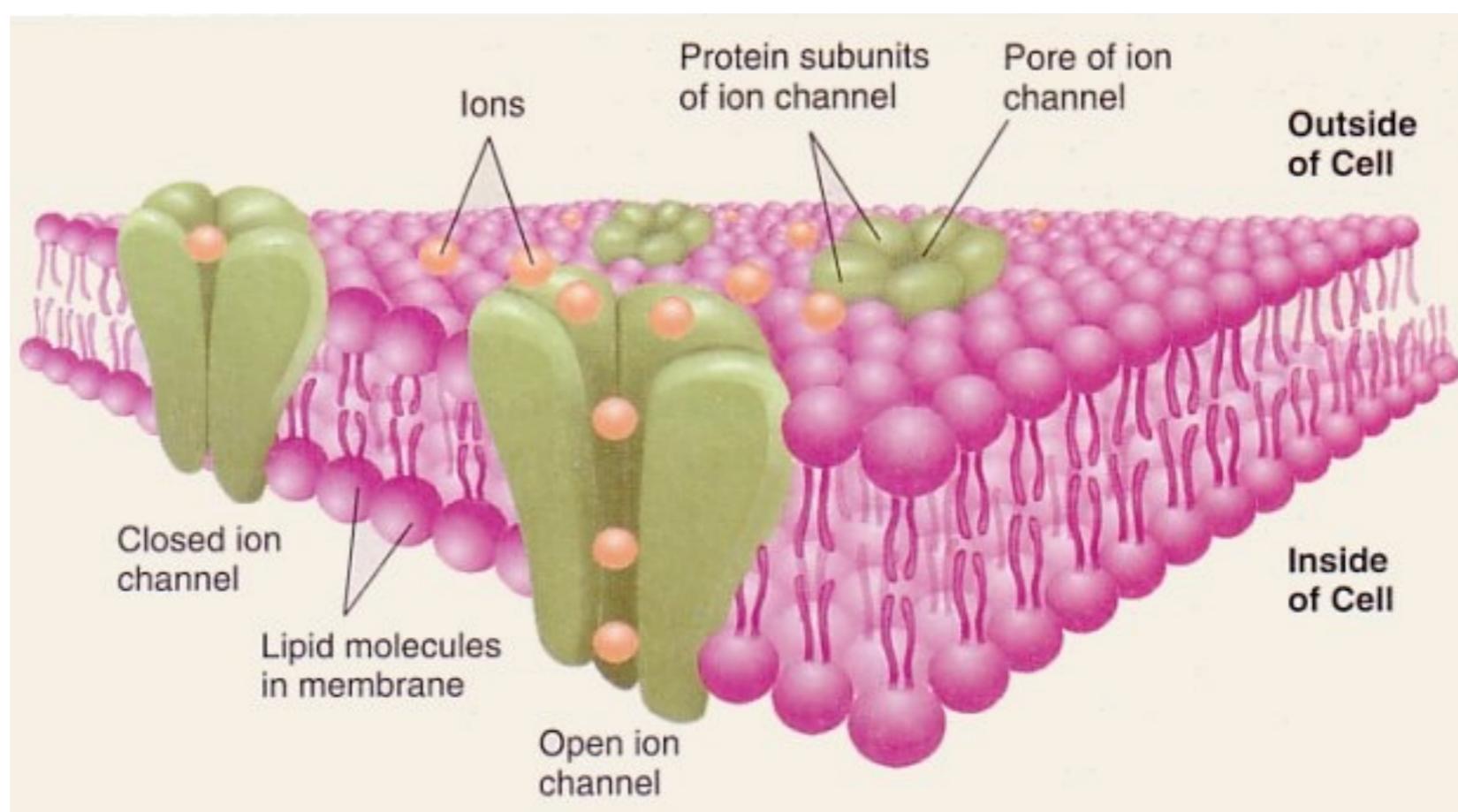
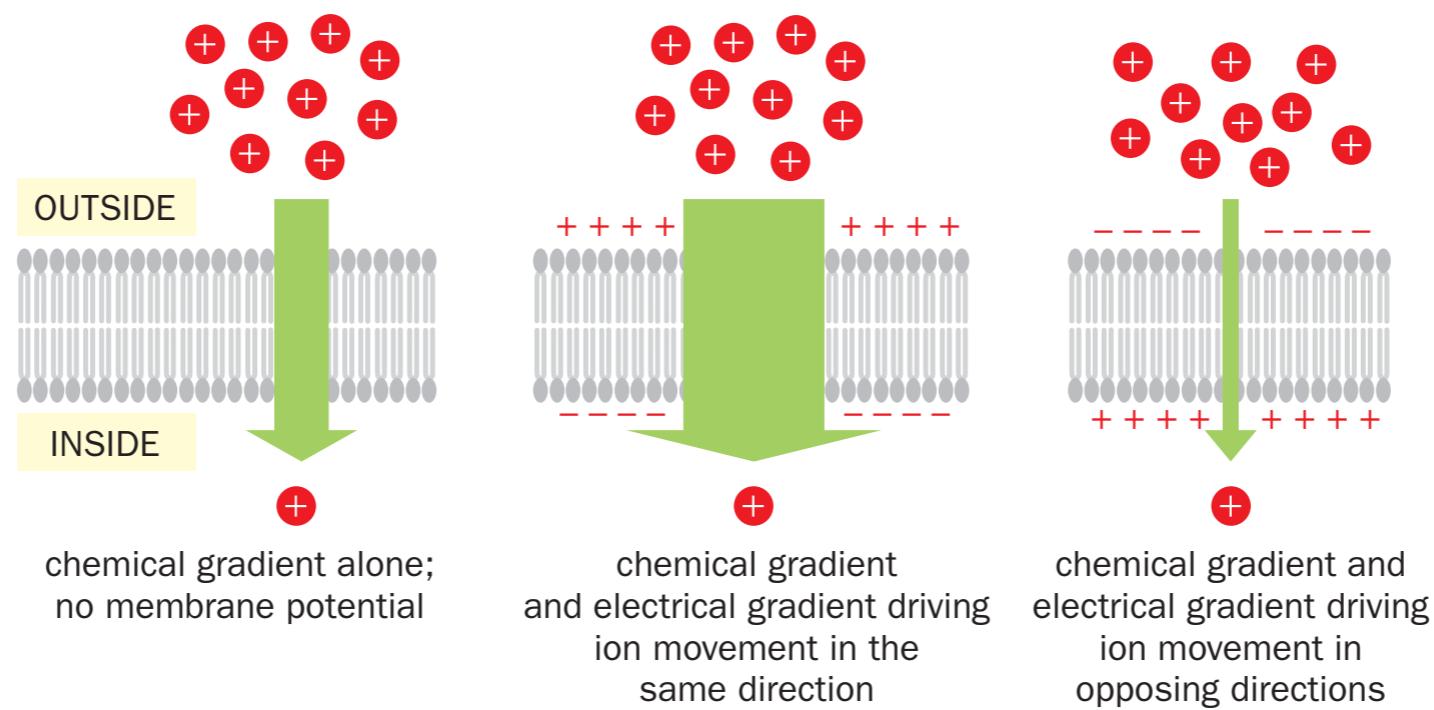


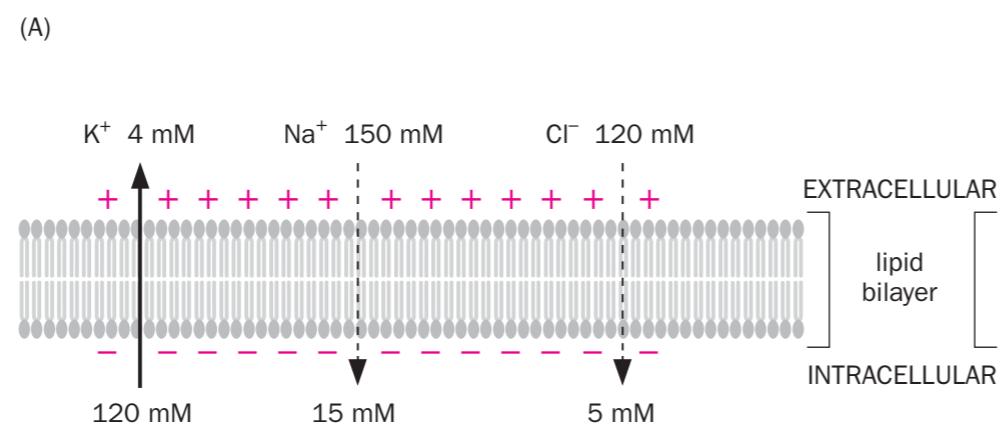
Single Neuron Dynamics



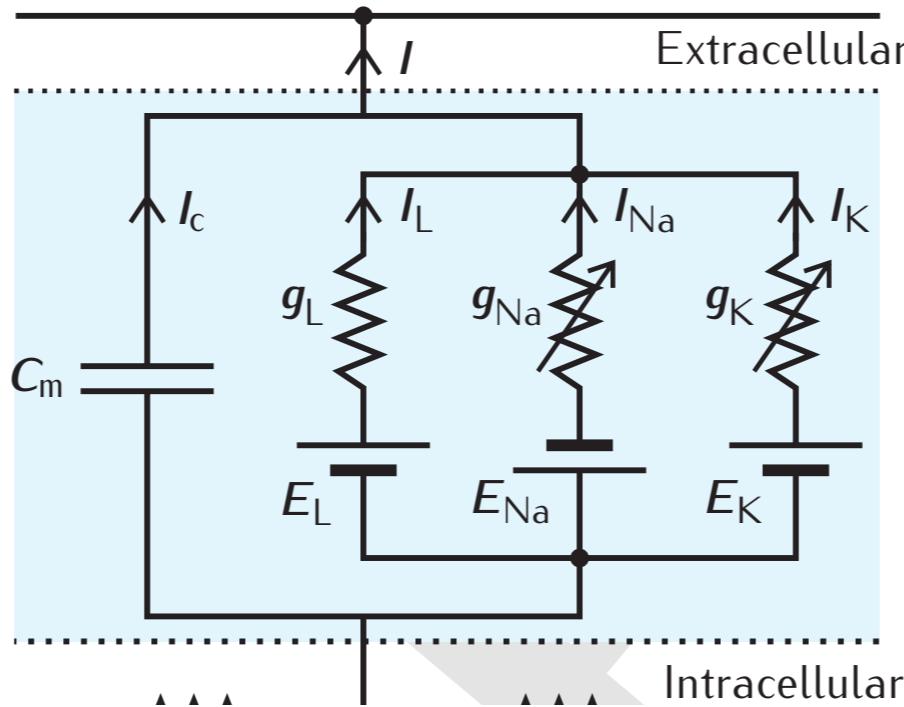
What determines the resting potential of a neuron?



Ion pump

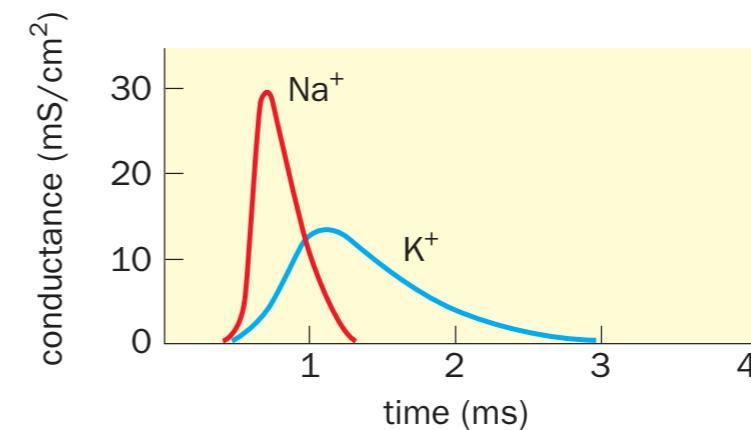
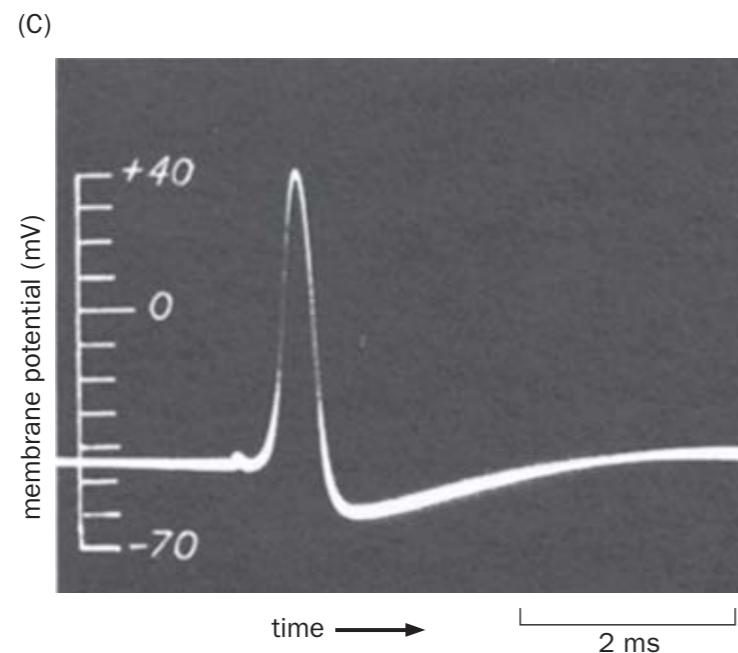


