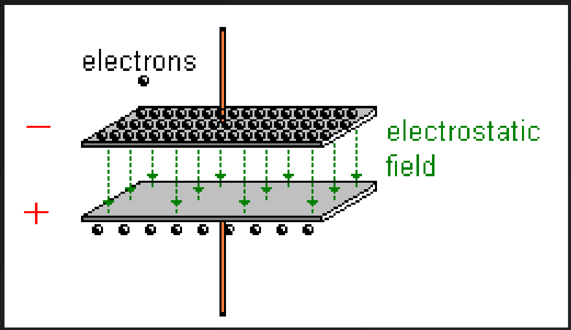


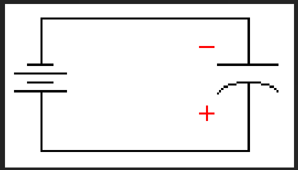
b) Parallel Circuit



Capacitance







Capacitor = two conductors separated by a dielectric.
Dielectric = material that is a good insulator (incapable of passing electrical current), but is capable of passing electrical fields of force. Examples include glass, porcelain.

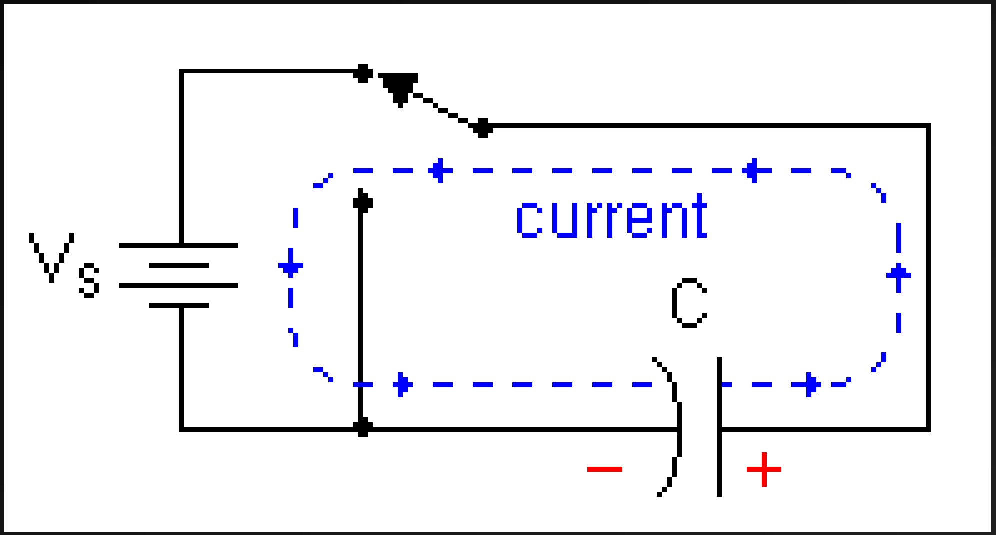
Charged Capacitor = more electrons on one conductor plate than on the other.

Capacitance

- Two closely spaced plates – offer essentially no resistance

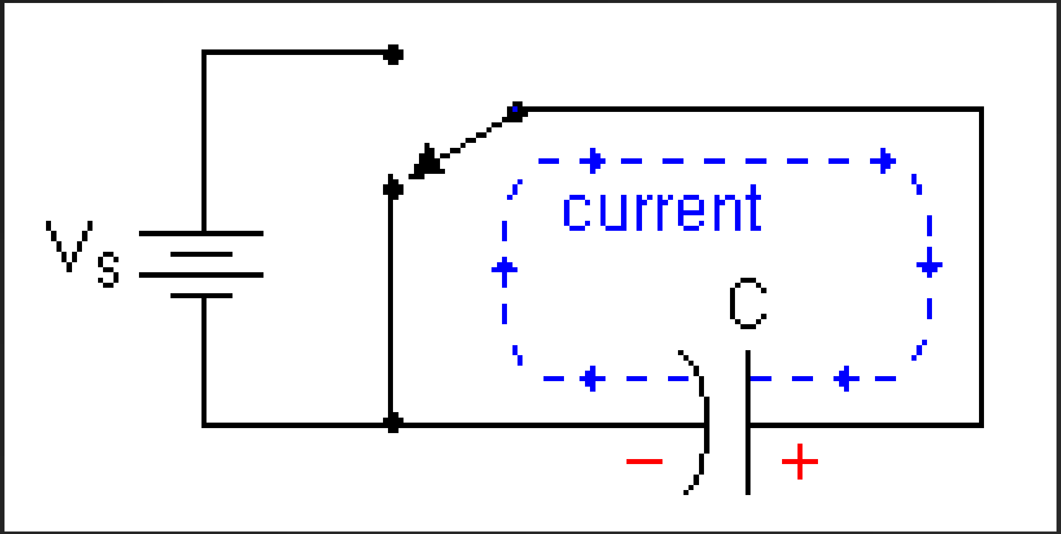
- As negative charge built up on first plate due to flow of electrons, a positive charge would build up on second plate
  - The current **charges** the plates of the capacitor, **but does not flow through the capacitor**, itself.

Capacitance



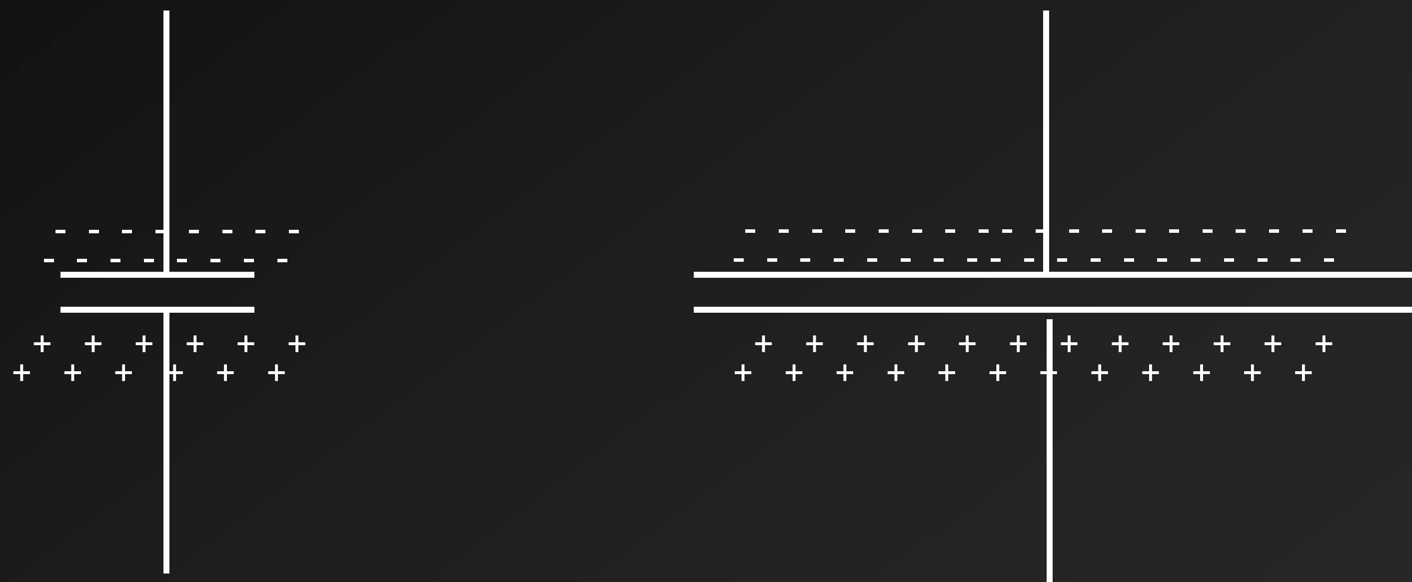
Charging – current flows until capacitor is fully charged, then stops

Discharging – current flows in reverse direction until capacitor fully discharged



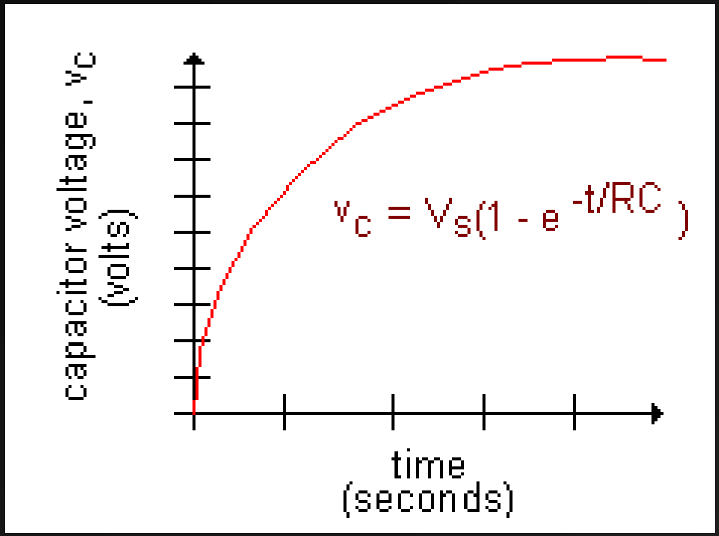
Capacitance – Size Matters

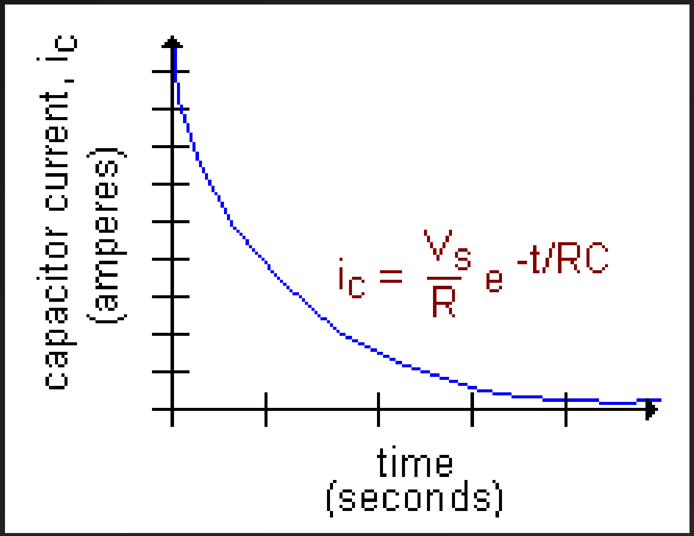
- Which has more capacity?



