2021 Fall "Physiology"

Neural Signaling: Cable Theory

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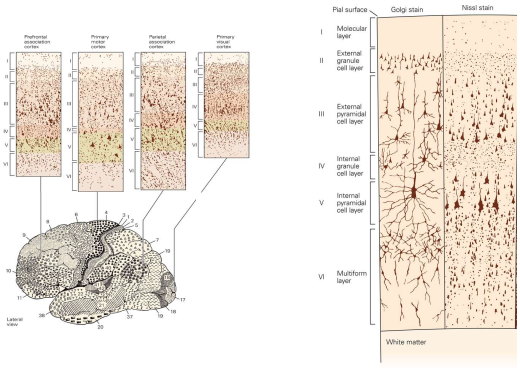
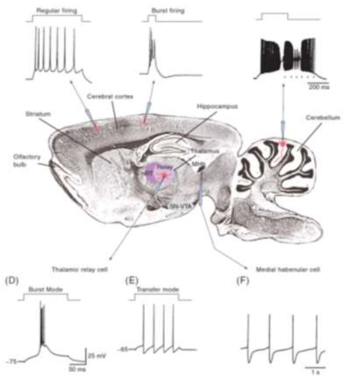
Structure of the Cortex



Diverse Neuronal Activity Patterns



Flow of Neural Signal

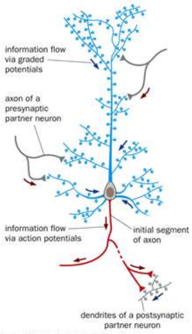
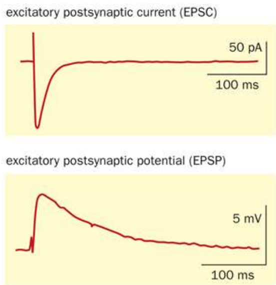


Figure 1-18 Principles of Neurobiology (© Garland Science 2016)



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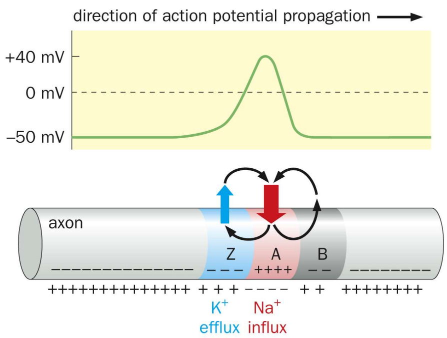
Propagation of Action Potential



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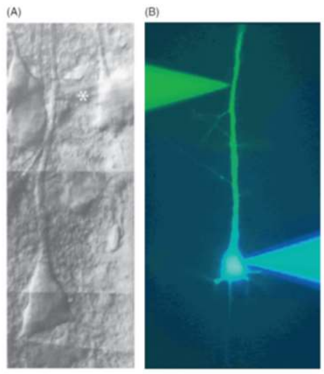
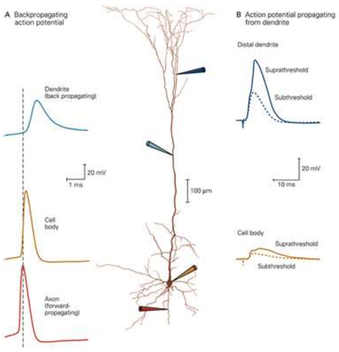
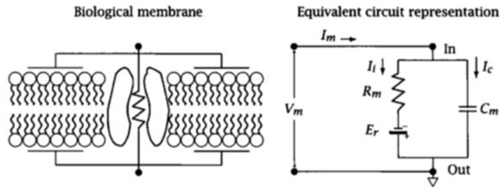
Dendritic Recording



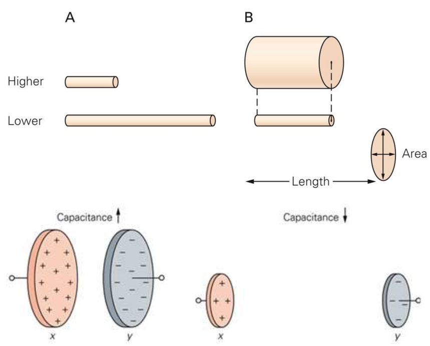
Back Propagation



Passive Properties of the Neuron



Neuron: Resistance + Capacitance



Passive Properties of the Neuron

Element	Symbol	Unit	Physiological magnitude
Battery (V)		Volts (V)	1 mV = 10^{-3} V
Resistor (R)		Ohms (Ω), g = 1/R(Ω^{-1} or Siemen)	1 GΩ = 10^{9} Ω
Capacitor (C)		Farad (F)	1 pF = 10^{-12} F

