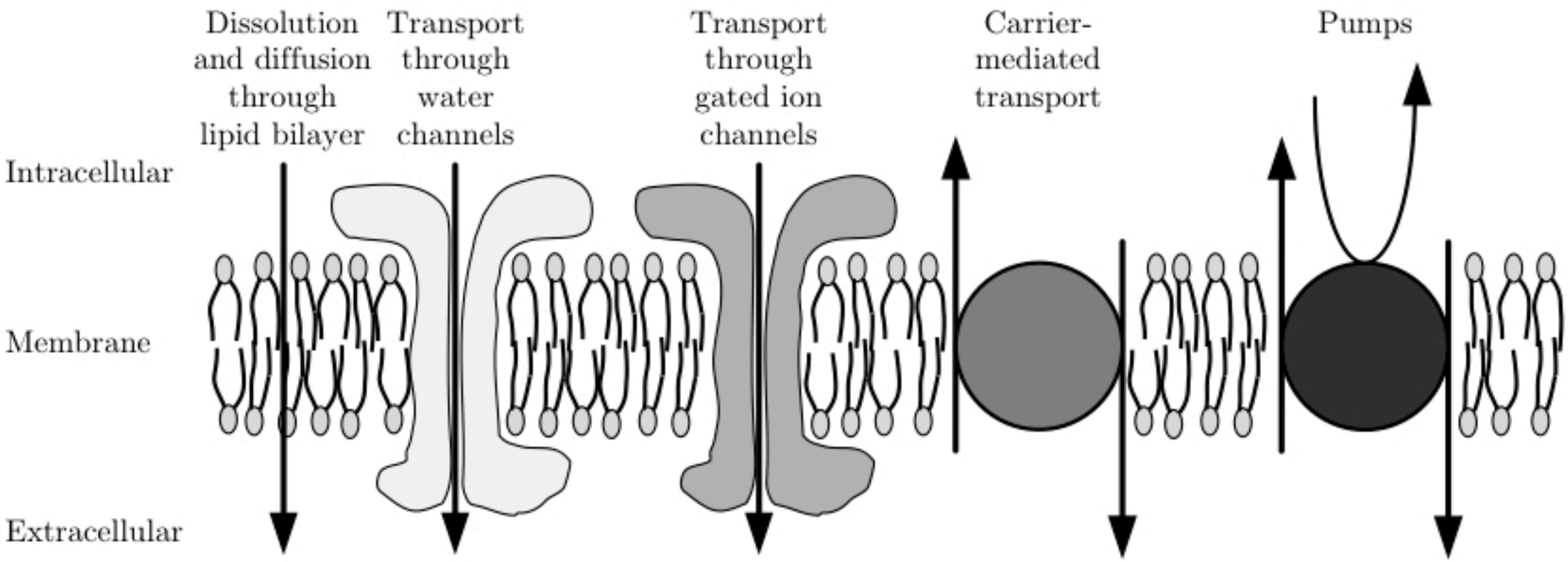
Biophysics I (BPHS 4080)

Instructors: Prof. Christopher Bergevin (cberge@yorku.ca)

Website: http://www.yorku.ca/cberge/4080W2018.html

York University
Winter 2018
Lecture 10

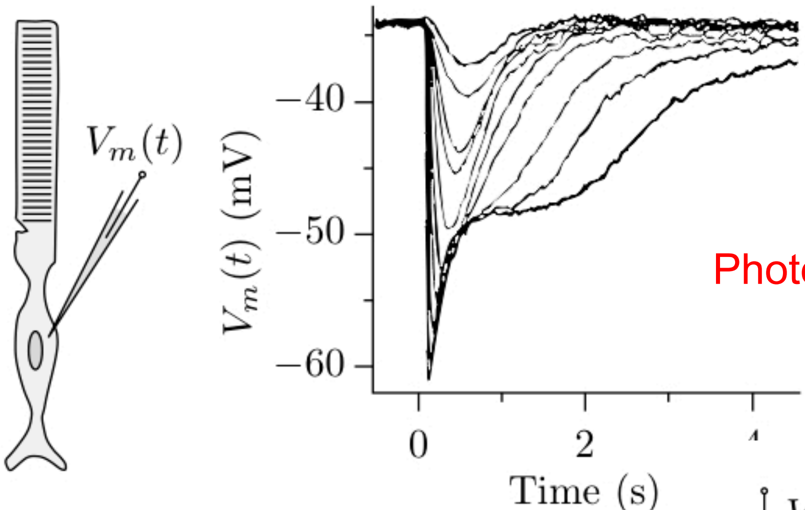
Reference/Acknowledgement:
- TF Weiss (Cellular Biophysics)
- D Freeman



Dissolution and diffusion through lipid bilayer
Transport through water channels
Transport through gated ion channels
Carrier-mediated transport
Pumps
Intracellular
Membrane
Extracellular

