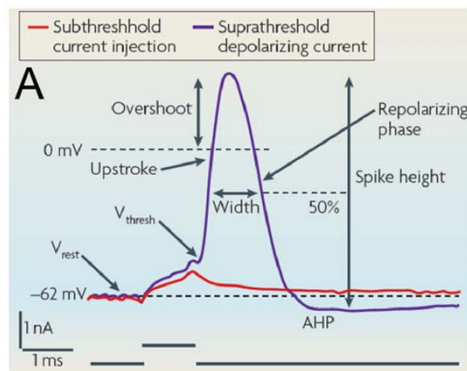


BIOL3833

Week 6: Ion channels – Part 2

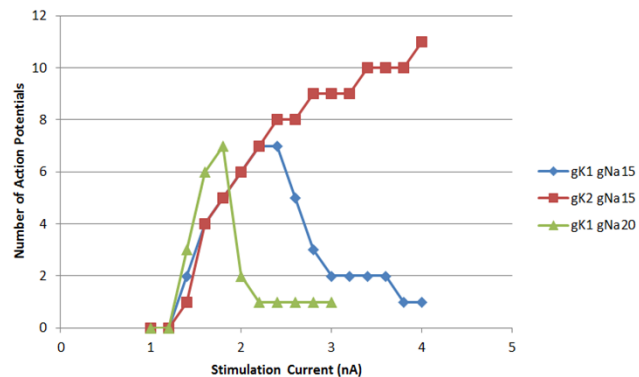
Significance of the Action Potential



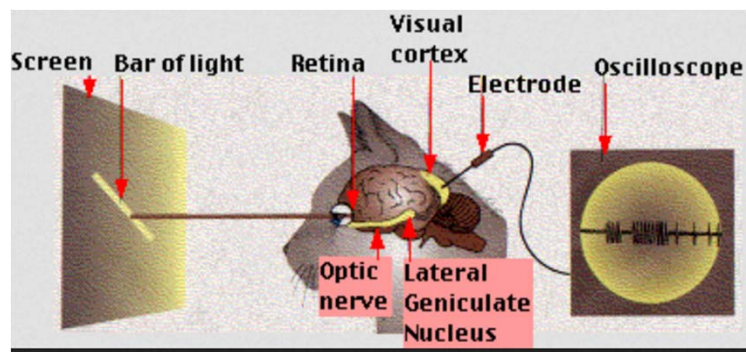
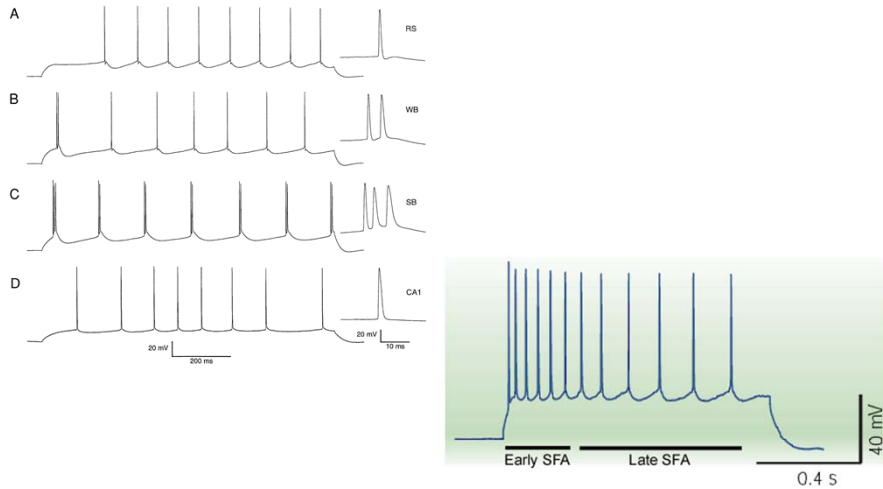
Action Potentials: Simple version

- Action potentials are initiated by the activation of voltage gated sodium channels
 - Result is inward sodium current
 - Threshold occurs when inward I_{Na} > outward I_K
- Terminated by inactivation of sodium channels and/or activation of potassium channels
 - Result is outward potassium current that repolarizes the cell

What can you do with a simple neuron?

