Biophysics I (BPHS 3090)

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Website: http://www.yorku.ca/cberge/3090W2015.html

York University
Winter 2015
Lecture 18

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

Action Potentials

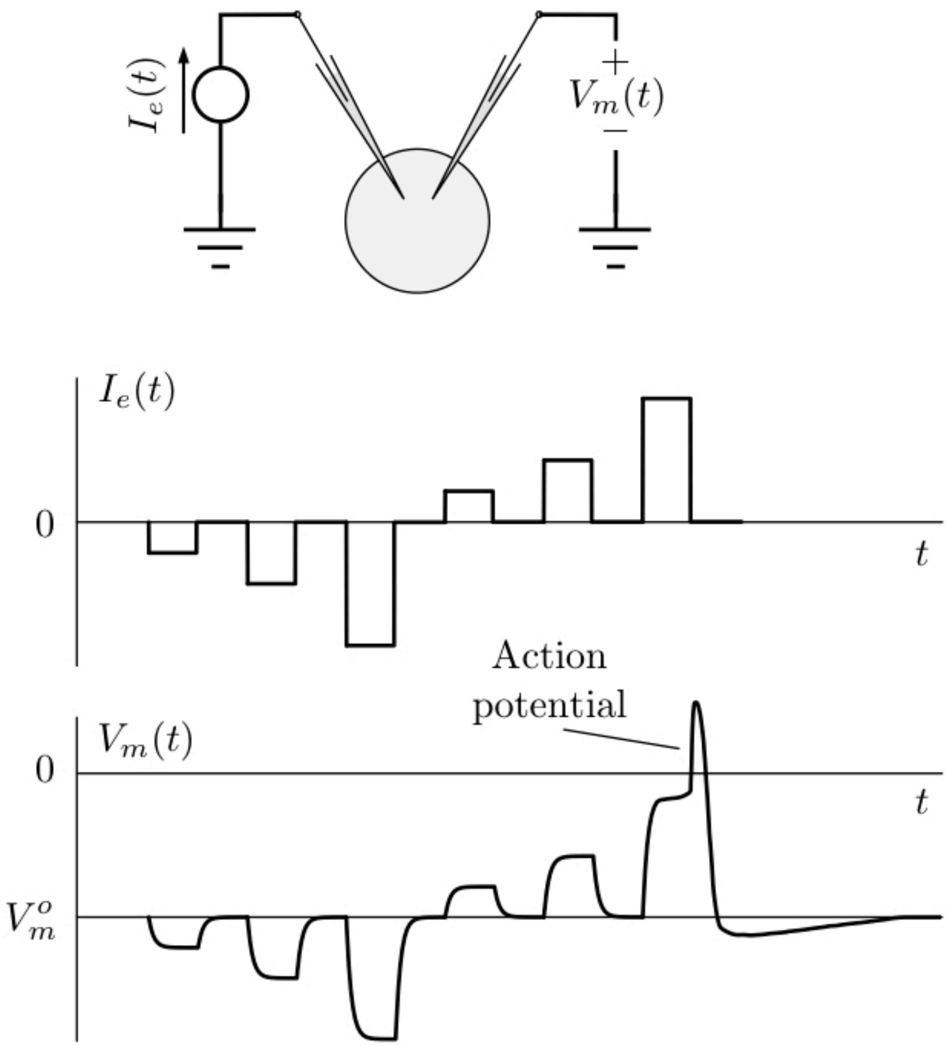


Figure 1.8

Not a graded potential!

(nonlinear; there is a *threshold*)