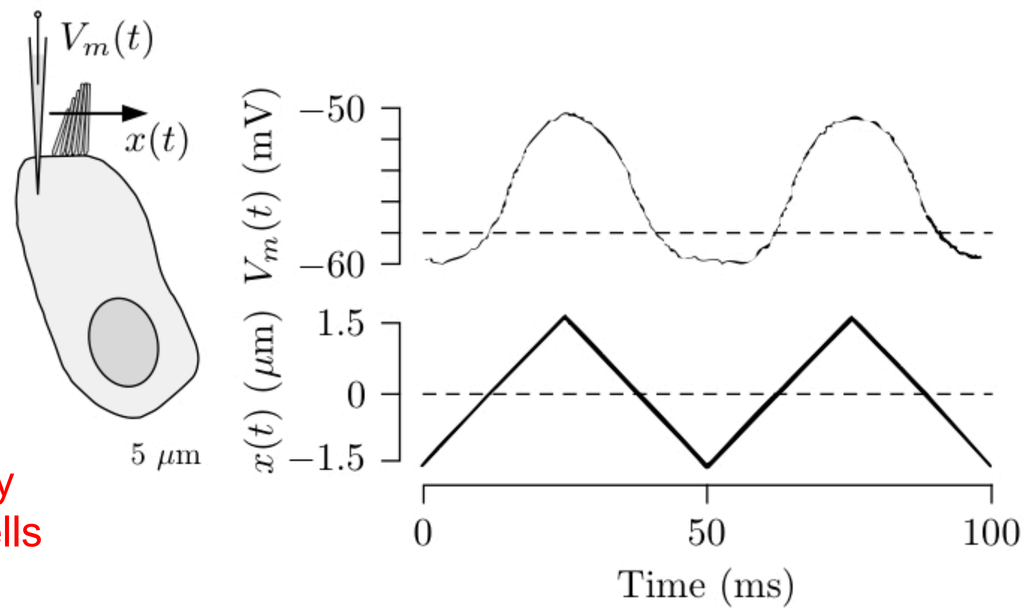
Figure 2.19

Electrical Responses in the Sensory Systems



Photoreceptors

Figure 1.3



Auditory
Hair Cells

Figure 1.5

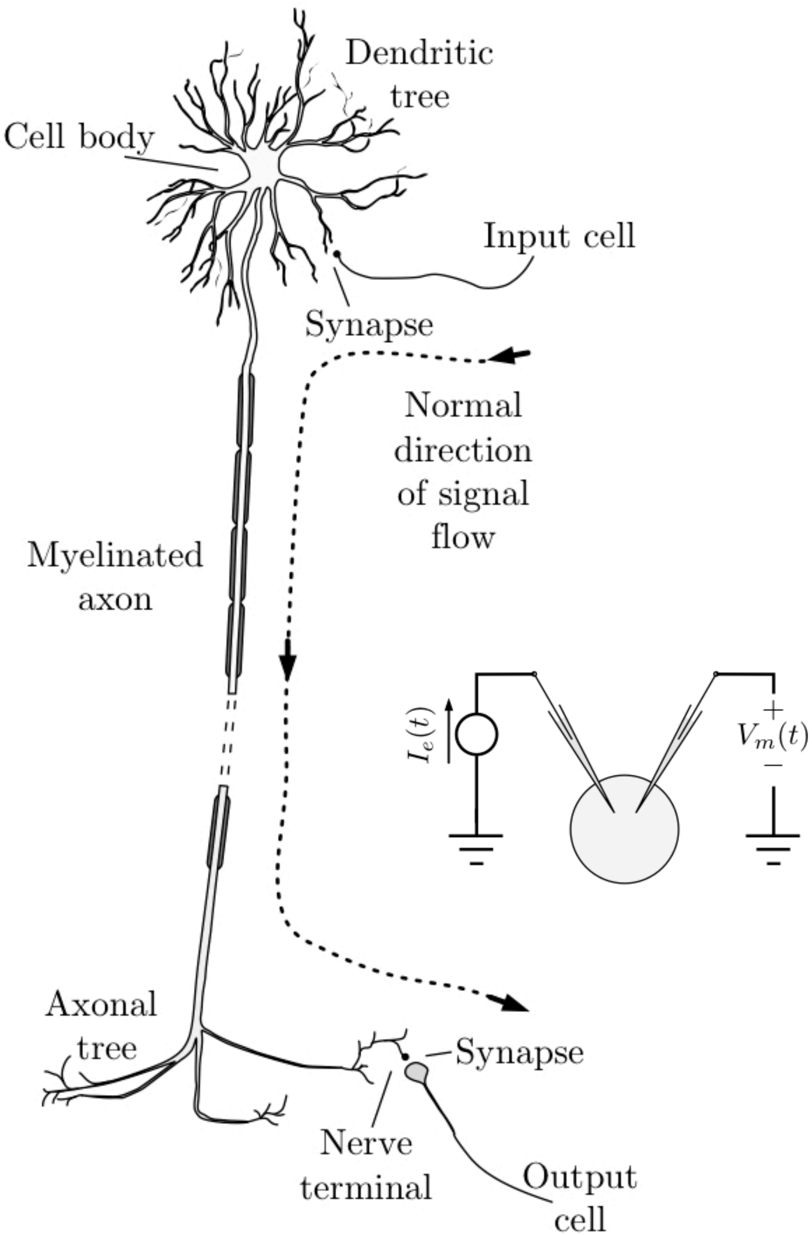


Figure 1.22

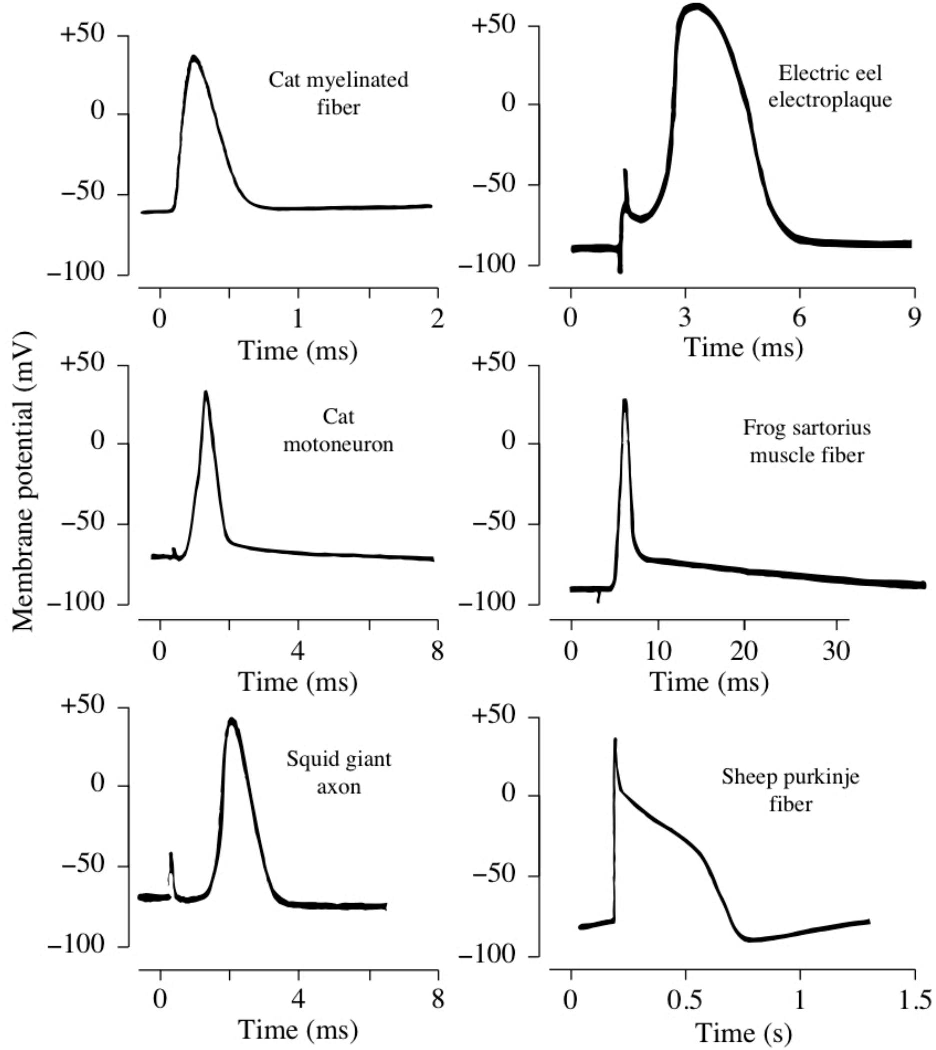
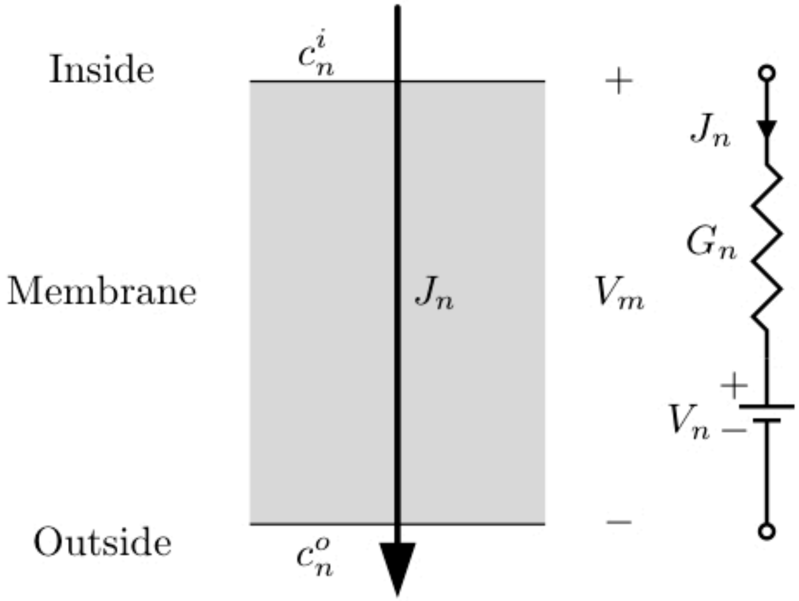


