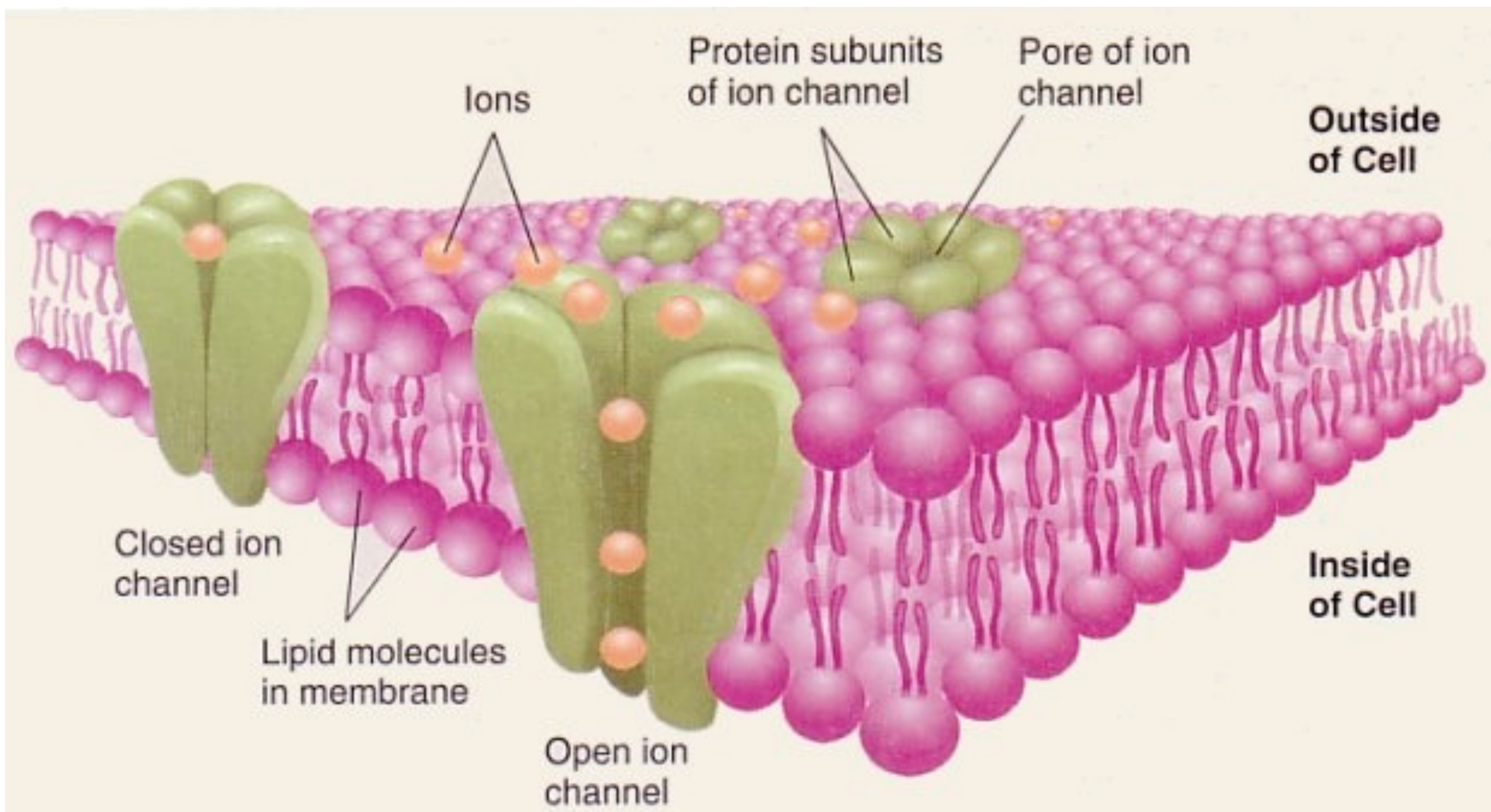
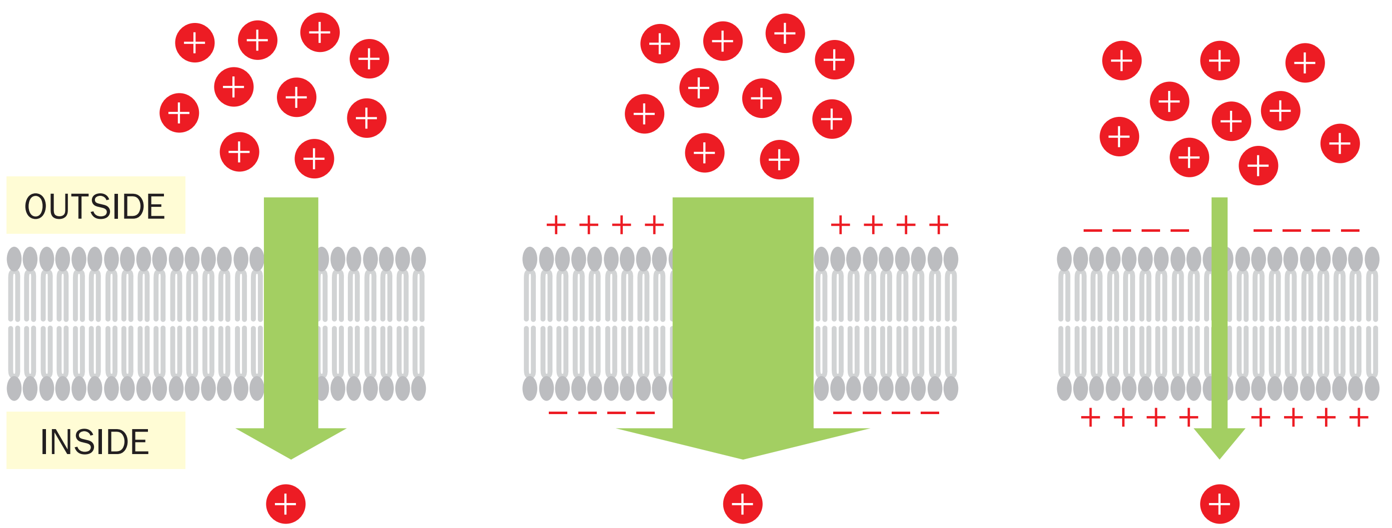
Single Neuron Dynamics


Ions
Protein subunits
of ion channel
Pore of ion
channel
Outside
of Cell
Closed ion
channel
Lipid molecules
in membrane
Open ion
channel
Inside
of Cell

What determines the resting potential of a neuron?