- More capacity, more current flows before capacitor is fully charged

Capacitor Time Constants





Over time…

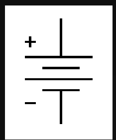
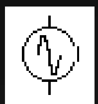
Capacitor's voltage increases

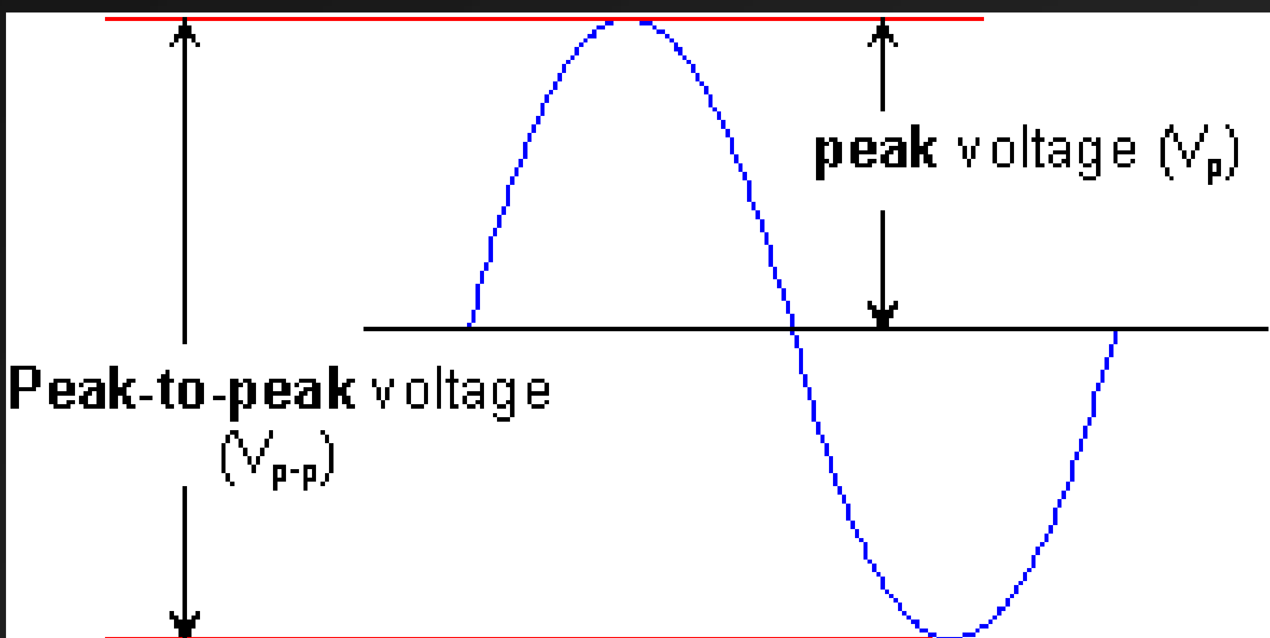
Current flow grinds to a halt

The capacitor's time constant TC=

- The time in seconds for it to become 63.2% charged
- The time in seconds for current flow have slowed by 63.2% from its starting value

AC Circuits

-  DC Circuit: Current Flow is unidirectional, from – to +
-  AC Circuit: Current Flow switches direction periodically (at a given frequency in Hz)



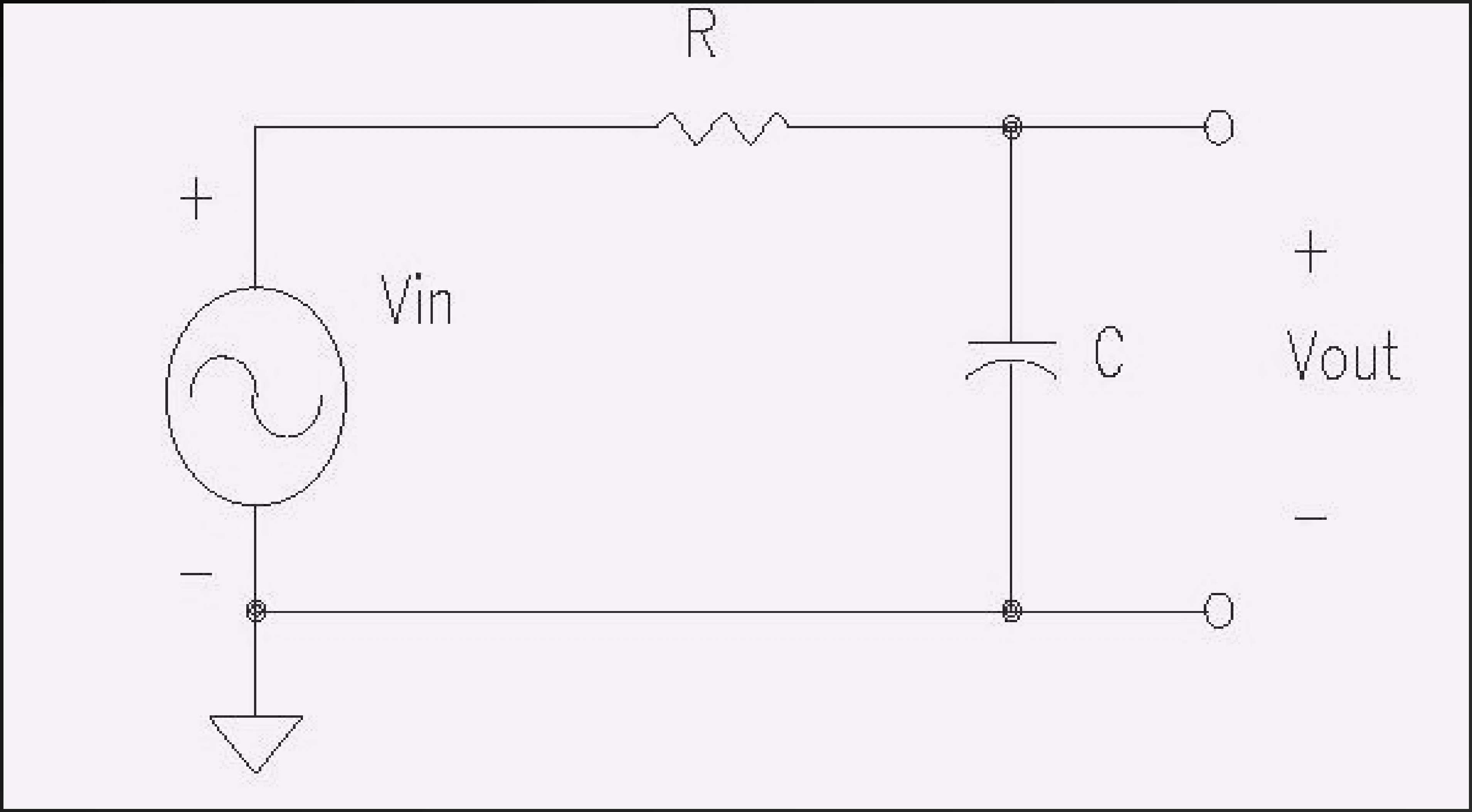
AC Circuits and Capacitance

- Slowly alternating signals
  - will fully charge capacitor, and signal will be impeded
- Rapidly alternating signals
  - will not fully charge the capacitor before the direction of flow reverses, allowing signals to pass unimpeded

http://micro.magnet.fsu.edu/electromag/java/capacitor/

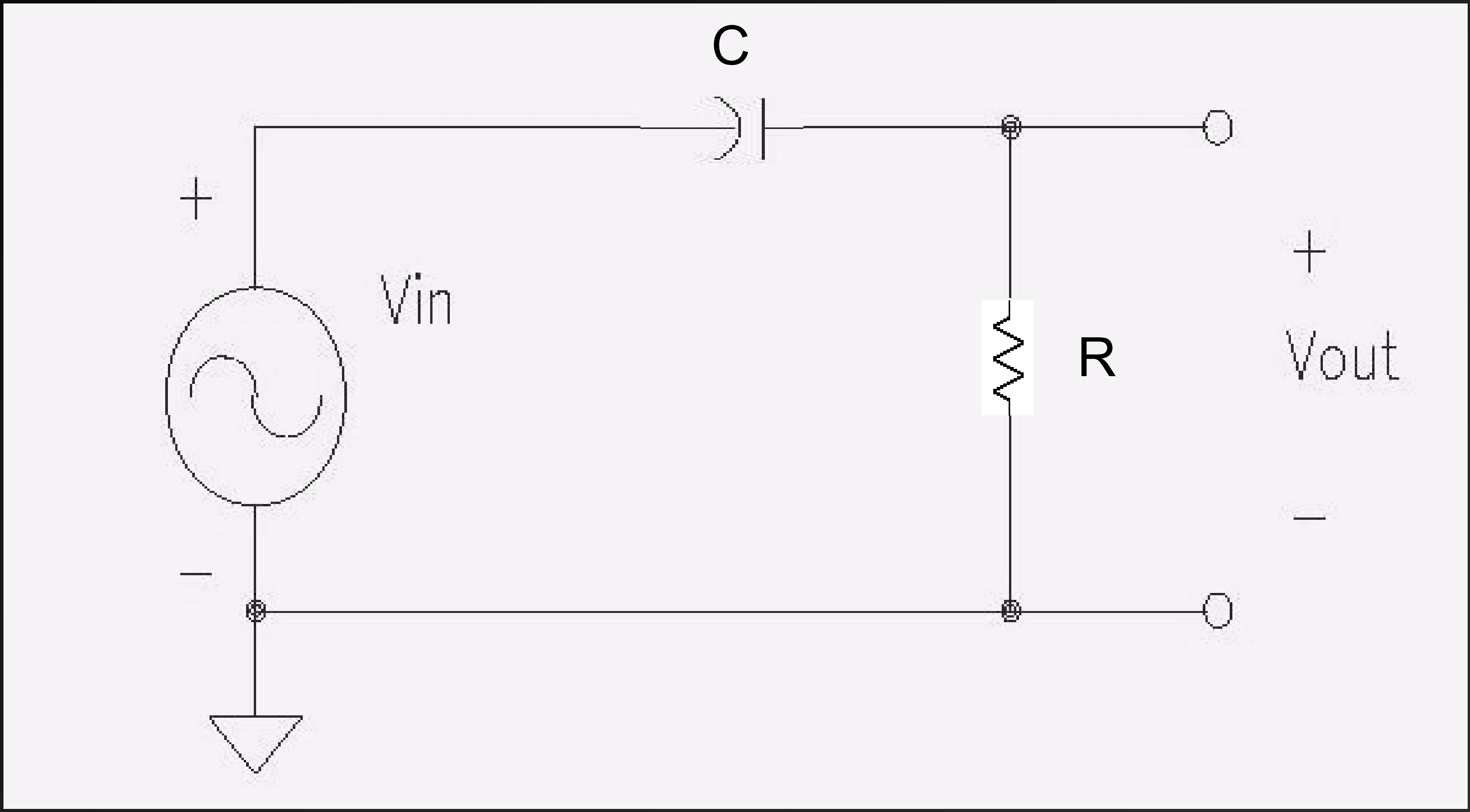
http://www.vjc.moe.edu.sg/academics/dept/physics_dept/applet/rc/rc.htm