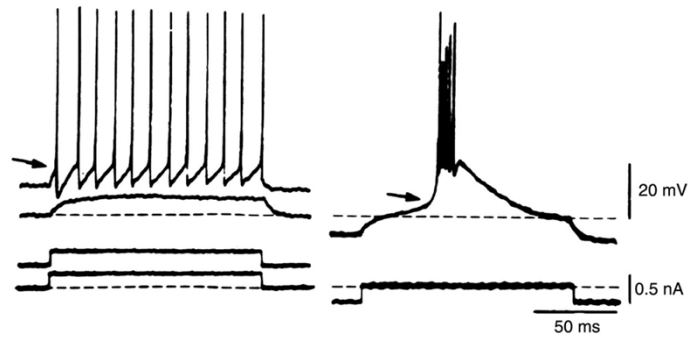


Spike frequency and patterning are important



[Encoding visual information in the brain:](#)

Multiple operating modes in one cell



Thalamic relay cell video

Action Potentials: Real Version

- Neurons don't just have one type of Na⁺ channel and one type of K⁺ channel
- Nine voltage-gated Na⁺ channel genes, multiple ways to fine-tune function
- Ten voltage-gated Ca²⁺ channels
- Hundreds of voltage-gated K⁺ channels
- K⁺ channels that are activated by calcium
- K⁺ channels that are activated by sodium

Voltage-gated calcium channels

- At least ten distinct genes encode calcium channels
- High-voltage-activated or Low-voltage activated
- Persistent (noninactivating) or transient (inactivating)
- We will focus for now on two types of calcium channel
 - L-type Ca^{2+} channel (large conductance, long lasting, high-voltage)
 - T-type Ca^{2+} channel (tiny conductance, transient, low-voltage)

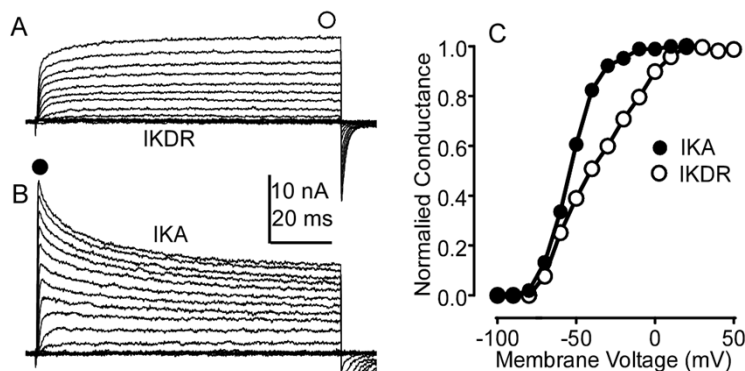
Effects of voltage-gated calcium channels

Potassium Channels drive Diversity

- Most CNS neurons have multiple potassium channels with different characteristics:
 - Voltage dependence of activation (Low-voltage activation vs. High voltage activation)
 - Some are activated by Ca^{2+} or Na^+
 - Rate of activation (how fast the population reaches maximum conductance)
 - Inactivation properties
 - Some inactivate quickly
 - Some inactivate slowly
 - Some don't inactivate at all
- This allows a huge diversity of spike waveforms and spike patterns for different cells

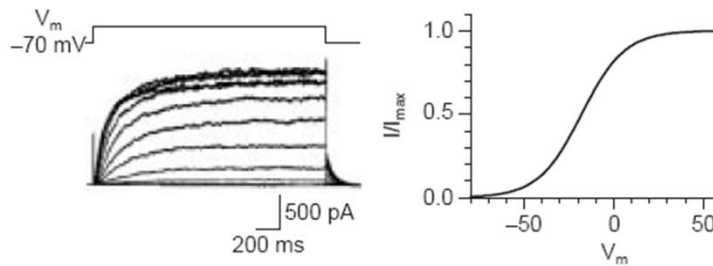
IK_{DR} and IK_{A}

- Common K^+ conductances in CNS neurons



I_{K_M} (M-Current)