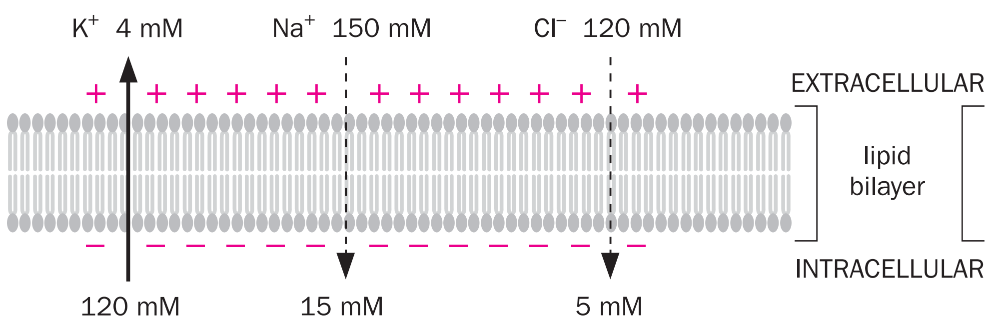
chemical gradient alone; no membrane potential

chemical gradient and electrical gradient driving ion movement in the same direction

chemical gradient and electrical gradient driving ion movement in opposing directions

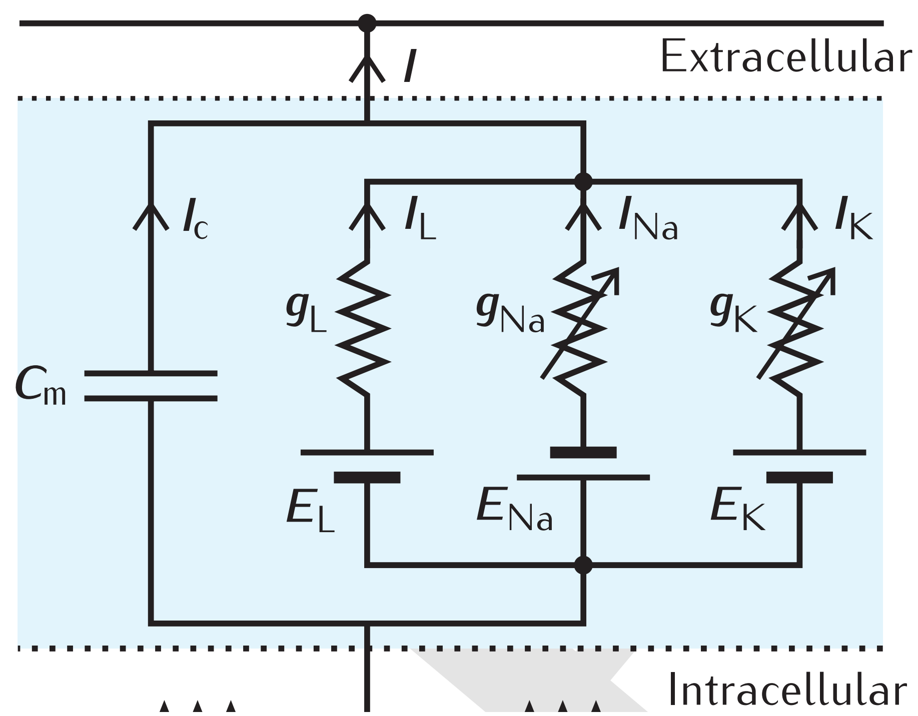
Ion pump

(A)



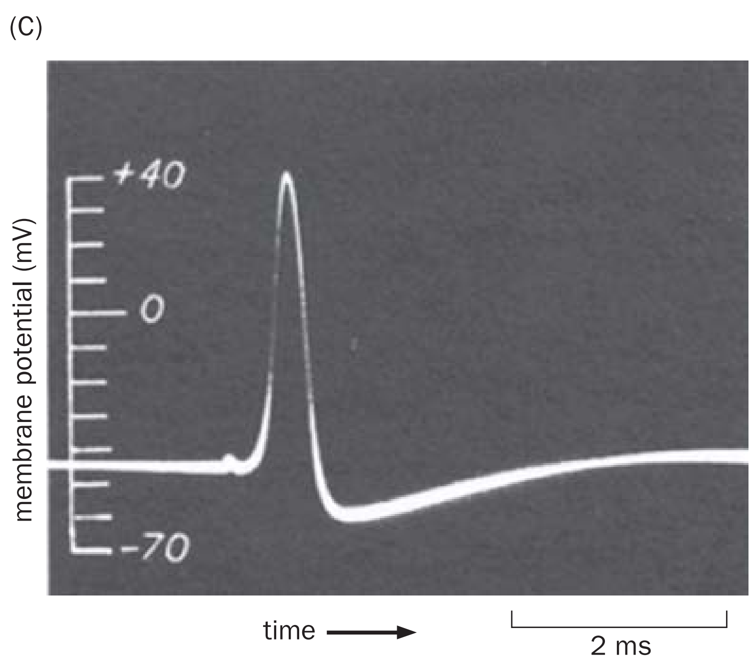
K+ 4 mM
Na+ 150 mM
Cl− 120 mM
EXTRACELLULAR
lipid bilayer
INTRACELLULAR
120 mM
15 mM
5 mM

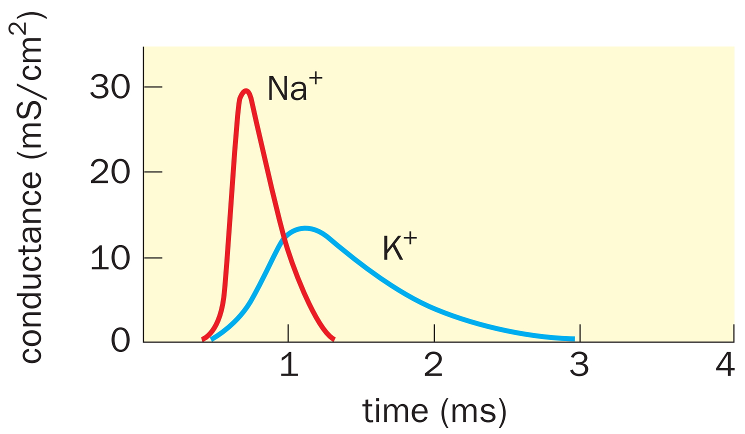
The Equivalent Electronic Circuit of a Neuron



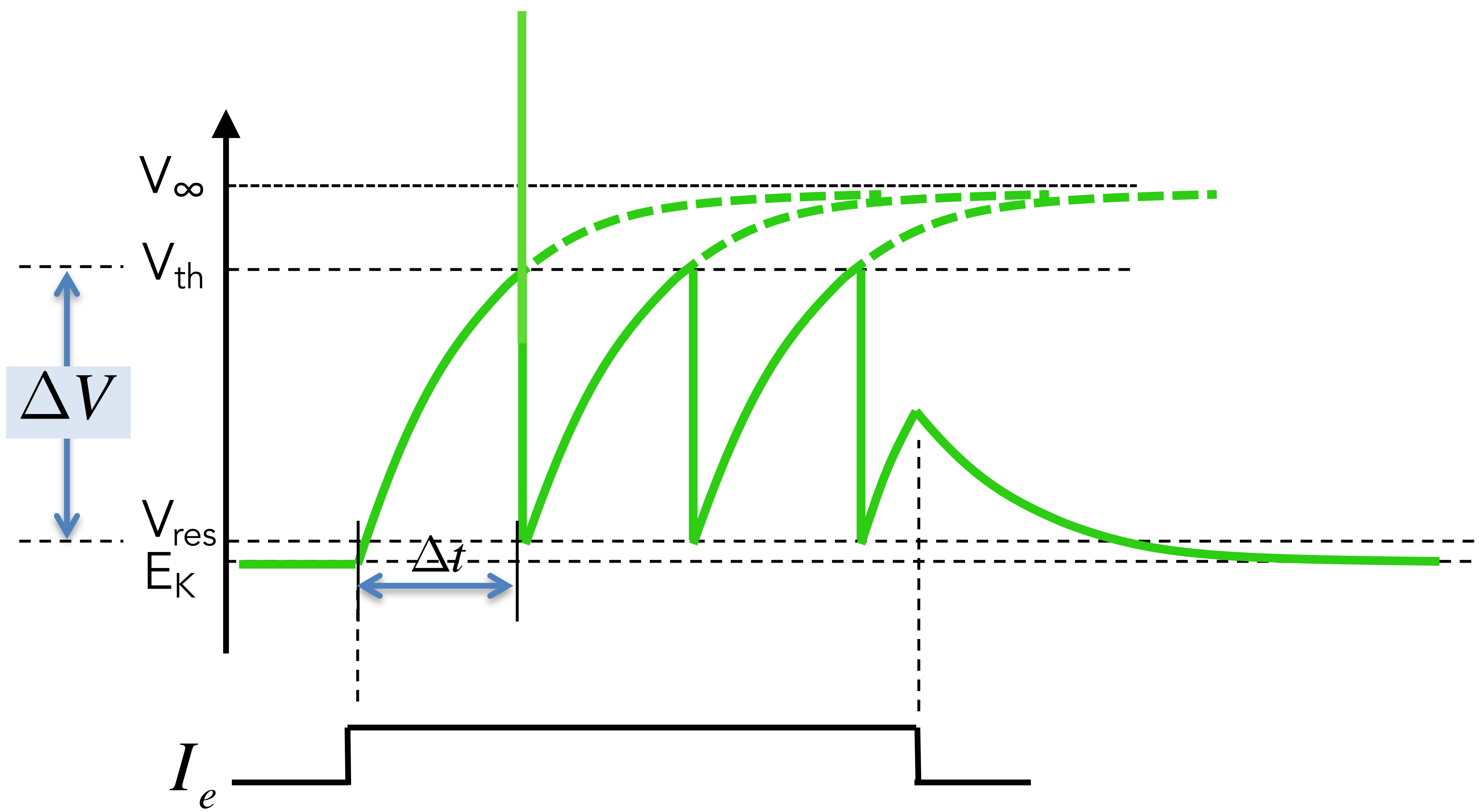
$$C_m \frac{dV}{dt} = -\sum_i g_i(V)(V - E_i) - \bar{g}_L(V - E_L) + I_e$$