Graded vs Action Potentials

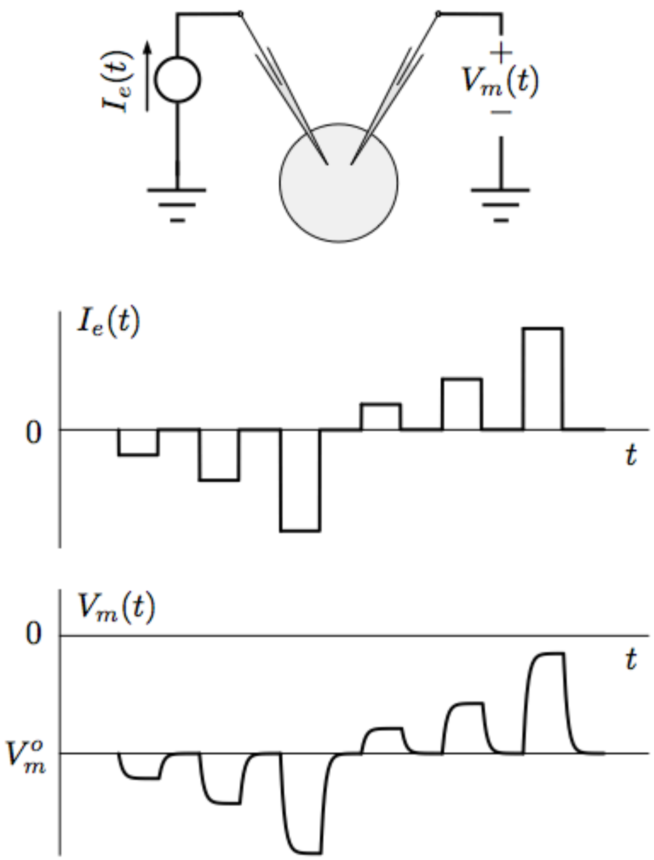


Figure 1.1

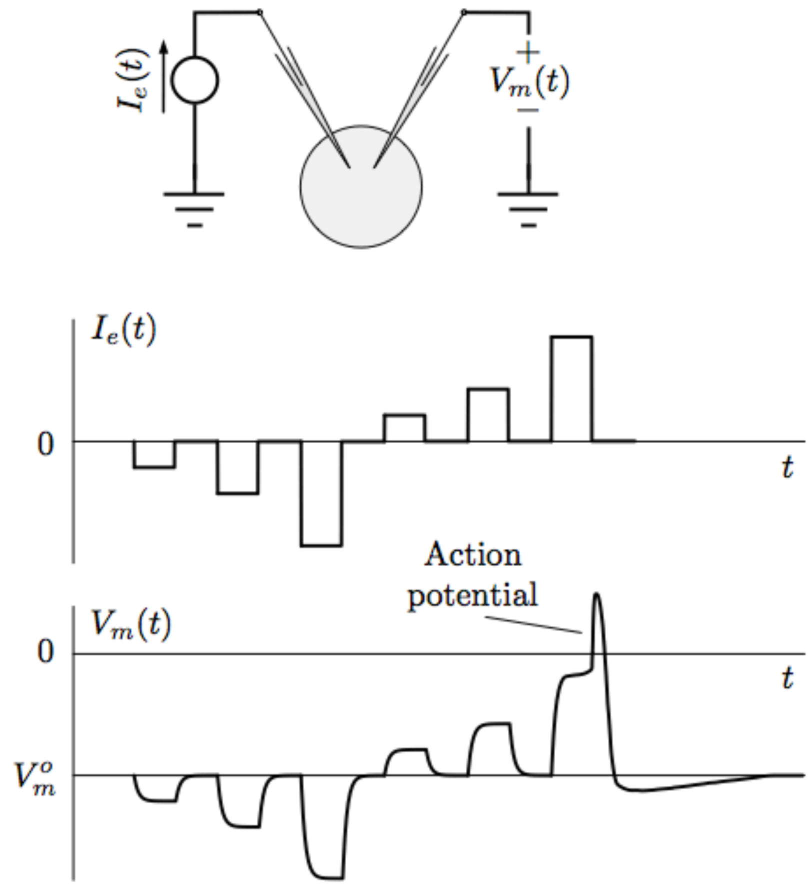


Figure 1.8

Electrically inexcitable cell

Electrically excitable cell

Action Potentials & Neurons

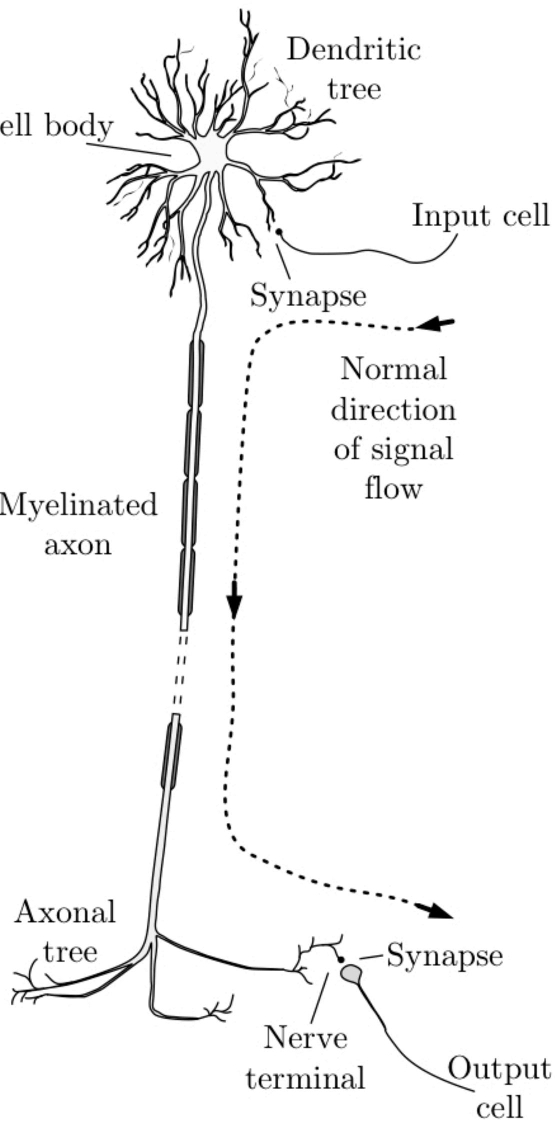


Figure 1.22

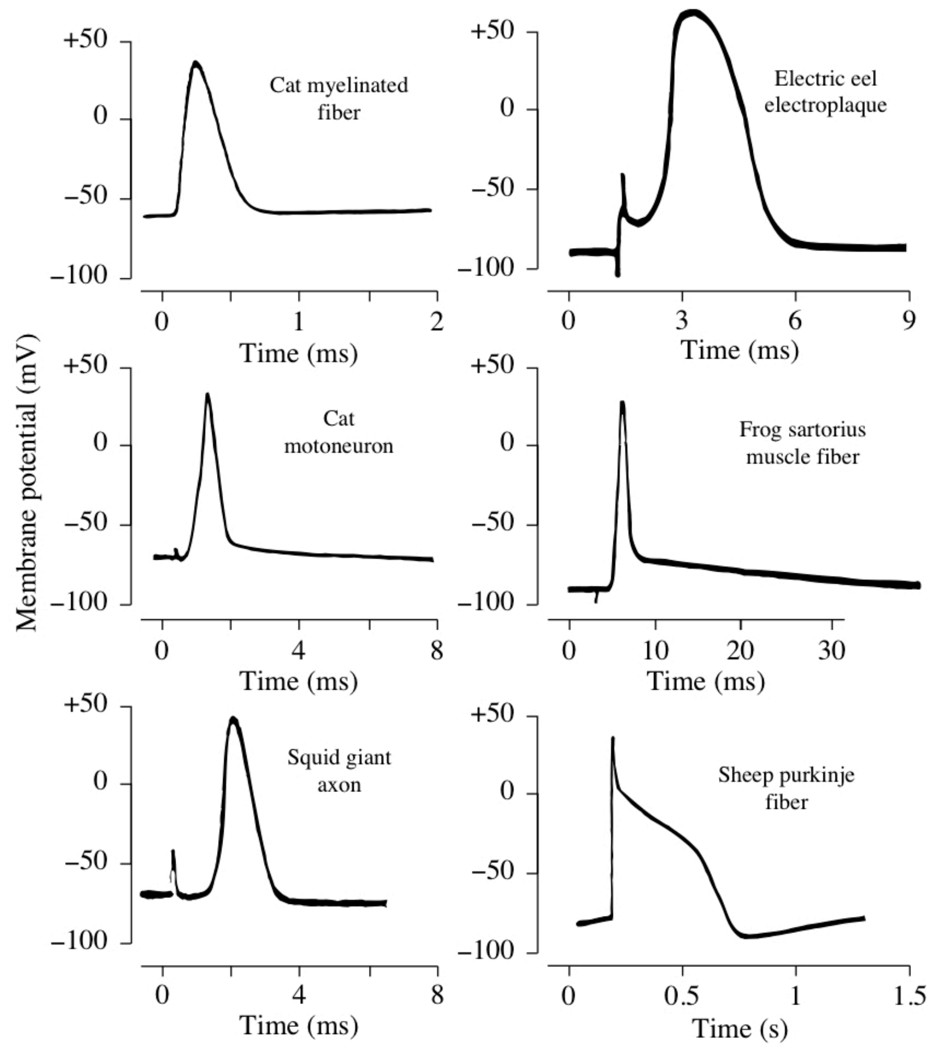


Figure 1.9

Action Potentials: Threshold

- Various shocks (i.e., current pulses) of varying strengths to a single crab axon
- Threshold effect apparent
- For top 6 traces, shock strength differed by less than 3 significant figs.
- → In threshold region, AP firing is probabalisitc

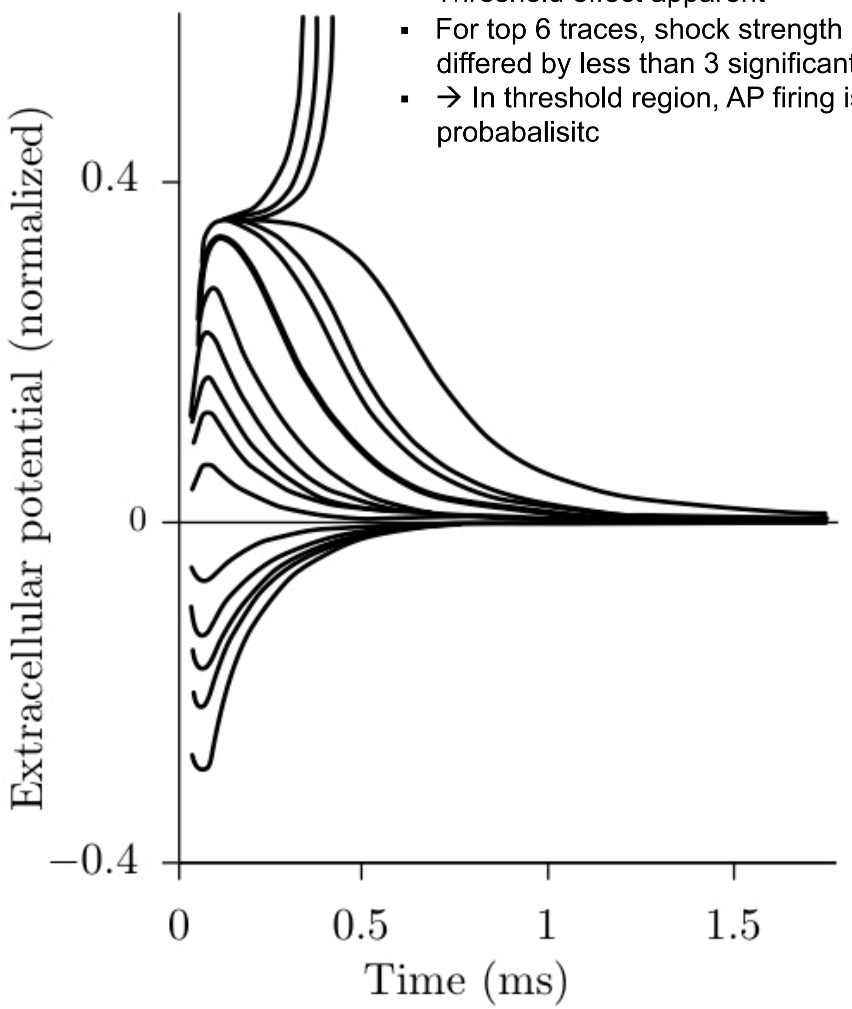


Figure 4.40

- Threshold of current pulse for toad sciatic nerve
- Pulse applied to nerve, a "response" being a muscle twitch downstream
- → "strength-duration relation"