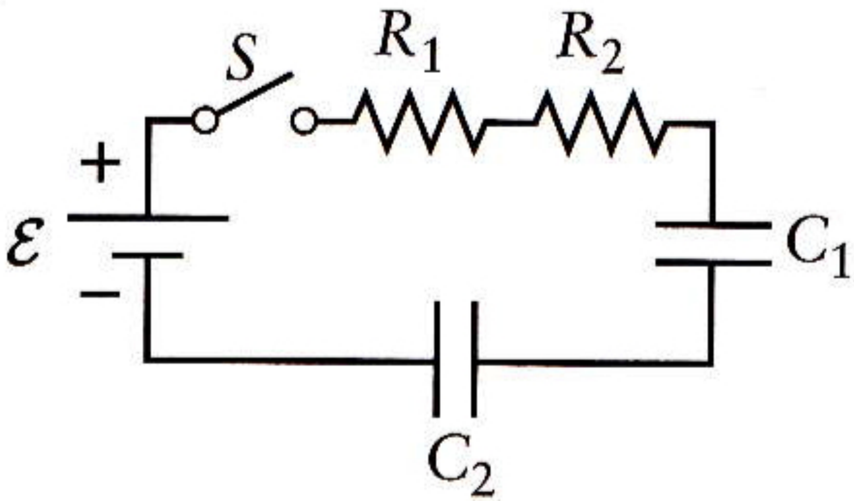
Figure 1.9

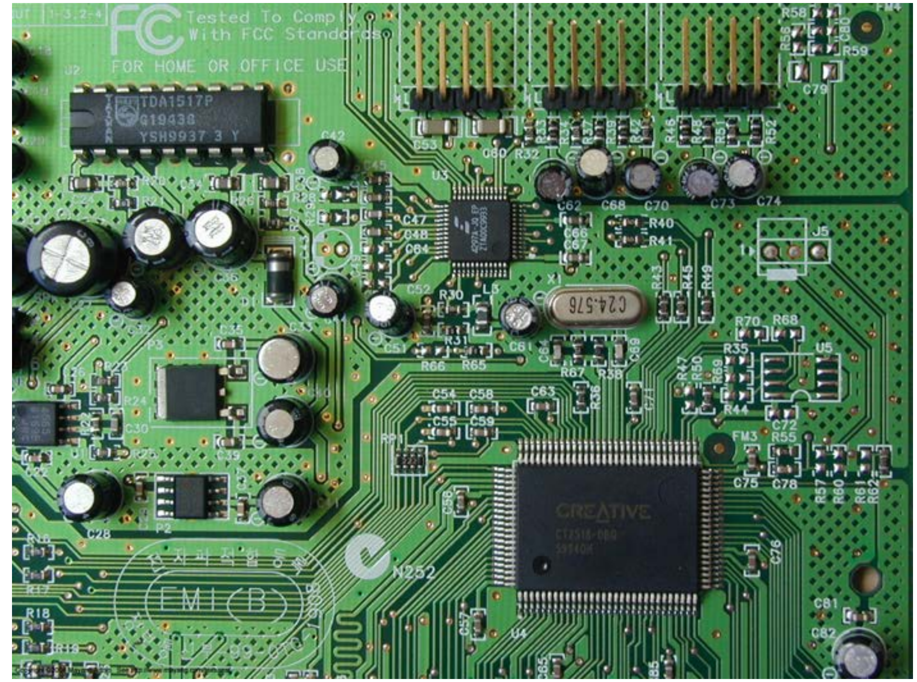
→ Electrical properties of cells are important!

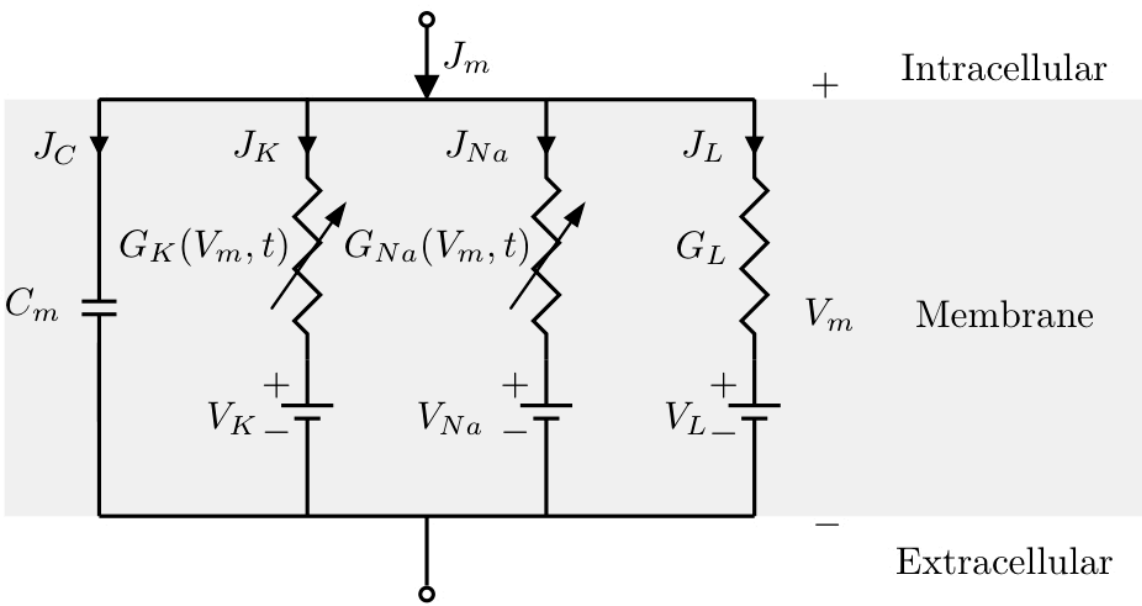
Model of Steady-State Electrodiffusion through Membranes



→ Now we will consider the effect of solutes having charge


S
R1
R2
+
ℰ
−
C1
C2


Tested To Comply
With FCC Standards
FOR HOME OR OFFICE USE
TDA1517P
CREATIVE


J_m
Intracellular
+
J_C
J_K
J_{Na}
J_L
$G_K(V_m, t)$
$G_{Na}(V_m, t)$
G_L
C_m
V_m
Membrane
V_K
V_{Na}
V_L
−
Extracellular

Basic E&M Review (well, the E part....)

- Charge

- Electric Potential (i.e., voltage)

- Circuit Elements: resistors, conductors, inductors, batteries, etc....

