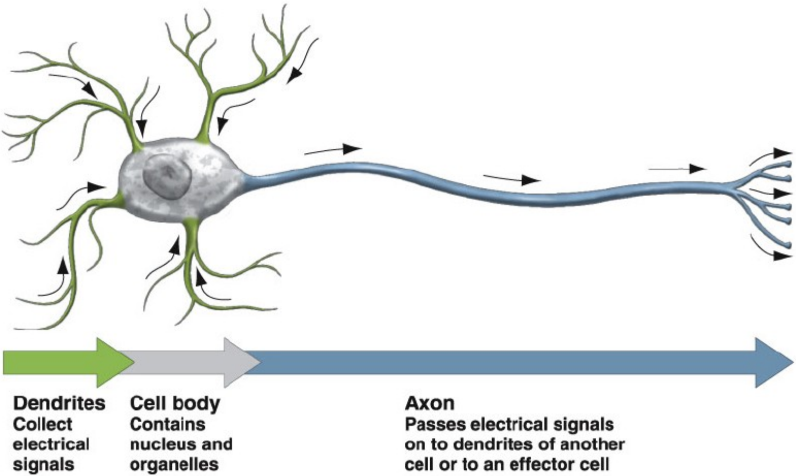
Hodgkin-Huxley Model of Action Potential

Neuron



Dendrites
Collect electrical signals
Cell body
Contains nucleus and organelles
Axon
Passes electrical signals on to dendrites of another cell or to an effector cell

Axon = Electrical Cable?

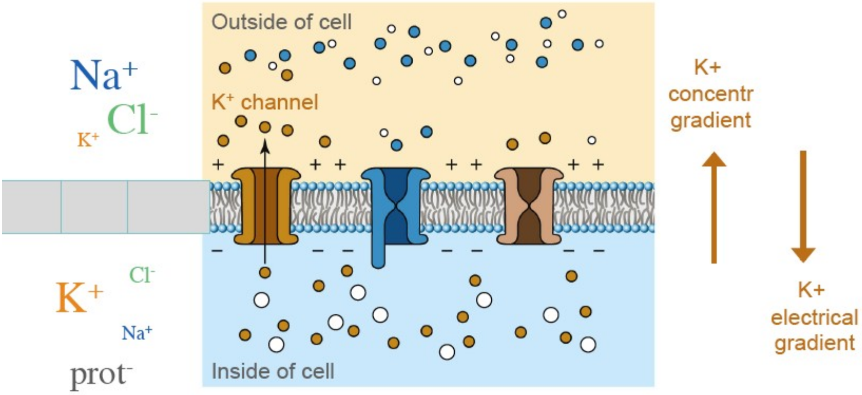
Resistance of

Nerve fiber		Copper wire
1m long	=	with a diameter of 0.6 mm
with a diameter of $1\mu m$		length $10x$ the distance to Saturn

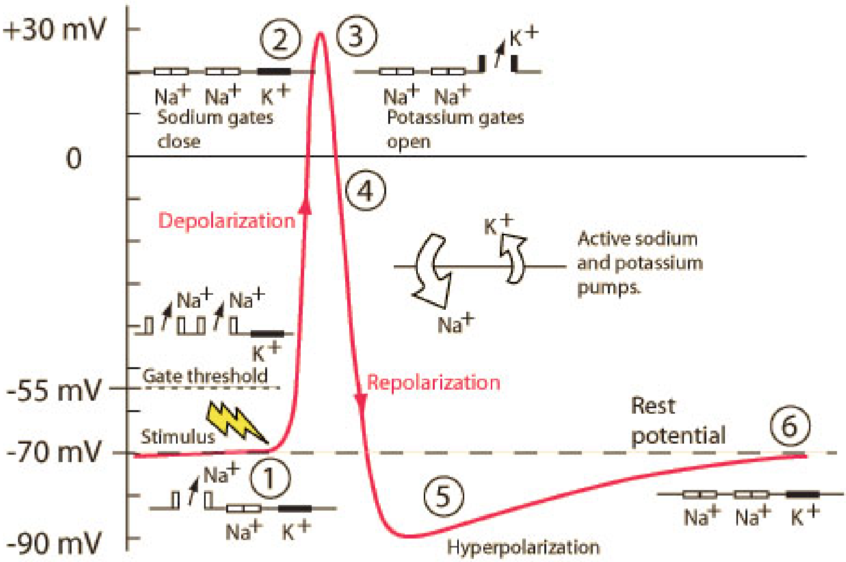
Current is a flow of ions, not electrons

