2021 Fall "Physiology"

电信号如何在一个cell上传递

Neural Signaling: Cable Theory

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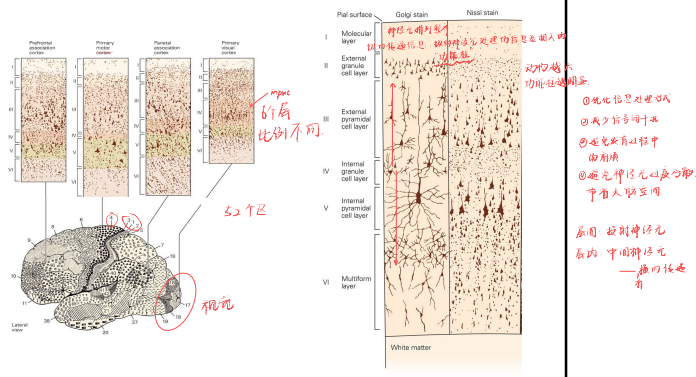
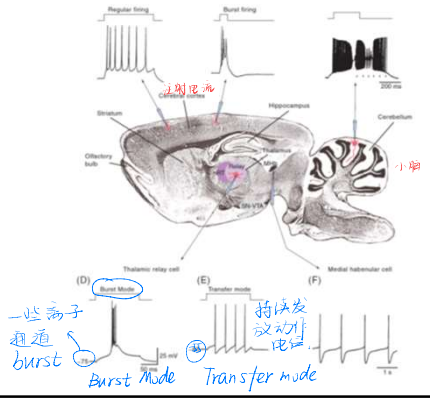
Structure of the Cortex