Qualitative explanation of action potential generation





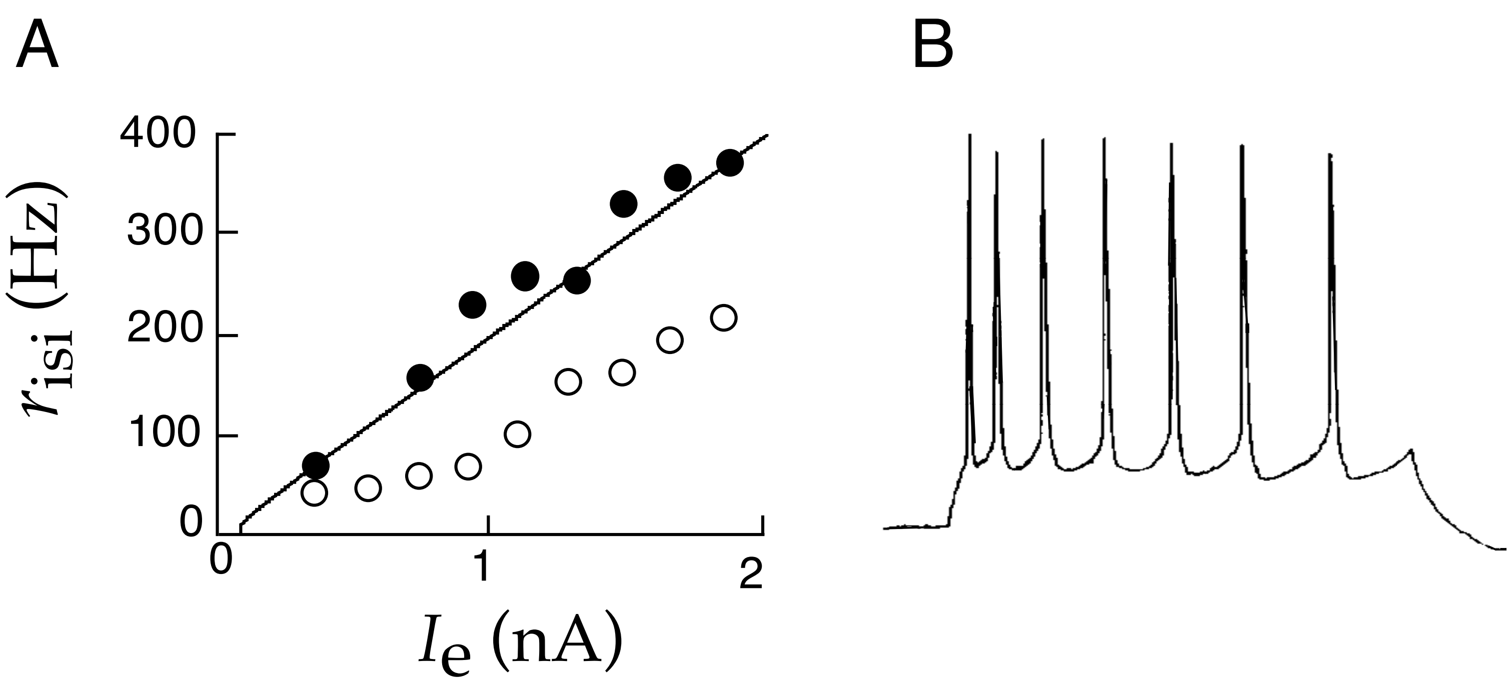
Integrate-and-Fire model



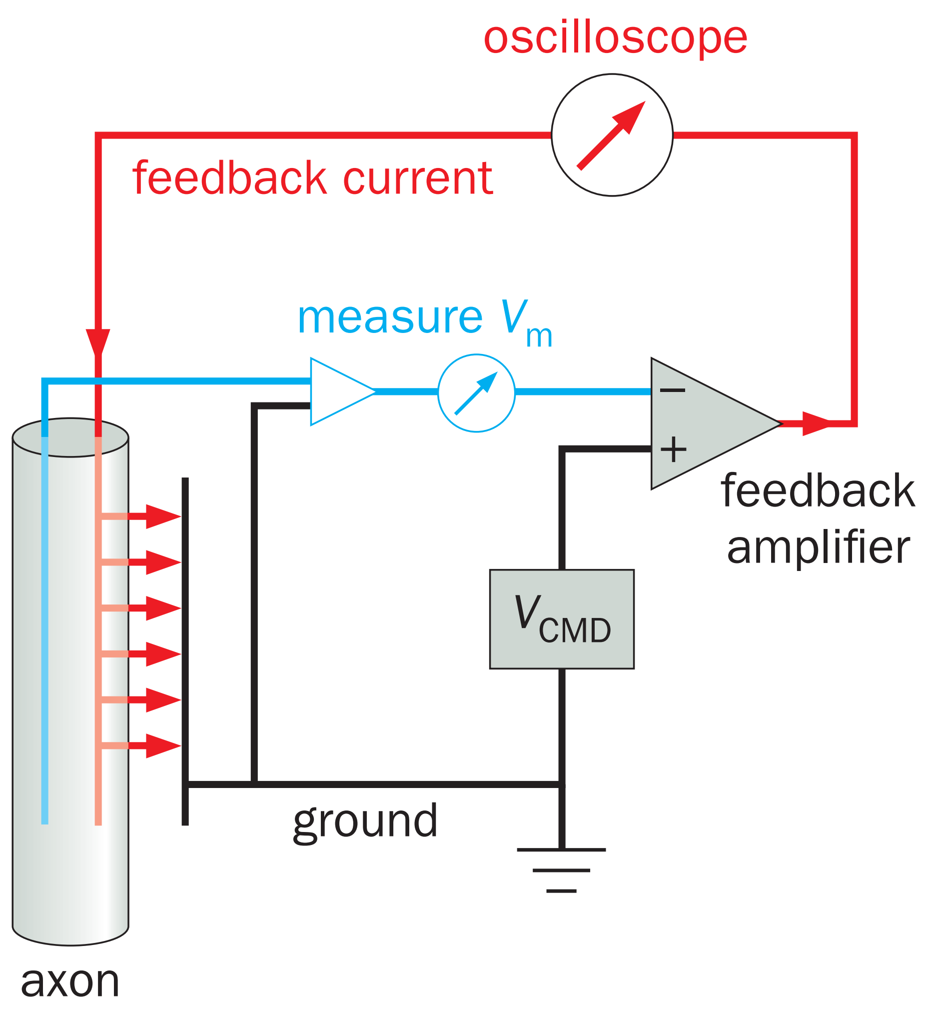
$$C\frac{dV}{dt} = -g(V - E_K) + I_e$$