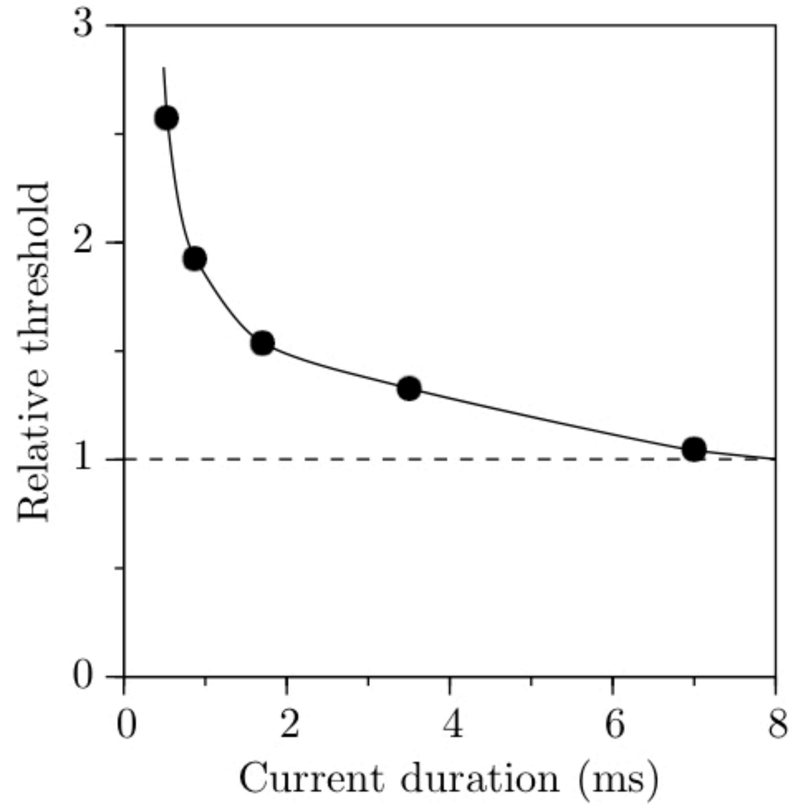


Figure 1.14

→ Must be some nonlinear mechanism to produce thresholding effect

Action Potentials: Refractory Period

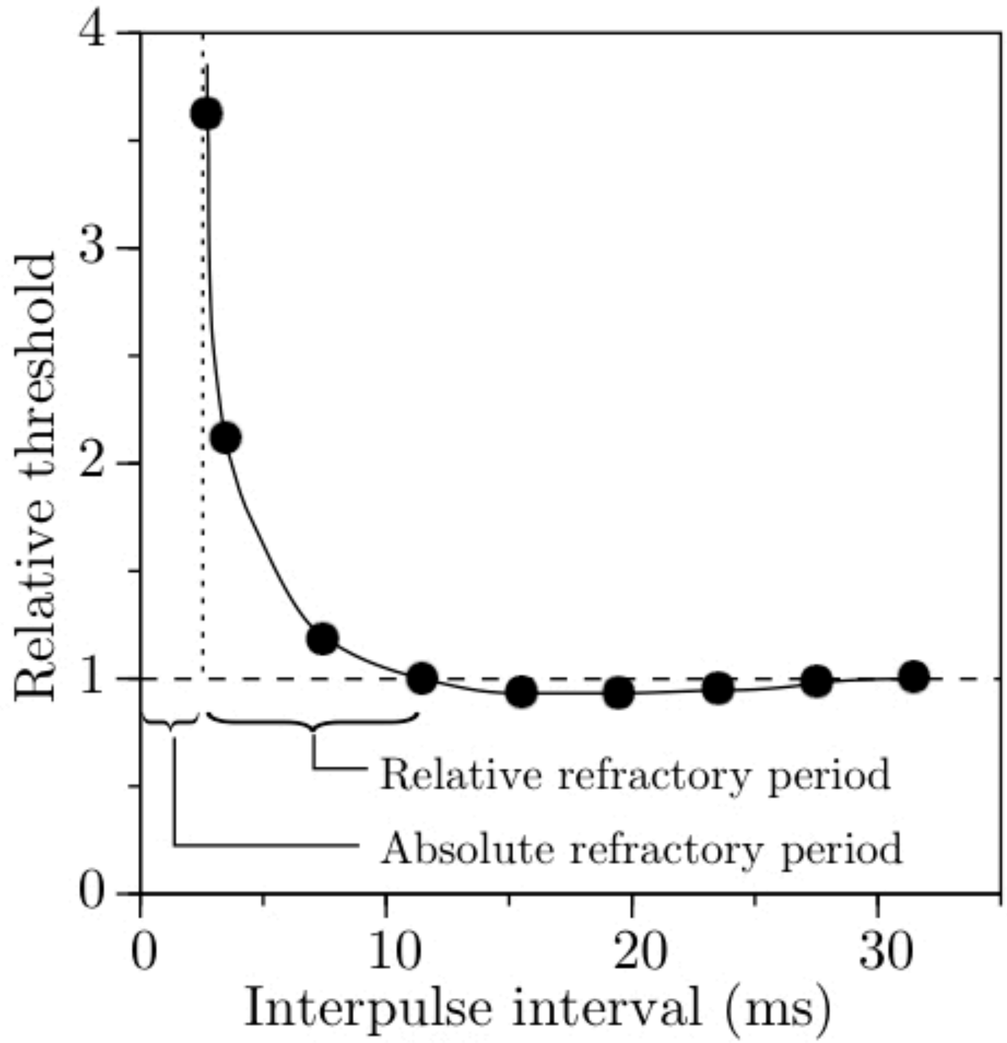


Figure 1.13

Action Potentials: Accommodation

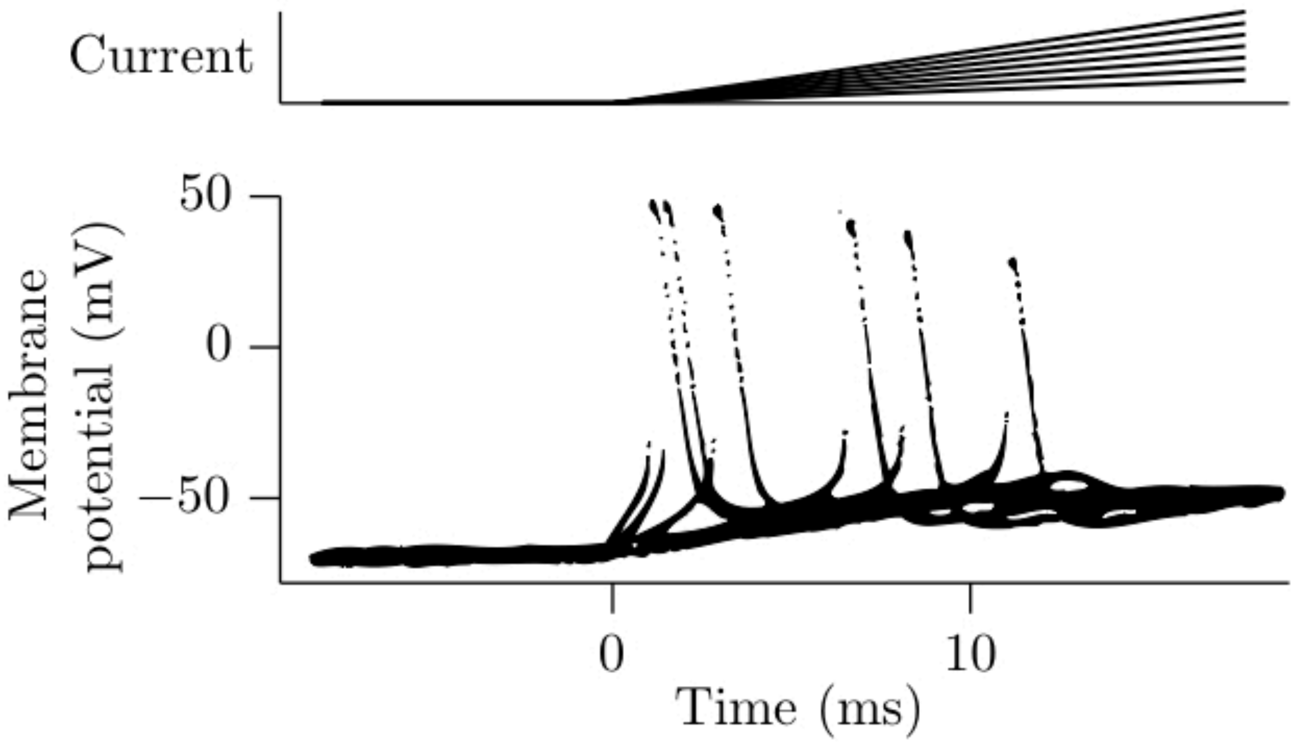
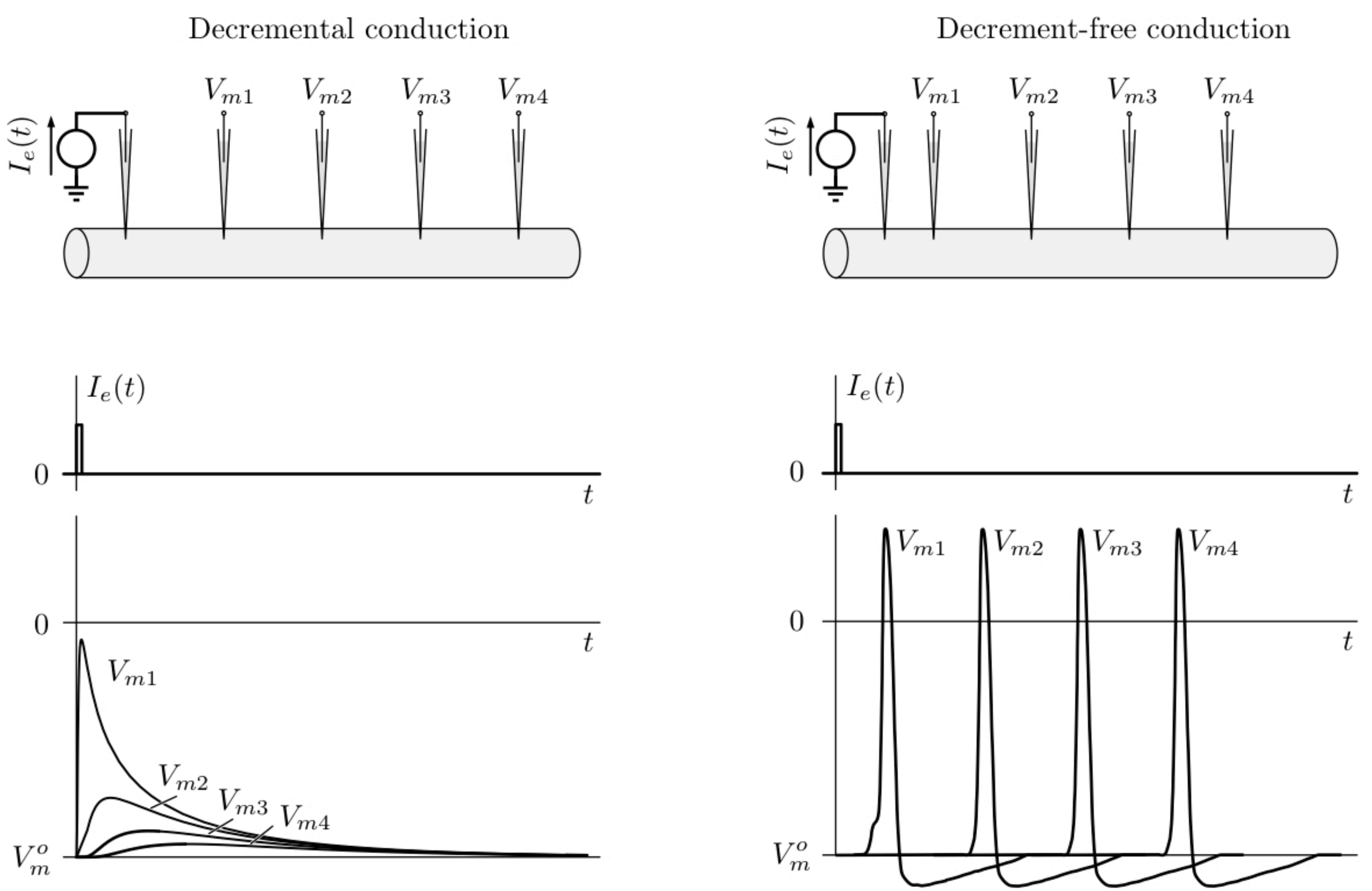