The Equivalent Electronic Circuit of a Neuron

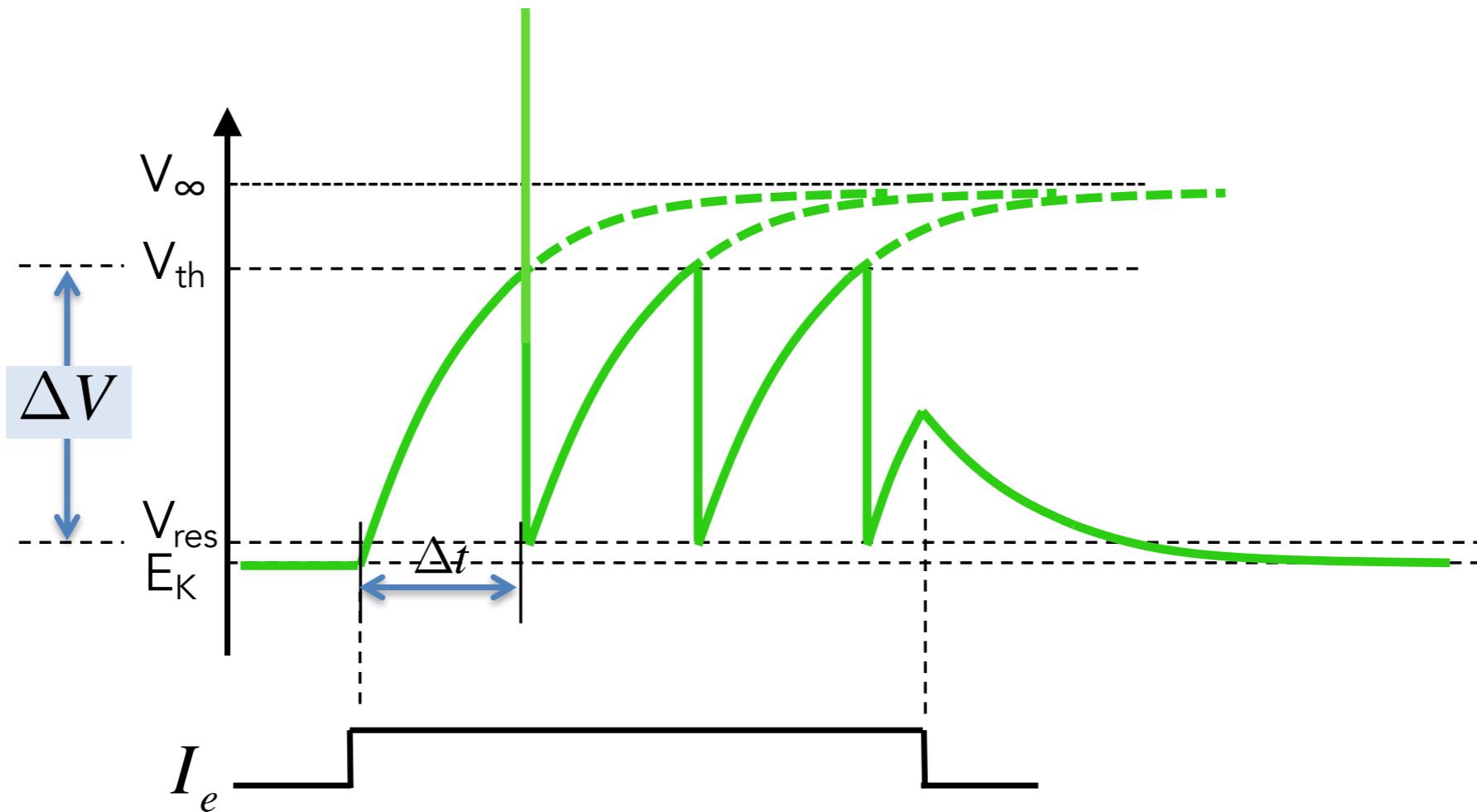


$$C_m \frac{dV}{dt} = - \sum_i g_i(V)(V - E_i) - g_L(V - E_L) + I_e$$

Qualitative explanation of action potential generation



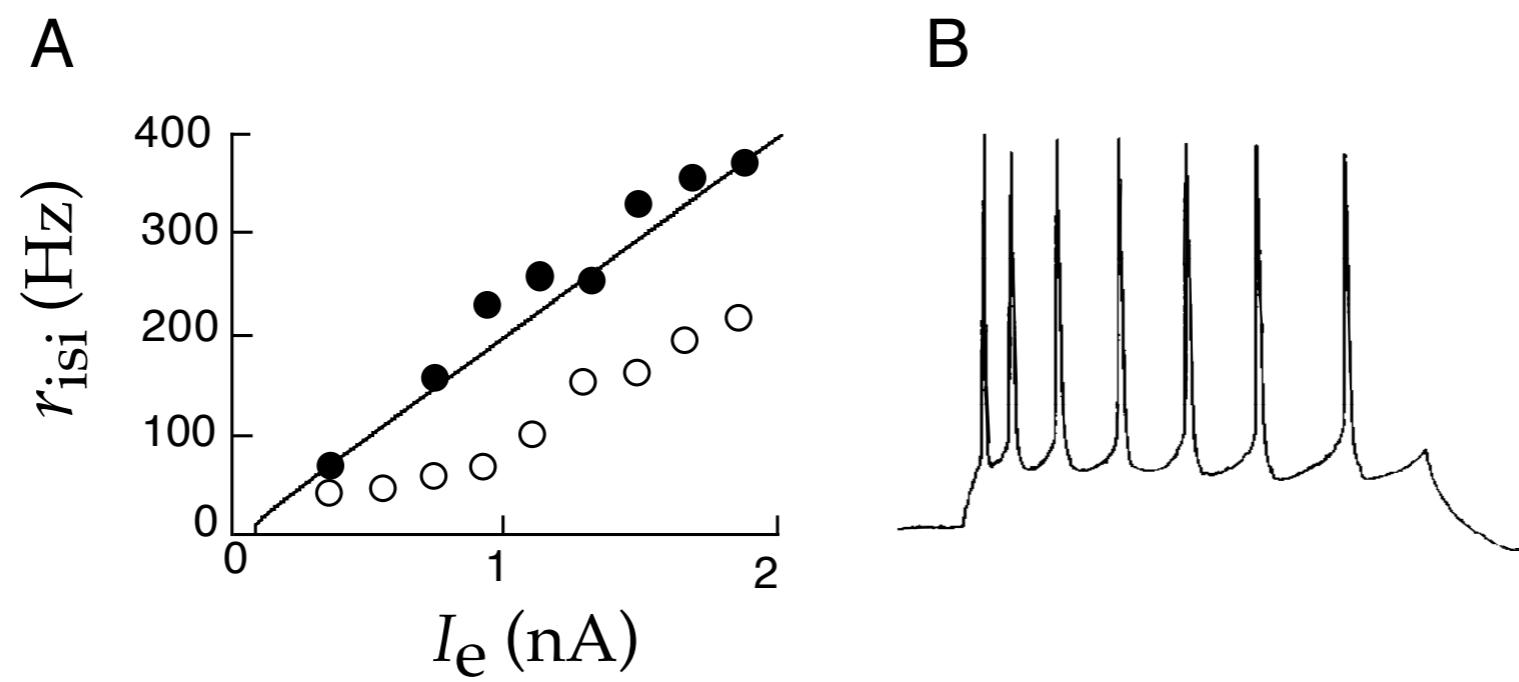
Integrate-and-Fire model



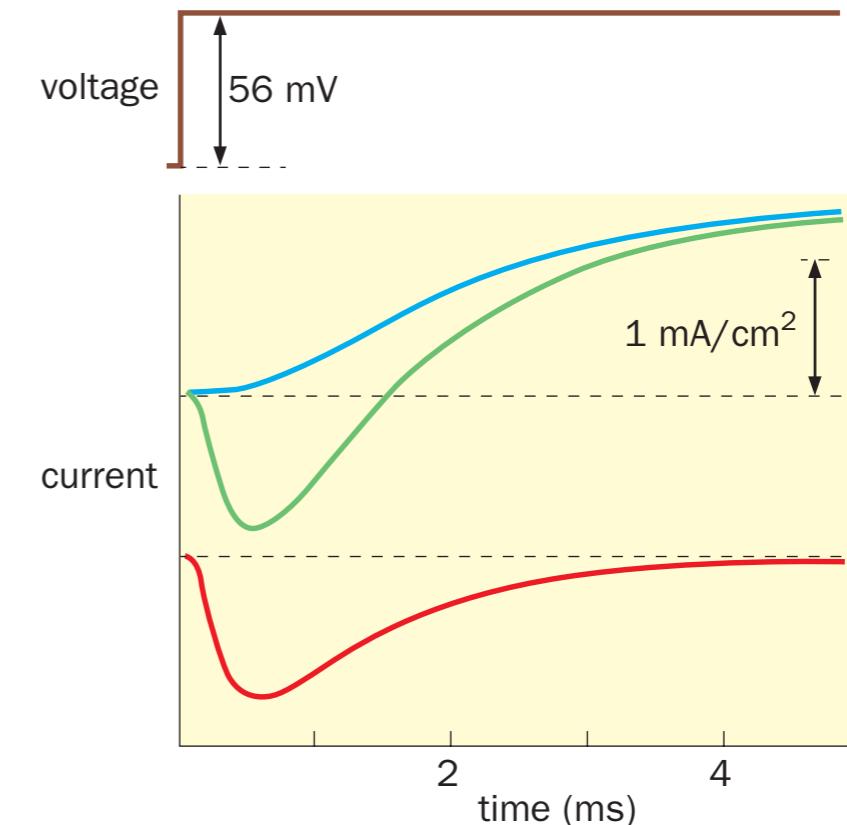
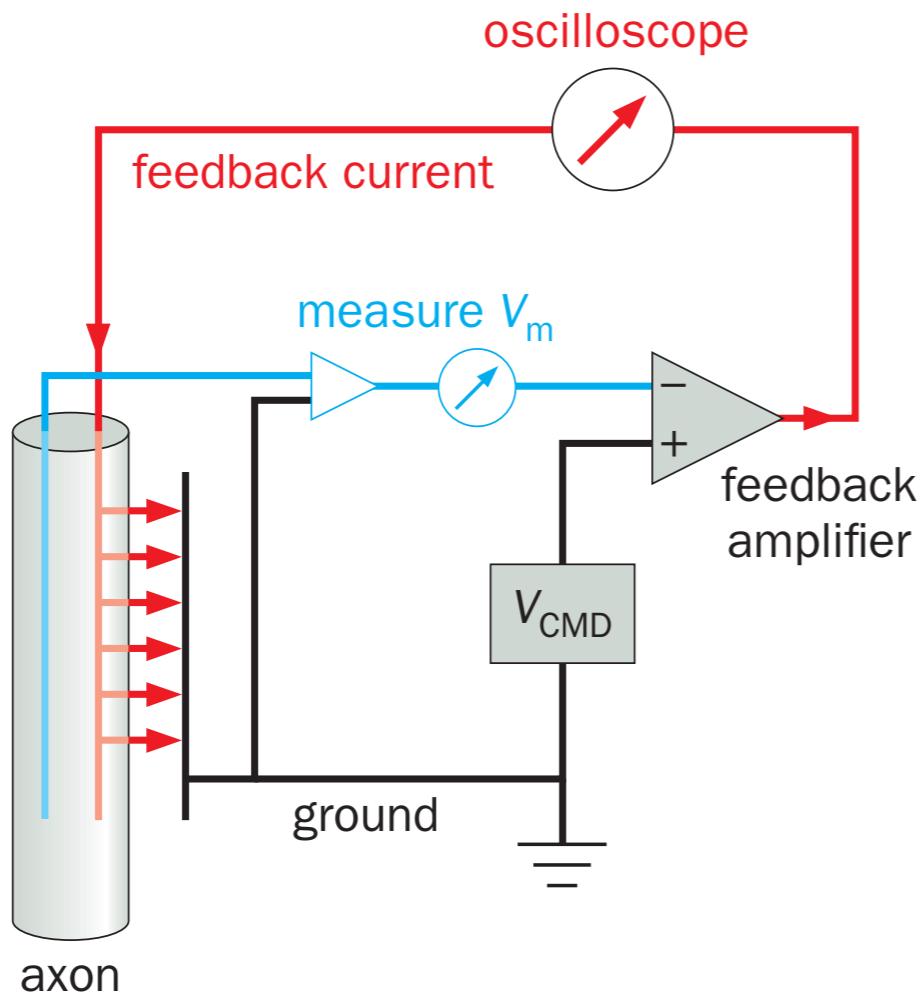
$$C \frac{dV}{dt} = -g(V - E_K) + I_e$$