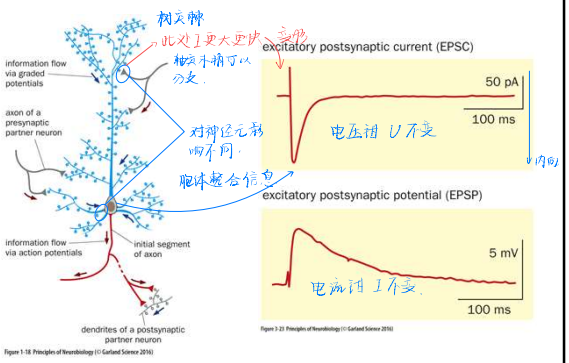


除了嗅觉其他的感觉都需要经过丘脑中转
睡眠时丘脑细胞处于bursting的状态，丘脑门控，信息无法进入大脑皮层

Diverse Neuronal Activity Patterns

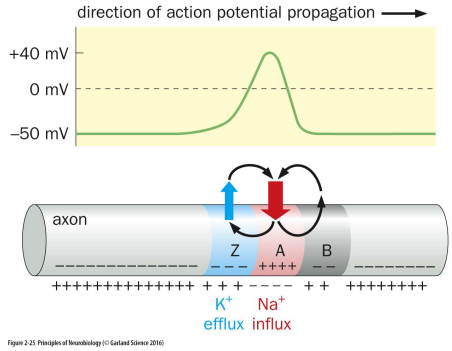


Flow of Neural Signal



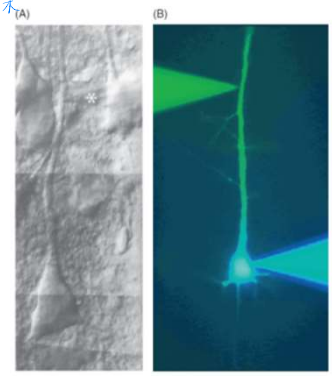
Propagation of Action Potential

单向传递：钠通道的不应期

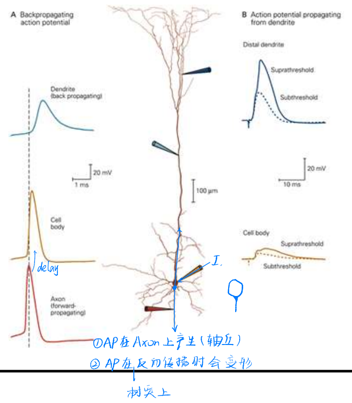


Dendritic Recording

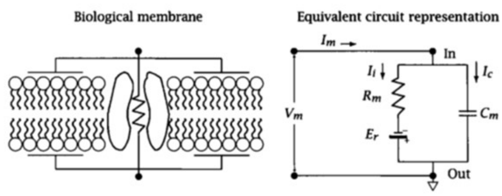
Sakmann's Lab
膜片钳技术
钳制电压



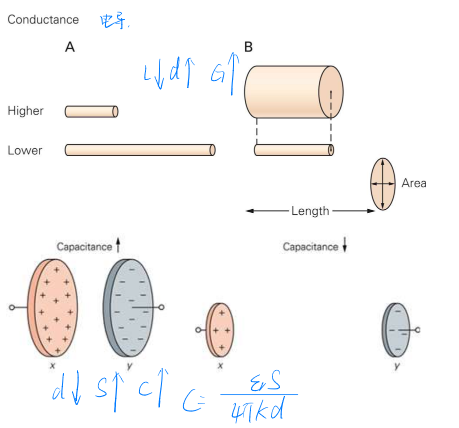
Back Propagation



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)

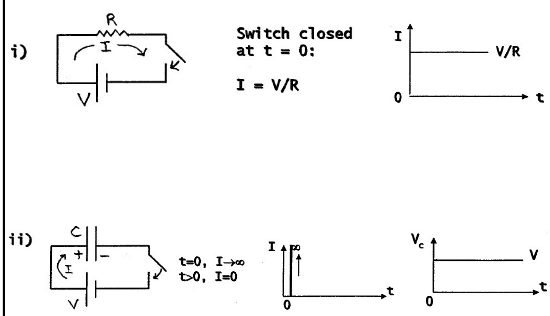
量级 $= 10^6$ pF / 10^8 μm^2 电容↔S

神经元可等效为:

A. 电阻和电容的组合

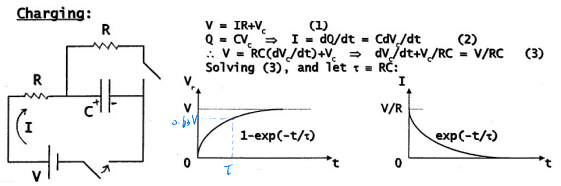
B. 电感和电阻的组合

C. 电导

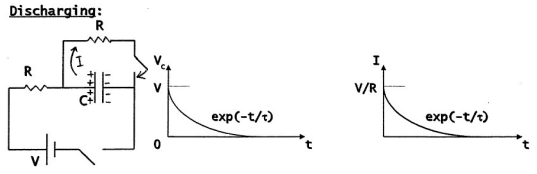


Time Constant

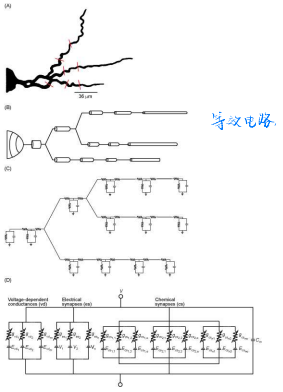
Charging:



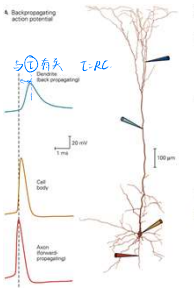
Discharging:



Cable Theory



Cable Theory



Time constant is independent of cell size

$\tau = R_m \times C_m$

$R_m = \frac{\rho l}{A}$

$c = \frac{\varepsilon_0 \varepsilon_r A}{d}$

$\tau = R_m C_m = \frac{\rho l}{A} \times \frac{\varepsilon_0 \varepsilon_r A}{d} = \rho \varepsilon_0 \varepsilon_r \frac{l}{d} = Const$

$\Rightarrow R_m = 10^3\ \Omega \cdot cm^2$

$c = 10^{-6}\ F/cm^2$

$\tau = 1\ ms$

AP

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

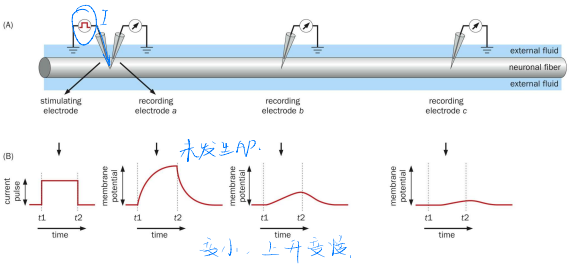
[1]Data from Katz B (1966) Nerve, Muscle, and Synapse. McGraw-Hill; length constants were measured in large extracellular volume.
[2]Data from Stuart G, Spruston N & Hausser M (1999) Dendrites. Oxford University Press.