Figure 1.15

→ Indicates that there is no simple constant voltage threshold

Spatial Conduction → Propagation

Figure 1.16



Electrically inexcitable cell

Electrically excitable cell

<u>Intercellular Transmission</u> (e.g., gap junctions, synapses)

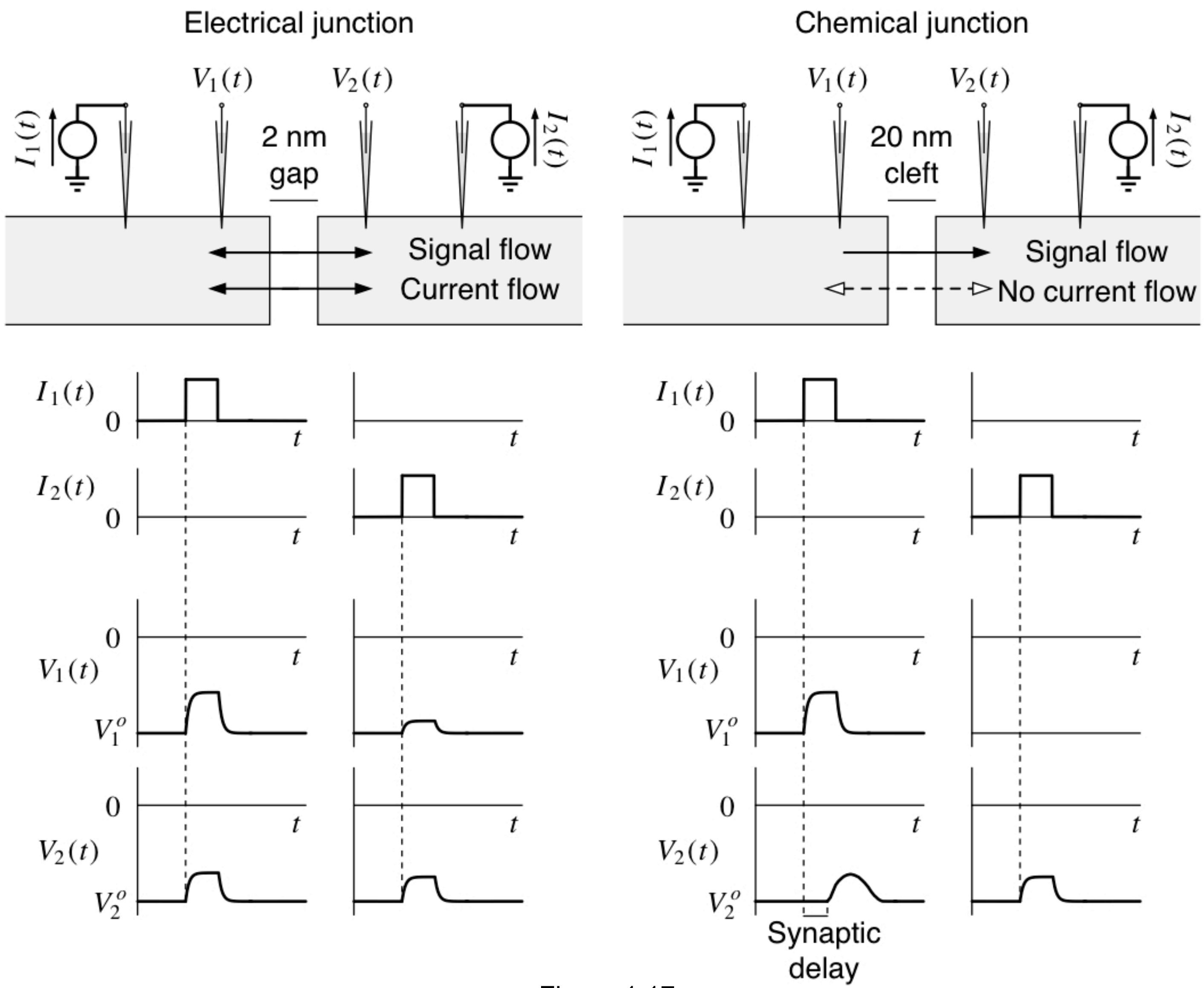


Figure 1.17

Ex. Visual periphery

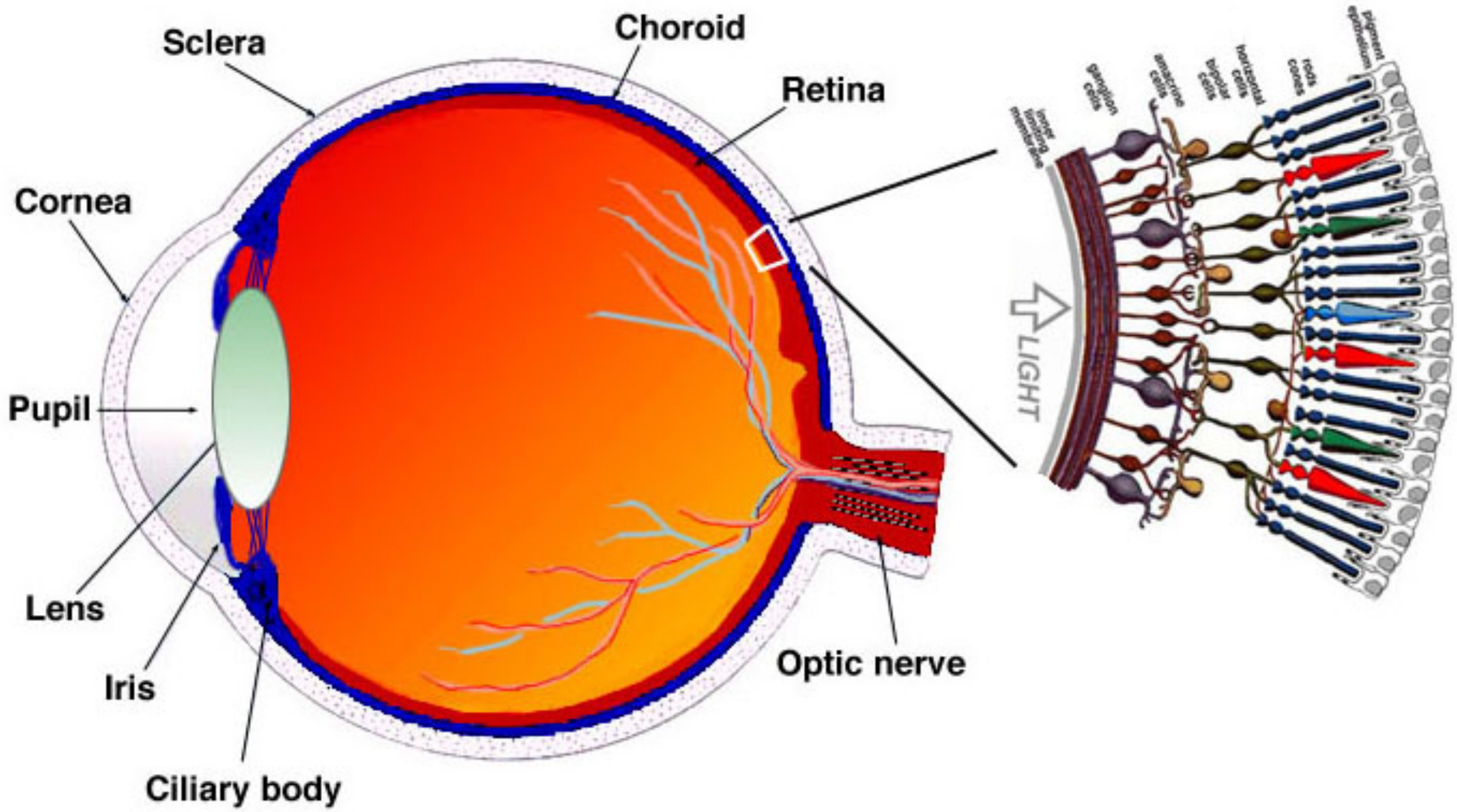


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

WebVision (Utah)

Ex. Visual periphery

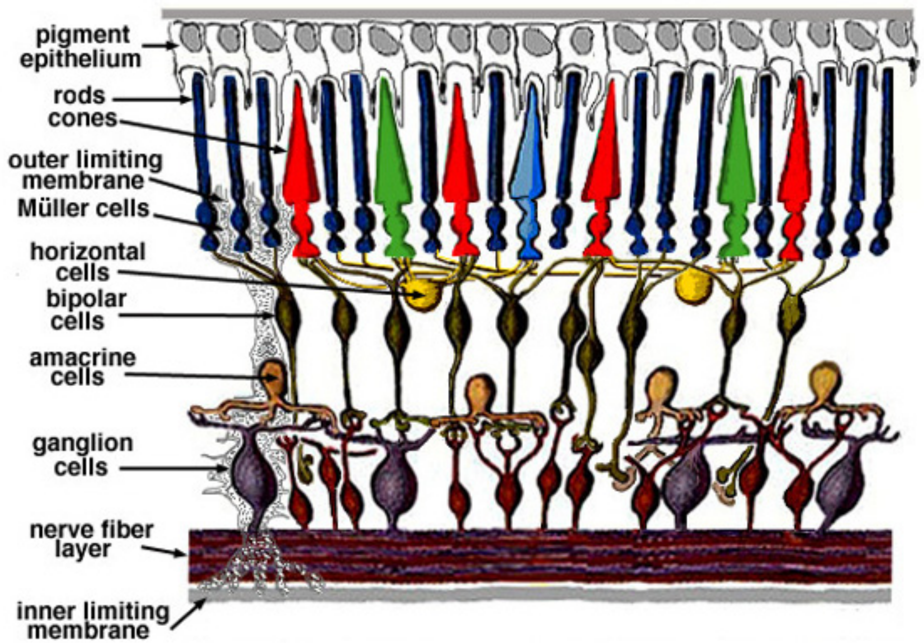


Fig. 2. Simple diagram of the organization of the retina.