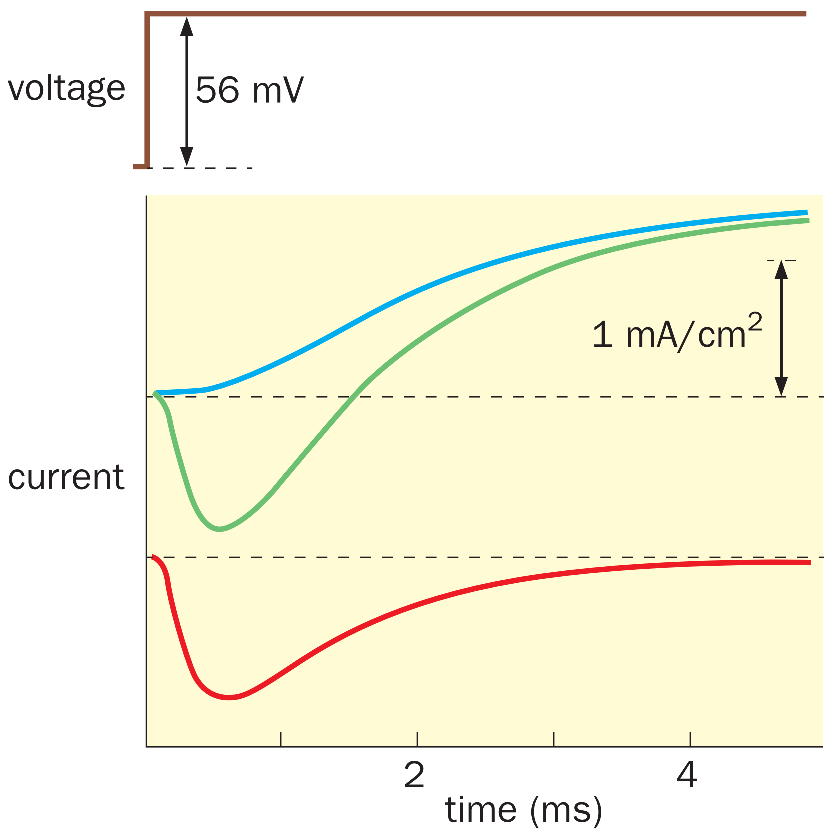
$$V(t^-_{spike}) = V_{th}$$

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

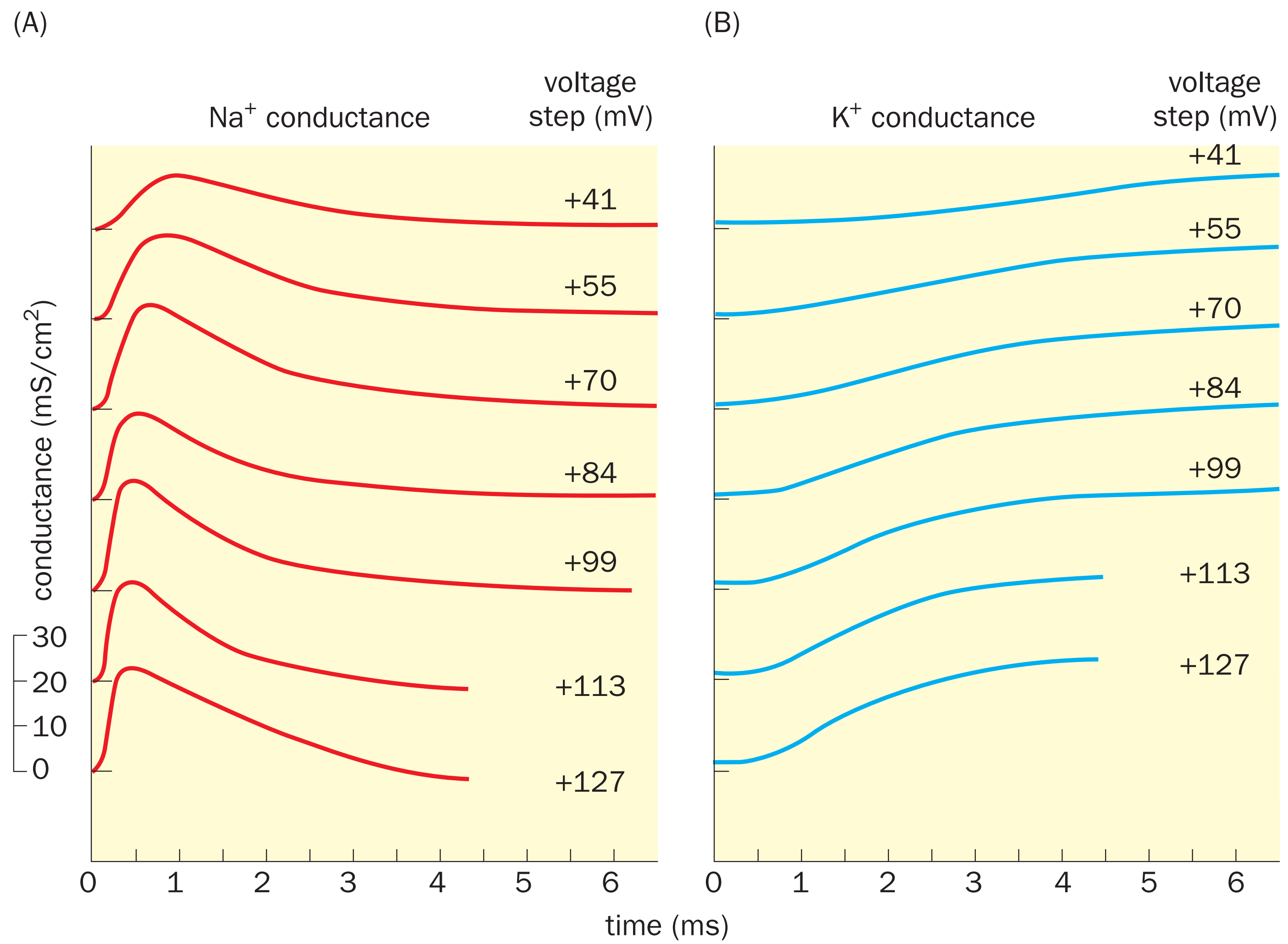

A
B
400
300
200
100
0
0
1
2
$r_{\rm isi}$ (Hz)
$I_{\rm e}$ (nA)