Direction is not longitudinal but transverse, passing into and out of the cell through ion channels in the membrane

Electrochemical Equilibrium



Action Potential



Modeling the Dynamics of Action Potential

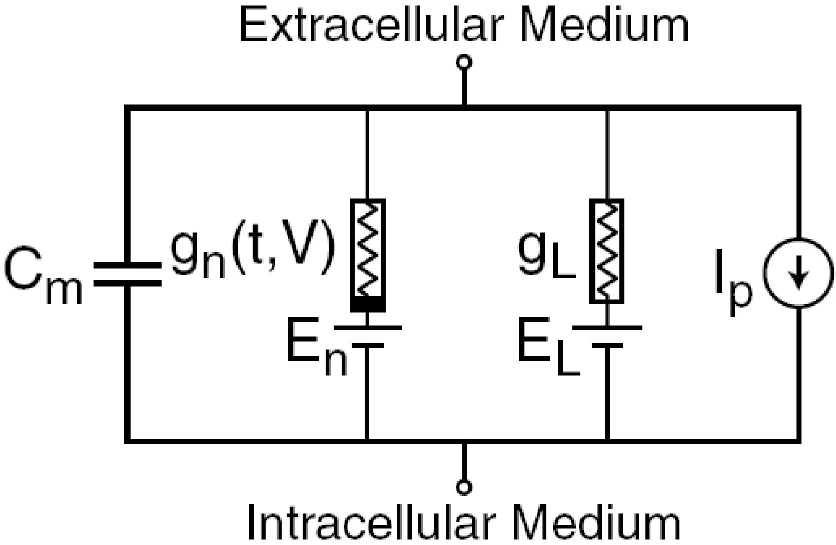
Past models

model constructed from knowledge of interactions
determine long term behavior

Hodgkin-Huxley

know the behavior
model to understand underlying mechanisms

Hodgkin-Huxley as Electrical Circuit



Circuit Terms

$q(t)$	the charge carried by particles in circuit at time t
$I(t)$	the current $= \frac{dq}{dt}$
	rate of flow of charge in the circuit at time t
$V(t)$	the voltage
	difference in the electrical potential at time t
$R(V,t)$	the resistance
	property of material that impedes flow of particles
$g(V,t)$	the conductance, $\frac{1}{R(V,t)}$
C	the capacitance
	property of an element that physically separates charges

- Capacitor causes the difference in electrical potential (voltage)
- $g(V,t) =$ voltage gated ion channels
- $C =$ lipid bilayer

Physical Relationships in a Circuit

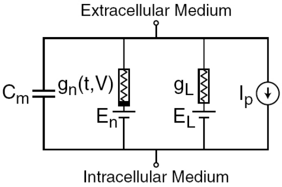
Ohm's Law - the voltage drop across a resistor is proportional to the current through the resistor; R is the factor of proportionality.

$$V_R(t) = I(t)R = \frac{I(t)}{g(V, t)}$$

Faraday's Law - the voltage drop across a capacitor is proportional to the electric charge; $\frac{1}{C}$ is the factor of proportionality.

$$V_C(t) = \frac{q(t)}{C}$$

Elements in Parallel



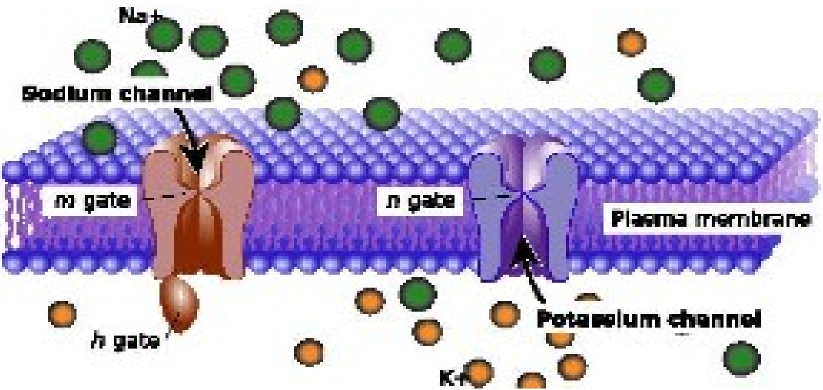
For elements in parallel,

the total current is equal to the sum of currents in each branch
voltage across each branch is the same