Using Capacitors to make Low Pass Filters

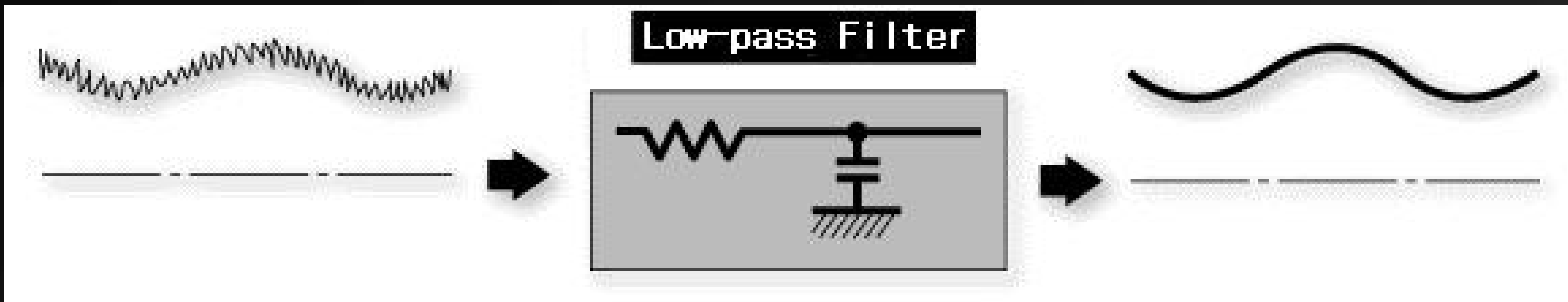


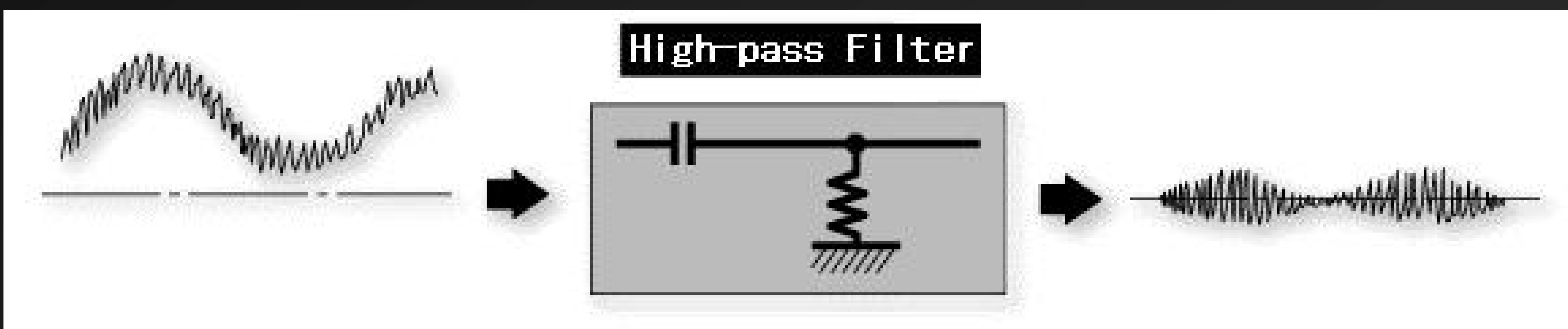
What will happen to fast signals; slow signals?

Using Capacitors to make High Pass Filters



What will happen to fast signals; slow signals?

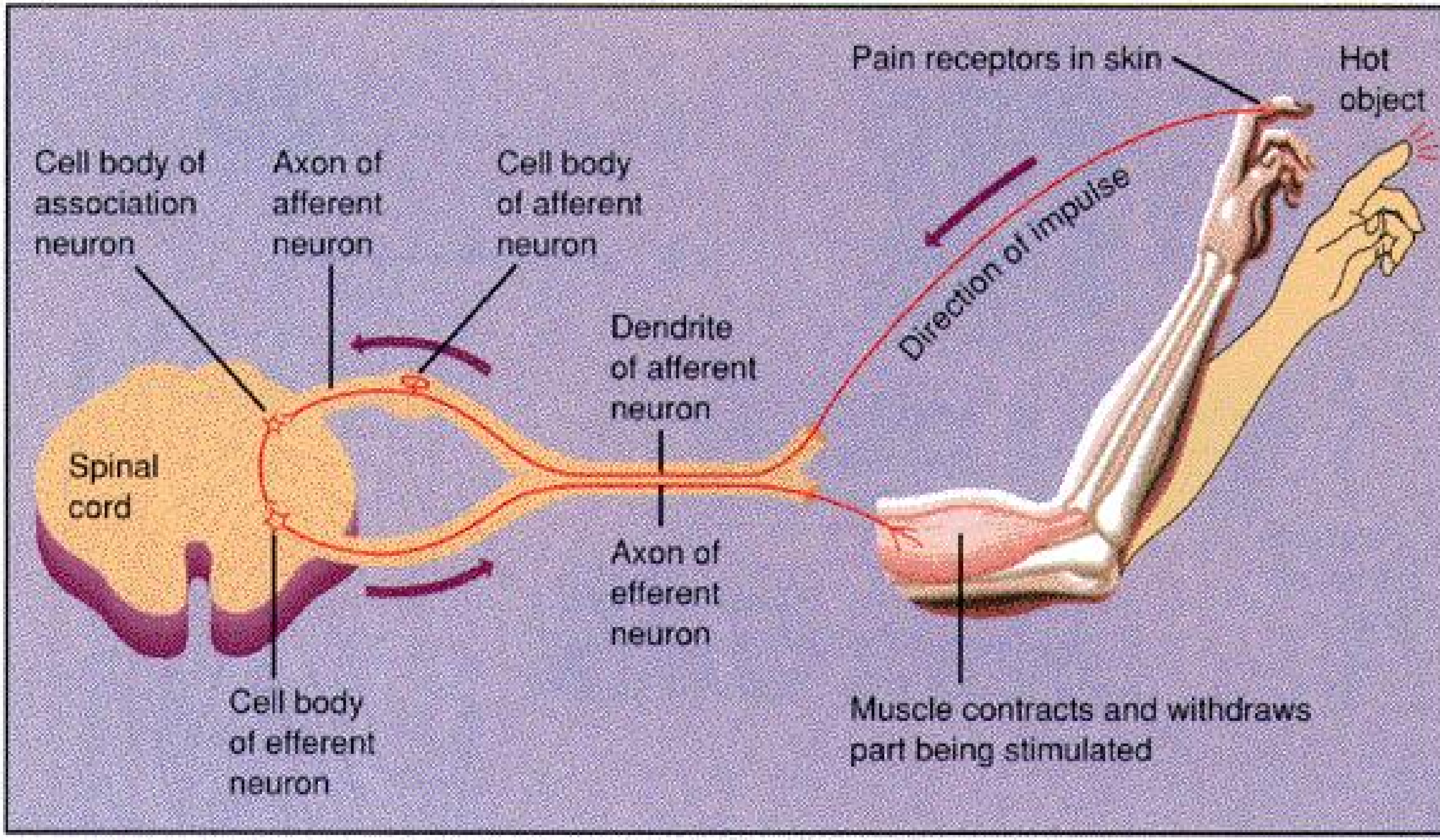

Low-pass Filter


High-pass Filter

Part II: Basic Neurophysiology

- Three basic units inside the brain
  - Glial cells
  - Extracellular space: not really space
  - The neuron
    - Three types:
      - Sensory
      - Motor
      - Interneuron

