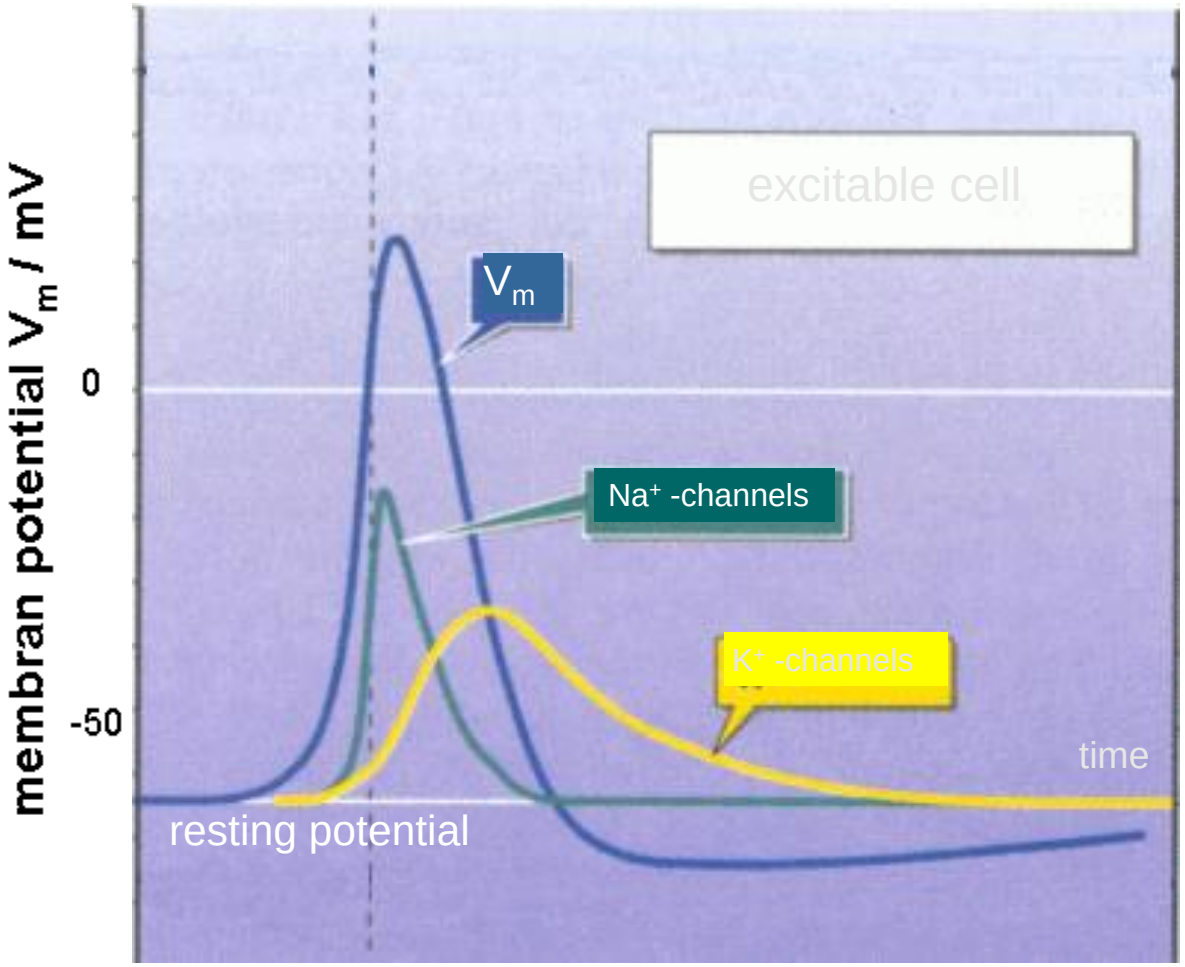
Action Potential

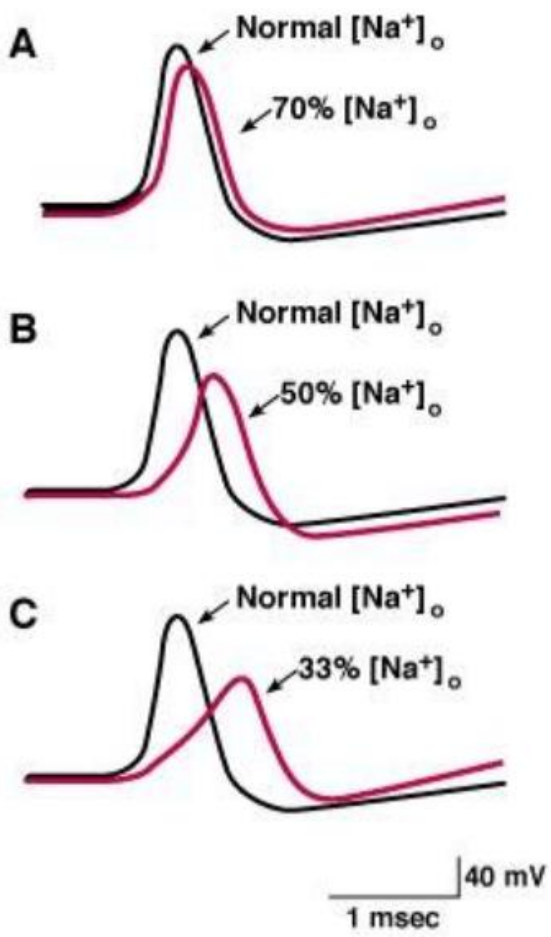
Assoc. Prof. Erkan Tuncay

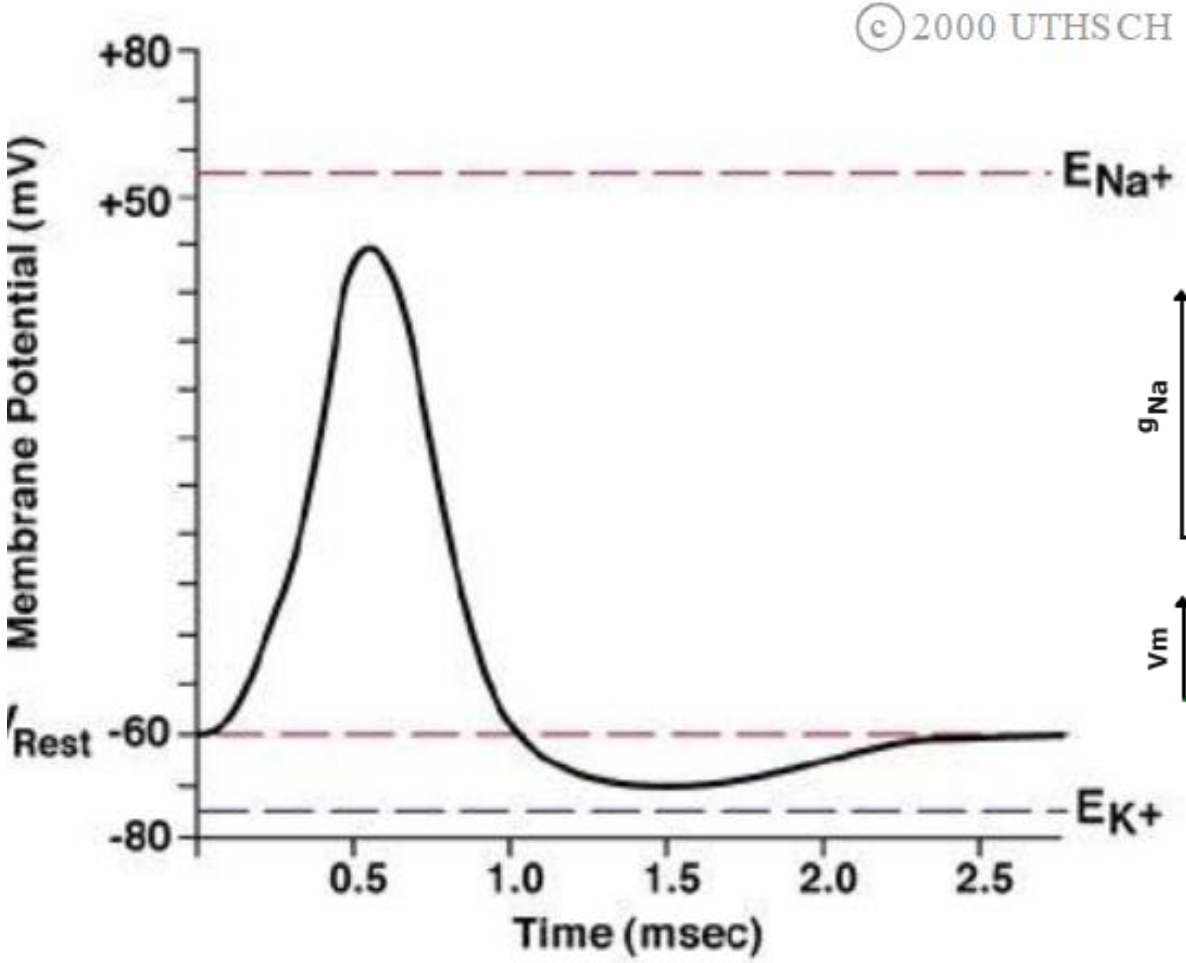
Department of Biophysics

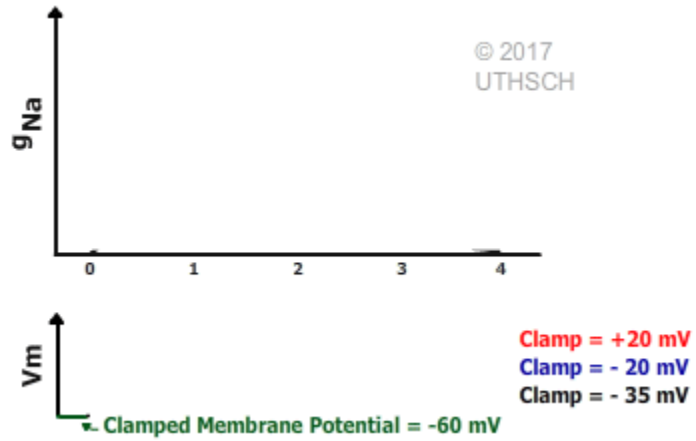
Action potential



Ionic Mechanisms of Action Potentials