- Circuit Basics (e.g., Kirchoff’ s laws)

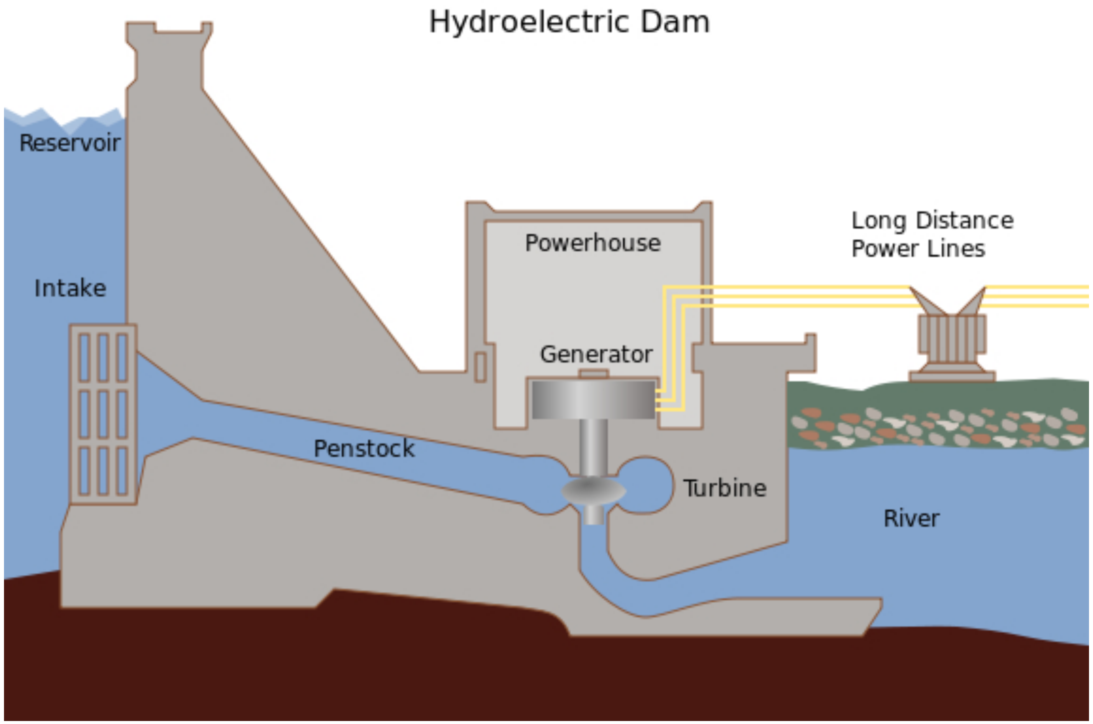
- RLC circuit

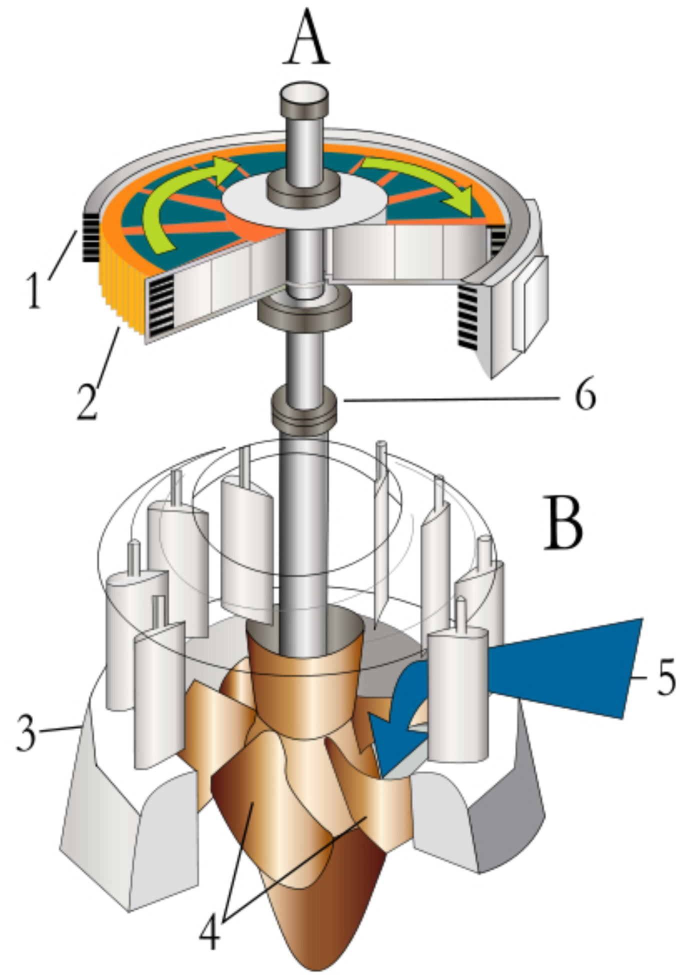
Duality here! River water has:

1. Kinetic energy (due to flow)

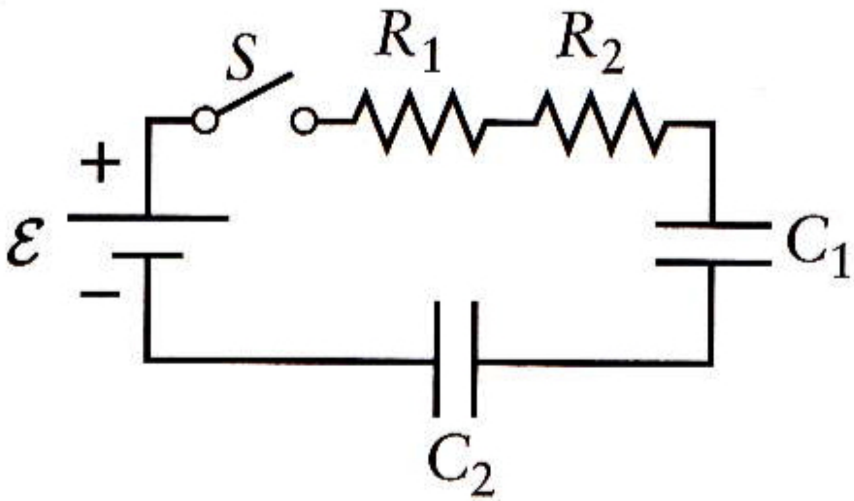
2. Potential energy (due to gravity)

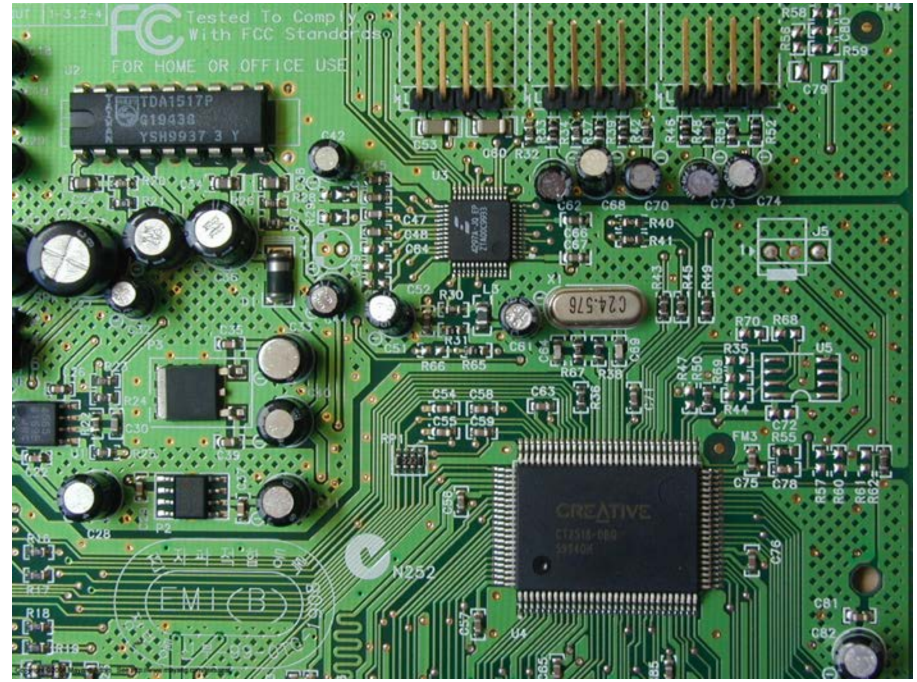
Question: What's the 'battery'?