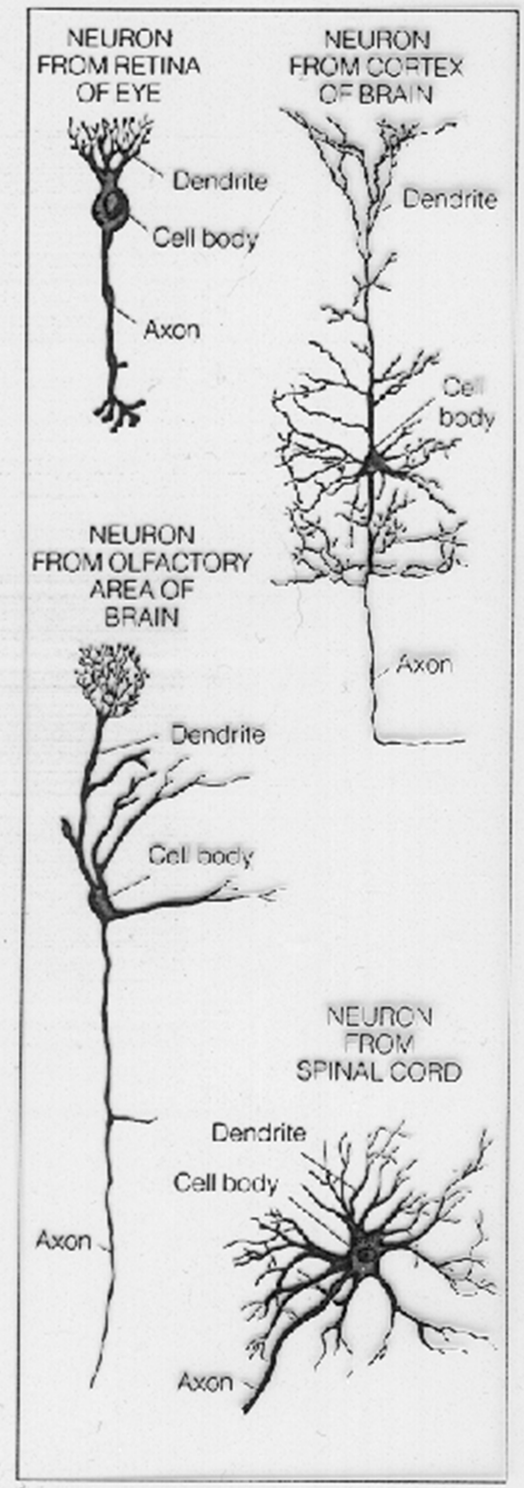
Withdrawal Reflex



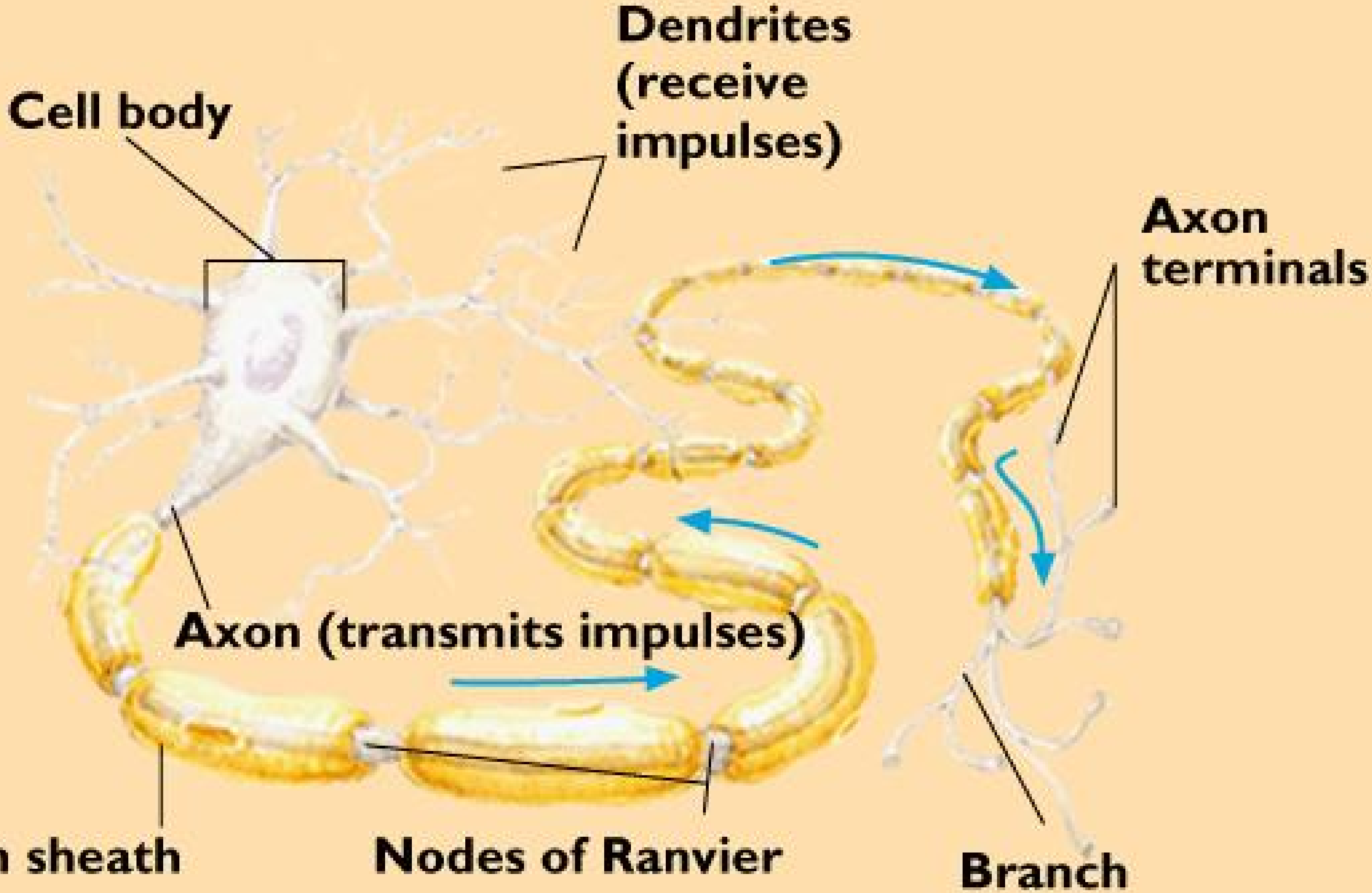
The Common Household Neuron

- Vary widely, but all have:
  - Cell body (soma)
  - Dendrites
  - Axon
    - Myelin sheath
    - Nodes of Ranvier
    - Microtubules
    - Terminal buttons (AKA synaptic knob)
- Nerve = a bundle of axons

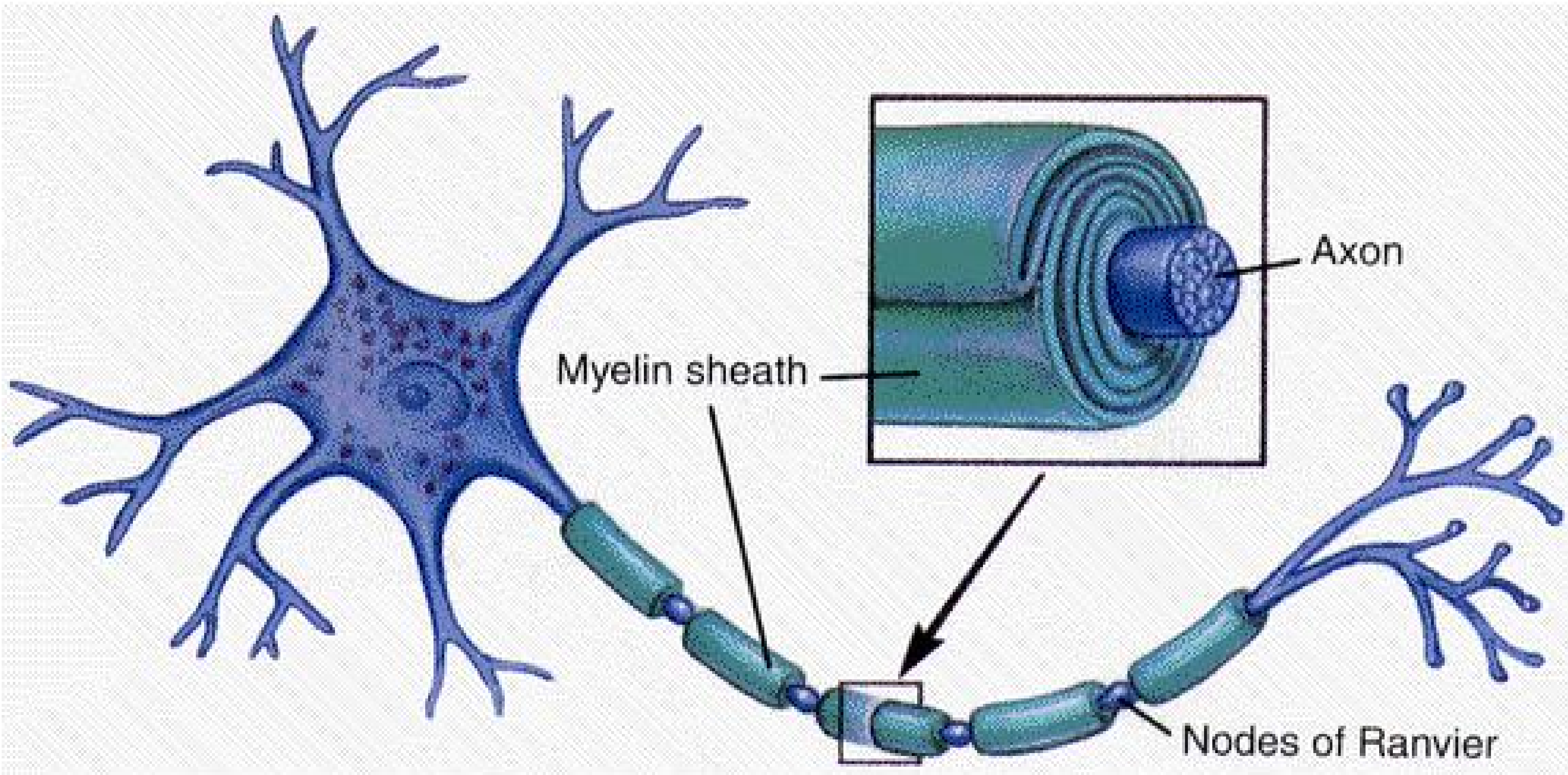
Jump to Next


NEURON
FROM RETINA
OF EYE
Dendrite
Cell body
Axon
NEURON
FROM CORTEX
OF BRAIN
Dendrite
Cell
body
Axon
NEURON
FROM OLFACTORY
AREA OF
BRAIN
Dendrite
Cell body
Axon
NEURON
FROM
SPINAL CORD
Dendrite
Cell body
Axon

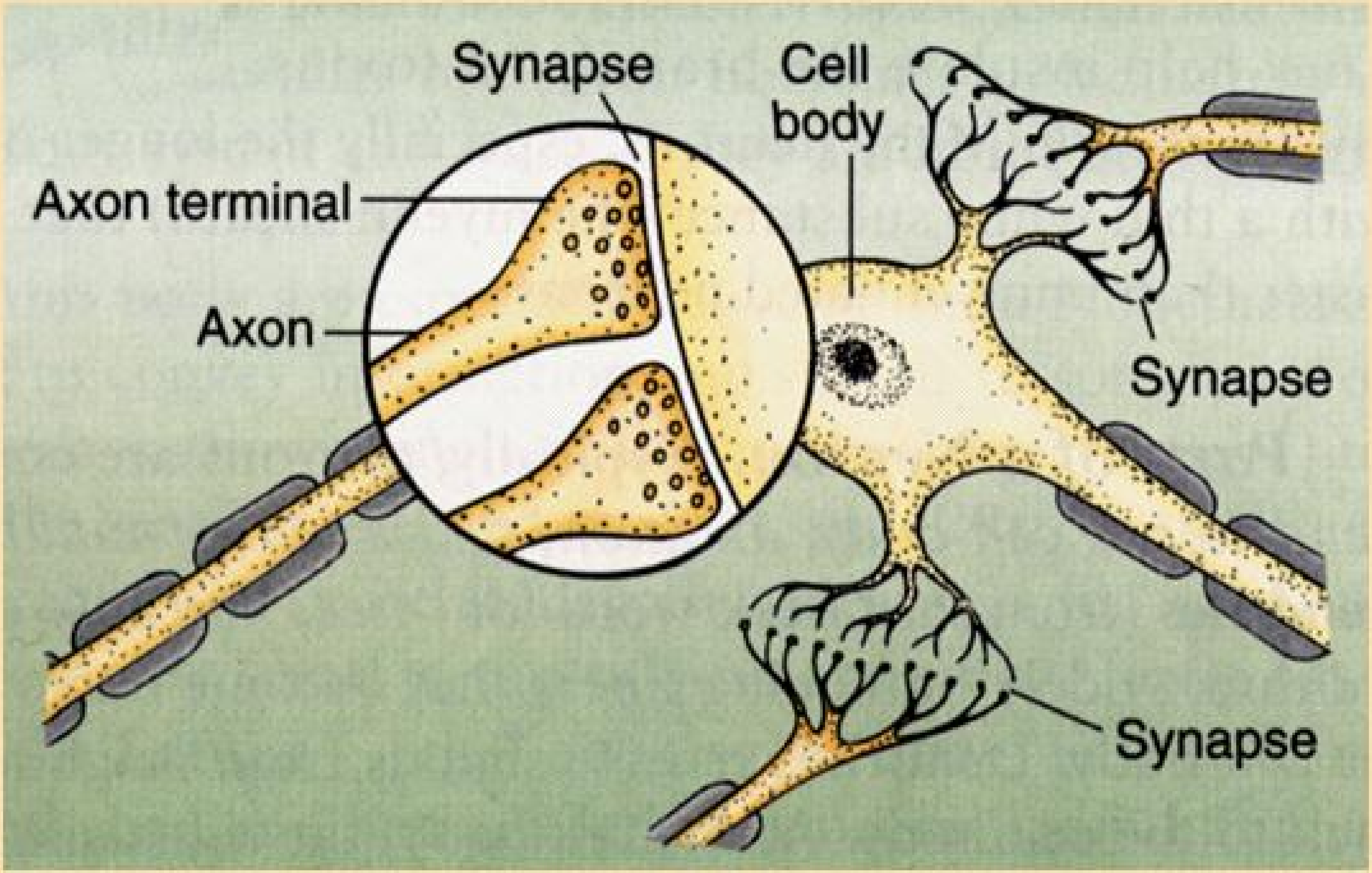
Neuron Structure



Myelin Sheath



The Synapse



Neural Communication

- Axonal Conduction (electro-chemical)
- Synaptic Transmission (chemico-eletrical)