- Slowly-activating, noninactivating K^+ conductance



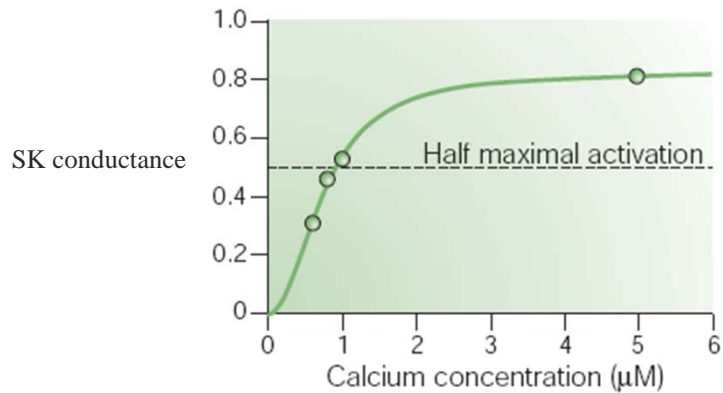
Rogawski (2000) Trends Neurosci.

Calcium entry during the AP activates K^+ channels

- Voltage-gated Ca^{++} channels open during the AP
- Calcium entry through multiple channel types
 - Small effect on membrane potential
 - Large effect on intracellular signaling
 - Activates calcium-gated K^+ channels

SK Channels

- Activated by intracellular Calcium

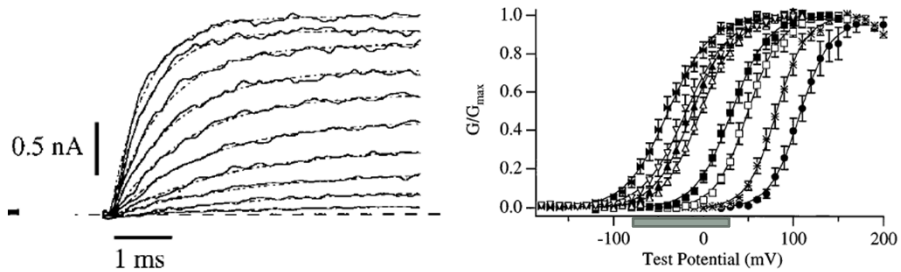


Stocker (2004) Nat. Rev. Neurosci.

The mystery current: I_{AHP}

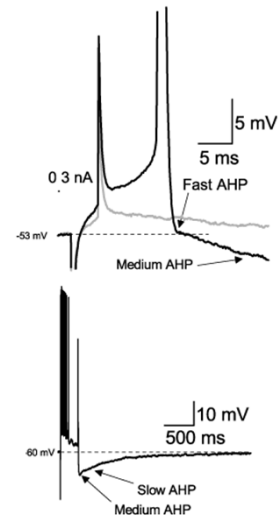
- Activated by intracellular Calcium
- Slow activation (100's of ms)
- Very slow deactivation (1000 – 3000 ms)
- Molecular identity of the responsible channel remains unknown

BK channels are activated by Ca^{++} and voltage



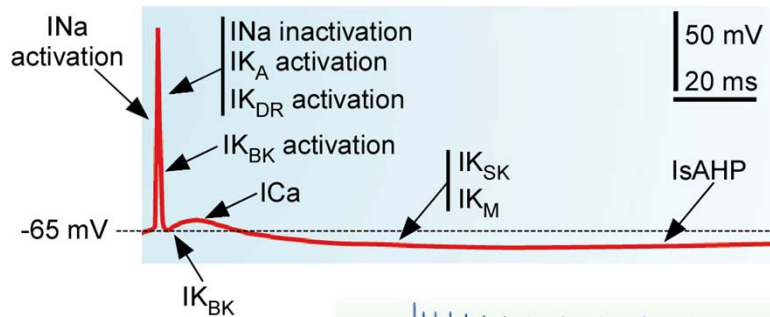
After the Action Potential

- Active processes continue after the action potential ends
- Afterhyperpolarization (AHP) occurs on at least three timescales
 - Fast AHP (2-5 ms)
 - mediated by BK channels
 - Medium AHP (10-100 ms)
 - mediated by SK and M-type channels
 - Slow AHP (100-3000 ms)
 - mediated by an unknown Calcium activated K^+ channel