WebVision (Utah)

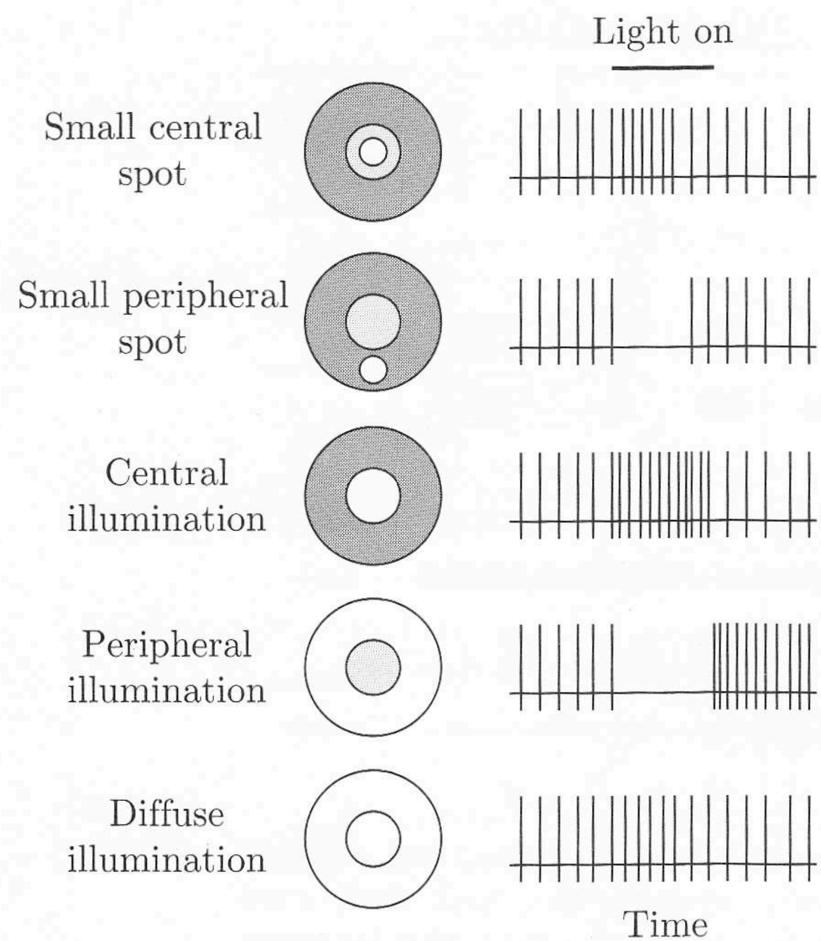


Fig. 1.26

receptive field

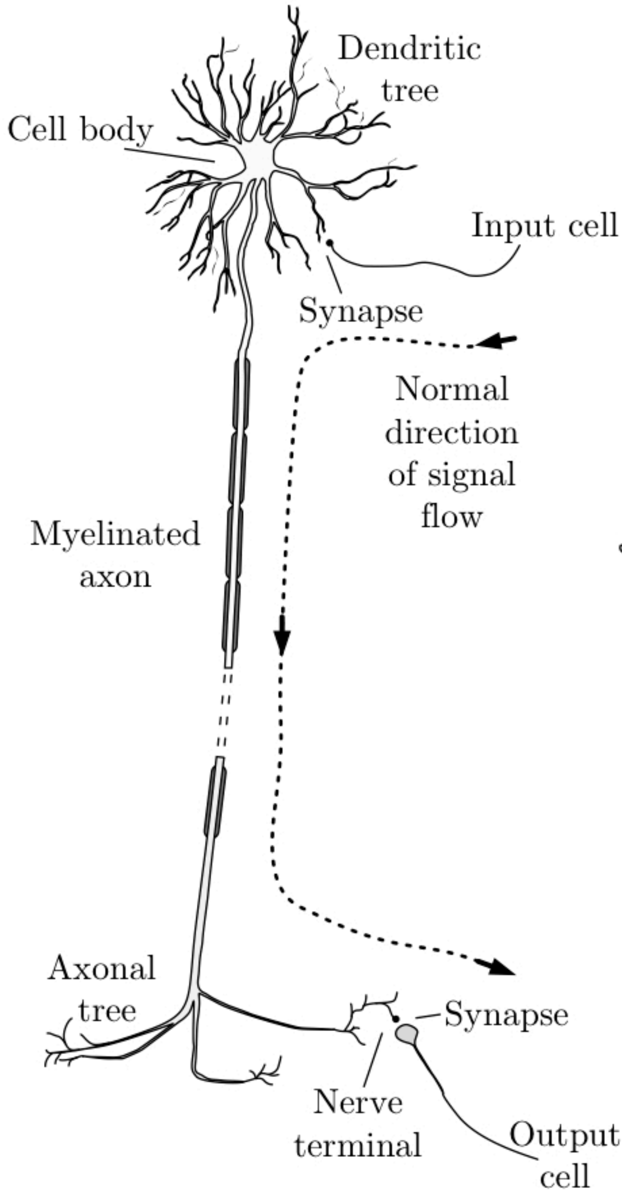


Figure 1.22

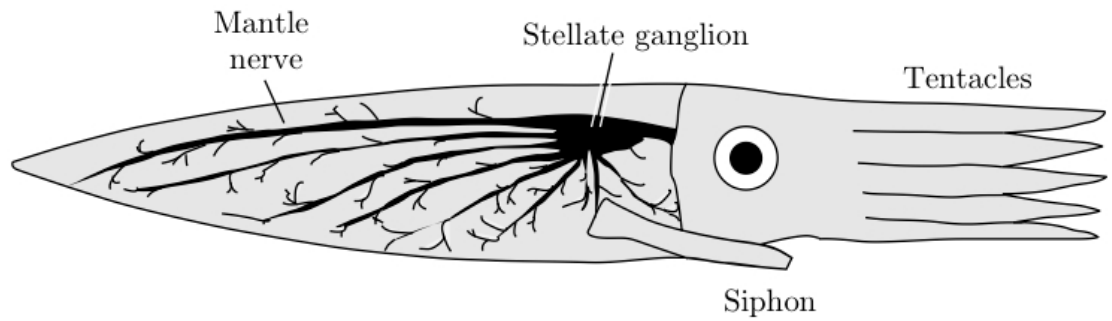


Figure 1.28

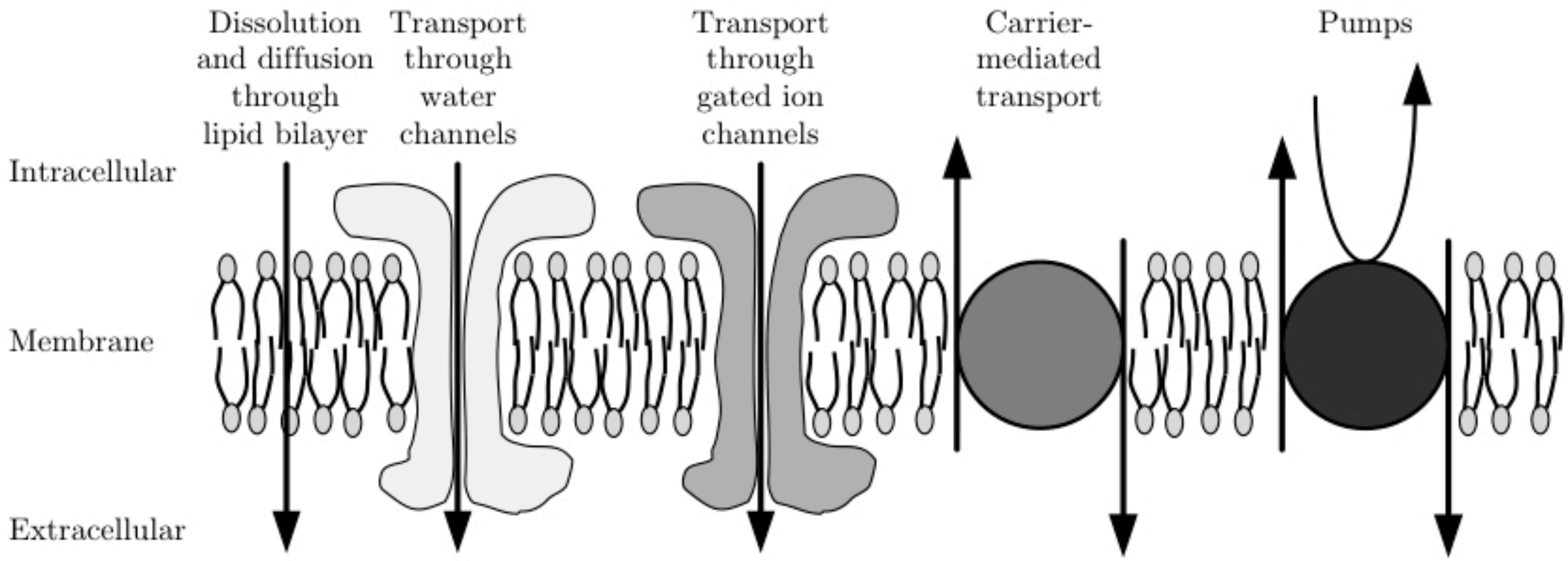

Dissolution and diffusion through lipid bilayer
Transport through water channels
Transport through gated ion channels
Carrier-mediated transport
Pumps
Intracellular
Membrane
Extracellular