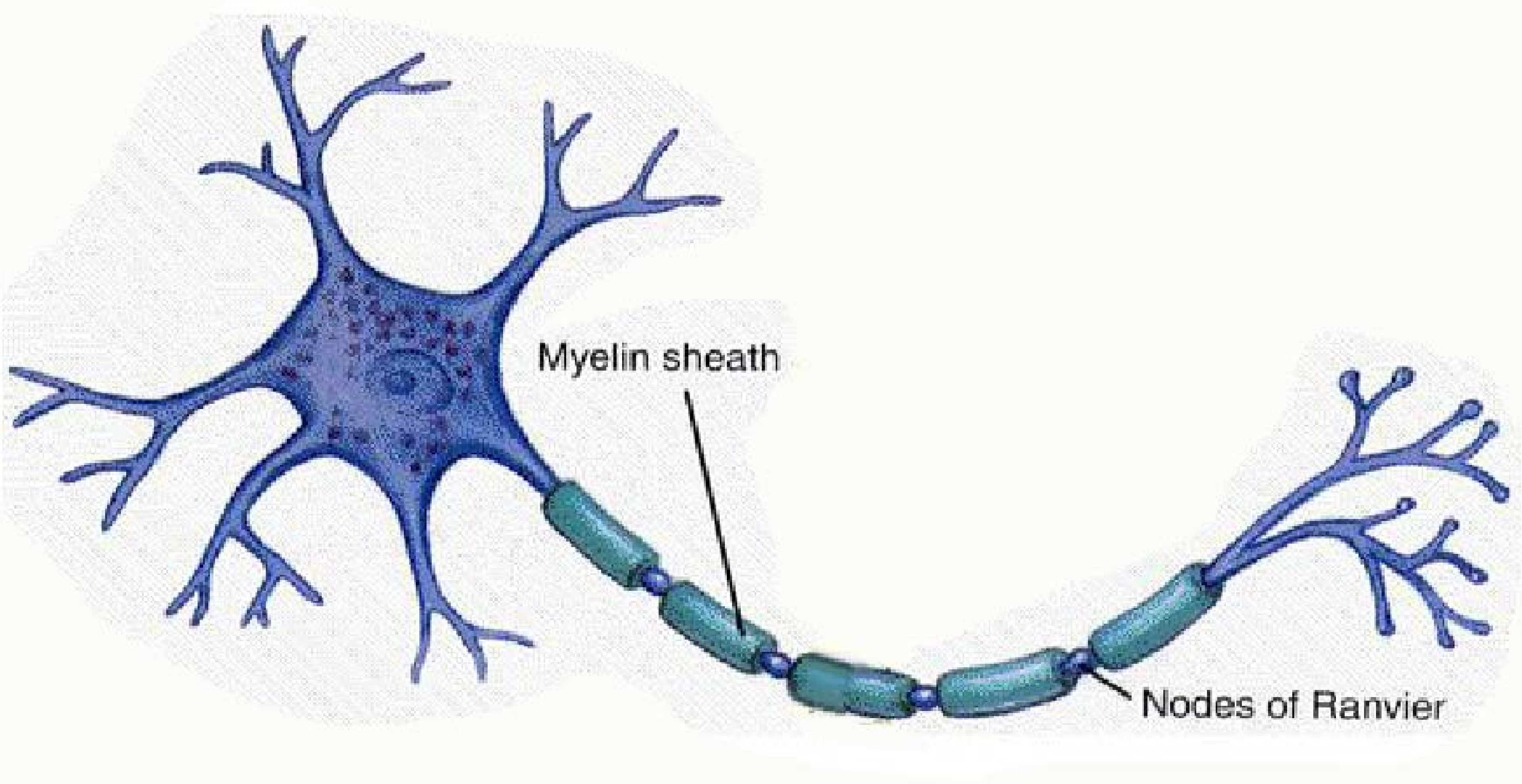
Axonal Conduction

- Resting potential
  - Inside of cell slightly negative
  - Two forces act upon these ions
    - Concentration gradient--osmotic force
    - Electromotive force
  - Equilibrium potential:
    - $E_{ion} = (R*T/z*F) * \ln(Conc_{Ex}/Conc_{In})$
    - where R is gas constant, T is temperature, z is ionic valence, and F is Faraday's constant.
  - The Hodgkin & Huxley Model

Axonal Conduction

- Depolarization
  - Threshold
  - Axon Hillock
  - Na ions rush in resulting in:
  - Action potential;
    - All or none phenomenon, high frequency
    - Afterpotentials; hyperpolarizing, depolarizing; slow frequency
    - Changes in membrane permeabilities
    - Propagation
- Refractory period

Jump to Next


Myelin sheath
Nodes of Ranvier

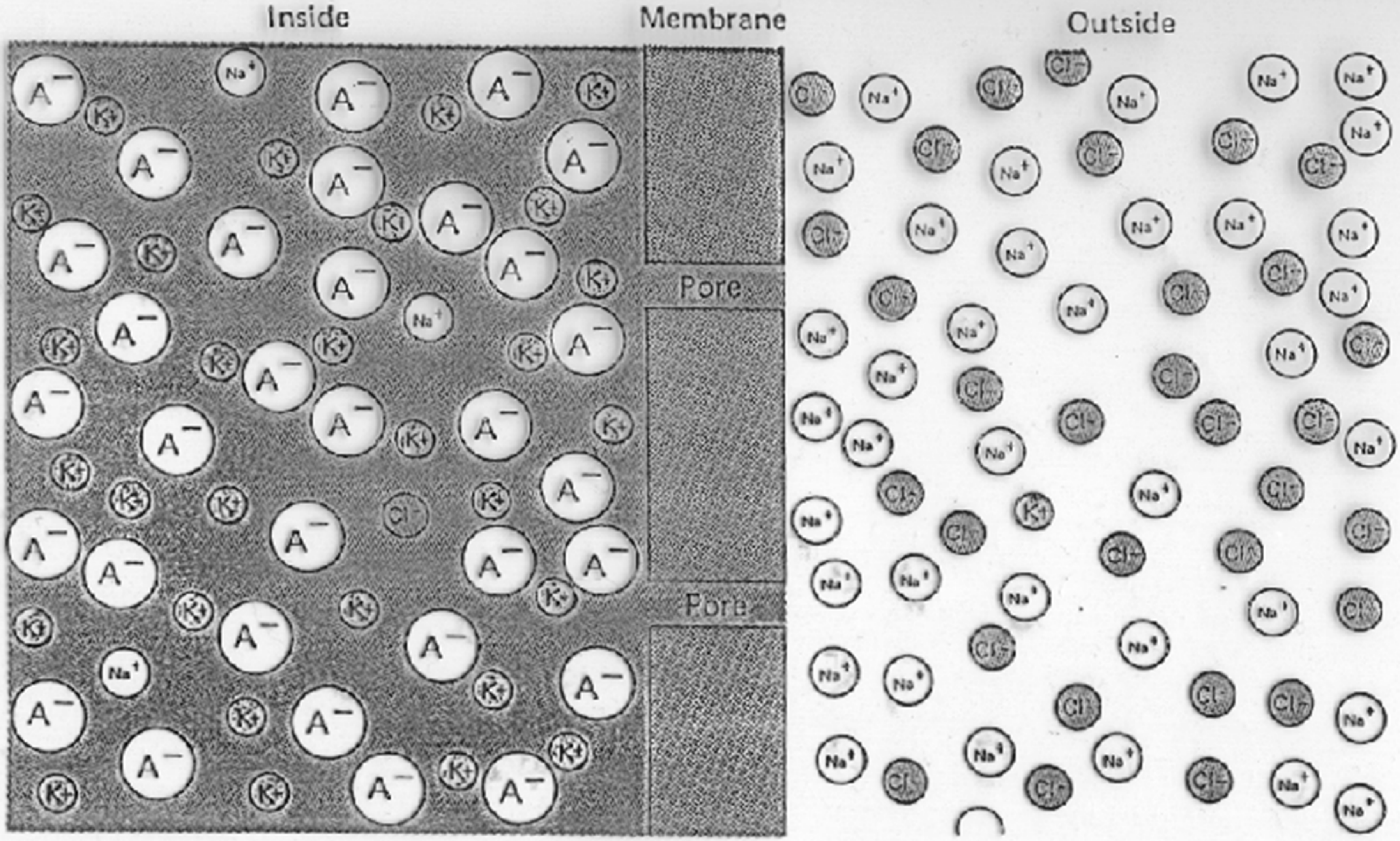
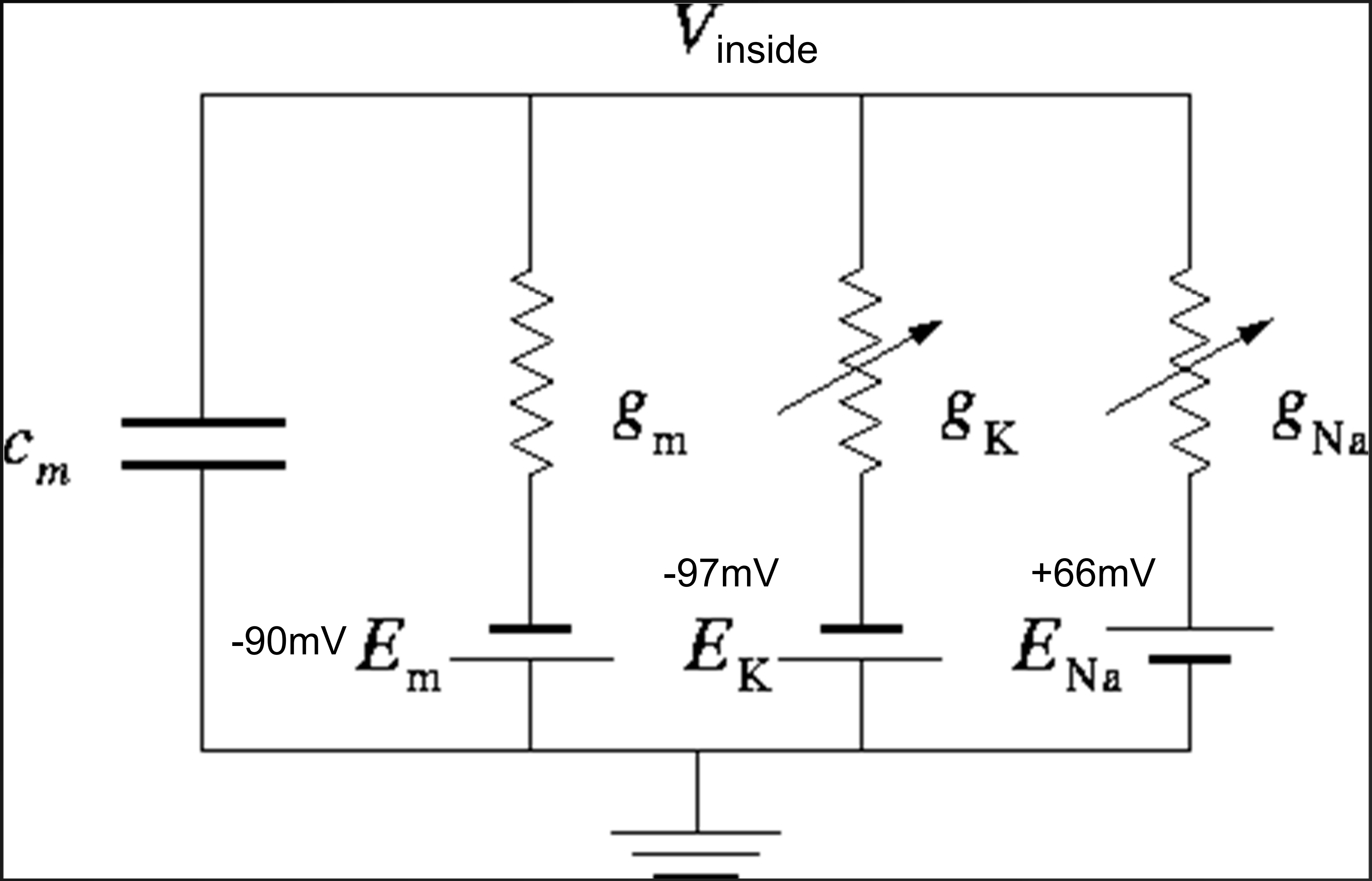
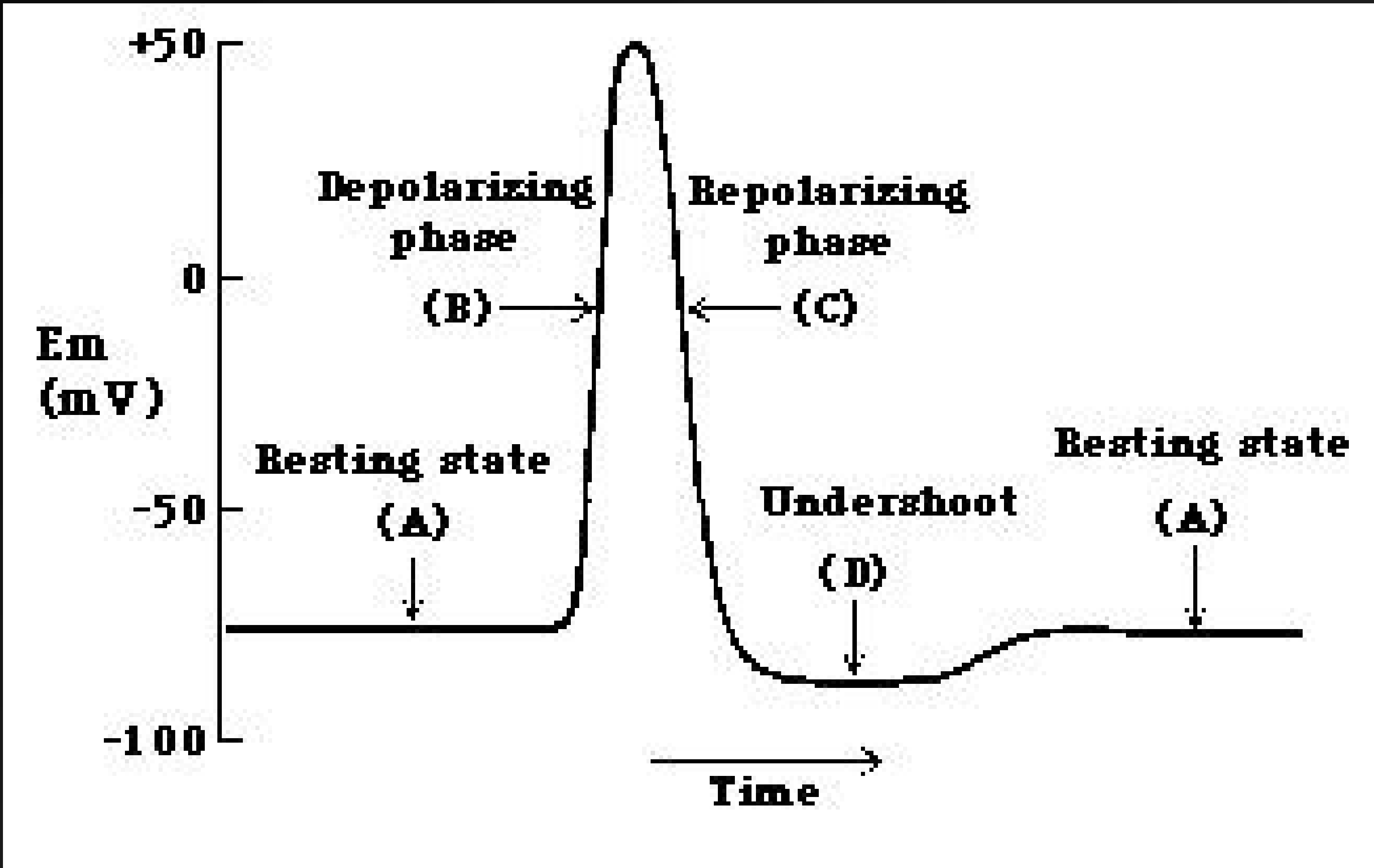