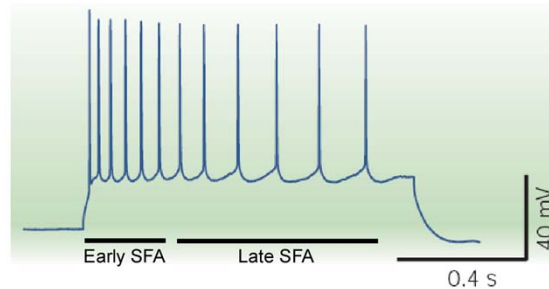


Functional Roles of the AHP

- Fast AHP (2-5 ms)
 - Shortens the AP by very quickly repolarizing the membrane
- Medium AHP (10-100 ms)
 - Controls early interspike interval
 - contributes to early spike-frequency adaptation
- Slow AHP (100 ms – 3000 ms)
 - Limits firing frequency
 - Controls late spike-frequency adaptation



SFA/serotonin video



Action Potentials: Real Version

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- Nine voltage-gated Na⁺ channel genes, multiple ways to fine-tune function
- Ten voltage-gated Ca²⁺ channels
- Hundreds of voltage-gated K⁺ channels
- Ca²⁺-activated K⁺ channels
- Na⁺-activated K⁺ channels

Voltage-gated calcium channels

- At least ten distinct genes encode calcium channels
- High-voltage-activated or Low-voltage activated
- Persistent (noninactivating) or transient (inactivating)
- Two key classes
 - L-type Ca²⁺ channel (persistent Ca²⁺)
 - T-type Ca²⁺ channel (transient Ca²⁺)

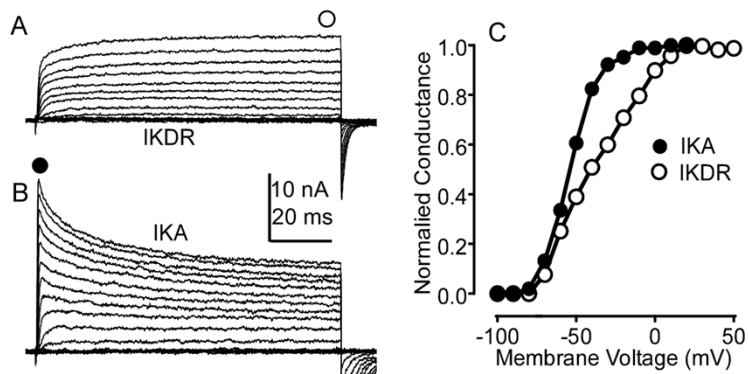
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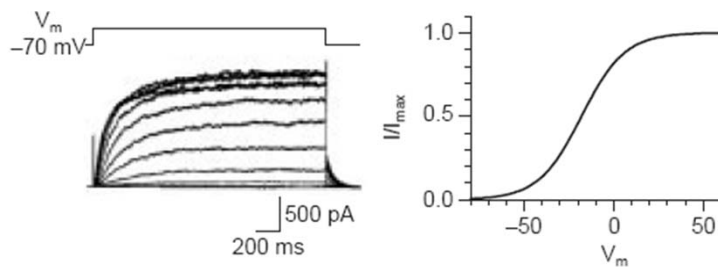
I_K and I_A

- Common K⁺ conductances in CNS neurons



I_M (M-Current)