$$V(t_{spike}^-) = V_{th}$$

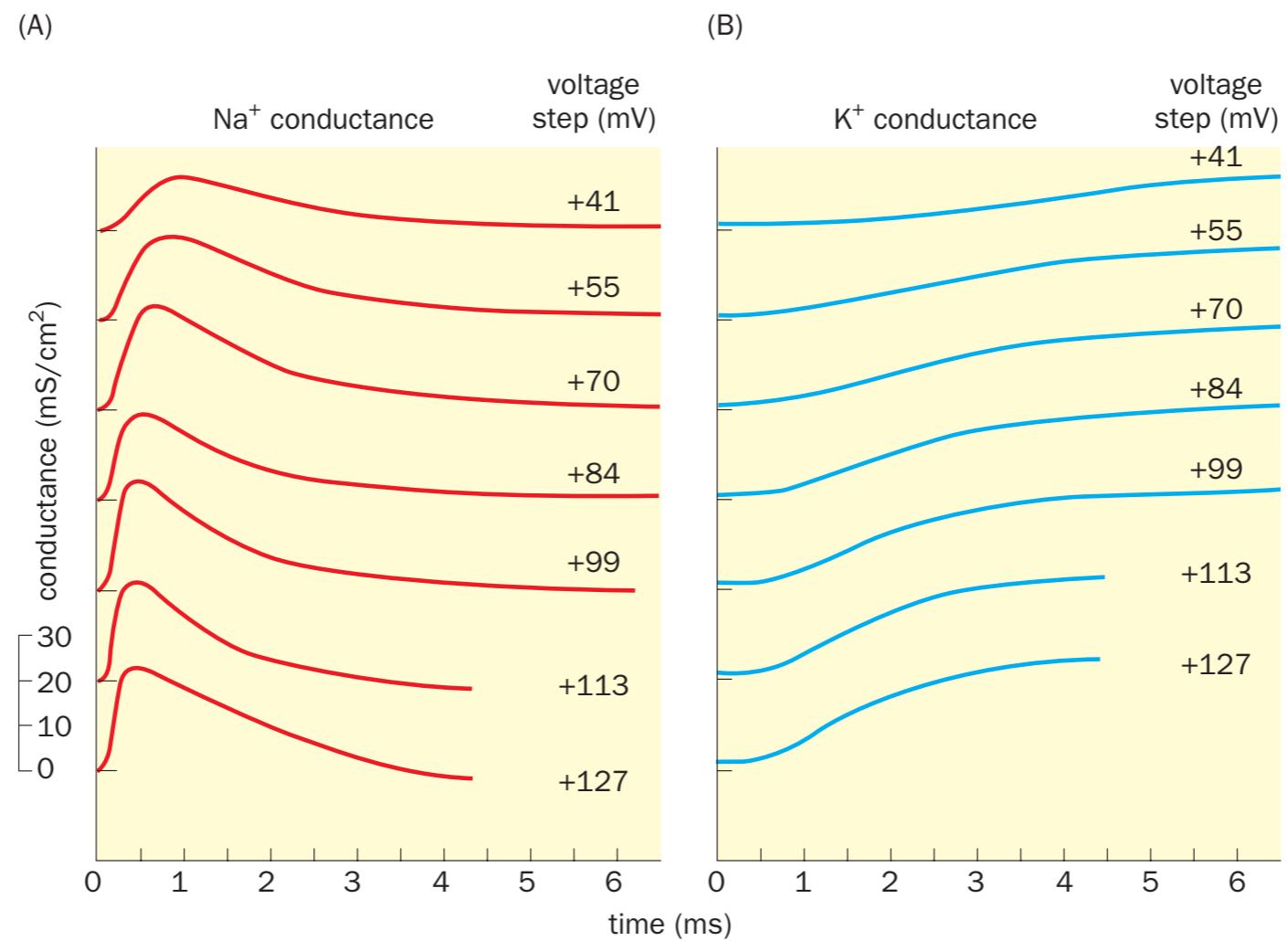
$$V(t_{spike}^+) = V_{res}$$



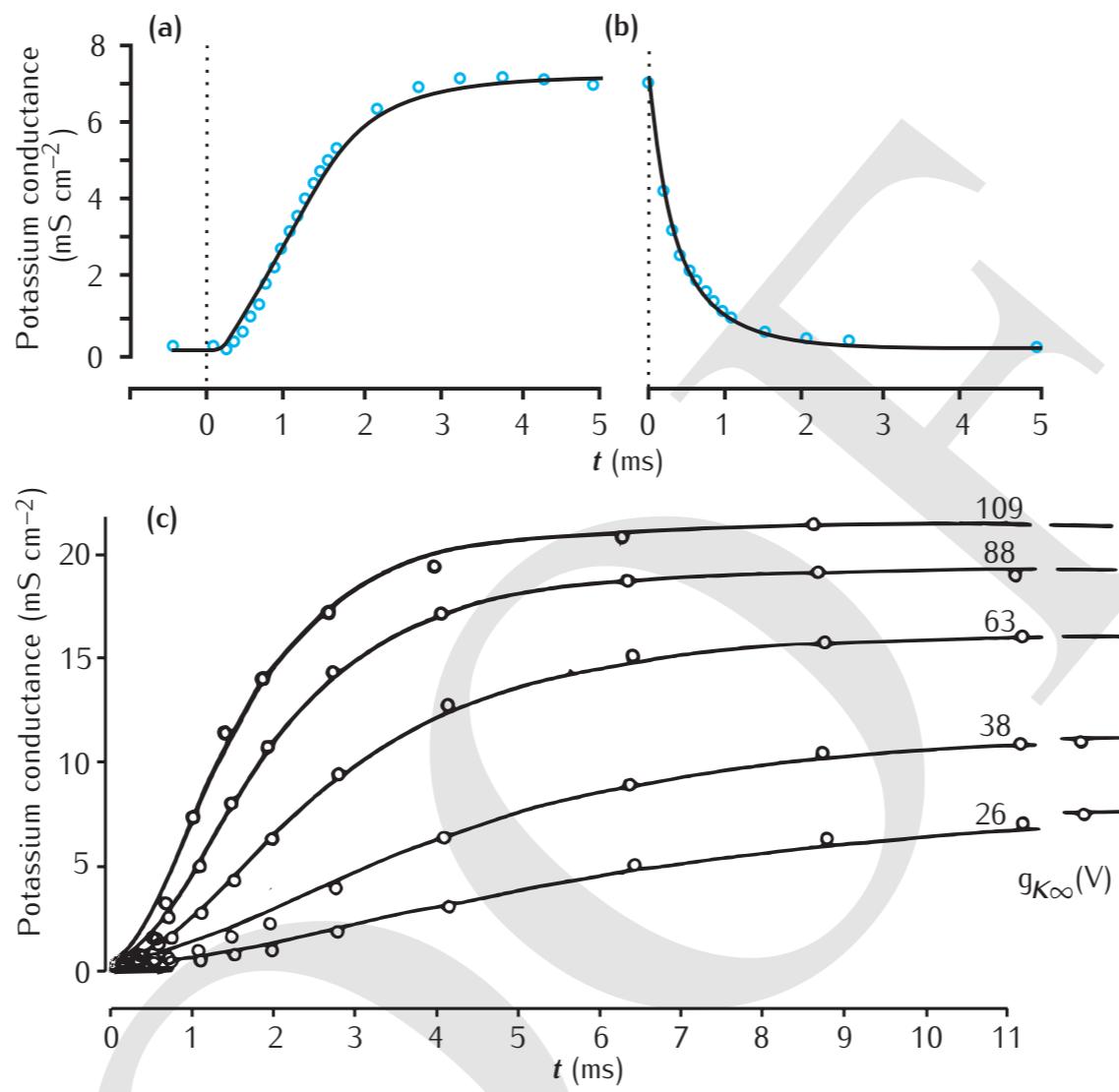
Voltage Clamp Recording



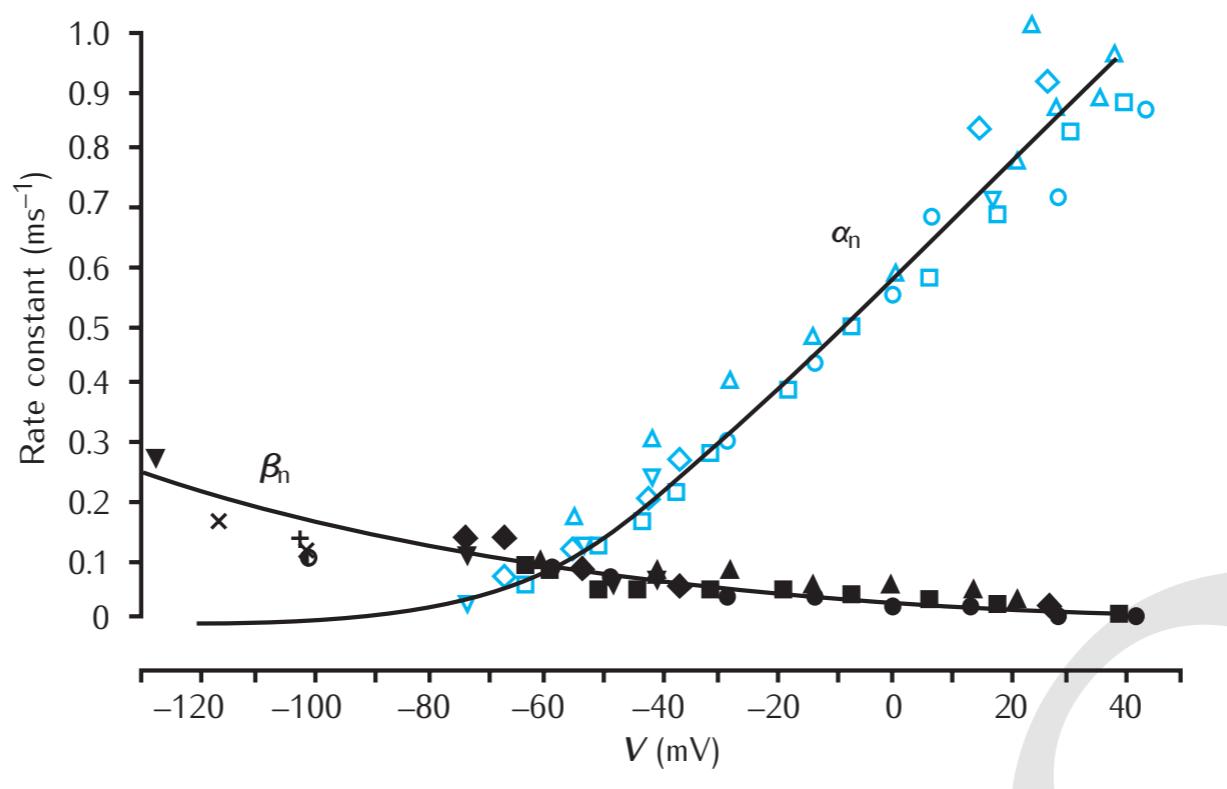
Voltage-gated Conductance



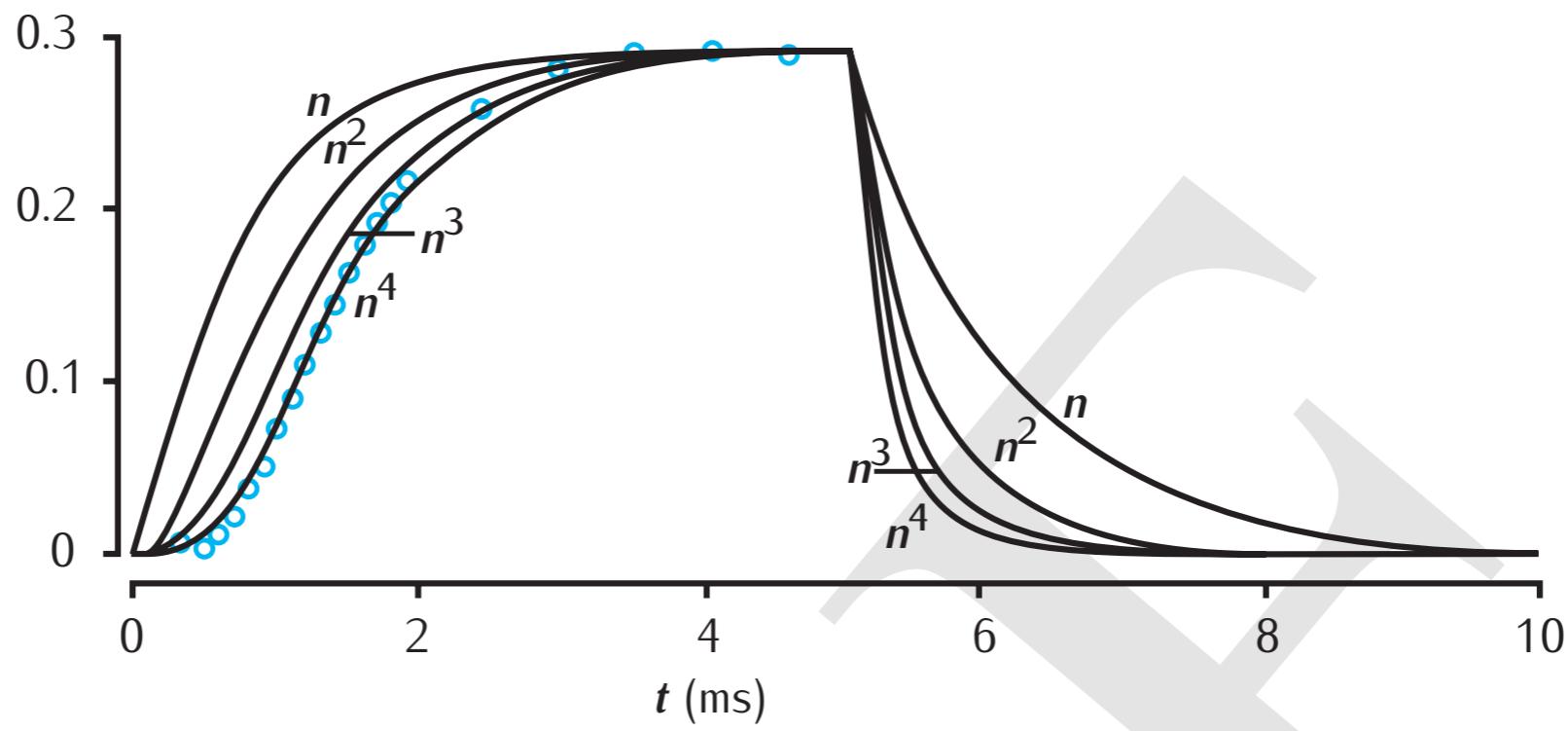
Voltage-gated Conductance of K⁺



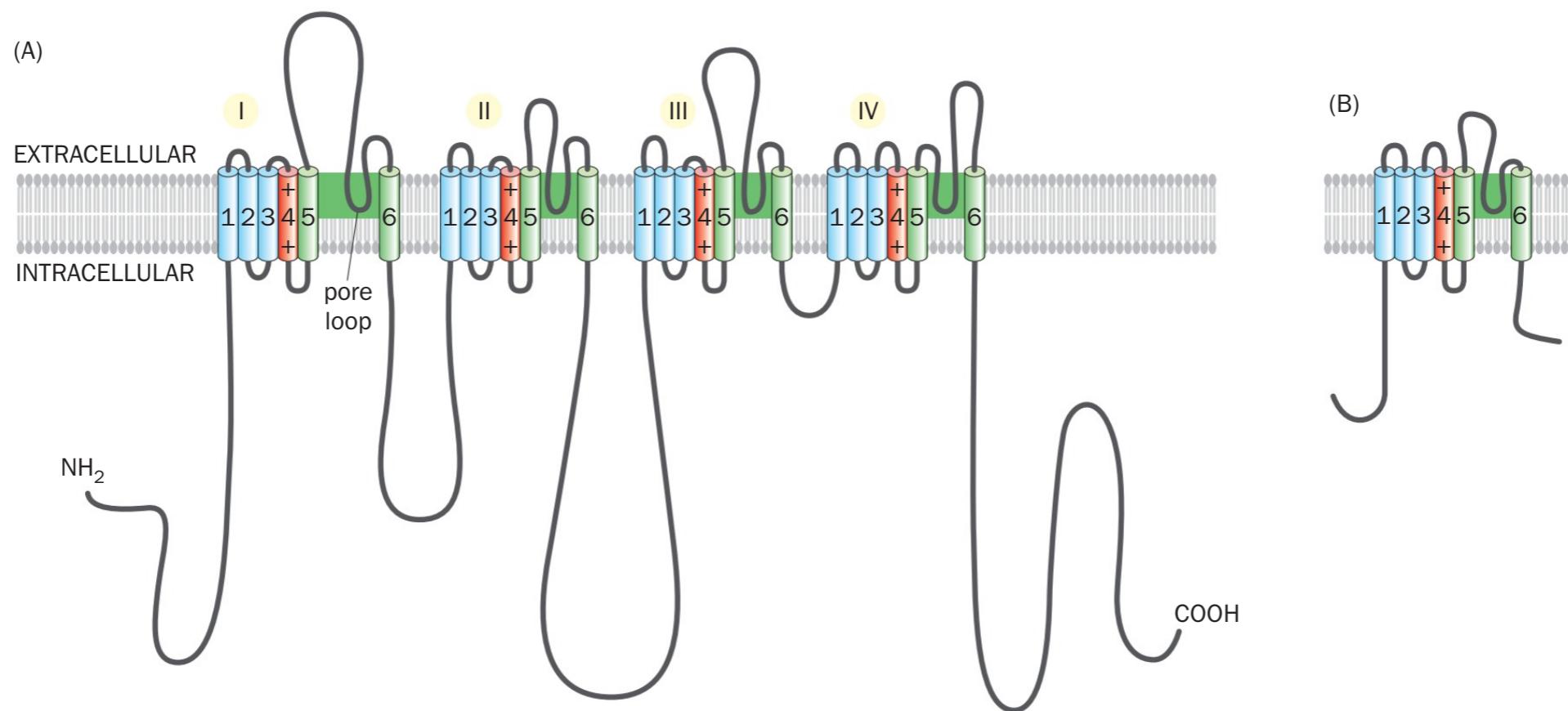
Voltage-gated Conductance of K⁺

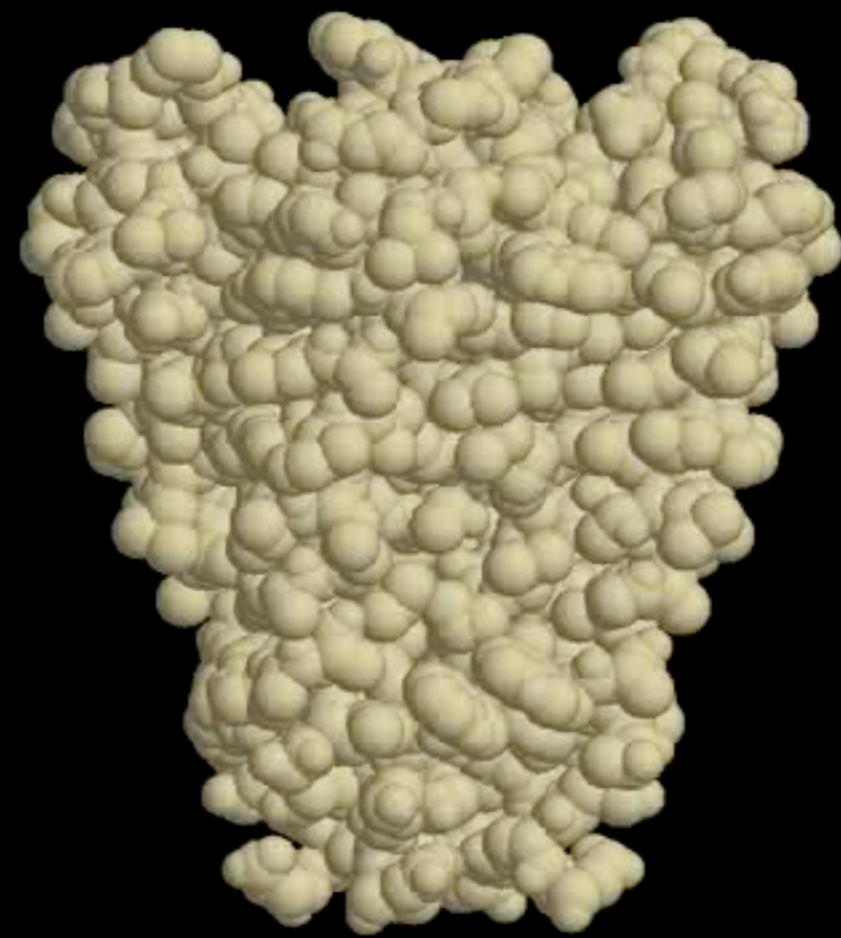


Voltage-gated Conductance of K⁺

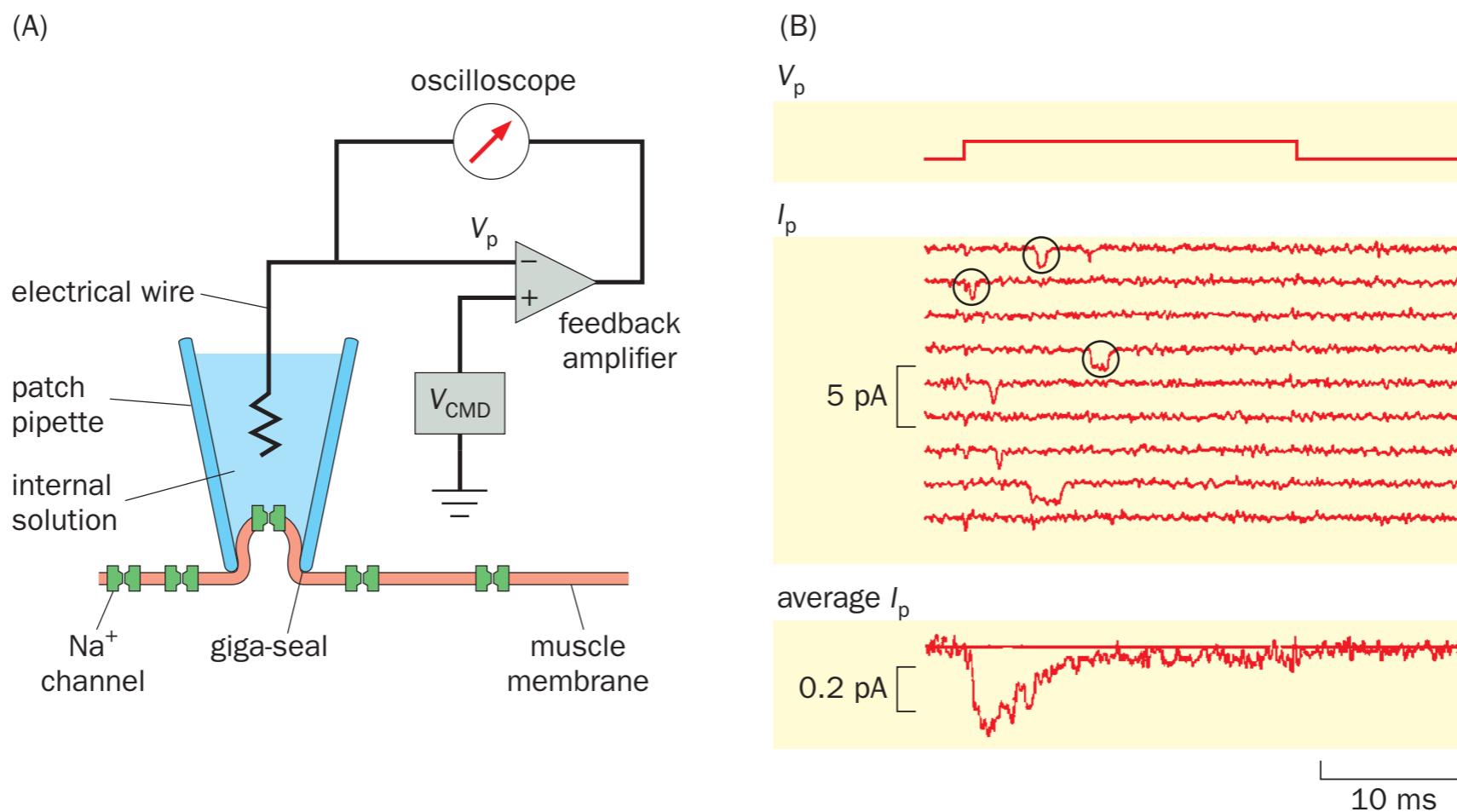


The structure of voltage gated Na^+ and K^+ channels