Figure 2.19

Electrically Small Cells

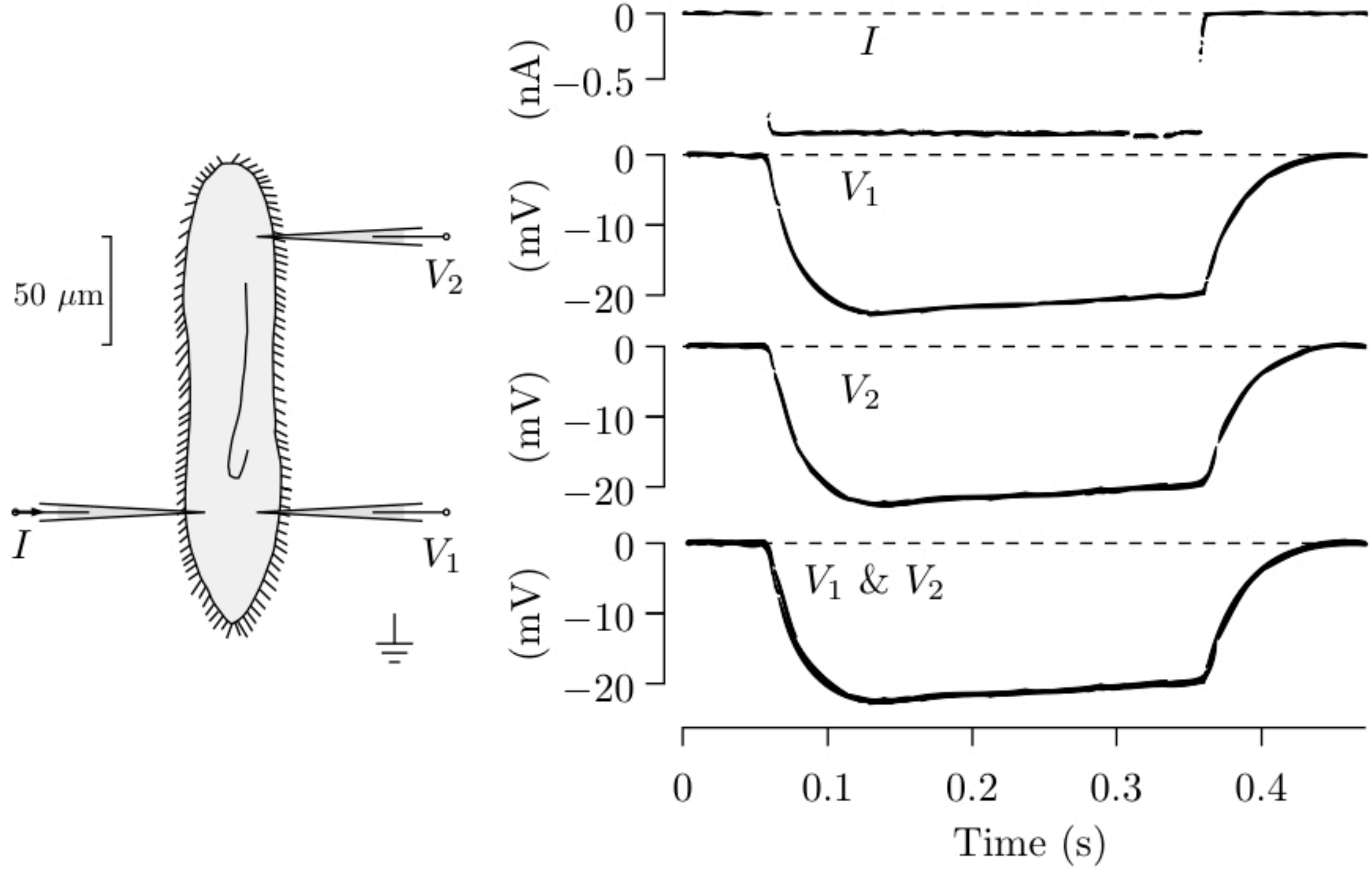


Figure 2.3

Paramecium caudatum
Eckert & Naitoh (1970)

<u>Electrically Large Cells</u>

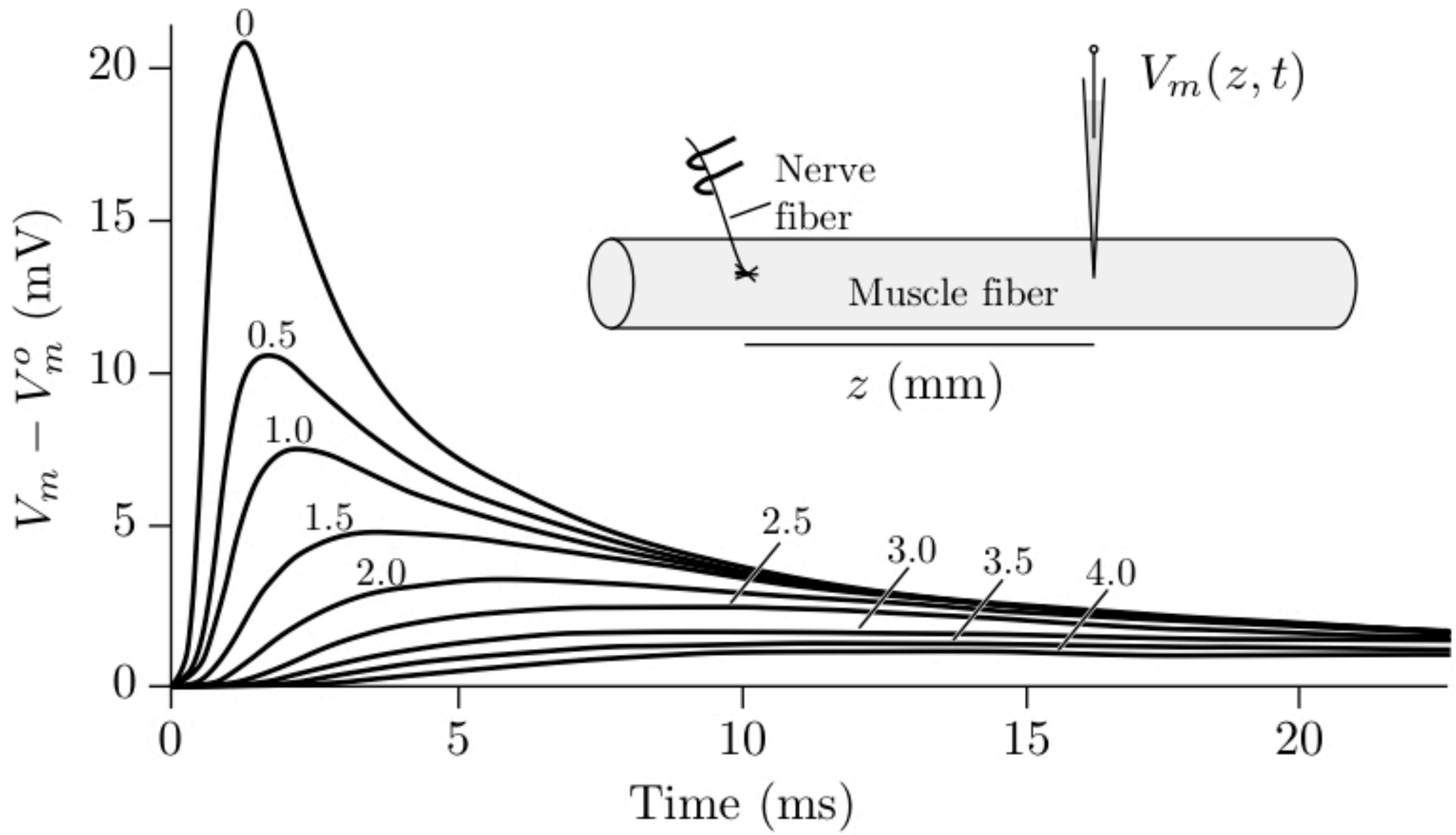


Figure 2.5

Rana temporaria
Fatt & Katz (1951)