Current (I): 1 Ampere (A) = 1 Coulomb/sec
1 µA = 10^{-6} A, 1 nA = 10^{-9} A (magnitude of whole-cell memb curr)
1 pA = 10^{-12} A (magnitude of curr through a single ion channel)

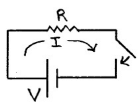
Cell membrane: 1µF/cm^2 (0.01 pF/µm^2)

神经元可等效为:

A. 电阻和电容的组合

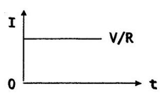
B. 电感和电阻的组合

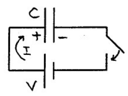
C. 电导

i) 

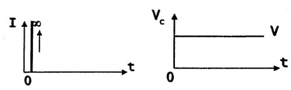
Switch closed at t = 0:

I = V/R



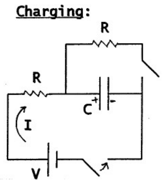
ii) 

t=0, I→∞
t>0, I=0

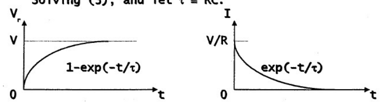


Time Constant

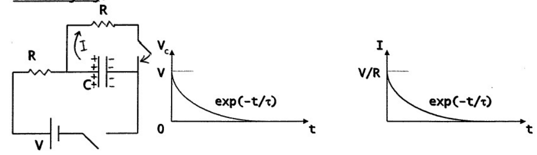
Charging:



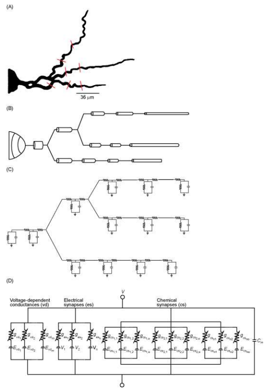
V = IR+V_c (1)
Q = CV_c ⇒ I = dQ/dt = CdV_c/dt (2)
∴ V = RC(dV_c/dt)+V_c ⇒ dV_c/dt+V_c/RC = V/RC (3)
Solving (3), and let τ ≡ RC:



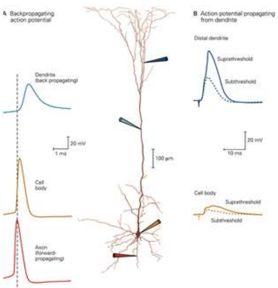
Discharging:



Cable Theory



Cable Theory



Time constant is independent of cell size

$$\tau = R_m \times C_m$$
$$R_m = \frac{\rho l}{A}$$
$$c = \frac{\varepsilon_0 k A}{d}$$
$$\tau = R_m C_m = \frac{\rho \cancel{l}}{\cancel{A}} \times \frac{\varepsilon_0 k \cancel{A}}{\cancel{d}} = \rho \varepsilon_0 \cdot k$$
$$\Rightarrow R_m = 10^3 \Omega \cdot cm^2$$
$$c = 10^{-6} F/cm^2$$
$$\tau \simeq 1\ ms$$

Passive Properties of the Neuron

Table 2–1: Time and length constants of axons, dendrites, and muscle cell

Fiber	Diameter (μm)	Length constant (mm)	Time constant (ms)
Squid giant axon[1]	500	5	0.7
Lobster nerve[1]	75	2.5	2
Frog muscle[1]	75	2	24
Apical dendrite of mammalian cortical pyramidal neuron[2]	3	1	~20

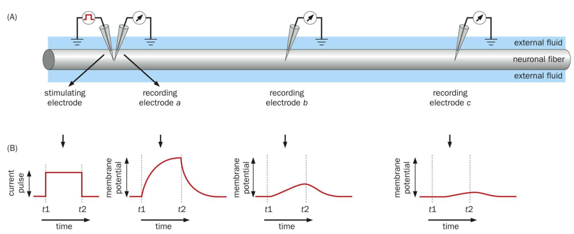
[1]Data from Katz B (1966) Nerve, Muscle, and Synapse. McGraw-Hill; length constants were measured in large extracellular volume.
[2]Data from Stuart G, Spruston N & Hausser M (1999) Dendrites. Oxford University Press.