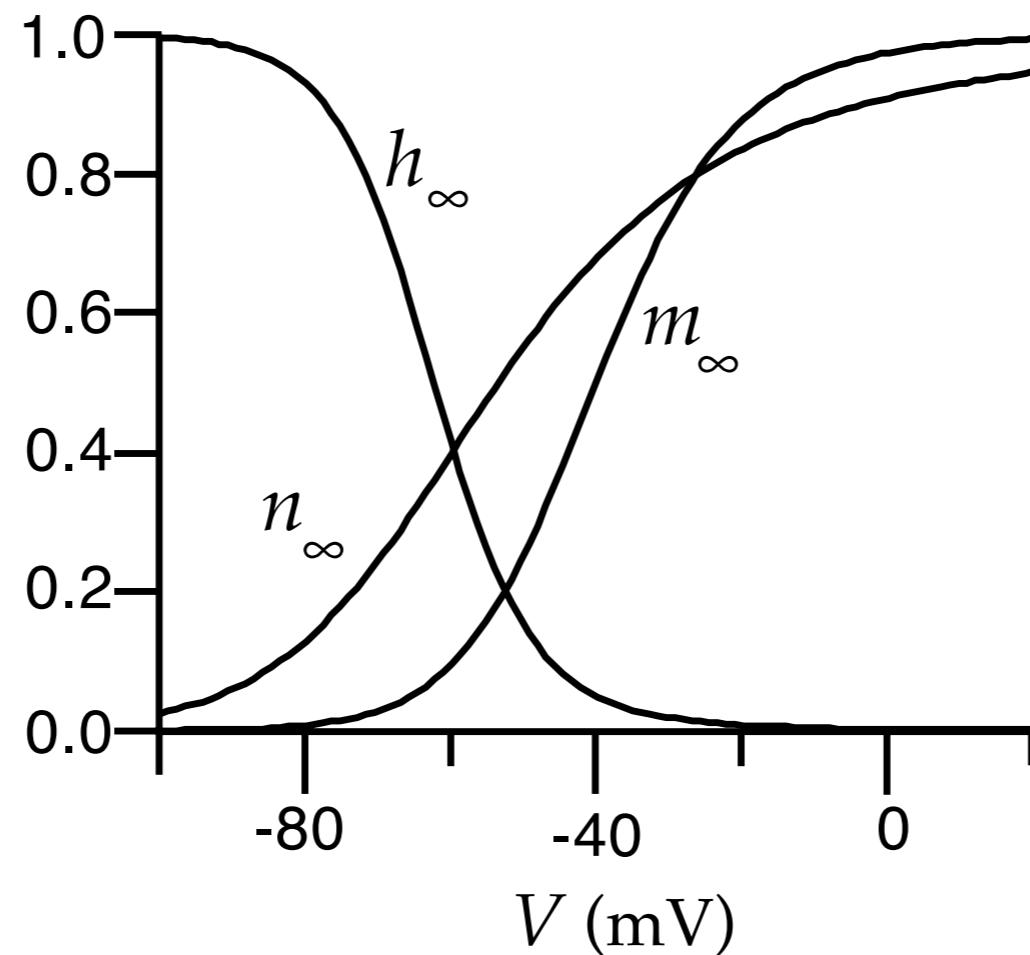




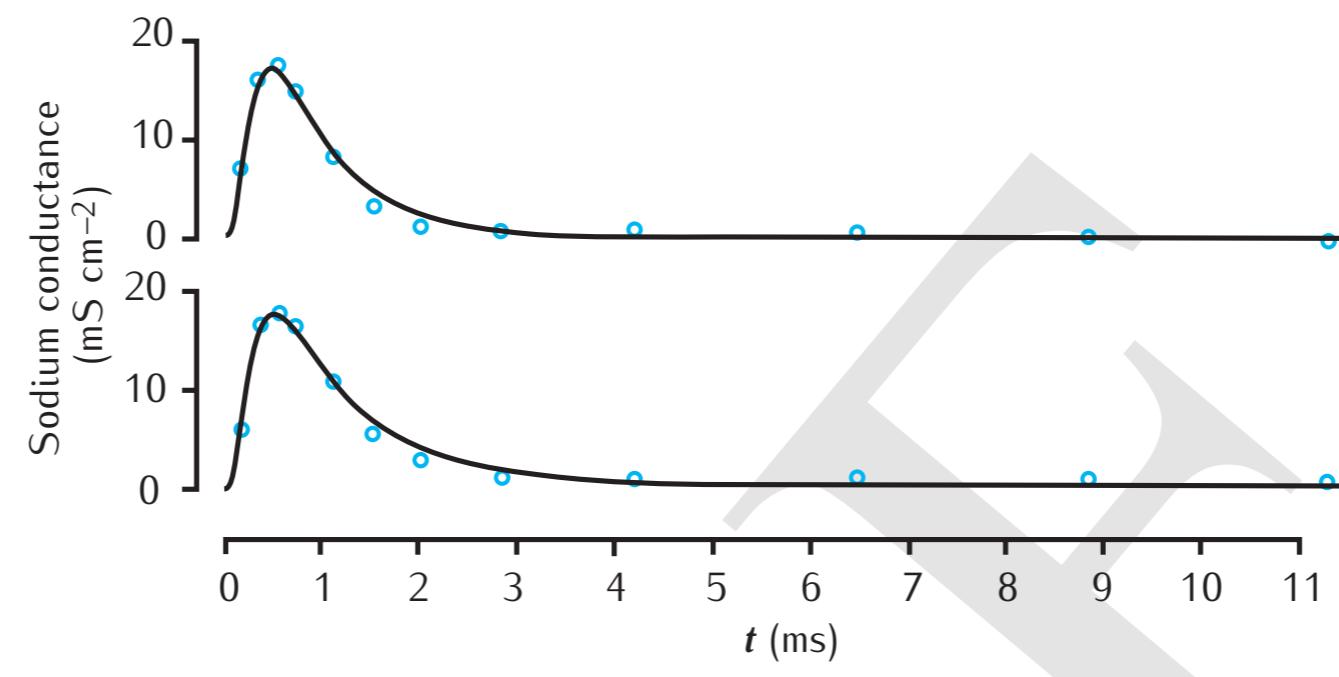
Transient Na^+ channel conductance



Transient Na^+ channel conductance



Transient Na^+ channel conductance

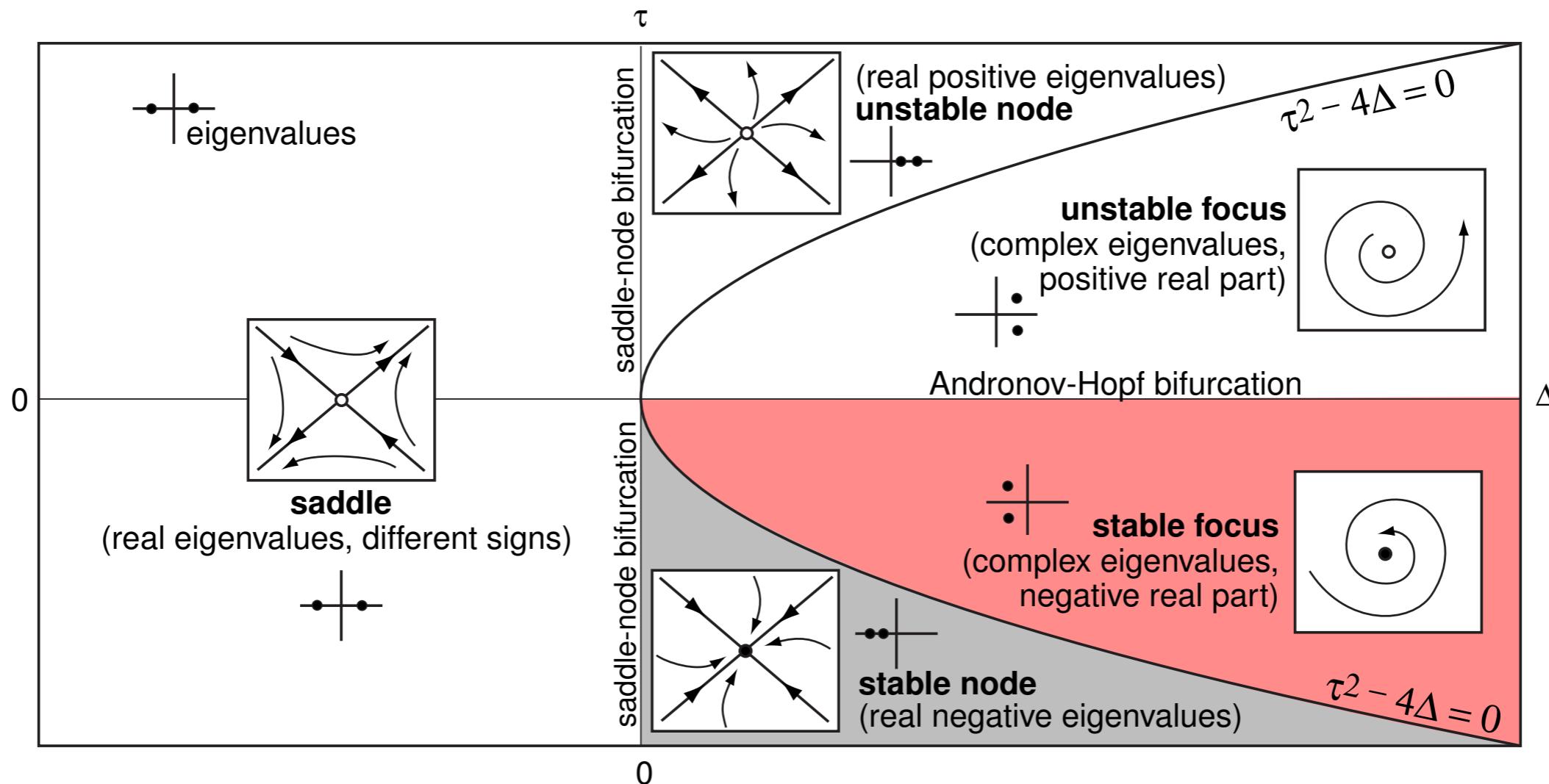


Fix Point one dimension

$$\frac{dV}{dt} = F(V)$$

$$F(V^*) = 0$$

Fix Point in two dimensions

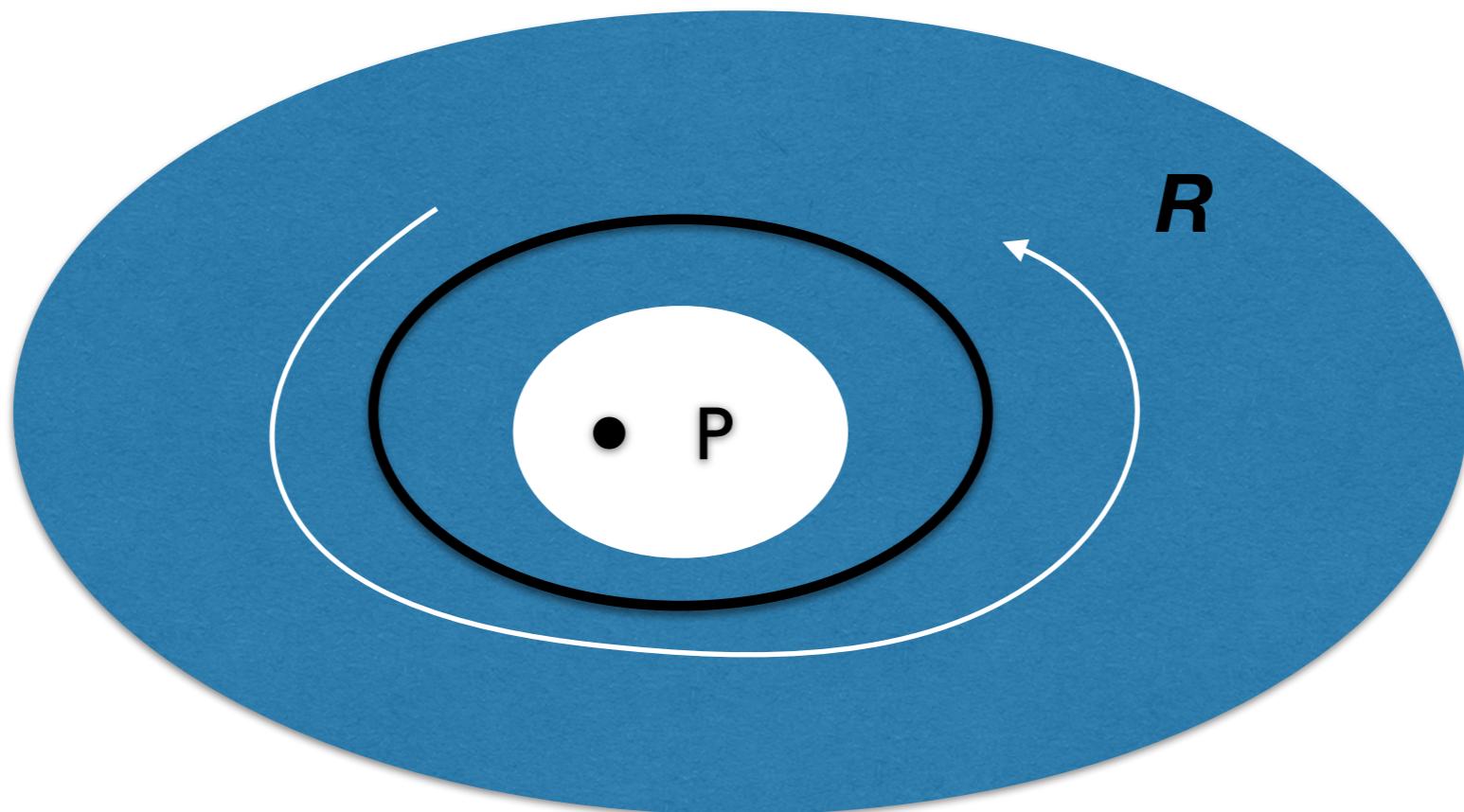


Poincare-Bendixson Theorem (2D)

- R is a closed, bounded subset of the plane;
- $\frac{d\mathbf{x}}{dt} = \mathbf{f}(\mathbf{x})$ is a continuously differentiable vector field on an open set containing R ;