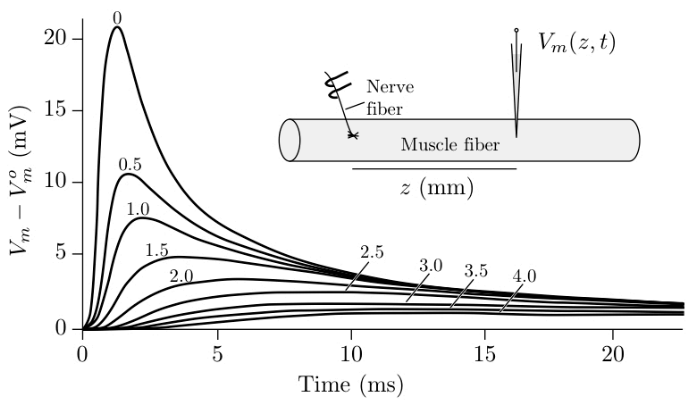
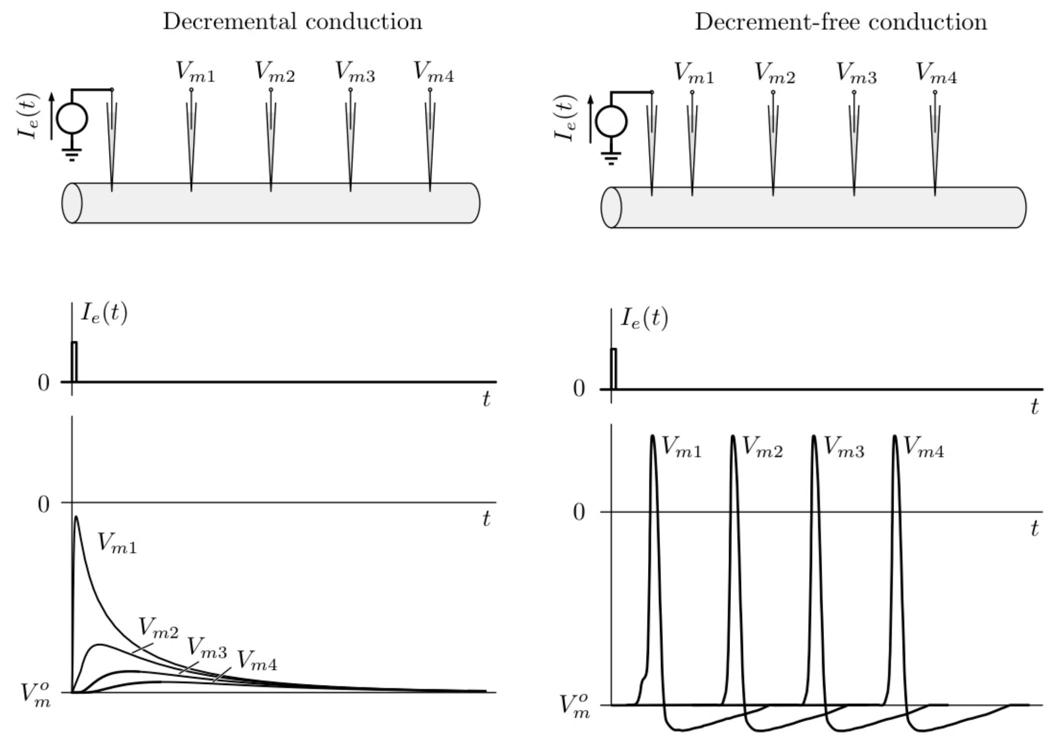


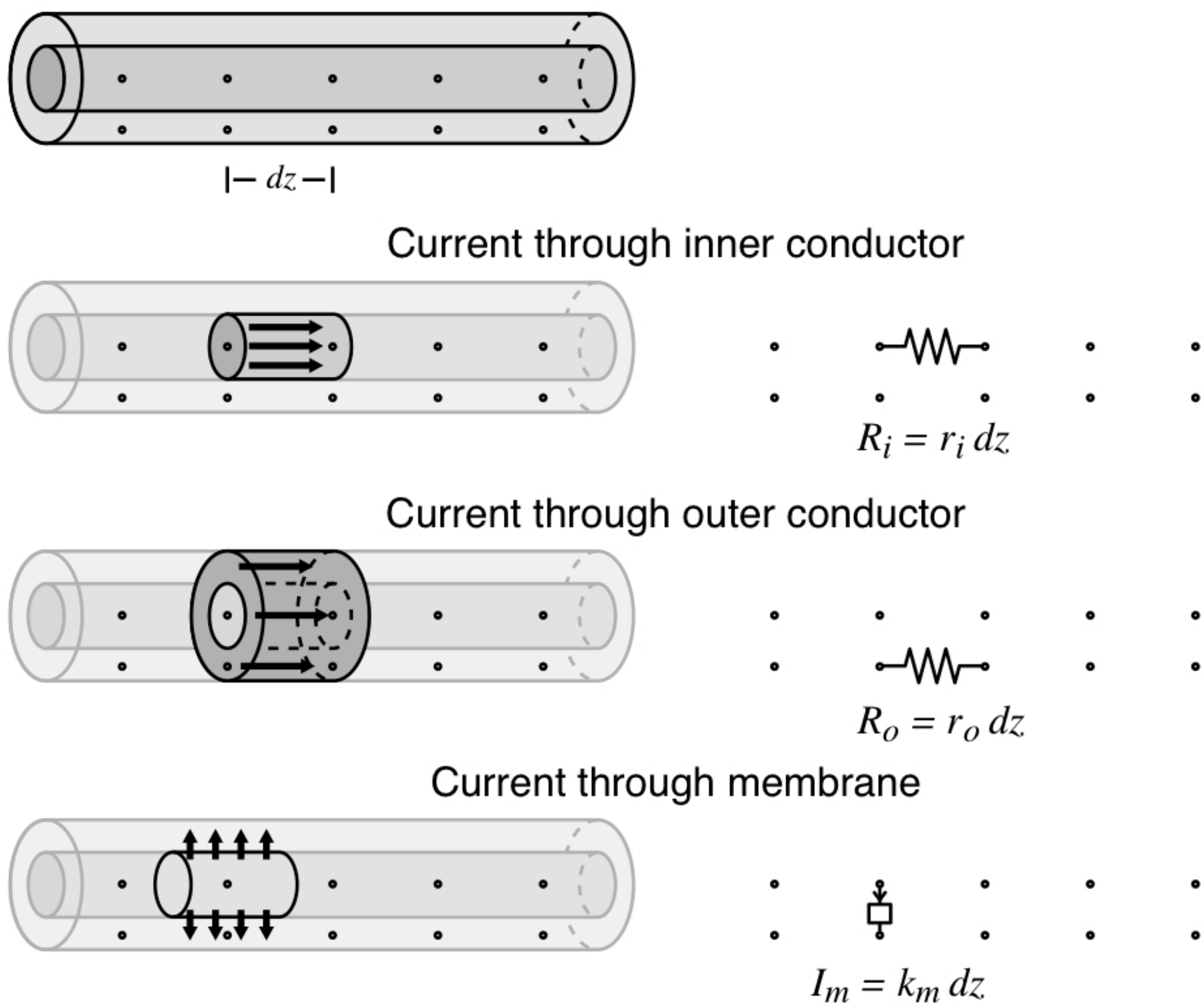
Figure 2.5



→ Model for electrically large cells?
(allowing for decremental & decrement free behavior)

Core-Conductor Model (as our starting point)