- Slowly-activating, noninactivating K⁺ conductance



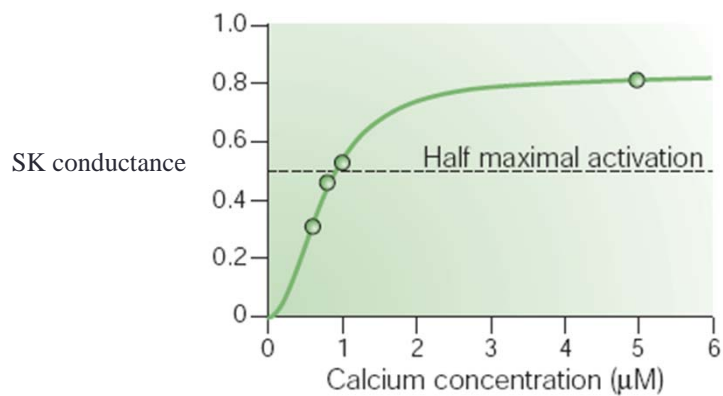
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- Activated by intracellular Calcium

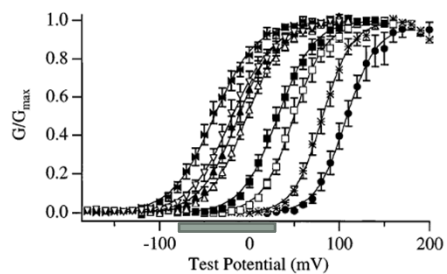
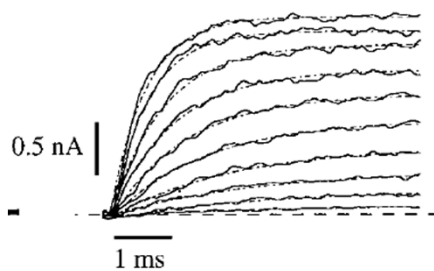


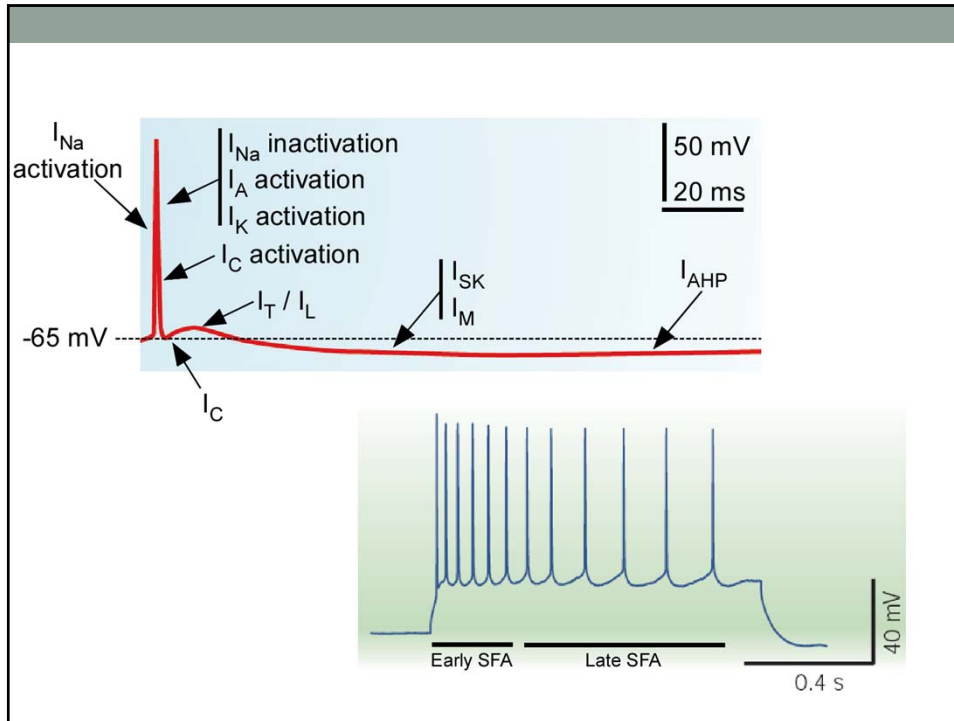
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I_C – produced by BK channels that are activated by Ca^{++} and voltage





Information coding by neurons