$$I(t) = I_1(t) + I_2(t) + I_3(t) = V(g_1 + g_2 + g_3)$$

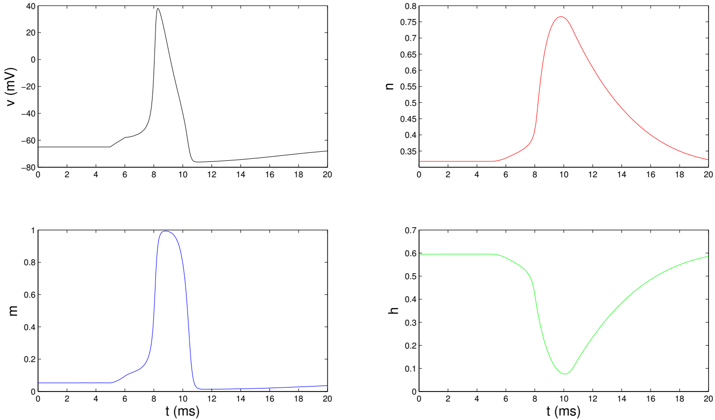
$$V(t) = \frac{q(t)}{C}$$

Gates



Na+
Sodium channel
m gate
n gate
Plasma membrane
h gate
Potassium channel
K+

Simulations



Hodgkin-Huxley Model

$$\frac{dV}{dt} = -\frac{1}{C}\left(\bar{g}_K n^4(V - V_K) + \bar{g}_{Na} m^3 h(V - V_{Na}) + \bar{g}_L(V - V_L)\right)$$

$$\tau_n(V)\frac{dn}{dt} = -(n - n_\infty(V))$$

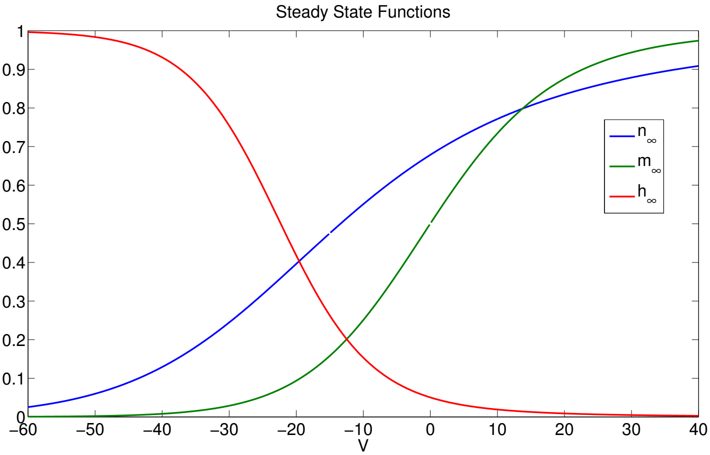
$$\tau_m(V)\frac{dm}{dt} = -(m - m_\infty(V))$$

$$\tau_h(V)\frac{dh}{dt} = -(h - h_\infty(V))$$

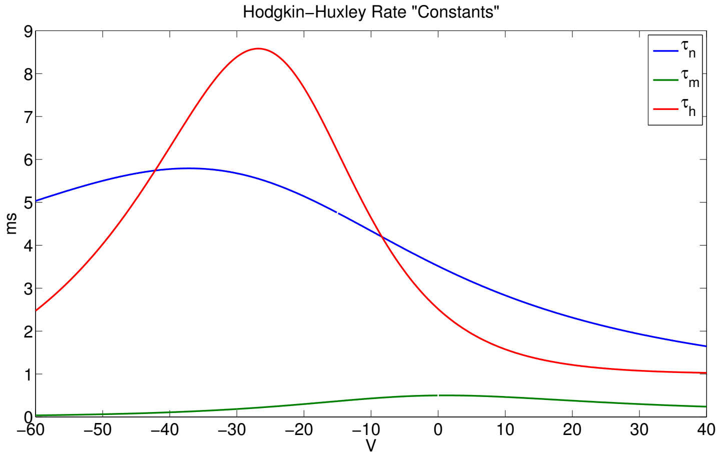
$$\tau_i(V) = \frac{1}{\alpha_i(V) + \beta_i(V)}\text{- time scales}$$

$$i_\infty(V) = \frac{\alpha_i(V)}{\alpha_i(V) + \beta_i(V)}\text{-steady state values}$$

Steady State Values



Time scales


Hodgkin−Huxley Rate "Constants"
ms
V
9
8
7
6
5
4
3
2
1
0
−60
−50
−40
−30
−20
−10
0
10
20
30
40
τn
τm
τh

Discussion Questions

1. Identify the biological events that explain the dynamics on "Solution" slide.
2. Interpret the "steady state" graphs.
3. Interpret the "time scales" graphs.
4. Identify the 'fast' and 'slow' variables.
5. Explain the bursting dynamic using the time scales identified.