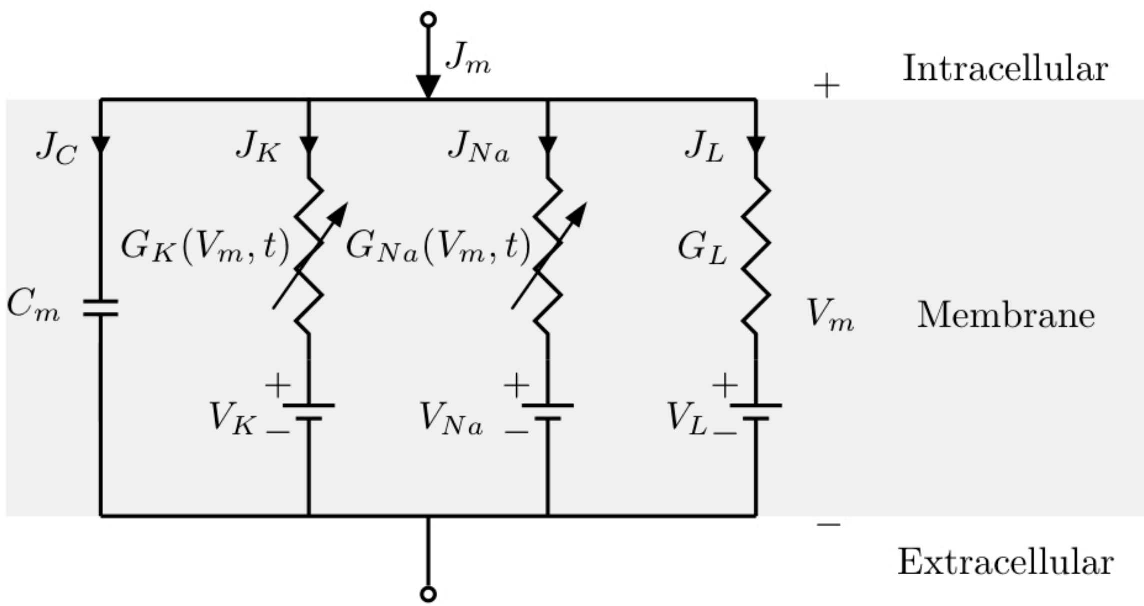

Hydroelectric Dam
Reservoir
Intake
Powerhouse
Long Distance
Power Lines
Generator
Penstock
Turbine
River


A
B
1
2
3
4
5
6

Wikipedi


S
R1
R2
+
ℰ
−
C1
C2


Tested To Comply
With FCC Standards
FOR HOME OR OFFICE USE
TDA1517P
CREATIVE


Jm
Intracellular
+
JC
JK
JNa
JL
GK(Vm, t)
GNa(Vm, t)
GL
Cm
Vm
Membrane
VK
VNa
VL
−
Extracellular

Basic E&M Review (well, the E part....)

- Circuit Basics (e.g., Kirchoff' s laws)

Junction rule
(conservation of charge)

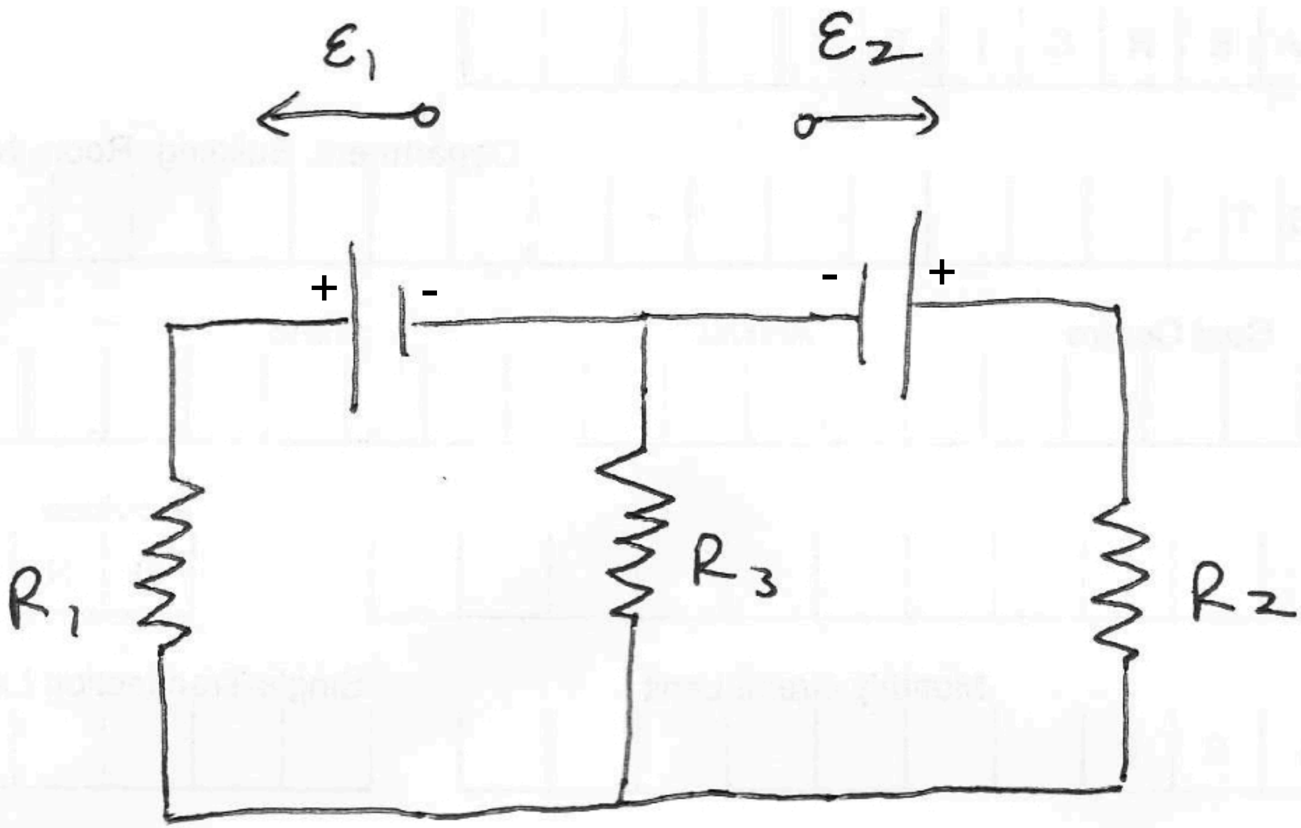
$$\sum_n I_{in}^n = \sum_n I_{out}^n$$

Loop rule
(conservation of energy)