- R does not contain any fixed points; and
- There exists a trajectory C that is “confined” in R , in the sense that it starts in R and stays in R for all future time

Then either C is a closed orbit, or it spirals toward a closed orbit at $t \rightarrow \infty$. In either case, R contains a closed orbit.

Poincare-Bendixson Theorem (2D)



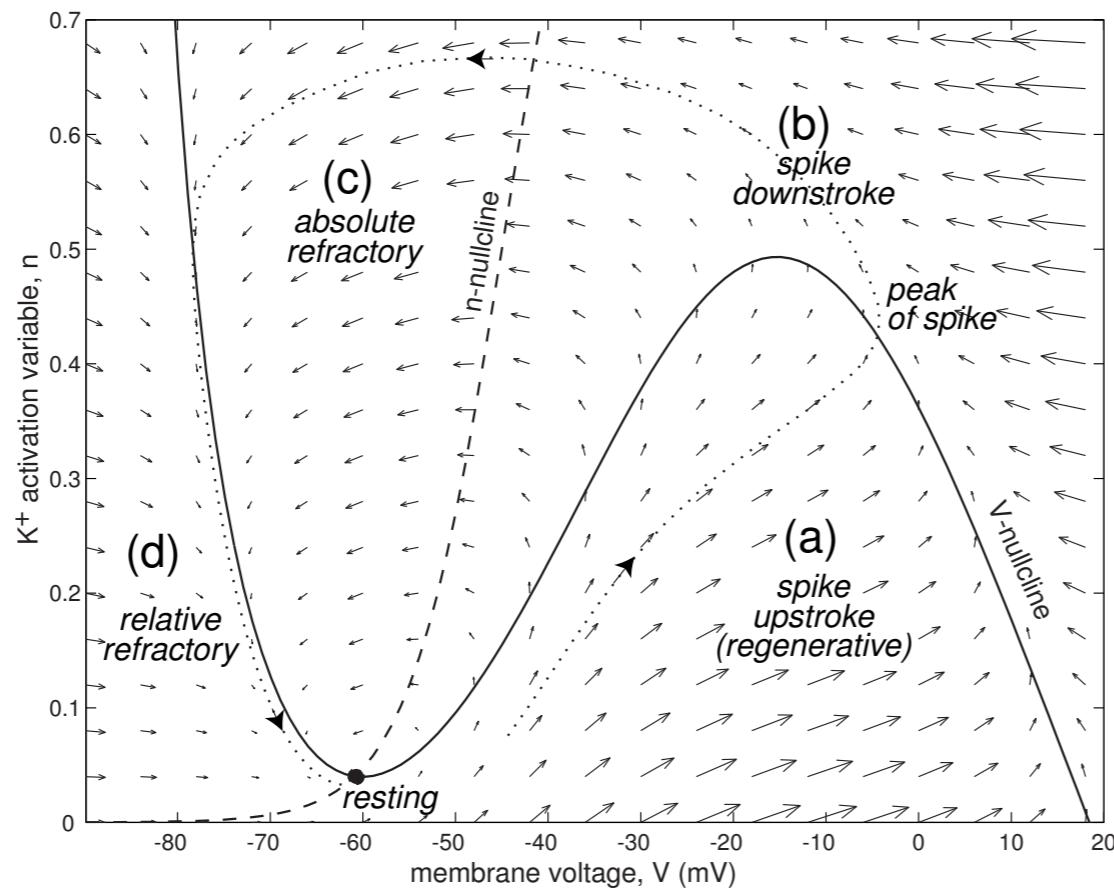


Figure 4.4: Nullclines of the $I_{Na,p} + I_K$ -model (4.1, 4.2) with low-threshold K^+ current in Fig.4.1b. (The vector field is slightly distorted for the sake of clarity of illustration).