Voltage Clamp Recording

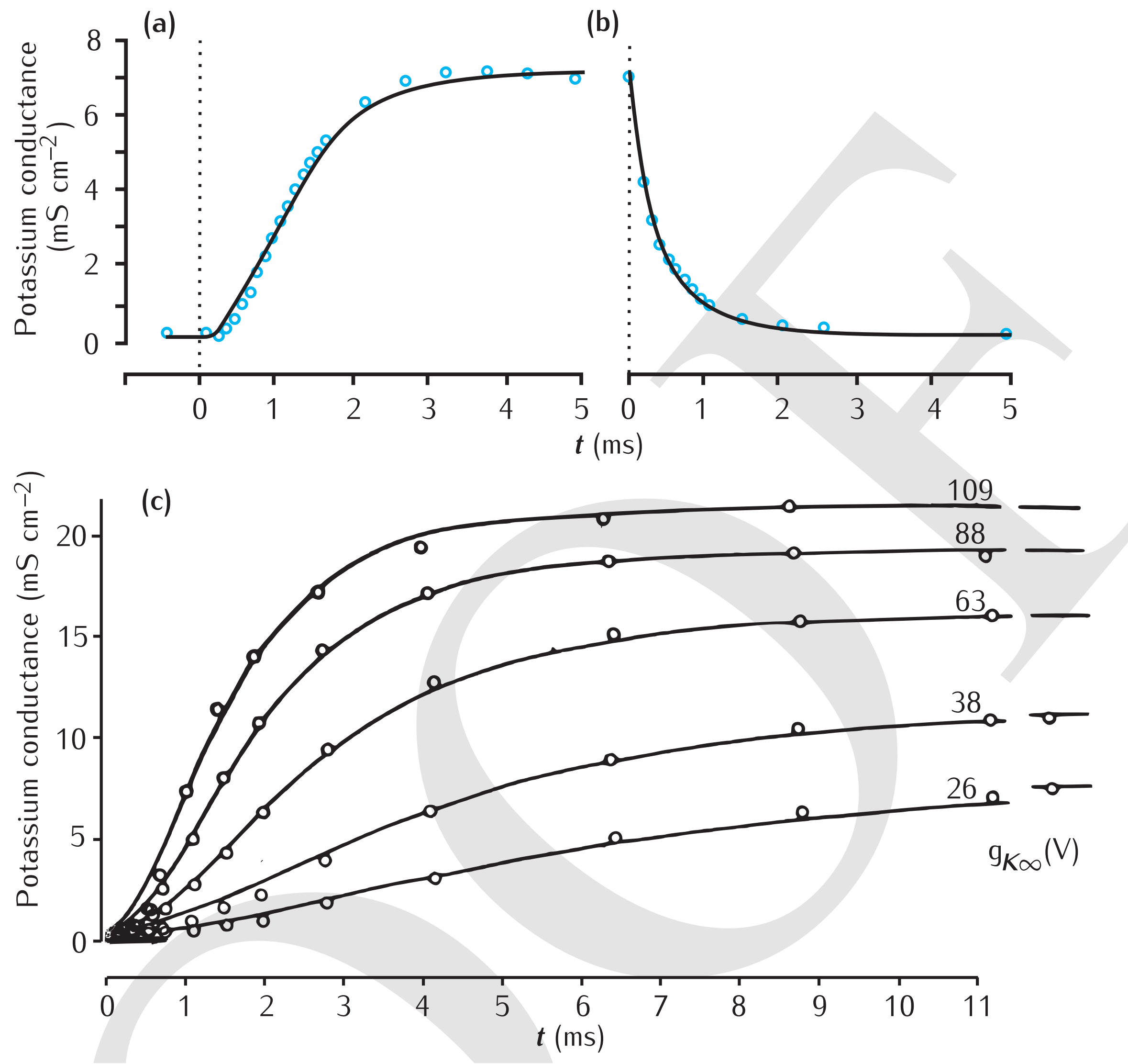




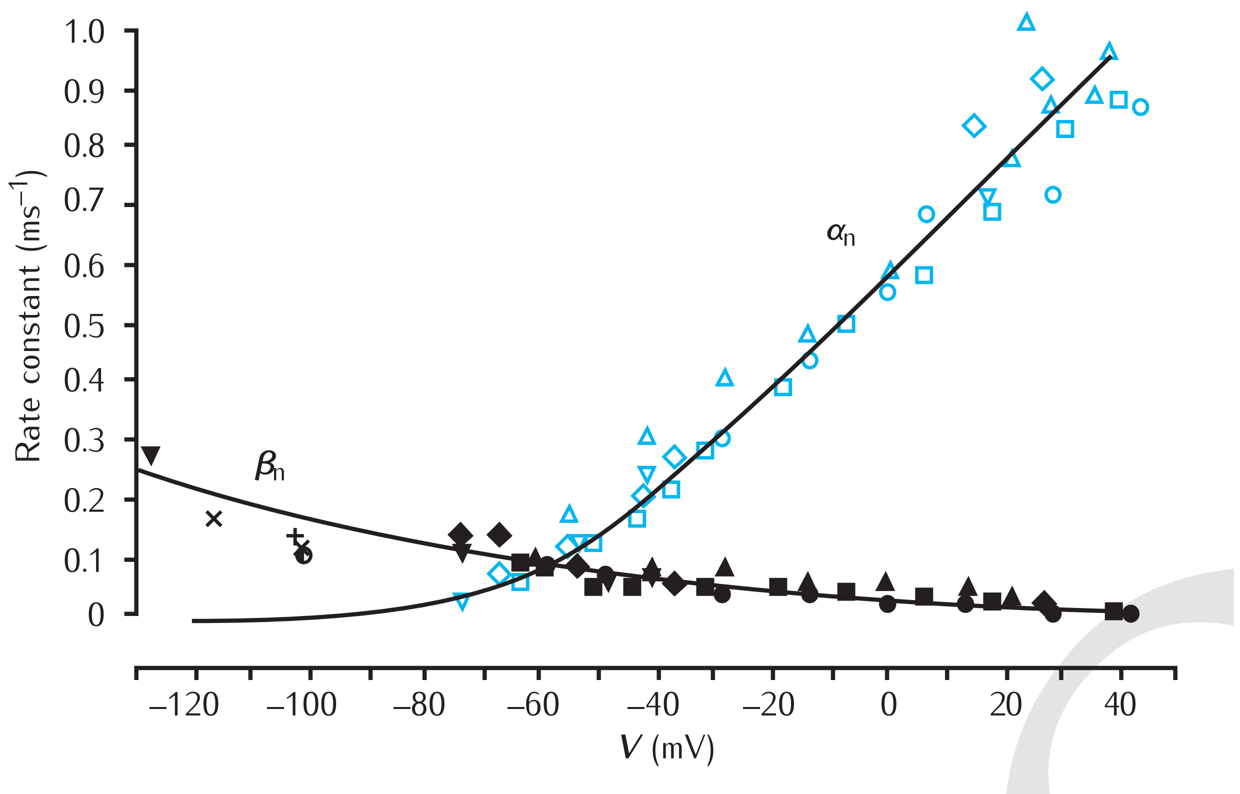
Voltage-gated Conductance



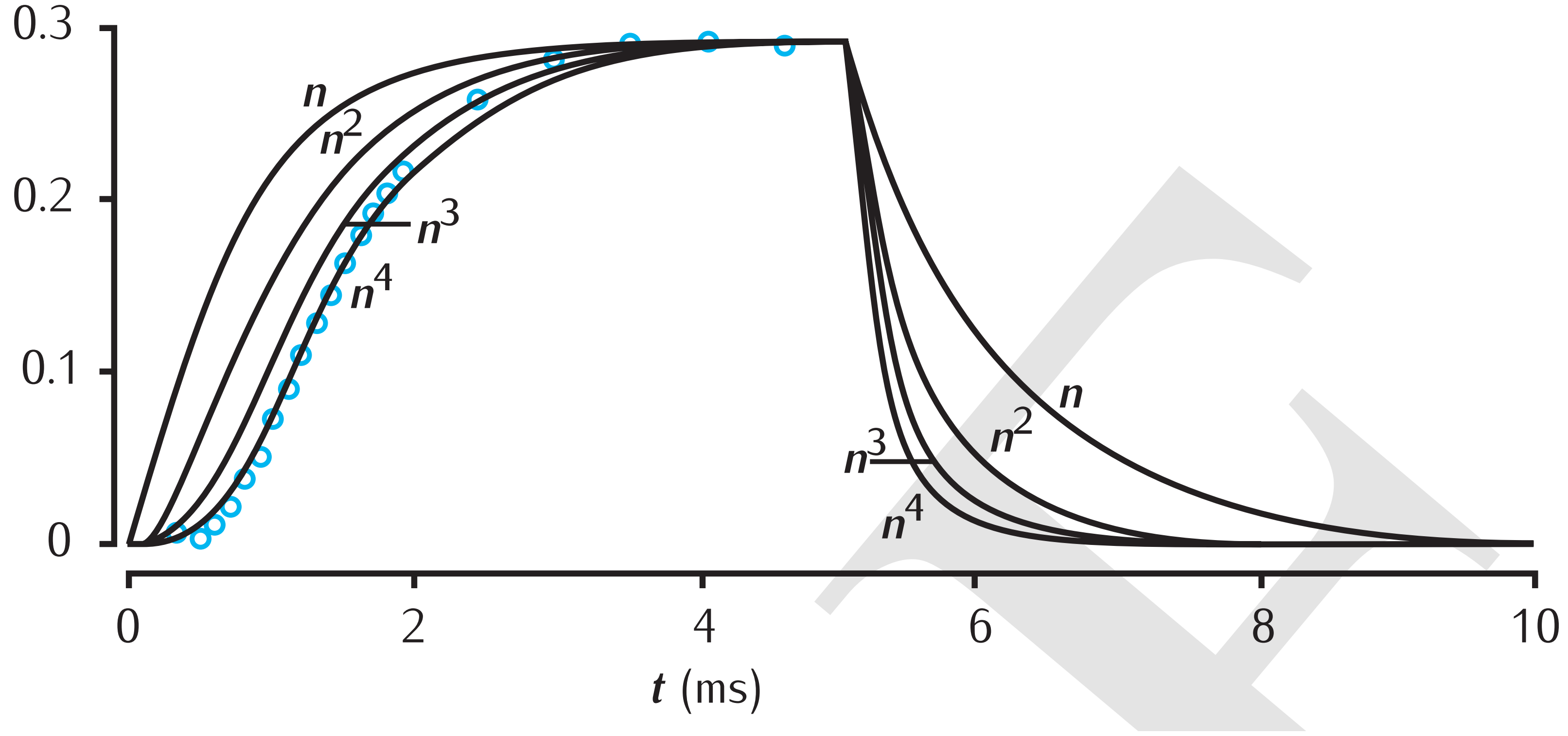