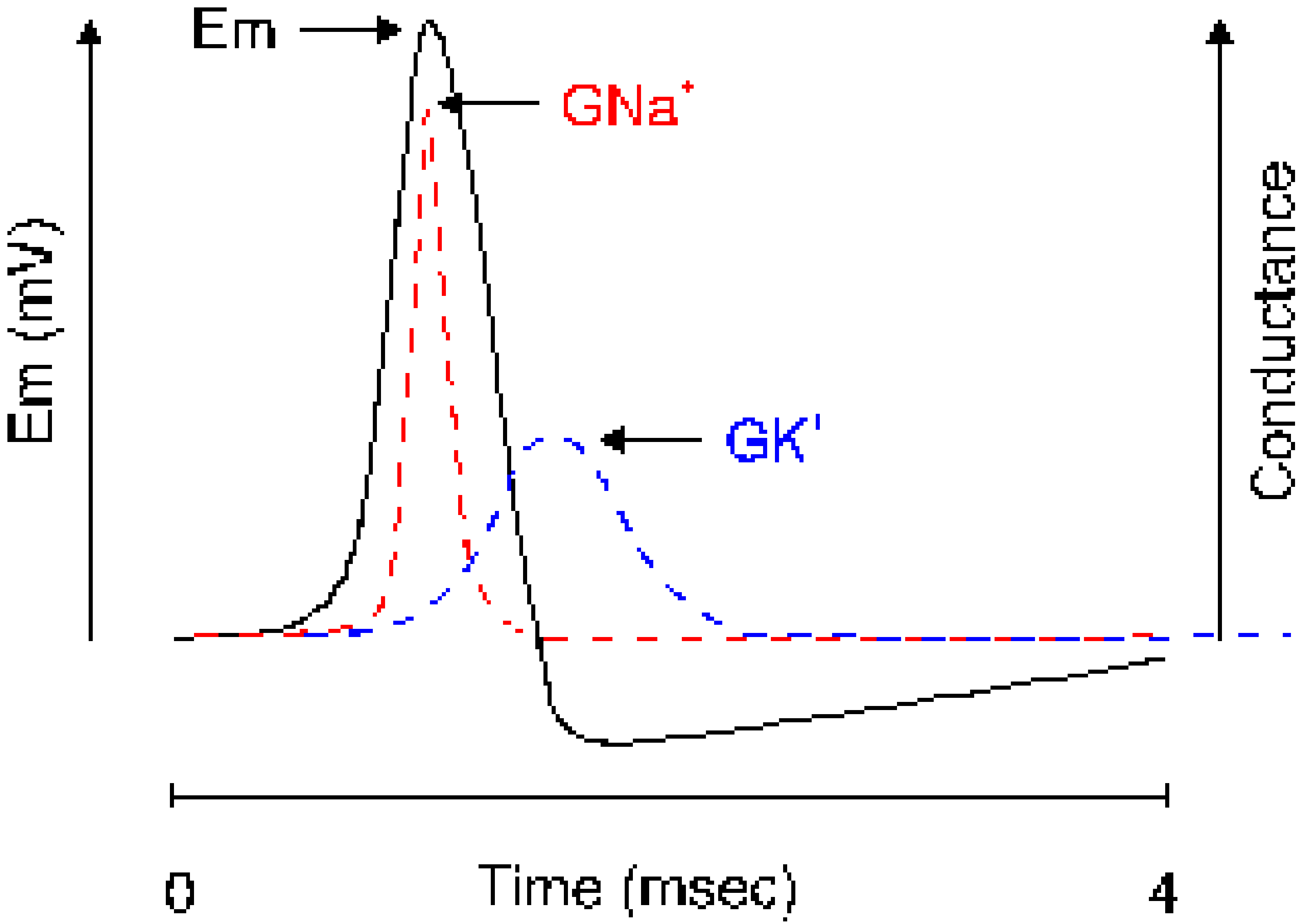
Fig. 2-3. Intra- and extracellular distribution of the ions. On both sides of the membrane, the different ions are indicated by *circles of different diameter*, proportional in each case to the diameter of the (hydrated) ion. A^- designates the large intracellular protein anions. The passages through the membrane, the "pores," are just large enough to permit the K^+ ions to diffuse through.



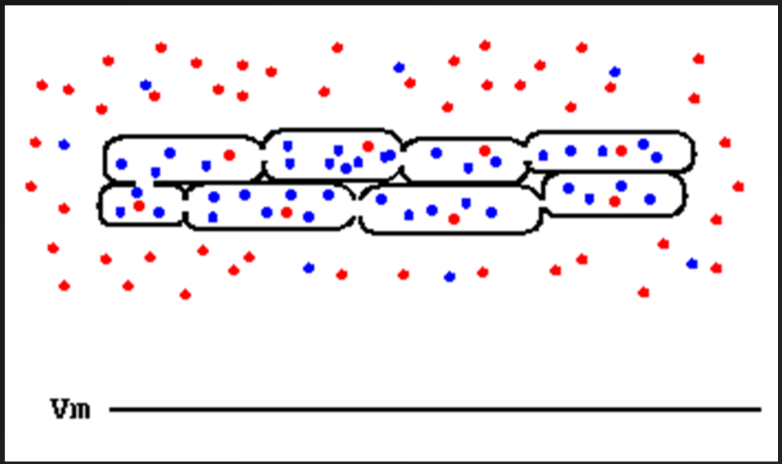
For interactive link: http://ssd1.bme.memphis.edu/icell/squid.htm



+50
0
-50
-100
Em
(mV)
Depolarizing
phase
(B)
Repolarizing
phase
(C)
Resting state
(A)
Undershoot
(D)
Resting state
(A)
Time