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

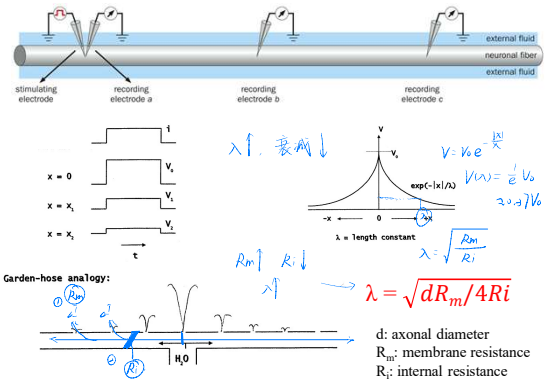
$R_m \uparrow \rightarrow \tau \uparrow$ Slow Response

通道打开↑ $R_m \downarrow \rightarrow \tau \downarrow$ Fast Response

Passive Properties of the Neuron



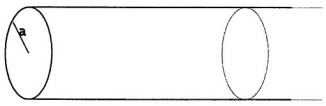
Space Constant



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

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

Size Effect:



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

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

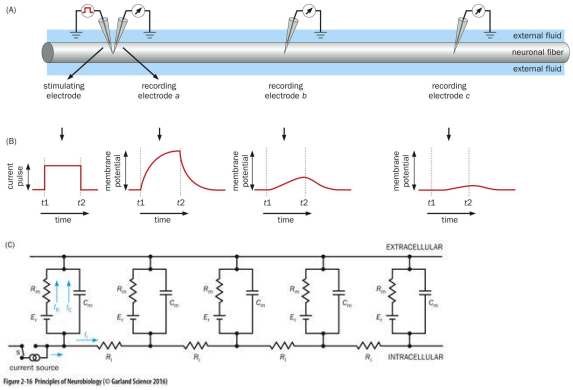


Figure 2-16 Principles of Neurobiology (© Garland Science 2016)

Passive Properties of the Neuron

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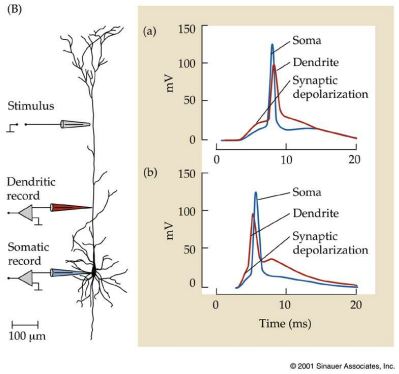

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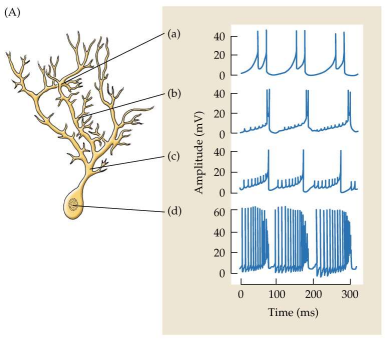

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Distribution of Synaptic Inputs

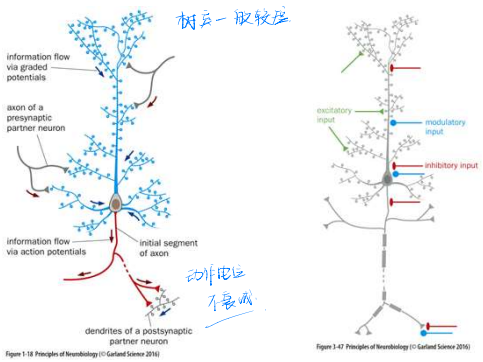
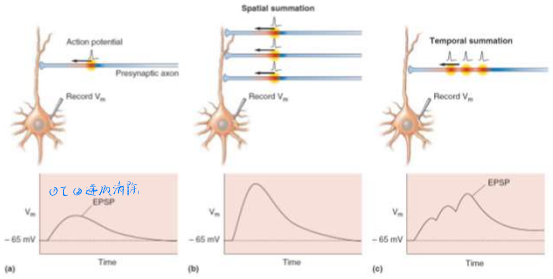


Figure 1-18 Principles of Neurobiology (© Garland Science 2016)

Figure 3-47 Principles of Neurobiology (© Garland Science 2016)

Synaptic Integration



Temporal and Spatial Integration