$$\Delta V_{loop} = \sum_n \Delta V^n = 0$$

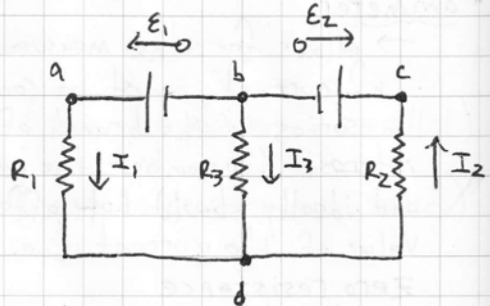
Review

Using Kirchoff's Laws, find the current through each of the three resistors



Kirchoff's Laws

[ex] Use the ~~[illegible]~~ to determine the currents I_1, I_2 and I_3



NOTE: we arbitrarily chose the direction of the currents. This provides a reference and the ultimate direction of the current should correctly emerge from our solution

make sure to correctly keep track of your chosen ref. direction!

Left loop: $\varepsilon_1 - I_1 R_1 + I_3 R_3 = 0$

Right loop: $-I_3 R_3 - I_2 R_2 - \varepsilon_2 = 0$

(NOTE that we went counter-clockwise through both loops)

Junction rule (say, at point d): $I_1 + I_3 - I_2 = 0$

→ Now we have three eqns. w/ three unknowns. Algebraically we can solve for the currents in terms of the resistances and potential diffs.

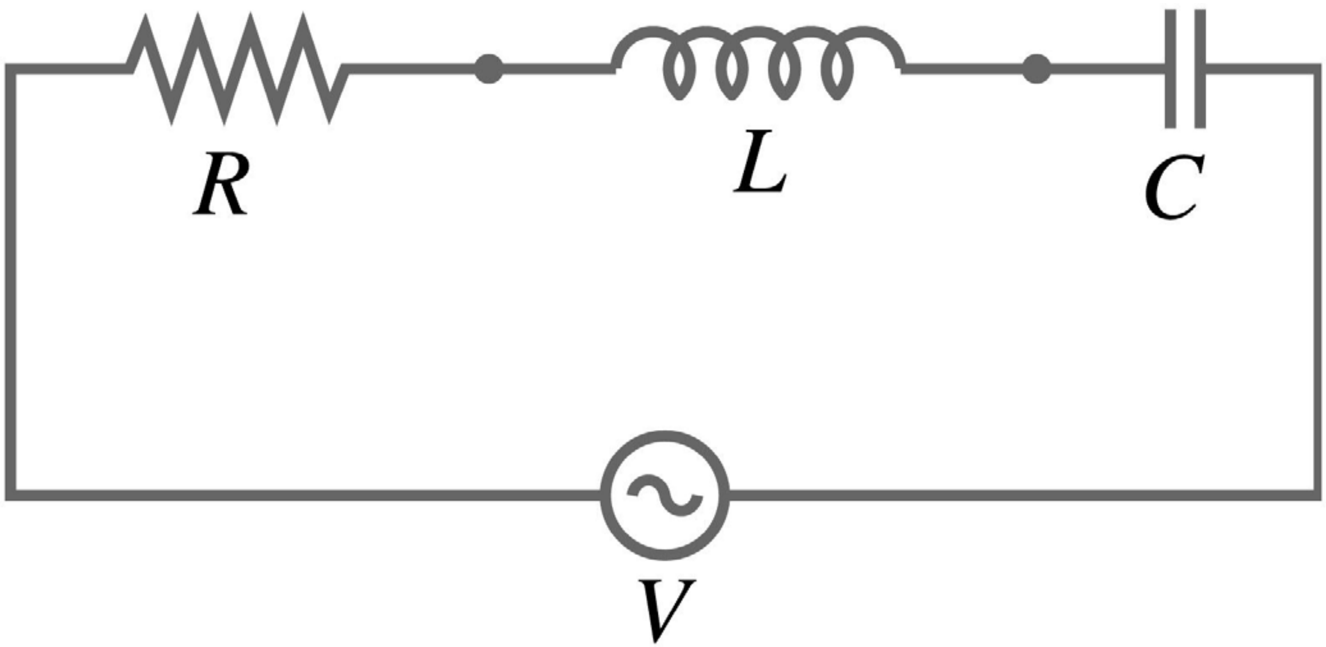
$$I_1 = \frac{\varepsilon_1 (R_2 + R_3) - \varepsilon_2 R_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

$$I_2 = \frac{\varepsilon_1 R_3 - \varepsilon_2 (R_1 + R_3)}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

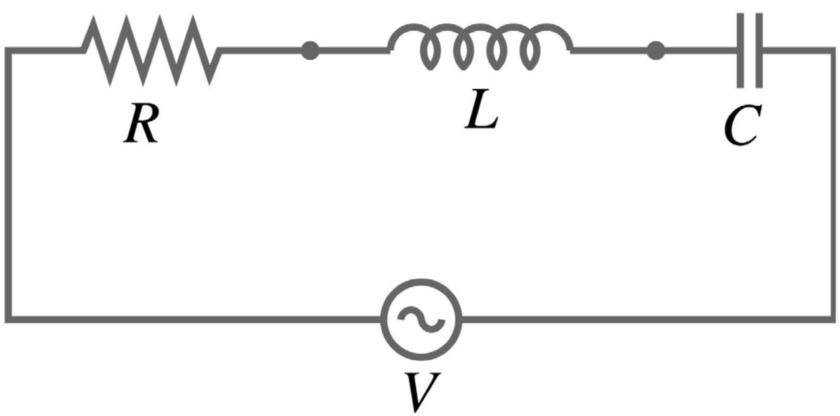
$$I_3 = \frac{-\varepsilon_1 R_2 - \varepsilon_2 R_1}{R_1 R_2 + R_2 R_3 + R_1 R_3}$$

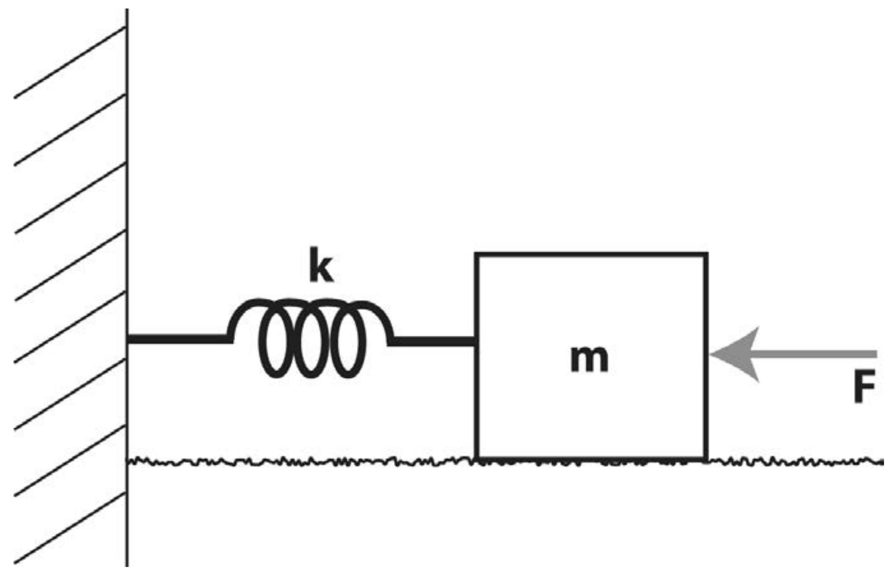
NOTE: $I_3 < 0$ (so we chose the ref. direction wrong no matter what ε and R values are!)