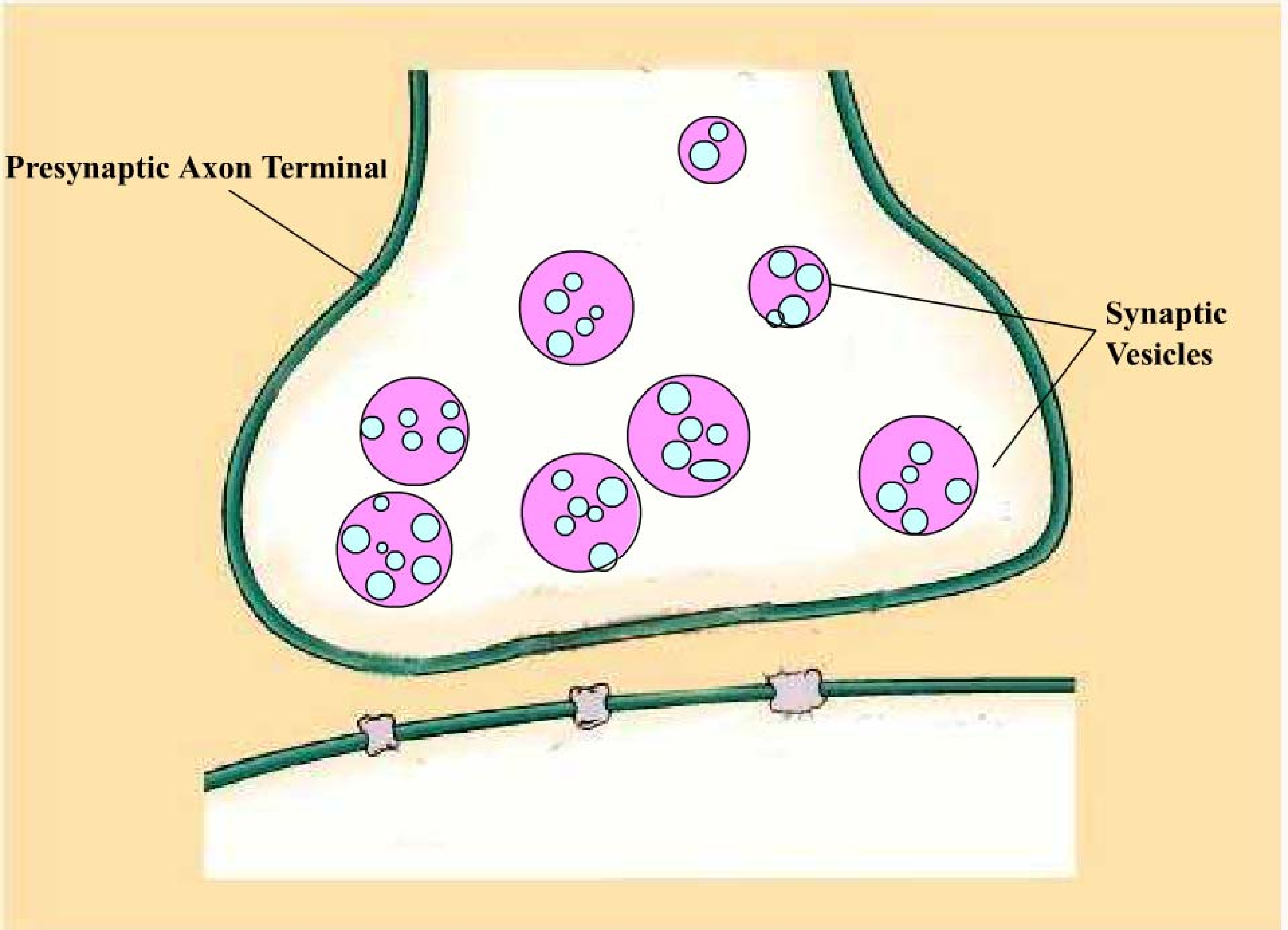


Em
GNa+
GK+
Em (mV)
Conductance
0
Time (msec)
4


Vm

Synaptic Transmission

- Not an all-or-none phenomenon
- Synaptic gap or cleft at the synaptic junction
- Single axon splits near end--**terminal arborization**
- As action potential arrives
  - Synaptic vesicles migrate to cell membrane fuse and release
  - Neurotransmitters diffuse across the synaptic cleft
  - combine with **post-synaptic receptors**
  - When neurotransmitter binds to a receptor on the post-synaptic cell, a slow electrical potential (**post-synaptic potential**) is generated:
  - 5 to 20 mV at peak amplitude
  - 20-150 msec in duration (50 to 6 Hz)



Presynaptic Axon Terminal
Synaptic
Vesicles

Synaptic Transmission

- Post-synaptic potentials (PSP's);
  - Excitatory
  - Inhibitory
  - Interaction
- **Summation/Integration**
  - **temporal**
  - **spatial**
  - **decremental conduction** on dendrites and soma
  - axon hillock is critical area at which threshold must be reached
- After release of neurotransmitter,
  - reuptake
  - degradation
- **Functional Synaptic Units**

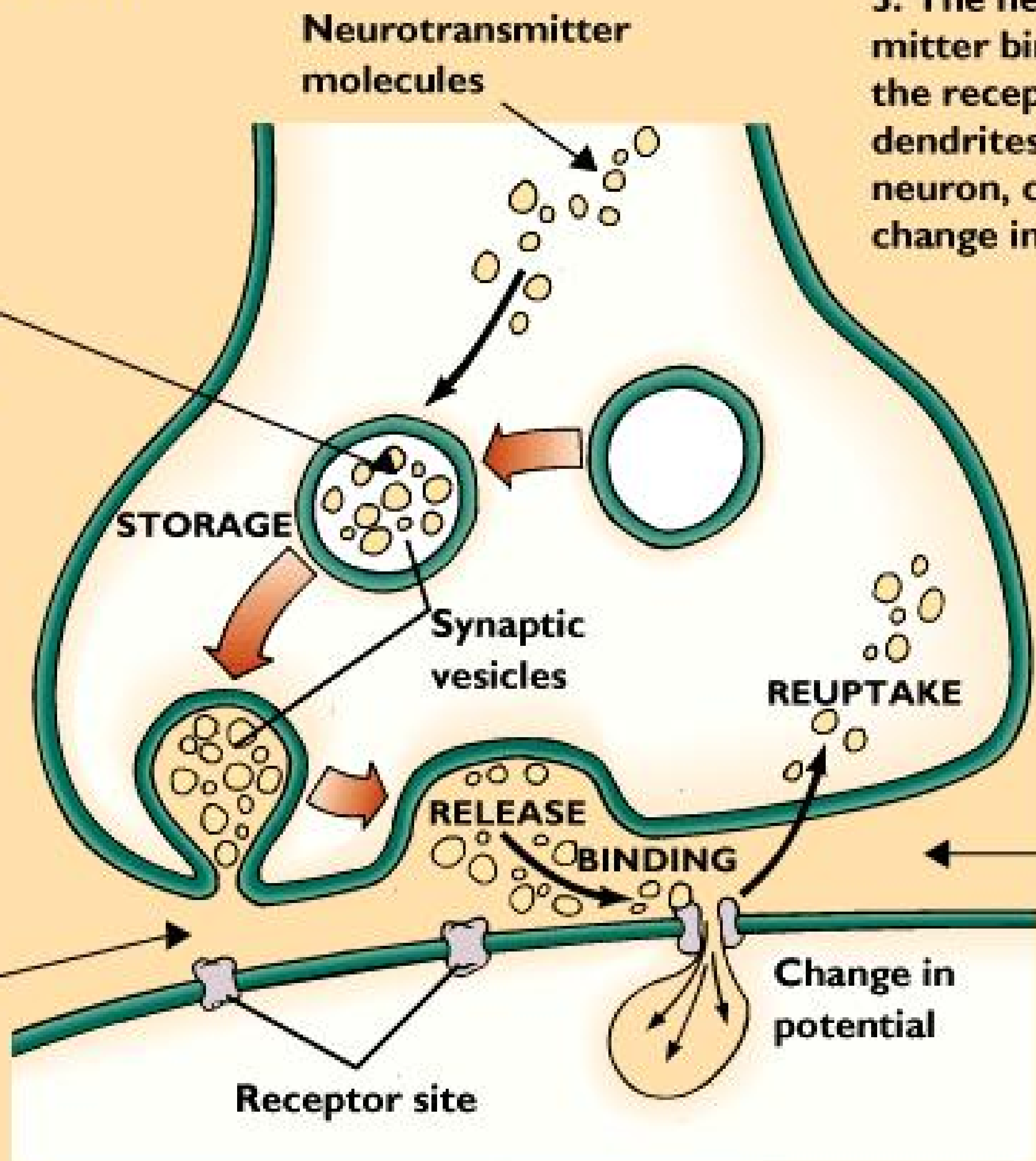
Jump to Next

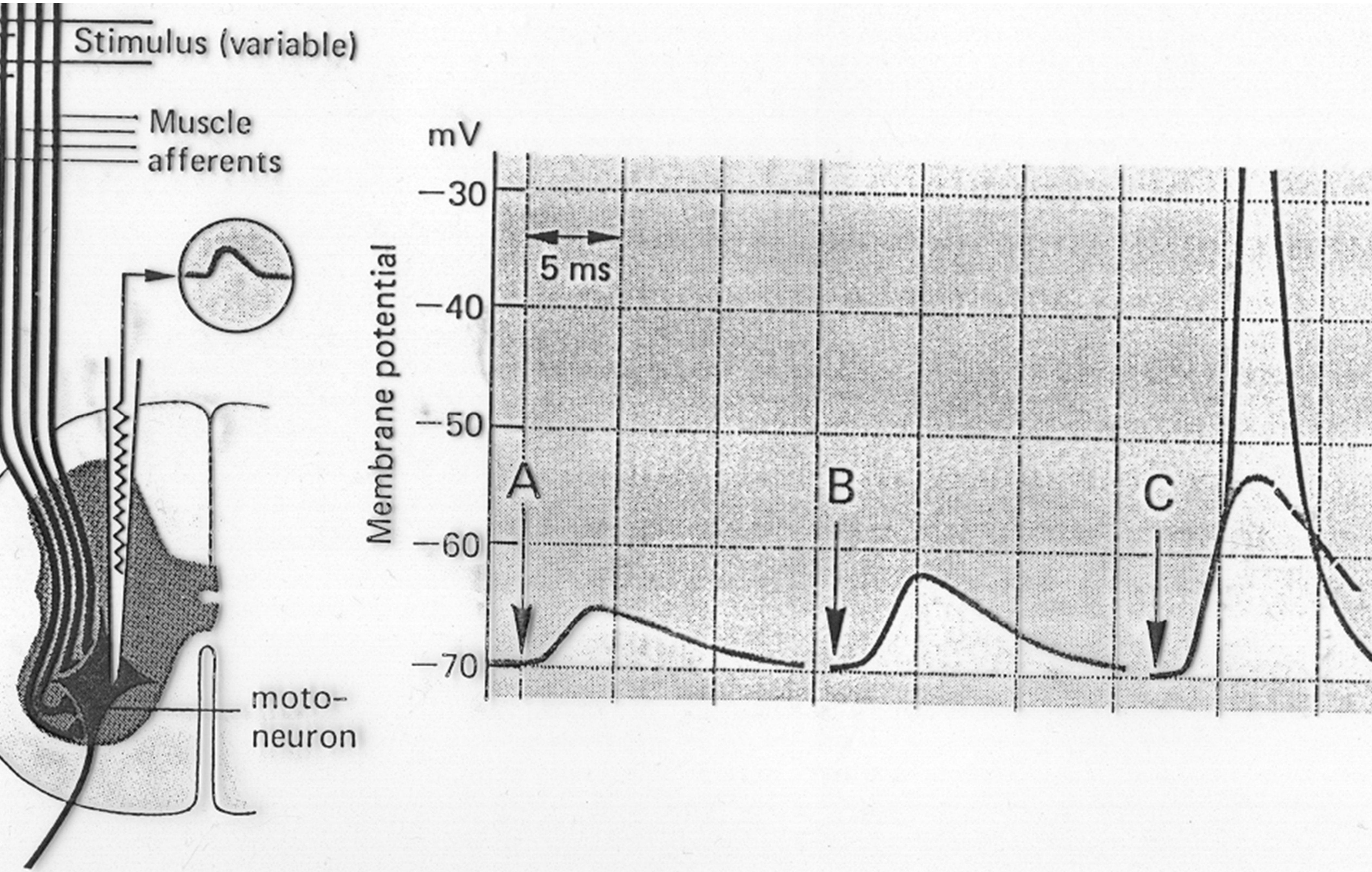
Synaptic Transmission

1. Within the axons of the neuron are neurotransmitters, which are held in storage-like vesicles until they are released when the neuron is stimulated.

2. The small space between the axon terminal and the dendrite of the next axon is called the synapse. An action potential stimulates the release of neurotransmitters across the synapse.

3. The neurotransmitter binds itself to the receptor sites on dendrites of the next neuron, causing a change in potential.