Dynamic systems in Neuroscience

Eugene Izhikevich 2007

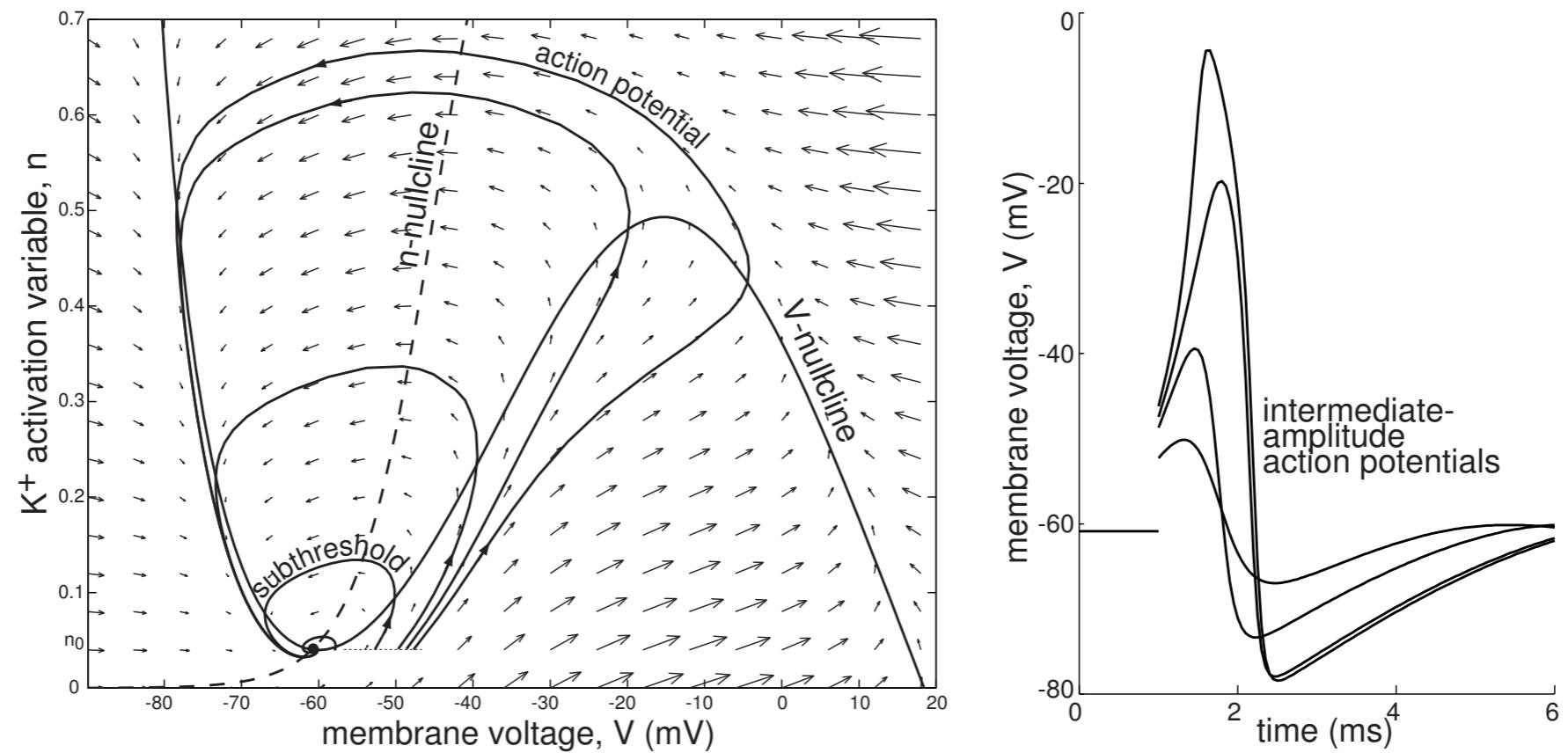
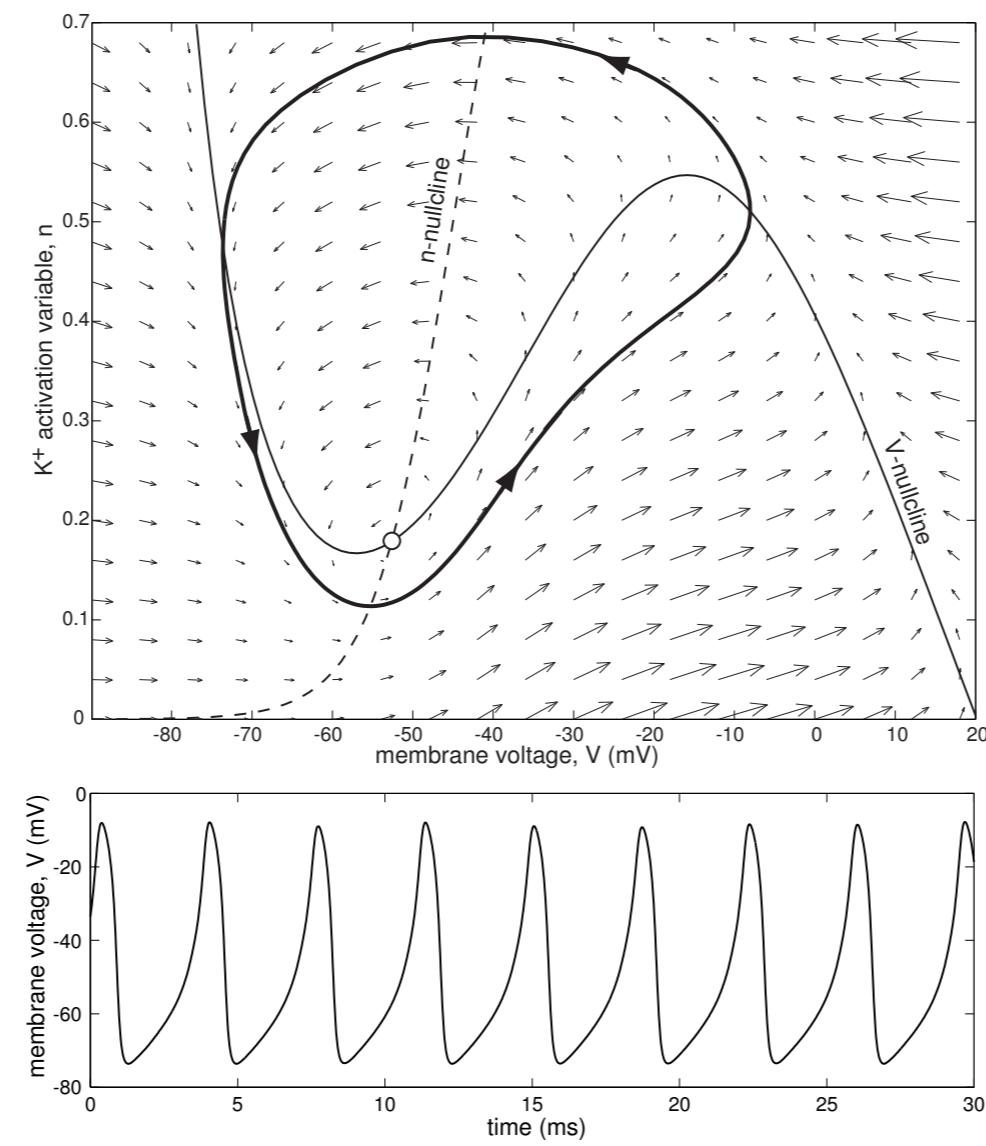


Figure 4.7: Failure to generate all-or-none action potentials in the $I_{Na,p} + I_K$ -model.

Dynamic systems in Neuroscience

Eugene Izhikevich 2007



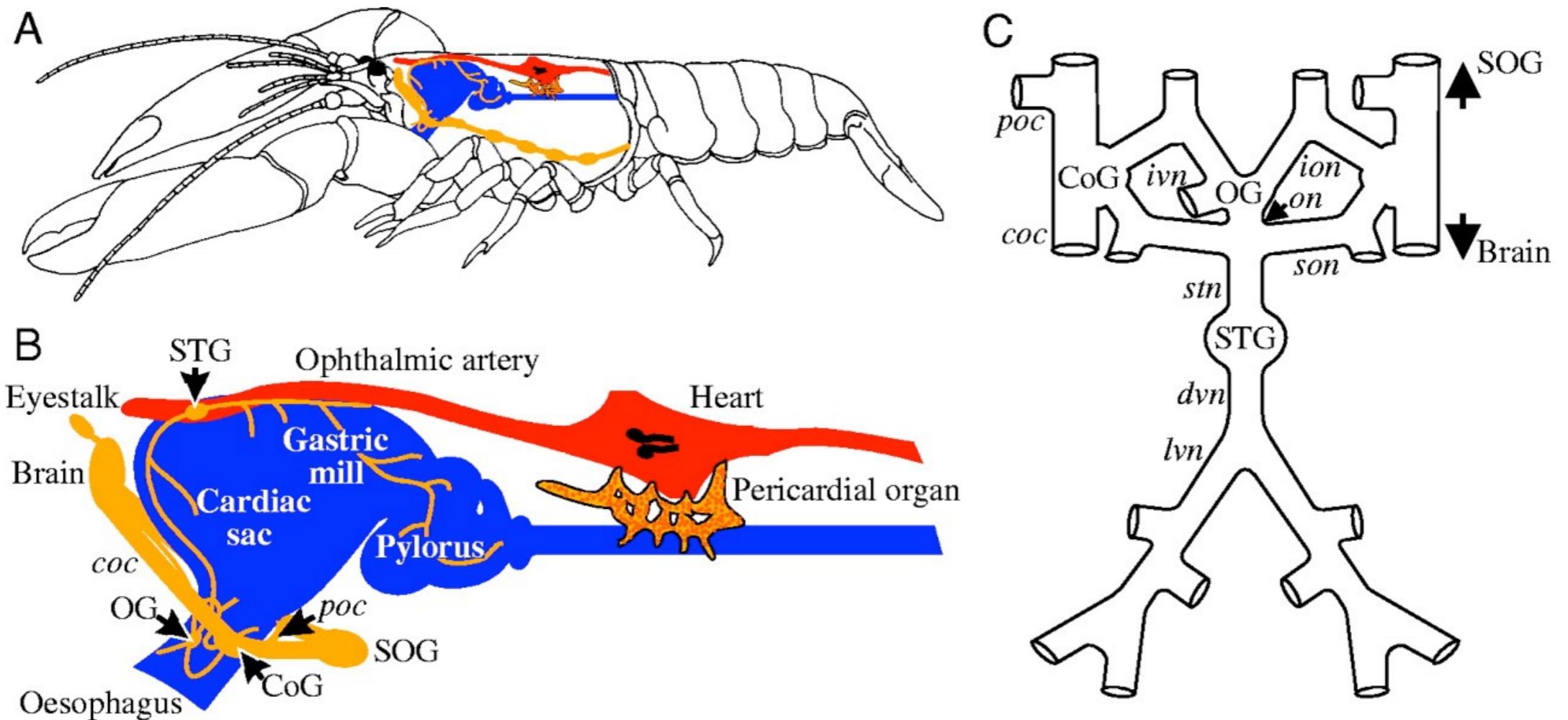
Dynamic systems in Neuroscience

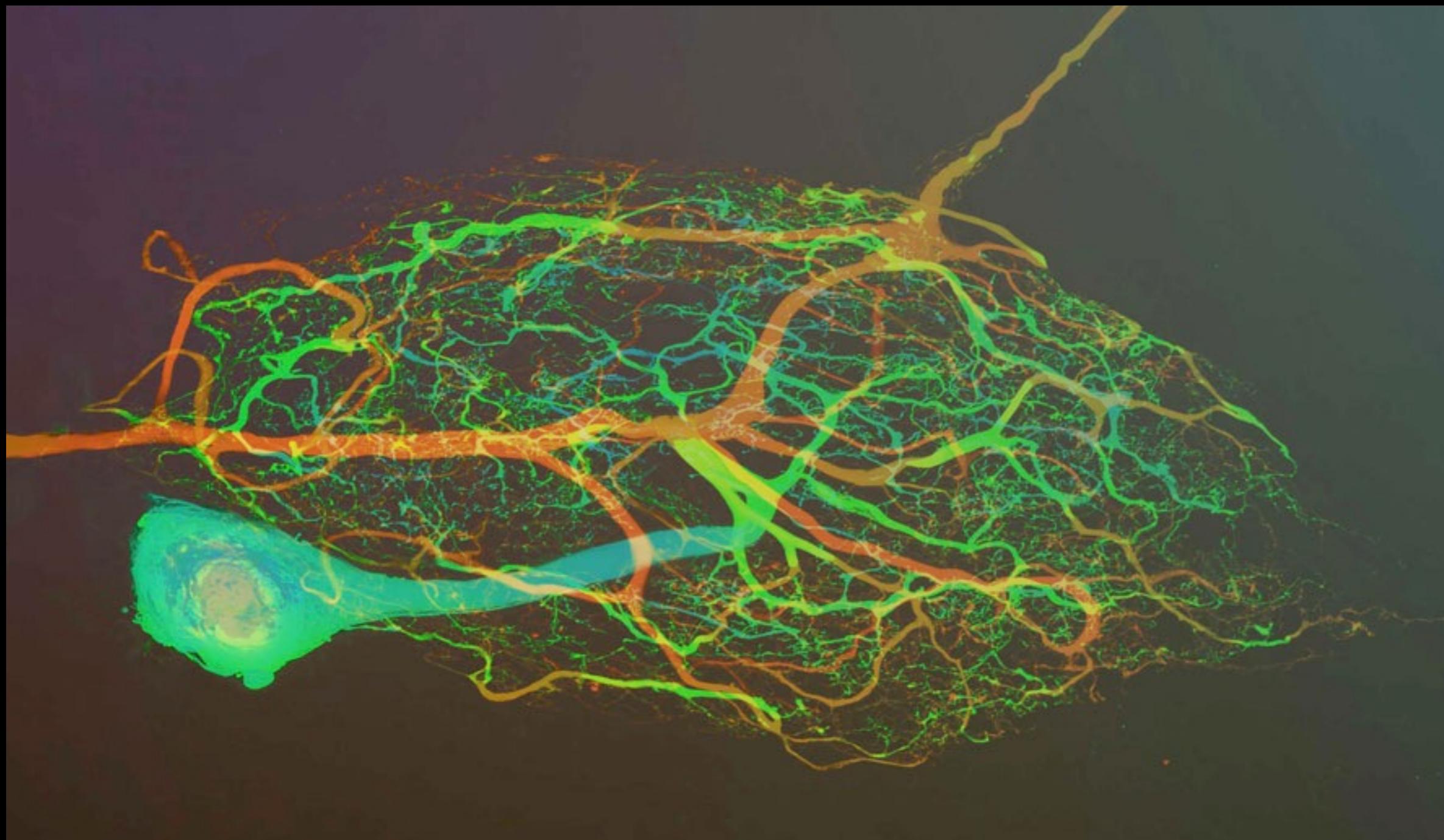
Eugene Izhikevich 2007

“With four parameters I can fit an elephant, and
with five I can make him wiggle his trunk.”