Voltage-gated Conductance of K+



Voltage-gated Conductance of K^+



Voltage-gated Conductance of K^+



Squid Giant Axon

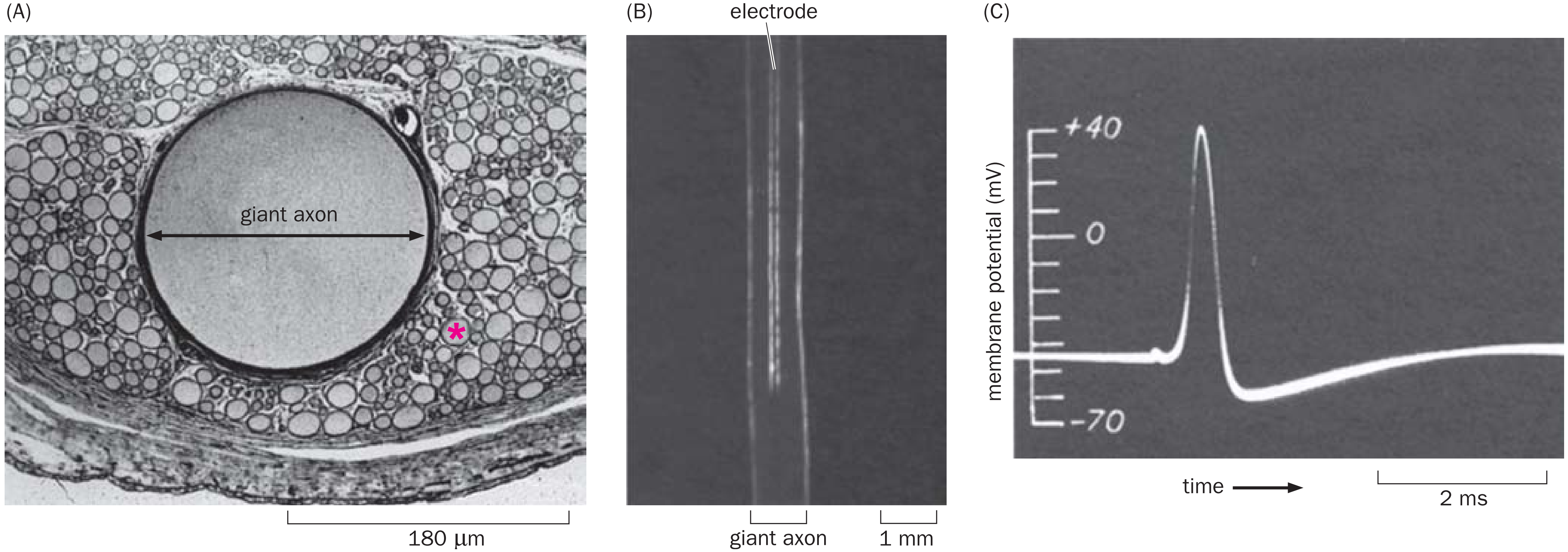
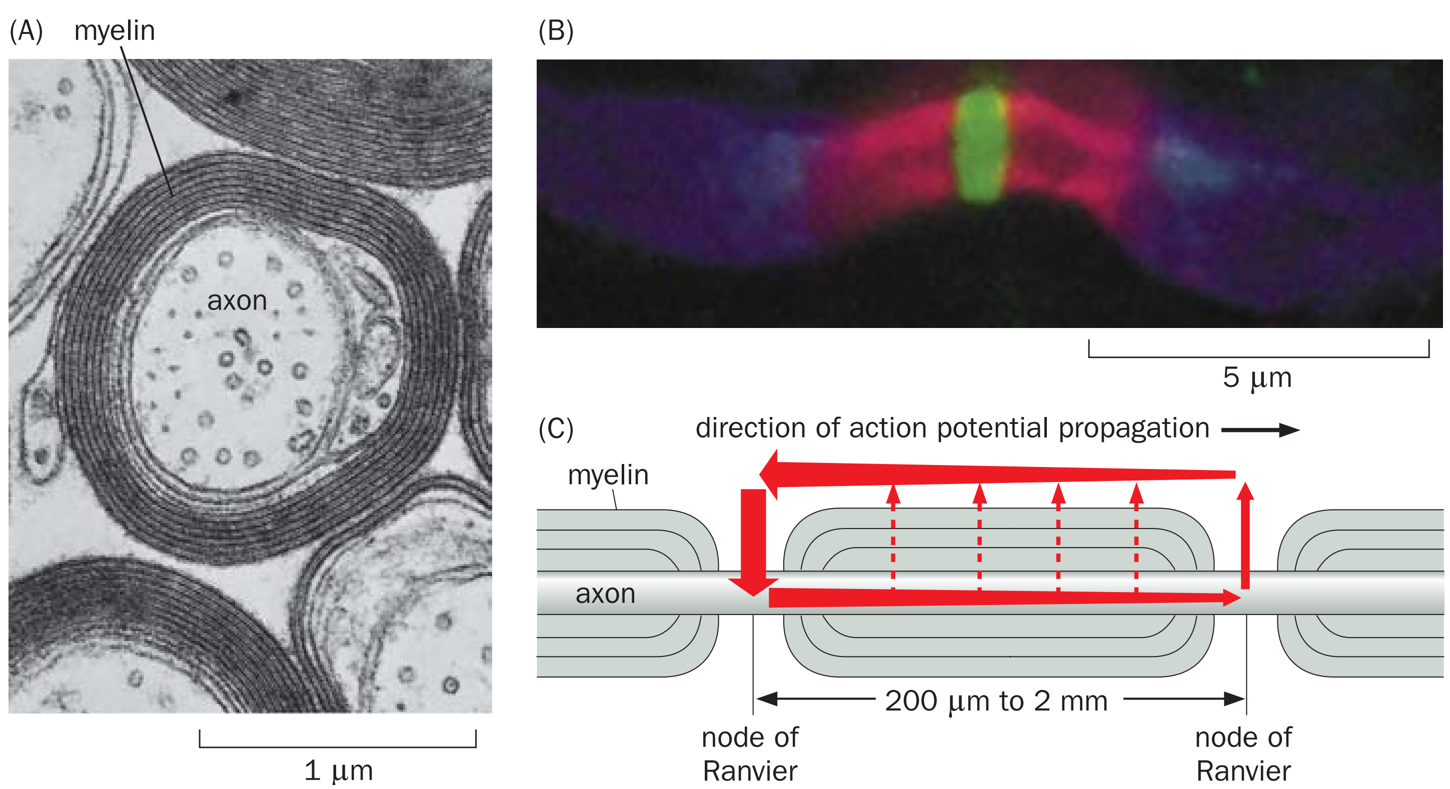