RLC Circuits as an example



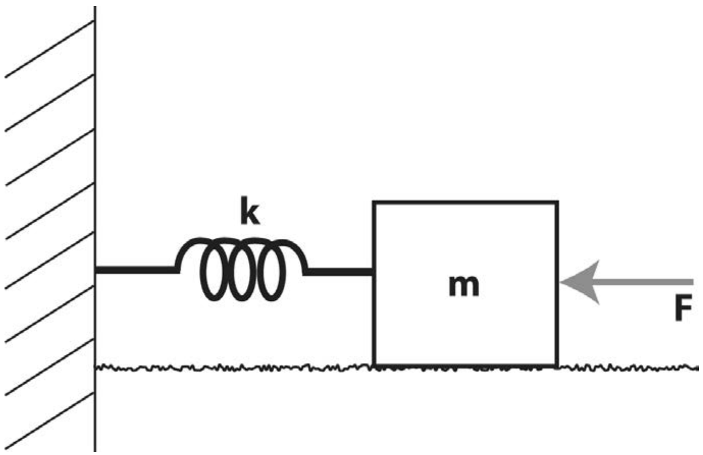
RLC circuit = Damped, Driven Harmonic Oscillator

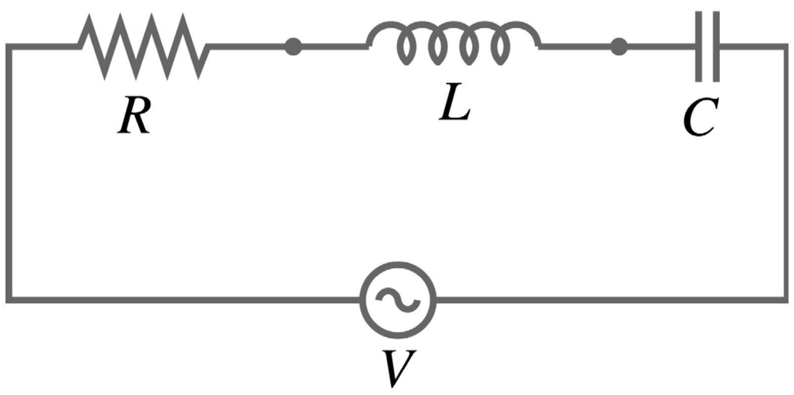




RLC circuit = Damped, Driven Harmonic Oscillator

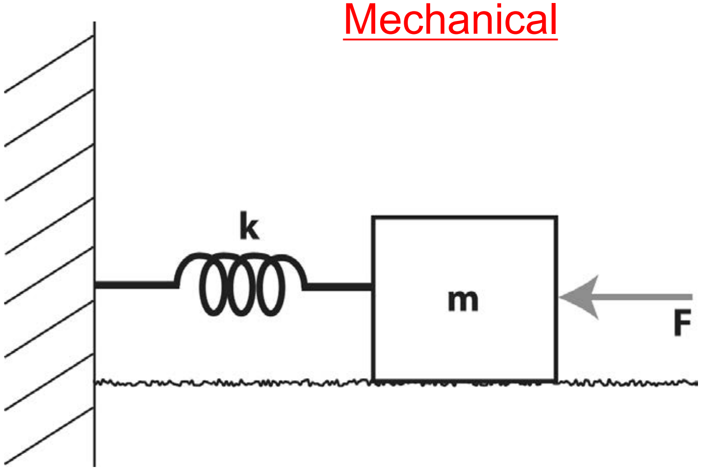
Mechanical		Electrical	
F (force)	↔	V (potential)	state variables
v (velocity)	↔	I (current)	
x (position)	↔	q (charge)	
m (mass)	↔	L (inductance)	
b (damping)	↔	R (resistance)	
k (spring)	↔	$1/C$ (capacitance)	



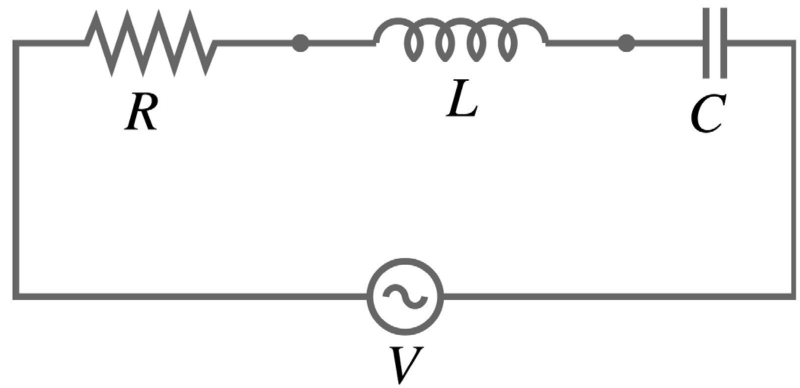


RLC circuit = Damped, Driven Harmonic Oscillator

Mechanical



Electrical



$$m\ddot{x} + b\dot{x} + kx = F_o e^{i\omega t}$$

$$L\ddot{q} + R\dot{q} + \frac{q}{C} = V_o e^{i\omega t}$$

Ohm's Law

'Simple' Version $$V = IR \qquad V, I \in \mathbb{R}$$

'Complete' Version $$\mathbf{V} = \mathbf{IZ} \qquad \mathbf{V}, \mathbf{I} \in \mathbb{C}$$

→ Note that DC (direct current) can be considered a special case of AC (alternating current). The 'complete' version of Ohm's Law thus allows for more dynamical behavior to be accounted for in an efficient fashion when using Fourier or Laplace transforms (and reduces to the 'simple' case for uni-directional currents).