John von Neumann

Stomatogastric nervous system (STG)



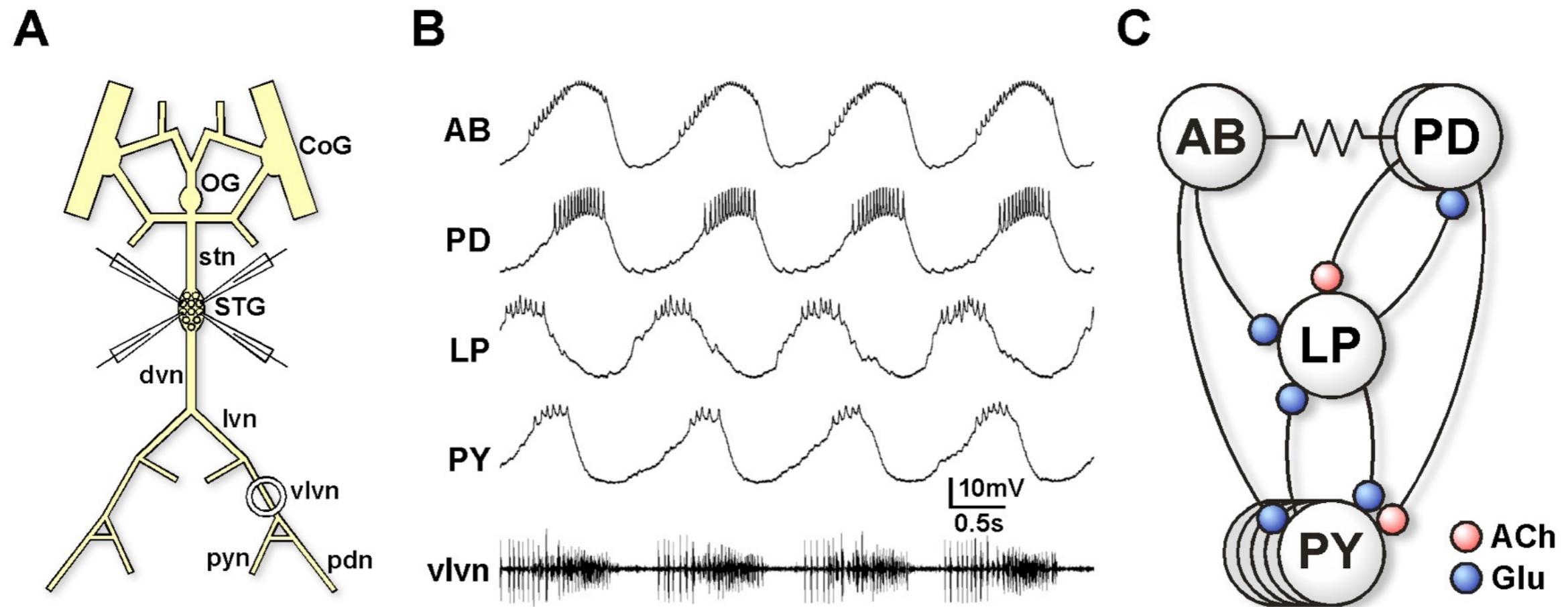


Eve Marder

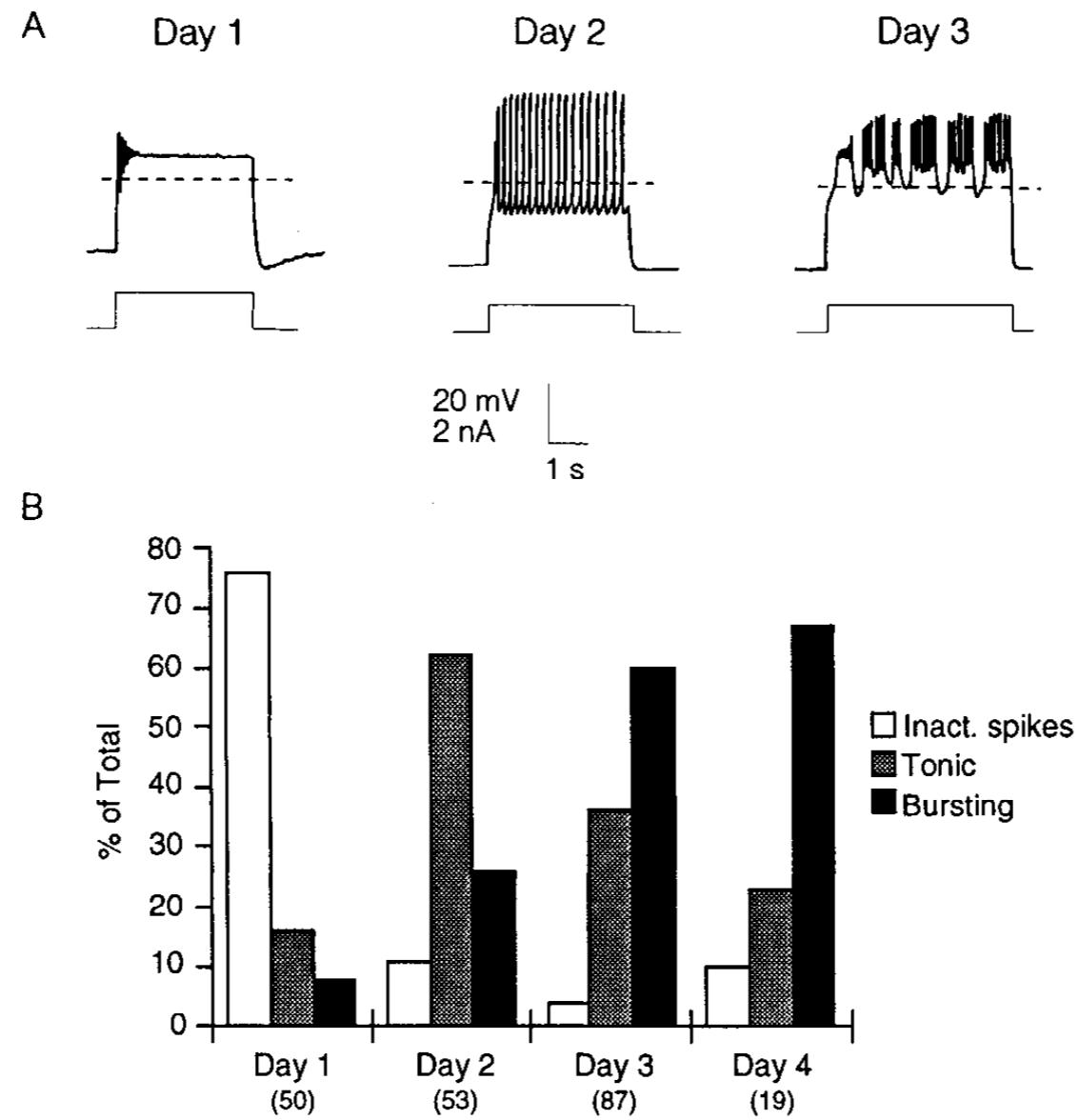
The voltage dependent conductances play a major role in determining the neural activity patterns

- I_{Na} : depolarization-activated transient sodium current that produces the rising phase of an action potential
- I_K : delayed rectifier potassium current that is responsible for the falling phase of the action potential
- I_{NaP} : a persistent sodium current that can initiate and maintain tonic or burst firing
- I_h : a hyperpolarization-activated inward current that can initiate bursting
- I_{CaN} : a calcium activated non-selective cation current that maintains a depolarized plateau
- $I_{K(Ca)}$: a calcium activated potassium current that could be responsible for burst termination
- I_A : a transient potassium current that is activated by depolarization and acts to delay spike and burst initiation

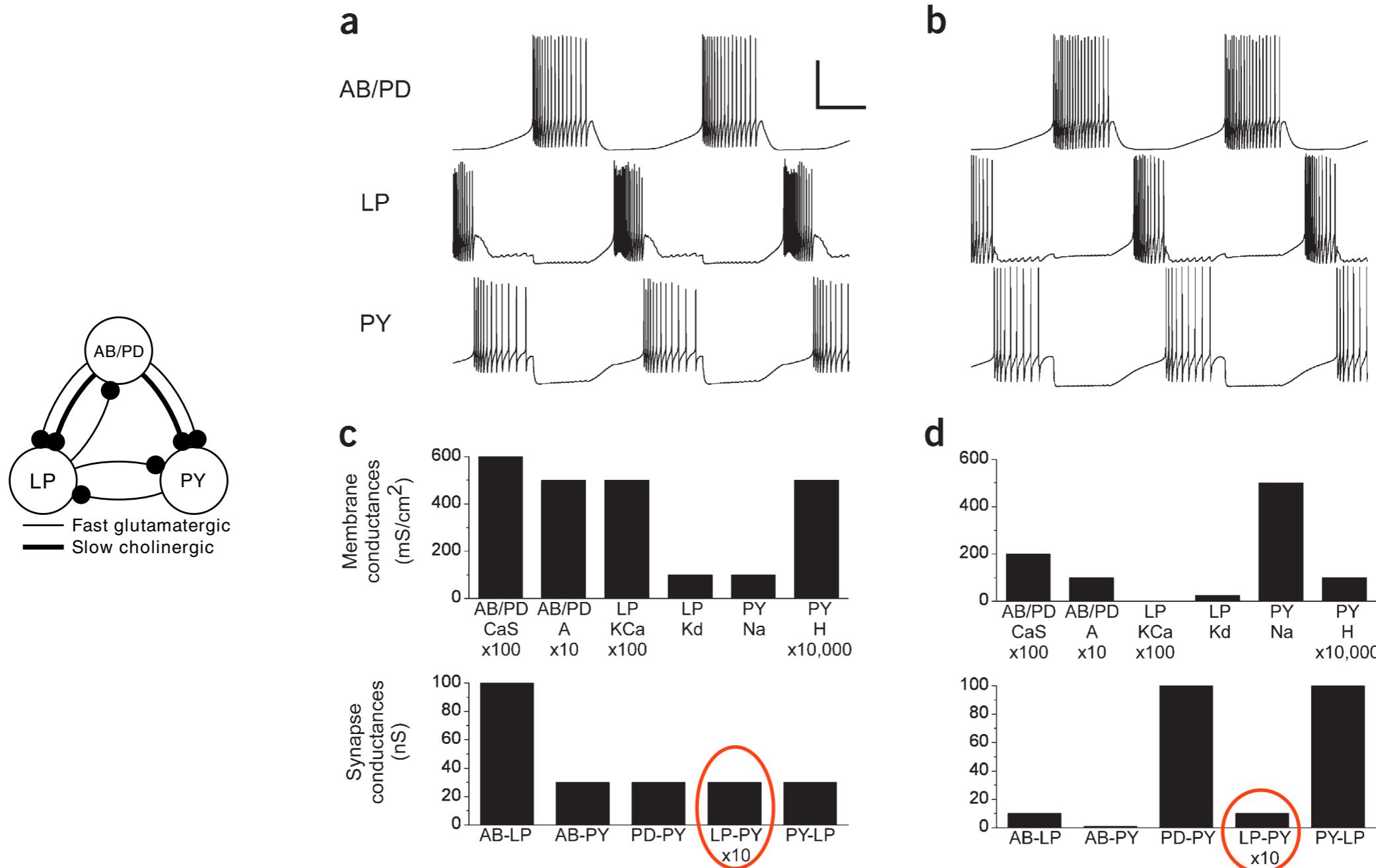
STG has identified neurons with stereotypical activity patterns