Figure 2–19 Studying action potentials in the squid giant axon. (A) Electron micrograph of a cross section of a squid giant axon showing its large diameter (~180 µm for this sample) as compared to neighboring axons (for example, the axon indicated by *). **(B)** Photograph of an electrode inserted inside 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.)

Myelinated axons



Conduction velocity of myelinated and unmyelinated axons

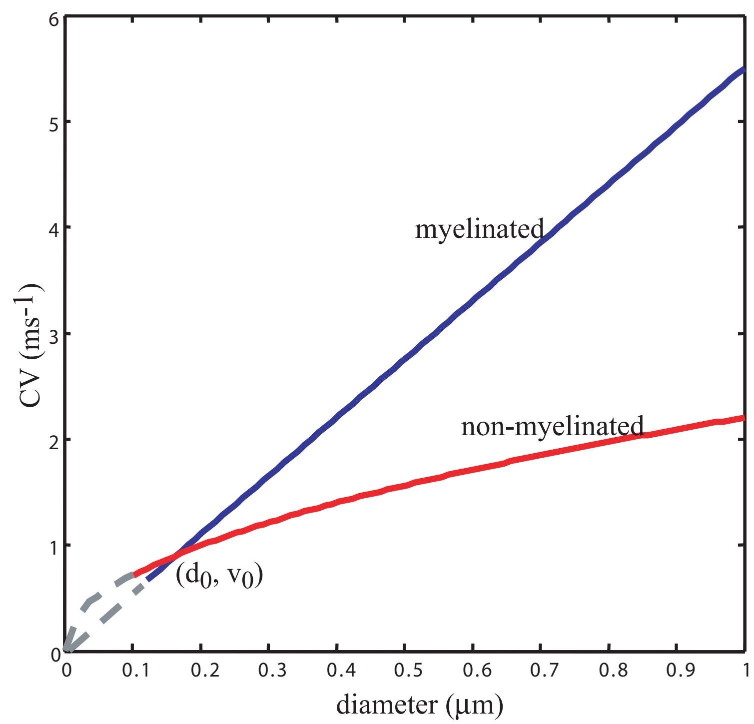
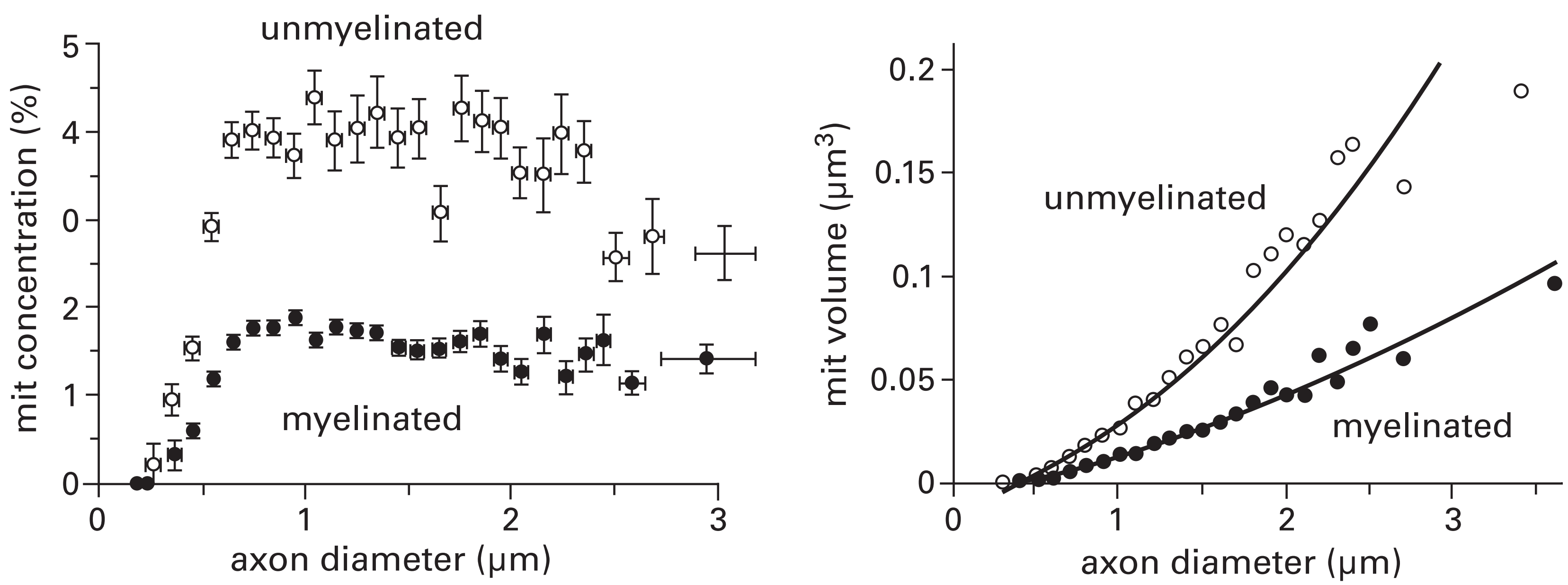
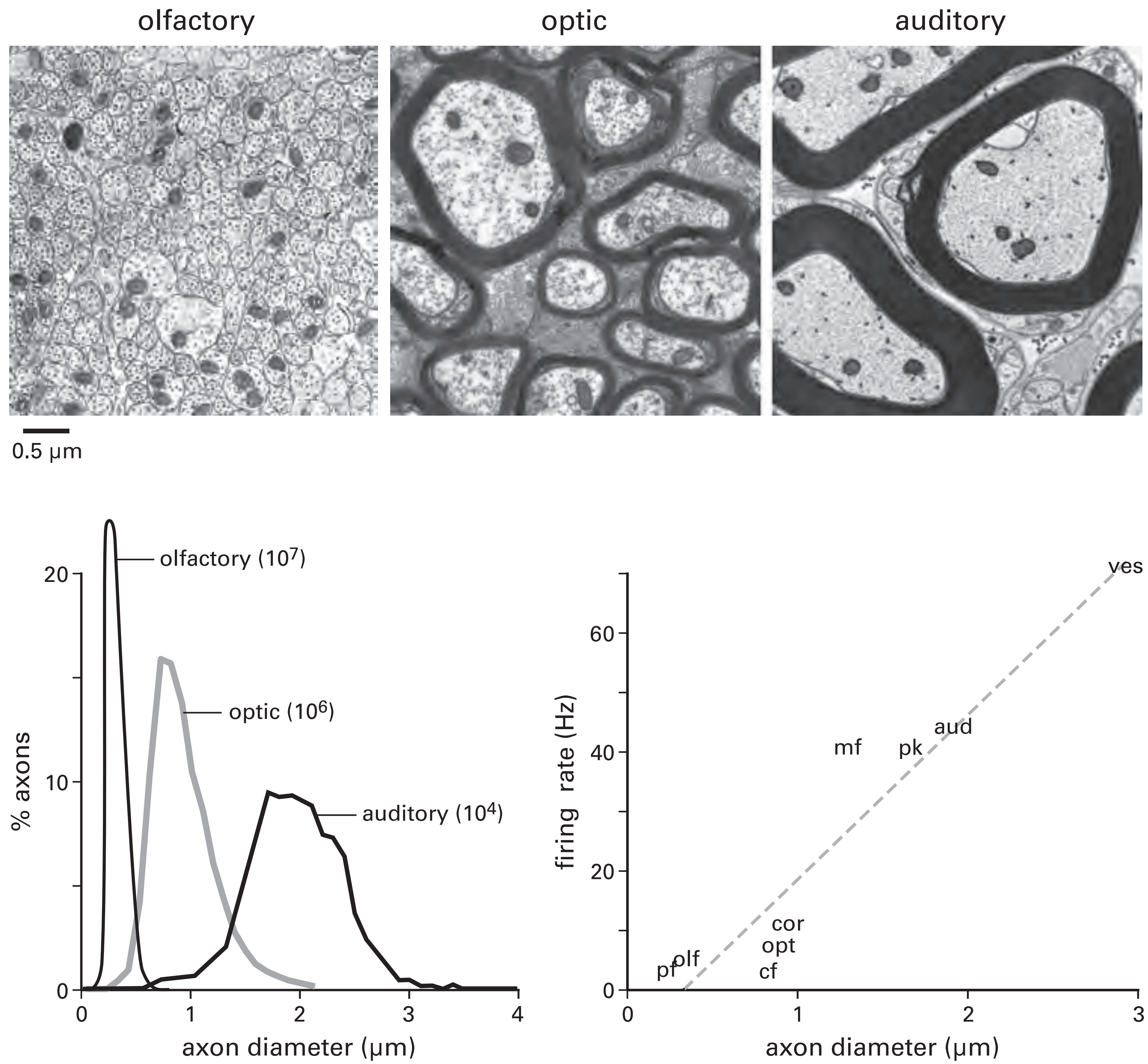


