Action Potentials **Propagate** along the Axon
Voltage Attenuation

(A) Axon

(B) Membrane potential (mV)

(C) Membrane potential (mV) vs. Distance along axon (mm)

NEUROSCIENCE, Third Edition, Figure 3.10 (Part 1) © 2004 Sinauer Associates, Inc.
Voltage attenuation along an axon: The length constant Lamda ($\lambda$)

For a cylindrical axon:
- $R_m$: membrane resistance of 1 cm of axon ($\Omega \cdot \text{cm}$)
- $R_{ax}$: axial resistance of 1 cm of axon ($\Omega / \text{cm}$)

$\lambda$ is the distance at which $V$ is 1/e of $V_0$ (i.e. where $V$ is about 37% of $V_0$).

Note: exponential decay of potential with distance

$V_x = V_0 \cdot e^{-x/\lambda}$

$\lambda = \sqrt{R_m / R_{ax}}$

Question: how does $\lambda$ change with axon diameter?
Voltage Attenuation Decreases with Axon Diameter

\[ R_m = \frac{r_m}{(\pi \times d)} \]
\[ R_{ax} = \frac{r_{ax}}{(\pi \times (d/2)^2)} \]

The proportionality factors \( r_m \) and \( r_{ax} \) are called specific resistivities.

\( r_m \): specific membrane resistivity (\( \Omega \times \text{cm}^2 \))
\( r_{ax} \): specific axial resistivity (\( \Omega \times \text{cm} \))

\[ \lambda = \sqrt[\lambda]{\frac{4r_m}{d}} \]

\( \lambda \) is proportional to the square root of the diameter of the axon.

Hence, propagation velocity of an action potential is proportional to the square root of the diameter of the axon.
Nerve fiber types in mammalian nerve.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Function</th>
<th>Fiber Diameter (μm)</th>
<th>Conduction Velocity (m/s)</th>
<th>Spike Duration (ms)</th>
<th>Absolute Refractory Period (ms)</th>
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</thead>
<tbody>
<tr>
<td>A α</td>
<td>Proprioception; somatic motor</td>
<td>12–20</td>
<td>70–120</td>
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<td></td>
</tr>
<tr>
<td>β</td>
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<td>30–70</td>
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<td>B</td>
<td>Preganglionic autonomic</td>
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</tr>
<tr>
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<td>Pain, reflex responses</td>
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<td>0.5–2</td>
<td>2</td>
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</tr>
<tr>
<td>sympathetic</td>
<td>Postganglionic sympathetics</td>
<td>0.3–1.3</td>
<td>0.7–2.3</td>
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A. Myelinated

B. Nonmyelinated

![Graph showing conduction velocity vs. fiber diameter](image)
To increase propagation velocity of an Action Potential:

1) Increase $\lambda$ by:
   - Increase $d$
   - Increase $R_{in}$

2) Decrease $C_m$

Remember: $I_m = I_c + I_i$

$I_c = C_m \cdot \frac{dV}{dt}$  $I_{ion} = \Delta V_m / R_{in}$

To decrease $I_m$ increase $R_{in}$ or decrease $C$

How do you decrease $C_m$?
Schwann cells in PNS
Oligodendrocytes in CNS
Schwann cells in PNS
Myelin reduces $C_m$ and increases $R_m$
Myelinated Axons are Faster

Conduction in Myelinated Axons is “Saltatory”
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**Diagram:**

- Myelinated
- Nonmyelinated

**Axes:**
- Fiber diameter (µm) on the x-axis
- Conduction velocity (m/s) on the y-axis
Pyramidal cell

Membrane with high density of voltage-gated sodium channels

Spike-initiation zone: axon hillock

Sensory neuron

Spike-initiation zone: sensory nerve ending

(a) (b)
Voltage Attenuation Decreases with Axon Diameter

R_m is inversely proportional to the circumference of the axon.
R_ax is inversely proportional to the cross-sectional area of the axon.
The proportionality factors r_m and r_ax are called specific resistivities.

\[ R_m = \frac{r_m}{\pi d} \]
\[ R_ax = \frac{r_ax}{\pi (d/2)^2} \]

\( r_m \): specific membrane resistivity (\( \Omega \cdot \text{cm}^2 \))
\( r_ax \): specific axial resistivity (\( \Omega \cdot \text{cm} \))
\( d \): axon diameter
\( \pi d \): axonal circumference
\( \pi (d/2)^2 \): axon cross-sectional area

\[ \lambda = \sqrt{\frac{dr_m}{4r_ax}} \]

\( \lambda \) is proportional to the square root of the diameter of the axon.
Hence, propagation velocity of an action potential is proportional to the square root of the diameter of the axon.