3-10. Excitatory postsynaptic potentials, recorded intracellularly from a moto
Afferents in the peripheral nerve from the associated muscle are stimulated el

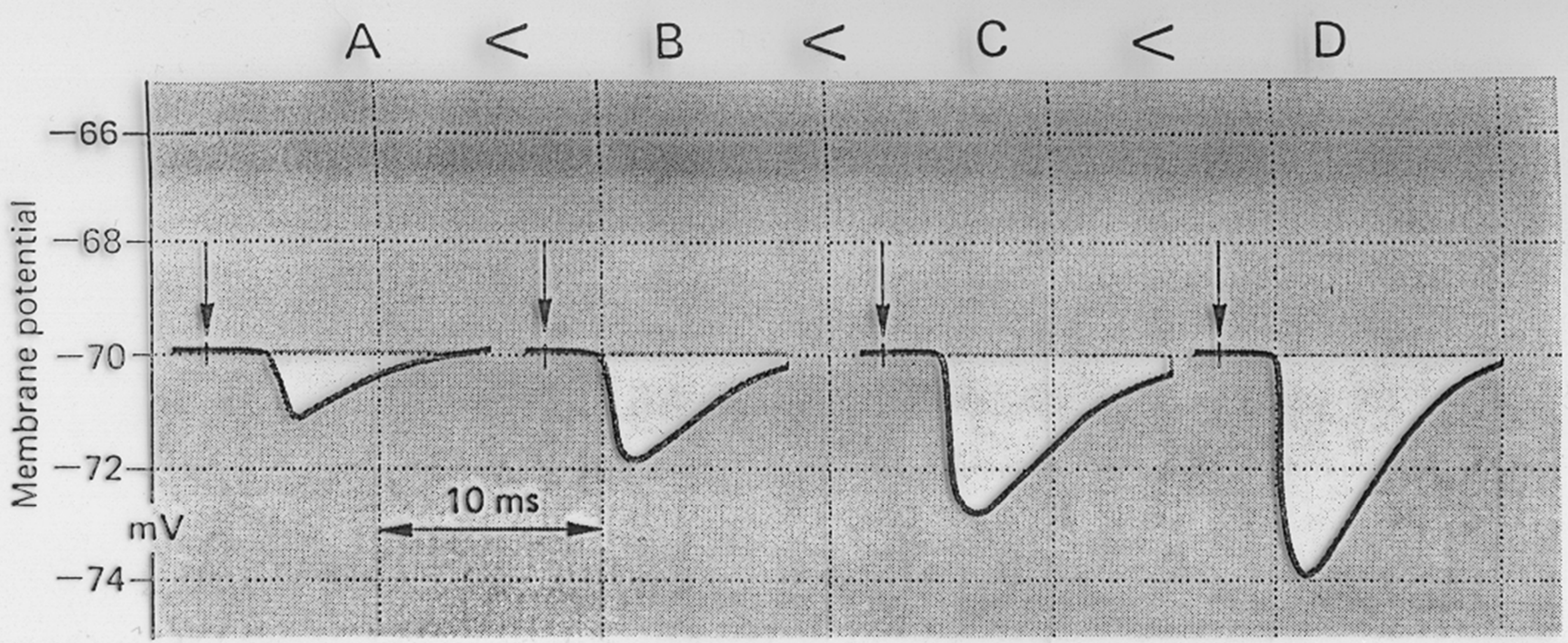


Fig. 3-11. Inhibitory postsynaptic potentials. Experimental arrangement as in Fig. 3-10, except that here an antagonist nerve is stimulated.

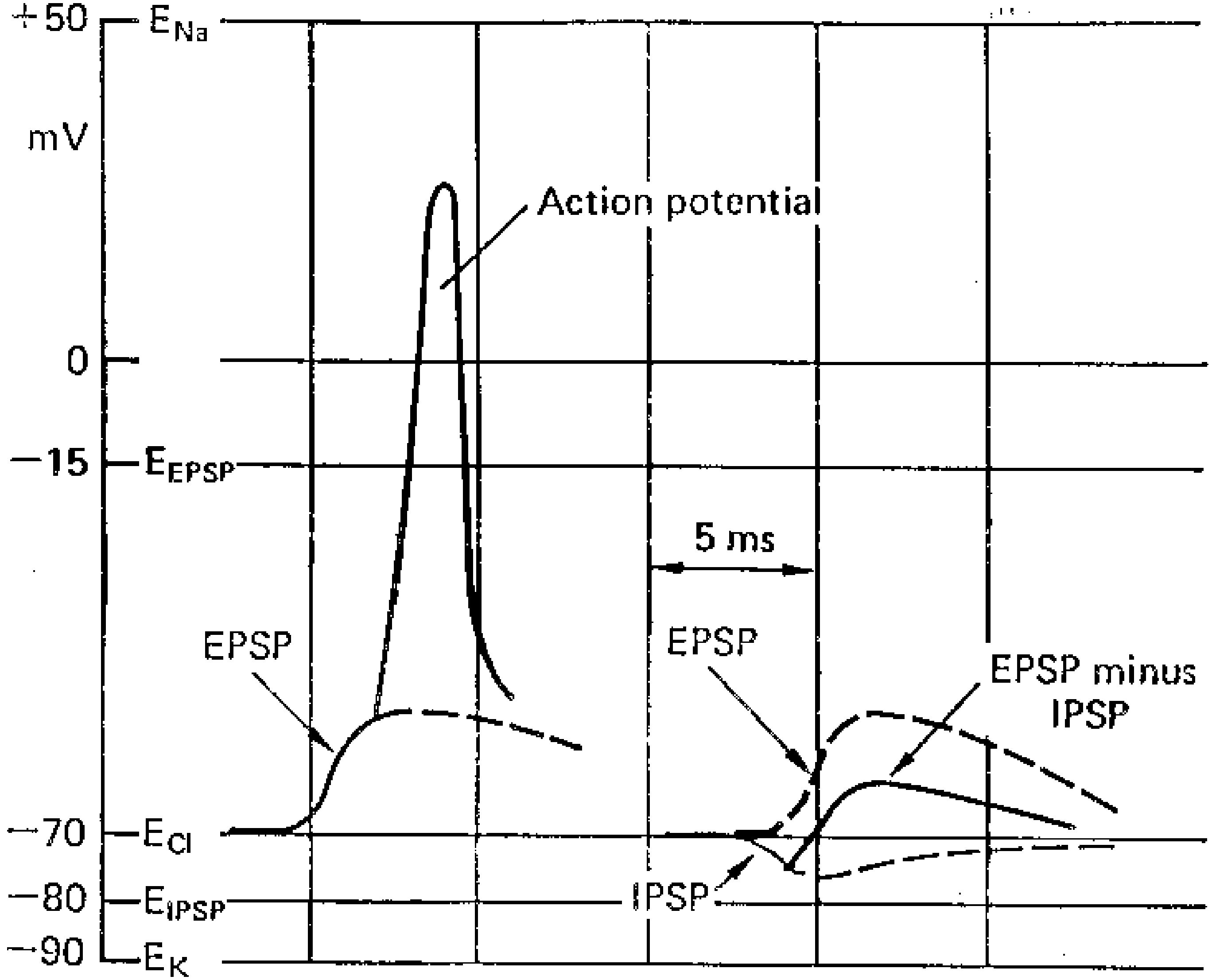
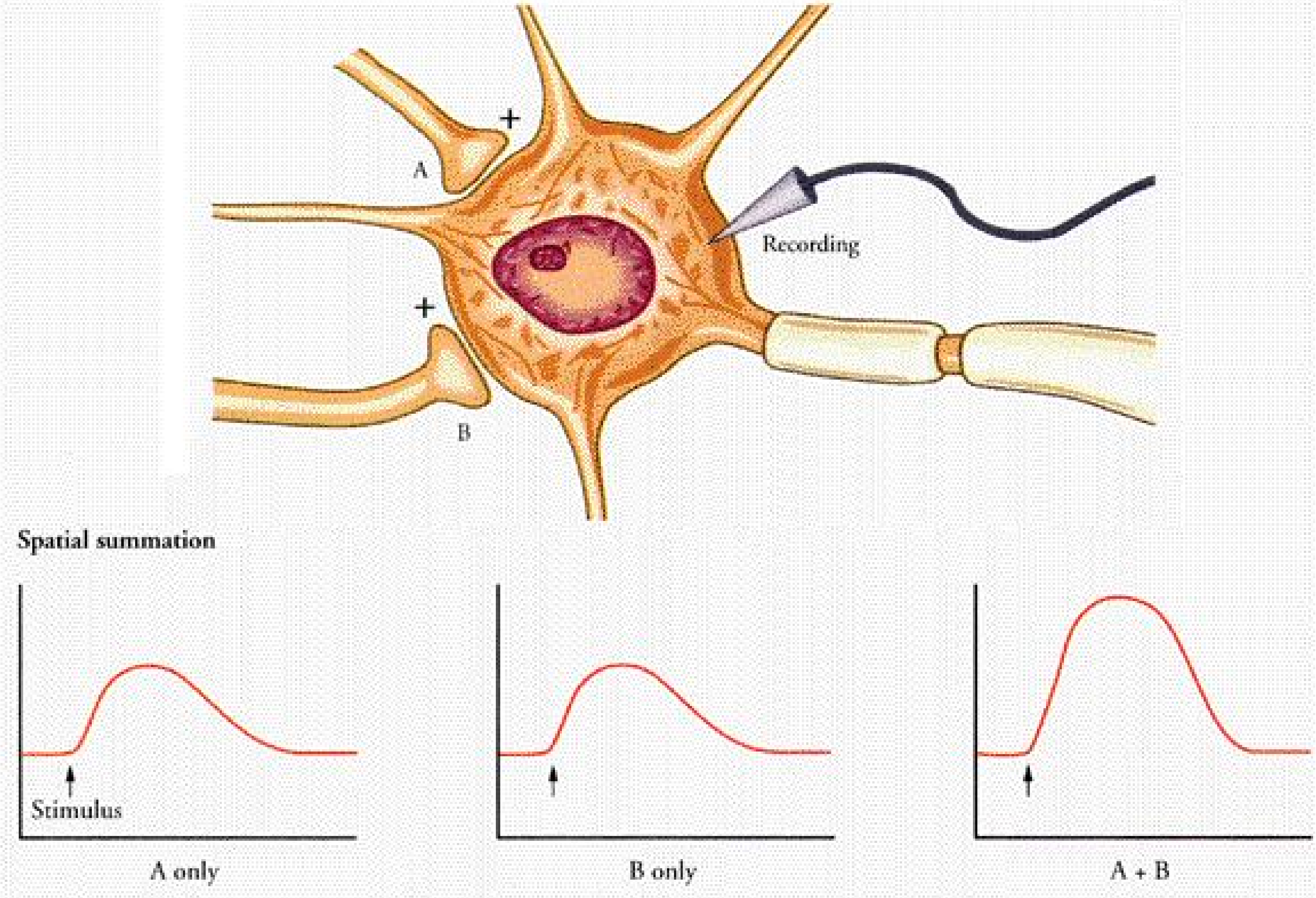


Fig. 3-14. The effect of an IPSP on the action potential; experimental arrangement as in Fig. 3-13. The homonymous nerve is stimulated strongly enough to produce a suprathreshold EPSP (*left*). On the *right*, the antagonist nerve is stimulated about 3 ms before the homonymous nerve. The equilibrium potentials of Na^+, K^+, Cl^-, EPSP, and IPSP are shown.

Spatial Summation. Figure 5.11



Temporal Summation. Figure 5.11