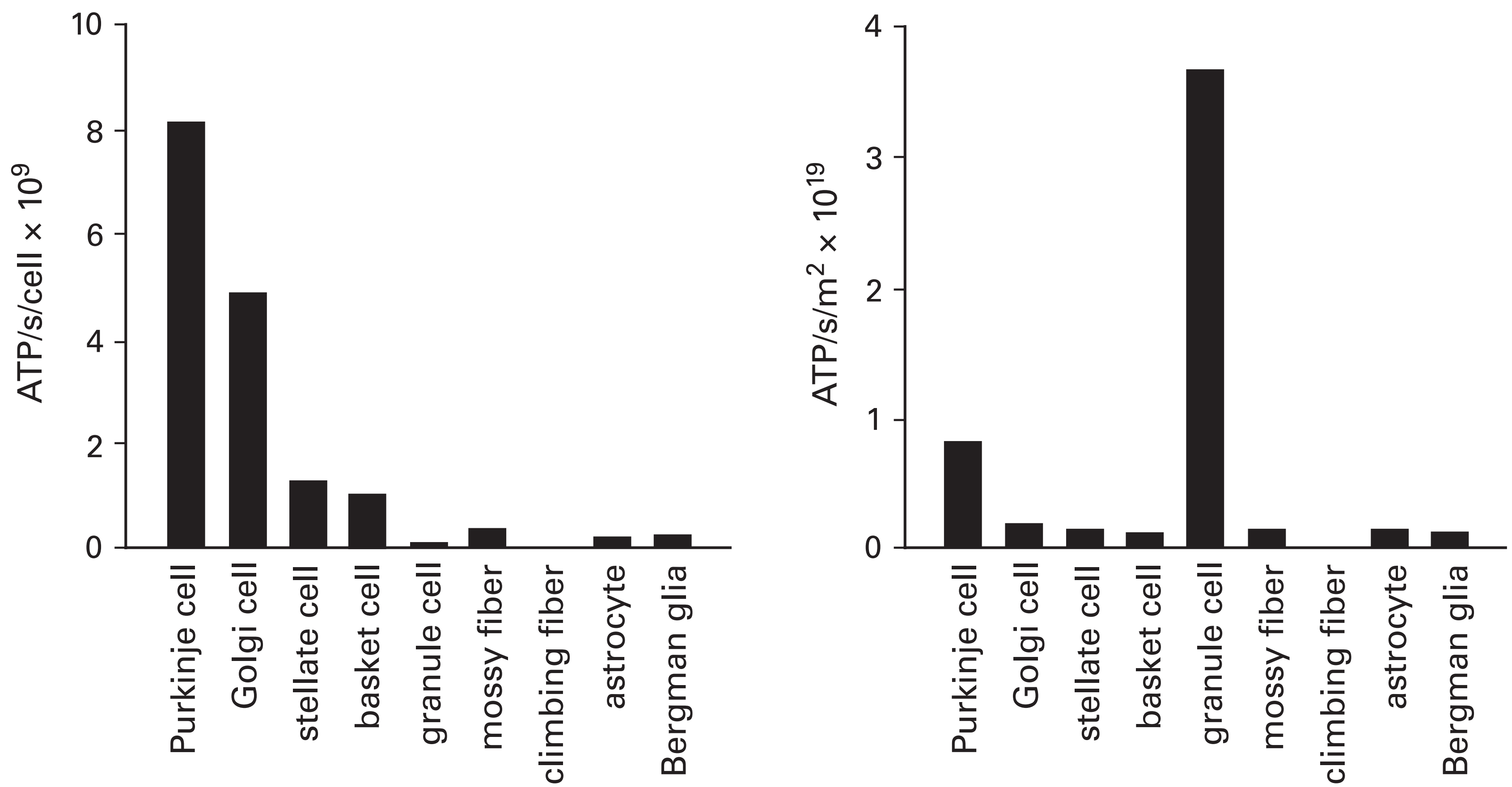
Figure 2.1: Conduction velocity as a function of the axon diameter for myelinated and non-myelinated axons, modified from Waxman and Bennett [2]. Axon diameters much smaller 0.1 micron are not observed experimentally and plots in this regime are represented by dashed lines. At d_0, myelinated and non-myelinated axons have the same CV, v_0.

Myelination saves not only time but also energy




olfactory
optic
auditory
0.5 μm
olfactory (10⁷)
optic (10⁶)
auditory (10⁴)
% axons
axon diameter (μm)
firing rate (Hz)
ves
aud
pk
mf
cor
opt
cf
olf
pf

Energy usage of different cell types in the cerebellum



Energy usage by cell function