Table 2-1 Principles of Neurobiology (© Garland Science 2016)

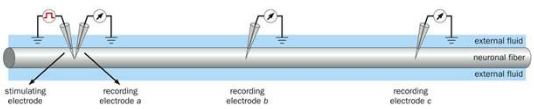
$R_m \uparrow \rightarrow \tau \uparrow$ Slow Response

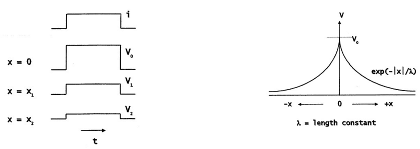
$R_m \downarrow \rightarrow \tau \downarrow$ fast Response

Passive Properties of the Neuron

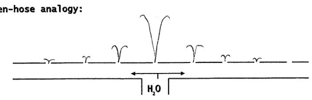


Space Constant





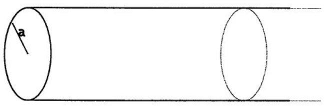
Garden-hose analogy:



$$\lambda = \sqrt{dR_m/4Ri}$$

d: axonal diameter
R_m: membrane resistance
R_i: internal resistance

Size Effect:



$$r_m \propto a^{-1},\ r_i \propto a^{-2}$$

Thus $r_{input} \propto a^{-3/2}$, or larger diameter gives lower axon input resistance

And $\lambda \propto a^{1/2}$, or larger diameter gives farther spread of signal on axon

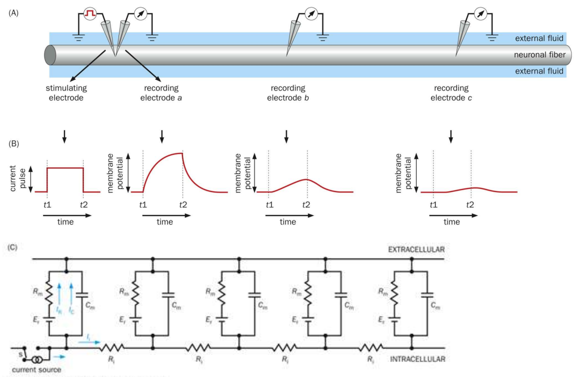
Some real examples:

λ = 13 mm for squid giant axon (1 mm diameter)

= 0.2 mm for mammalian nerve fiber (1 µm diameter).

Both short compared to axon length, ∴need active conduction.

Passive Properties of the Neuron



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Passive Properties of the Neuron

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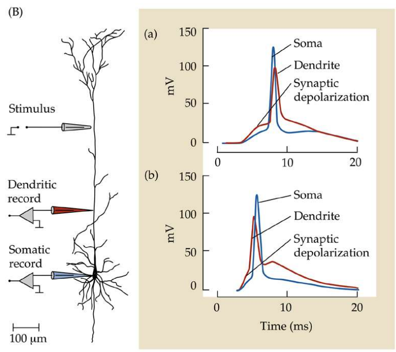
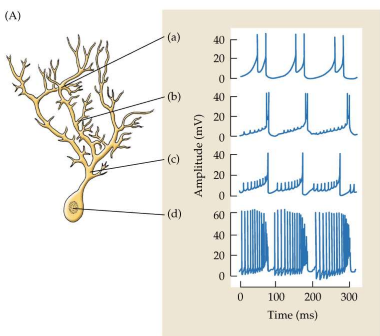
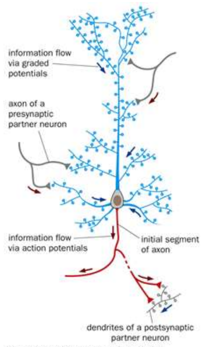




Distribution of Synaptic Inputs



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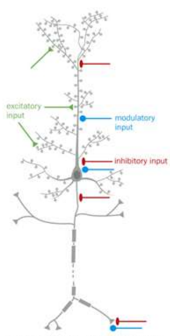

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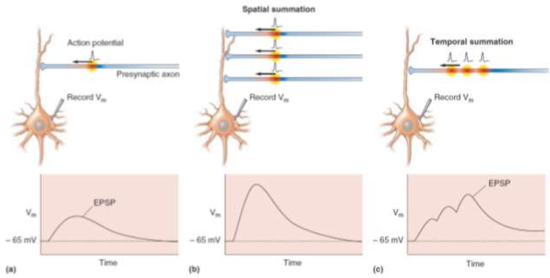
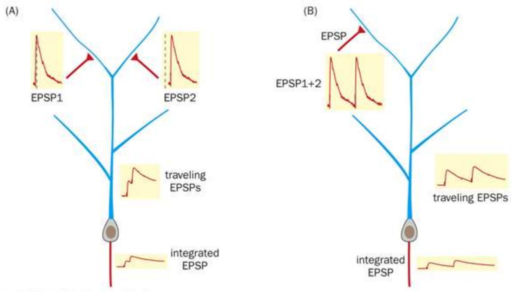
Synaptic Integration



Temporal and Spatial Integration



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