RLC circuit = Damped, Driven Harmonic Oscillator

Mechanical Impedance

$$Z \equiv b + i\left[m\omega - \frac{k}{\omega}\right]$$

Electrical Impedance

$$Z \equiv R + i\left[\omega L - \frac{1}{\omega C}\right]$$

→ Admittance (Y) = (Impedance)$^{-1}$

→ Conductance (G) = (Resistance)$^{-1}$

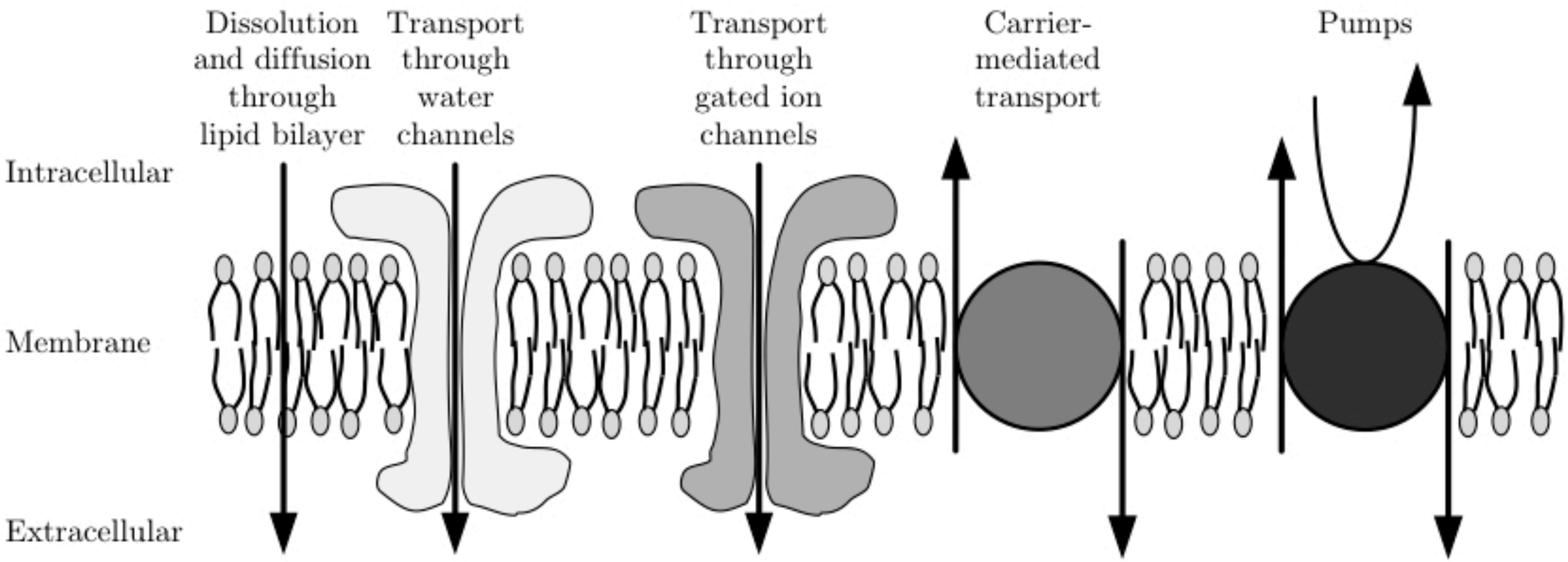

Dissolution and diffusion through lipid bilayer
Transport through water channels
Transport through gated ion channels
Carrier-mediated transport
Pumps
Intracellular
Membrane
Extracellular

Figure 2.19

Example → Auditory hair cells as RLC Systems

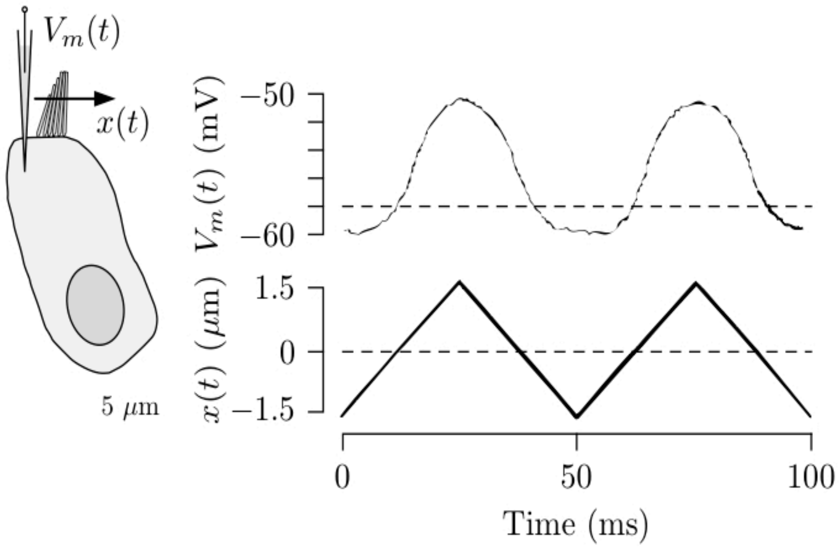
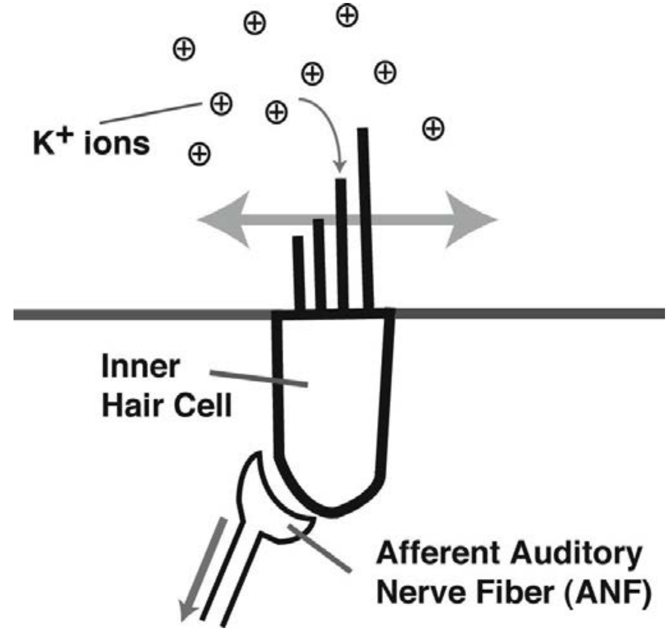
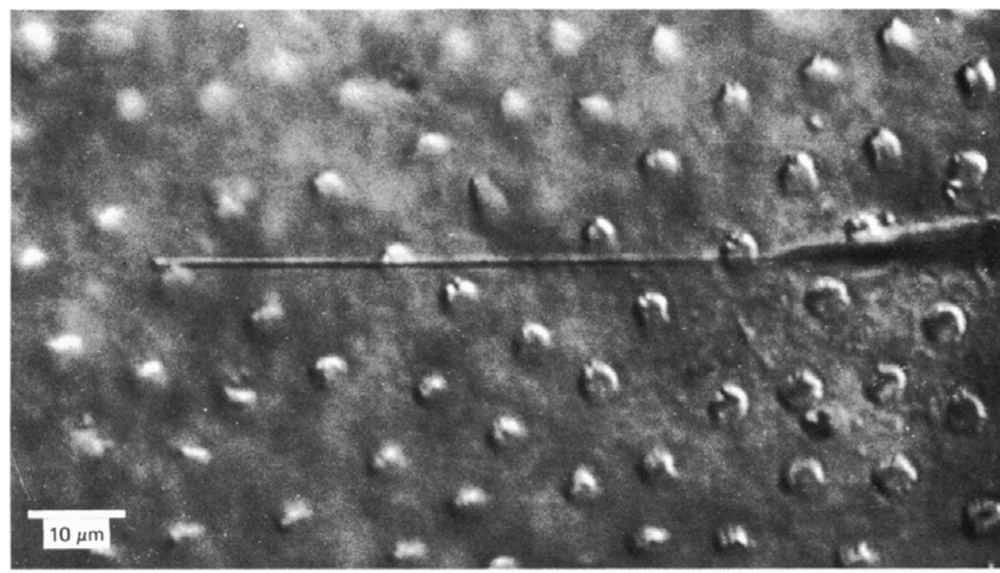


Figure 1.5





Crawford & Fettiplace (1985)