Core Conductor Model



Core Conductor Model

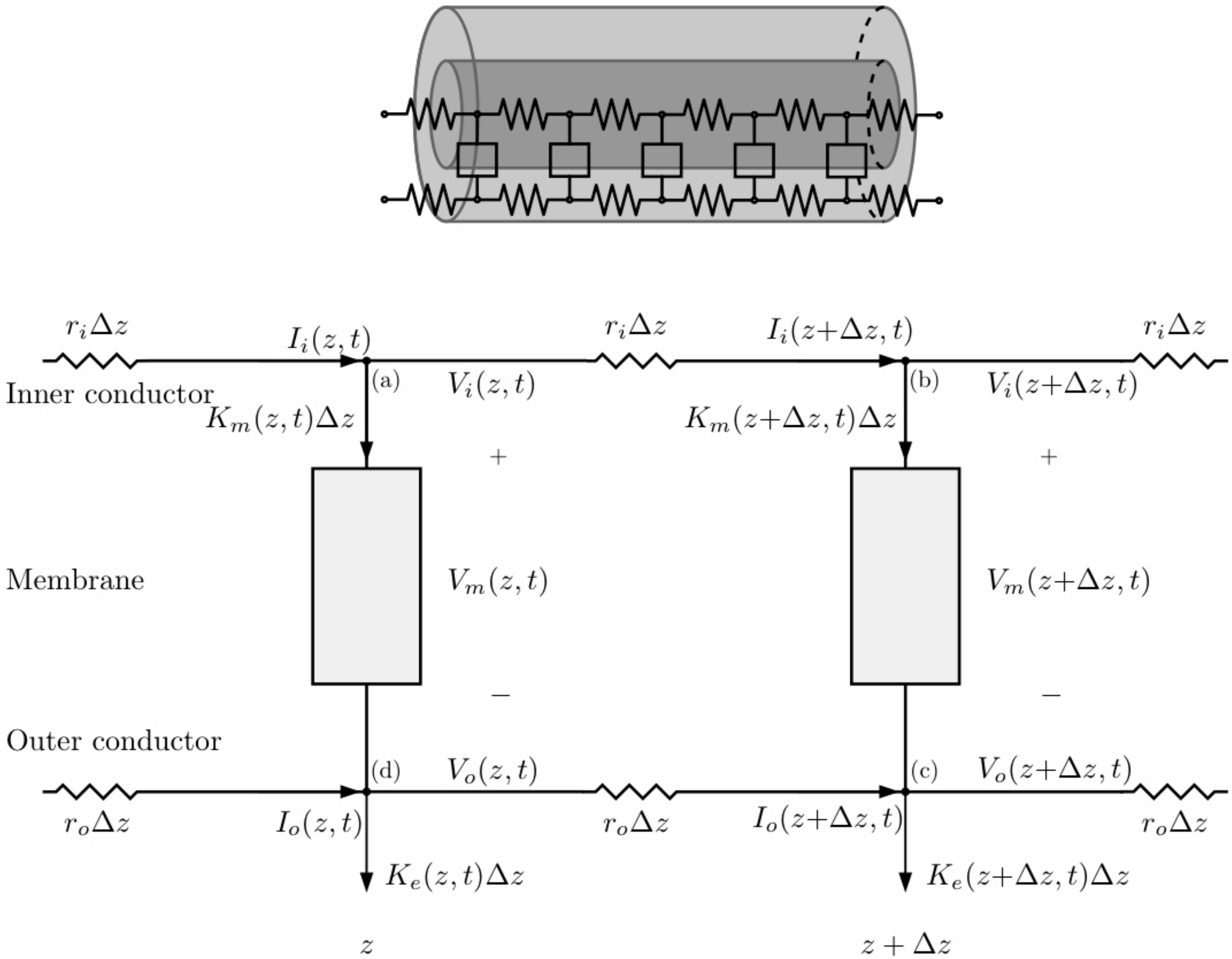


Figure 2.7

Ex. 1

Two compartments of a fluid-filled chamber are separated by a membrane as shown in Fig.5. The

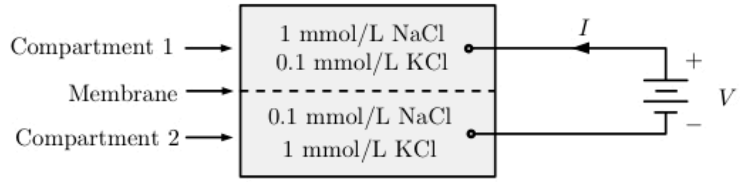


Figure 5:

area of the membrane is 100 cm^2 and the volume of each compartment is 1000 cm^3. The solution in compartment 1 contains 1 mmol/L NaCl and 0.1 mmol/L KCL. The solution in compartment 2 contains 0.1 mmol/L NaCl and 1 mmol/L KCL. The temperatures of the solutions are 24degC. The membrane is known to be permeable to a single ion, but it is not known if that ion is sodium, potassium, or chloride. Electrodes connect the solutions in the compartments to a battery. The current I was measured with the battery voltage $V = 0$ and was found to be $I = -1$ mA.

a. Identify the permeant ion species. Explain your reasoning.

b. Draw an equivalent circuit for the entire system, including the battery. Indicate values for those components whose values can be determined.

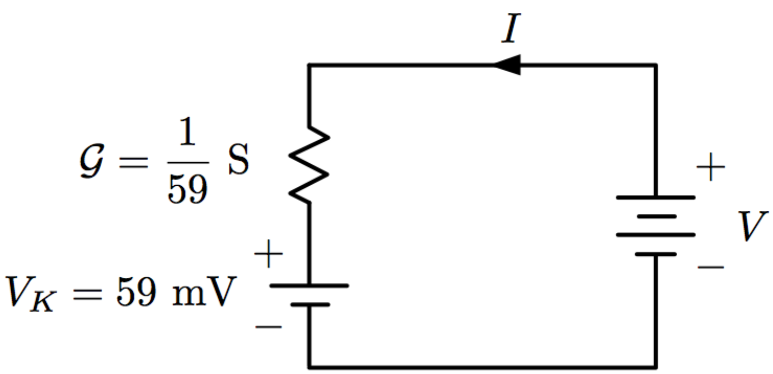
c. Determine the current I that would result if the battery voltage were set to 1 V. Explain your reasoning.

Ex. 1 (ANSWERS)

a) Identify the permeant ion species. Explain your reasoning.

Potassium

b. Draw an equivalent circuit for the entire system, including the battery. Indicate values for those components whose values can be determined.



$$V_K = \frac{RT}{F} \ln \frac{c_K^2}{c_K^1} = 59 \text{ mV} \times \log\left(\frac{1 \text{ mmol/L}}{0.1 \text{ mmol/L}}\right) = +59 \text{ mV}.$$

$$\mathcal{G} = \frac{I}{V - V_K} = \frac{-1 \text{ mA}}{-59 \text{ mV}} = \frac{1}{59} \text{ S}.$$

c. Determine the current I that would result if the battery voltage were set to 1 V. Explain your reasoning.

$$I = \mathcal{G}(V - V_K) = \frac{1}{59}(1 - 0.059) = 15.9 \text{ mA}$$

Ex. 2

Consider the model of a cell shown in Fig.6 The cell has channels for the passive transport of

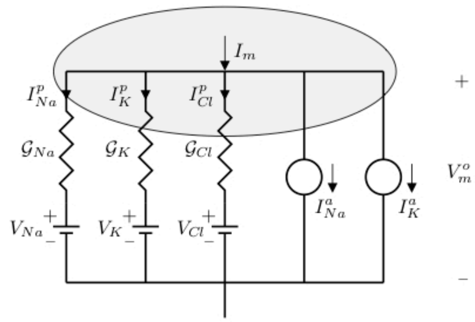


Figure 6:

sodium, potassium, and chloride as well as a pump that actively transports sodium out of the cell and potassium into the cell. The pump ratio is $I^a_{Na}/I^a_K = -1.5$. The following table shows the intracellular and extracellular concentrations, Nernst equilibrium potentials, and conductance ratios for sodium and potassium. Some information is also given for chloride; blank entries represent unknown quantities. The cell also contains impermeant intracellular ions. Assume that the cell is in equilibrium at $t = 0$, i.e., assume that at $t = 0$ the cell has reached a condition for which all solute concentrations, the cell volume, and the membrane potential are constant.

	c^i_n	c^o_n	V_n	$\mathcal{G}_n/\mathcal{G}_K$
	(mmol/L)		(mV)	
Na^+	10	140	+68	0.1
K^+	140	10	−68	1
Cl^-		150		1

Figure 7:

a. Determine V^o_m.

b. At $t = 0$, the external concentration of chloride is reduced from 150 mmol/L to 50 mmol/L by substituting an isosmotic quantity of an impermeant anion for chloride. Assume that the concentrations of sodium and potassium both inside and outside the cell remain the same and that the volume of the cell does not change. Determine $V^o_m(0^+)$, the value of the membrane potential immediately after the change in solution. You may ignore the effect of the membrane capacitance.

Ex. 2 (ANSWERS)

Determine V_m^o

Cell at equilibrium plus no Cl^- pumps (i.e., Cl^- current is zero) means chloride plays no direct role → resting potential must be same as Cl^- Nernst potential

Equilibrium indicates no net flux of either Na^+ or K^+:

$$\begin{aligned} \mathcal{G}_{Na}(V_m^o - V_{Na}) + I_{Na}^a &= 0, \\ \mathcal{G}_K(V_m^o - V_K) + I_K^a &= 0. \end{aligned} \qquad \frac{\mathcal{G}_{Na}(V_m^o - V_{Na})}{\mathcal{G}_K(V_m^o - V_K)} = \frac{I_{Na}^a}{I_K^a}.$$

This equation can be expressed in terms of the dimensionless ratios $\gamma = \mathcal{G}_{Na}/\mathcal{G}_K$ and $\alpha = -I_{Na}^a/I_K^a$ as

$$\gamma \frac{(V_m^o - V_{Na})}{(V_m^o - V_K)} = -\alpha.$$

$$V_m^o = \frac{\gamma V_{Na} + \alpha V_K}{\gamma + \alpha} \qquad V_m^o = \frac{0.1 \cdot 68 + 1.5 \cdot (-68)}{0.1 + 1.5} = -59.5 \text{ mV}$$

Ex. 2 (ANSWERS)

Determine $V_m^o(0^+)$, the value of the membrane potential immediately after the change in solution. You may ignore the effect of the membrane capacitance.

Changing chloride concentration will change Nernst potential for chloride (assuming that the intracellular concentration of chloride does not change instantaneously:

$$\Delta V_{Cl} = \frac{-RT}{F} \ln\left(\frac{50}{c^i_{Cl}(0^+)}\right) - \frac{-RT}{F} \ln\left(\frac{150}{c^i_{Cl}(0^-)}\right) = \frac{RT}{F} \ln\left(\frac{150}{50}\right)$$

Temperature not given, but can be deduced from other quantities:

$$V_{Na} = \frac{RT}{F \log_{10} e} \log\left(\frac{c^o_{Na}}{c^i_{Na}}\right) \qquad RT/(F \log_{10} e) \approx 59 \text{ mV}.$$

$$68 = \frac{RT}{F \log_{10} e} \log\left(\frac{140}{10}\right), \qquad \Delta V_{Cl} = 59 \log\left(\frac{150}{50}\right) \approx 28 \text{ mV}.$$

Now the change in the membrane resting potential can easily be deduced from superposition:

$$\Delta V_m^o = \frac{\mathcal{G}_{Cl}}{\mathcal{G}_m} \Delta V_{Cl} = \frac{1}{1+1+0.1} 28 = 13.3 \text{ mV}. \qquad V_m(0^+) = -59.5 + 13.3 = -46.2 \text{ mV}.$$