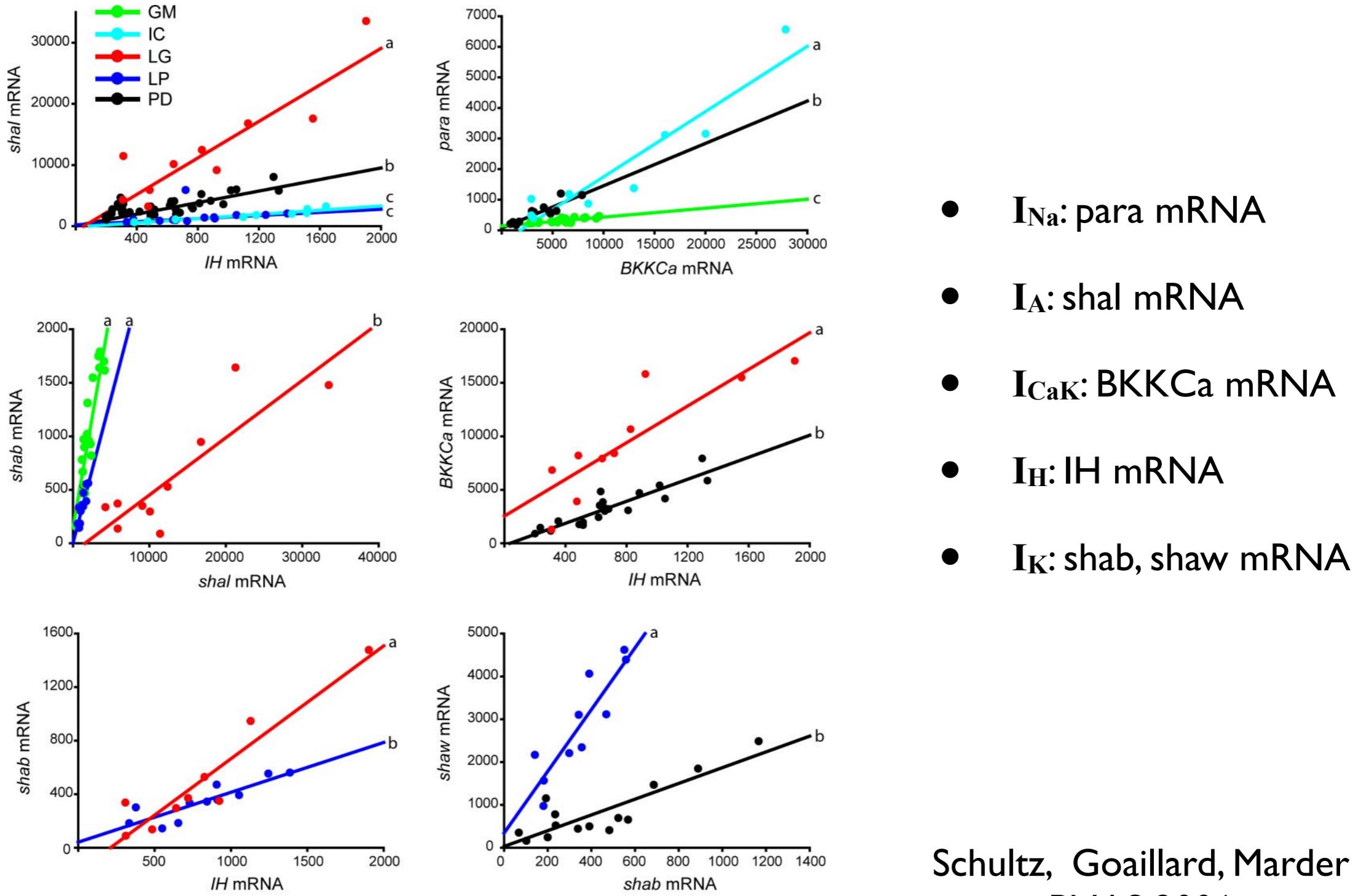
Change of activity pattern over time



Similar neural activities with widely different model-network properties



Pair-wise correlation of ion channel expression levels in different cells



Schultz, Goaillard, Marder
PNAS 2006

Squid Giant Axon

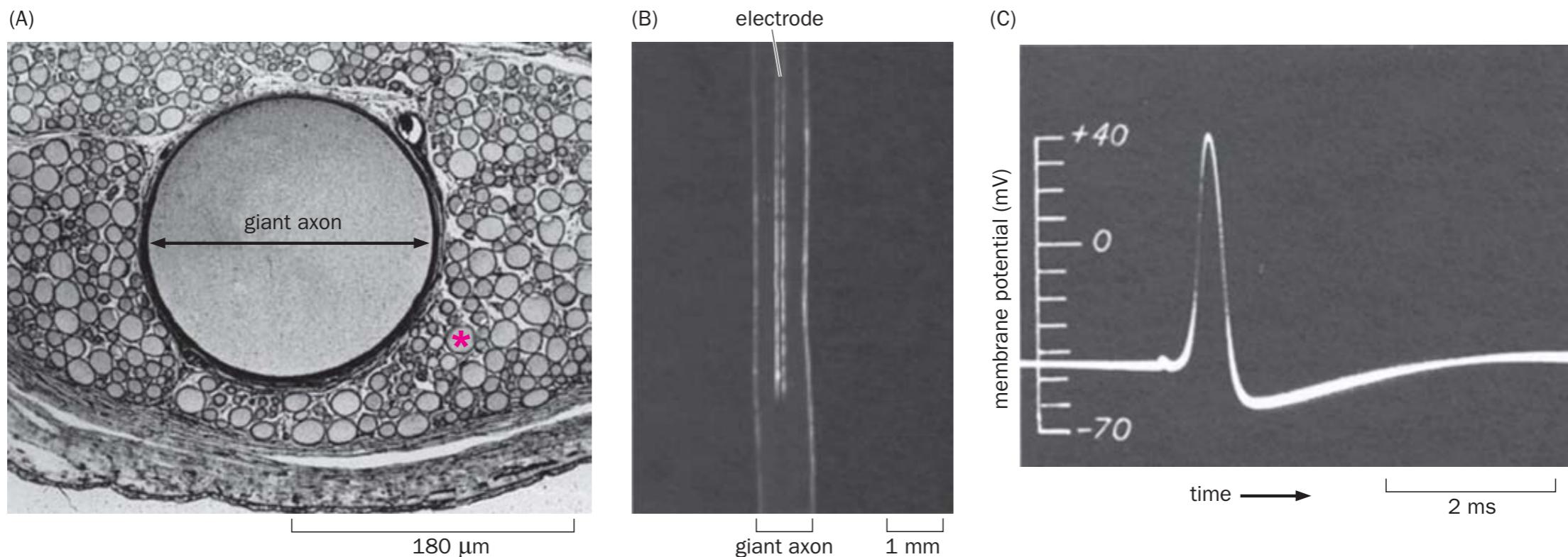
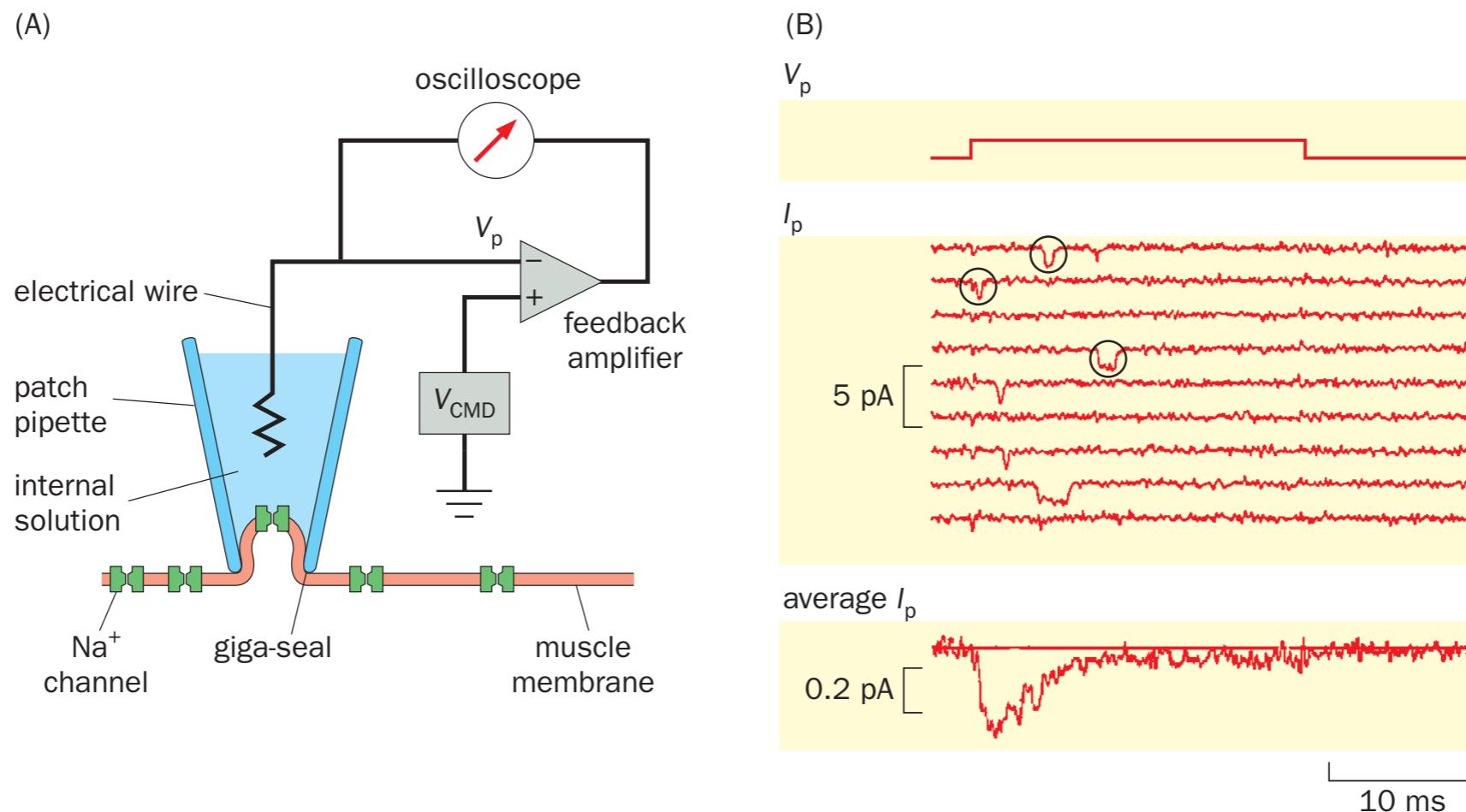
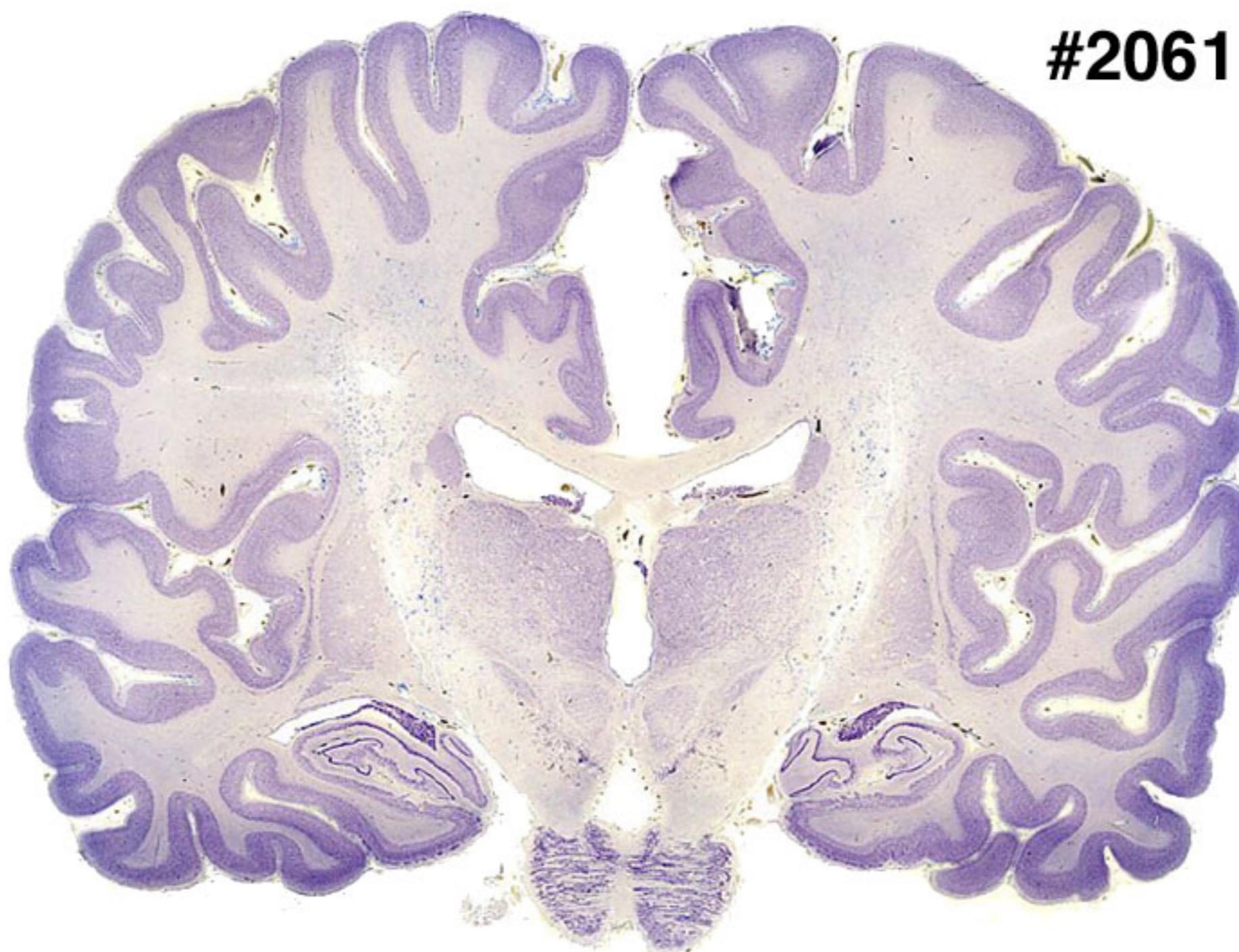


Figure 2–19 Studying action potentials in the squid giant axon. **(A)** Electron micrograph of a cross section of a squid giant axon showing its large diameter ($\sim 180 \mu\text{m}$ for this sample) as compared to neighboring axons (for example, the axon indicated by *). **(B)** Photograph of an electrode inserted inside a squid giant axon whose diameter is close to 1 mm. **(C)** An action potential recorded from the squid giant axon. (A, courtesy of Kay Cooper and Roger Hanlon; B, from Hodgkin AL & Keyes RD [1956] *J Physiol* 131:592–616; C, from Hodgkin AL & Huxley AF [1939] *Nature* 144:710–711. With permission from Macmillan Publishers Ltd.)

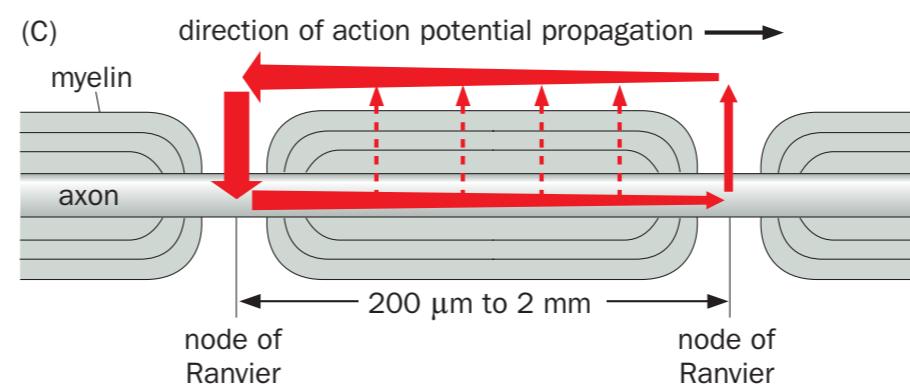
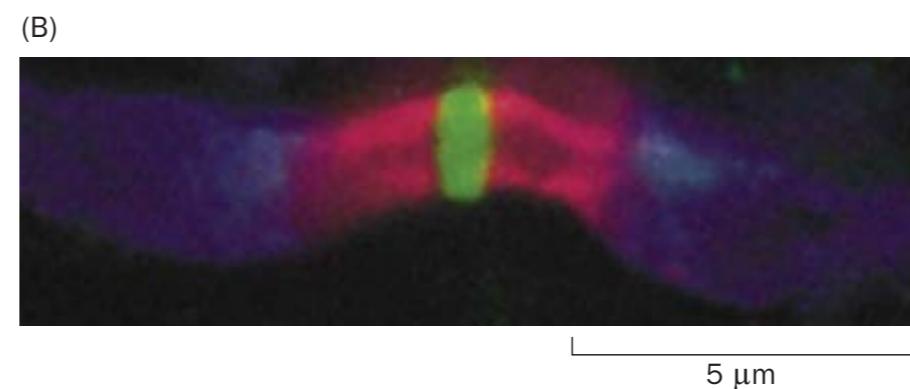
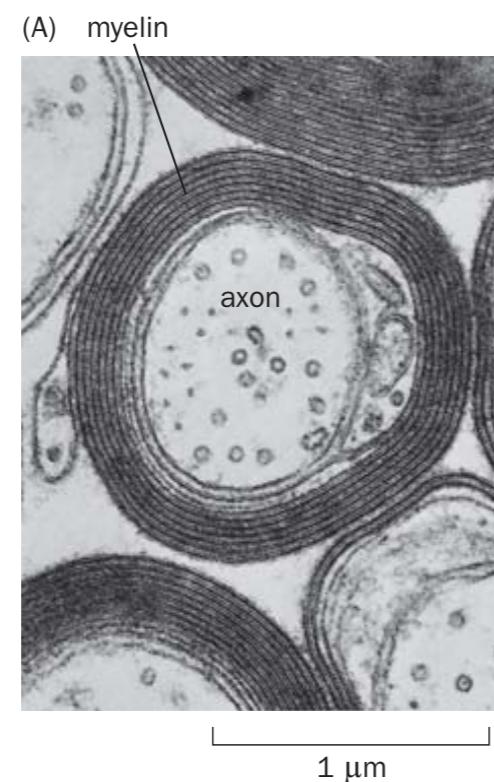
Patch-clamp recording allows the measurement of single channel conductance



Gray and White Matter



Myelinated axons



Patch-clamp recording allows the measurement of single channel conductance