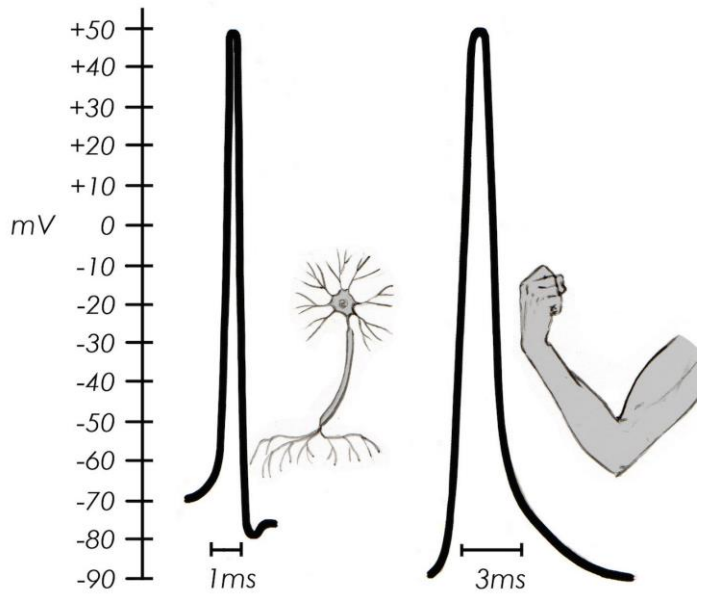


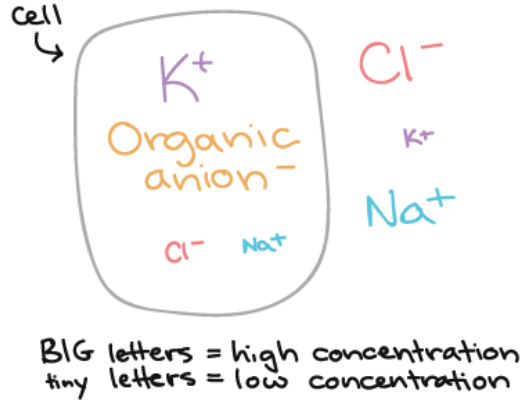




Is there any difference between skeletal muscle and neuronal membrane potentials?

- Skeletal muscle membrane potential maintains more negative membrane potential then the neuronal membrane potential.
  - The more negative Vm due to
    - Increased K+ gradient
    - Increased Cl- gradient
    - Greater resting Cl- permeability
  - The T-tubule membranes contains chloride channel that contributes to the resting Vm potential together with leaky K channel.





Comparison between neuronal action potential and action potentials in other cell types

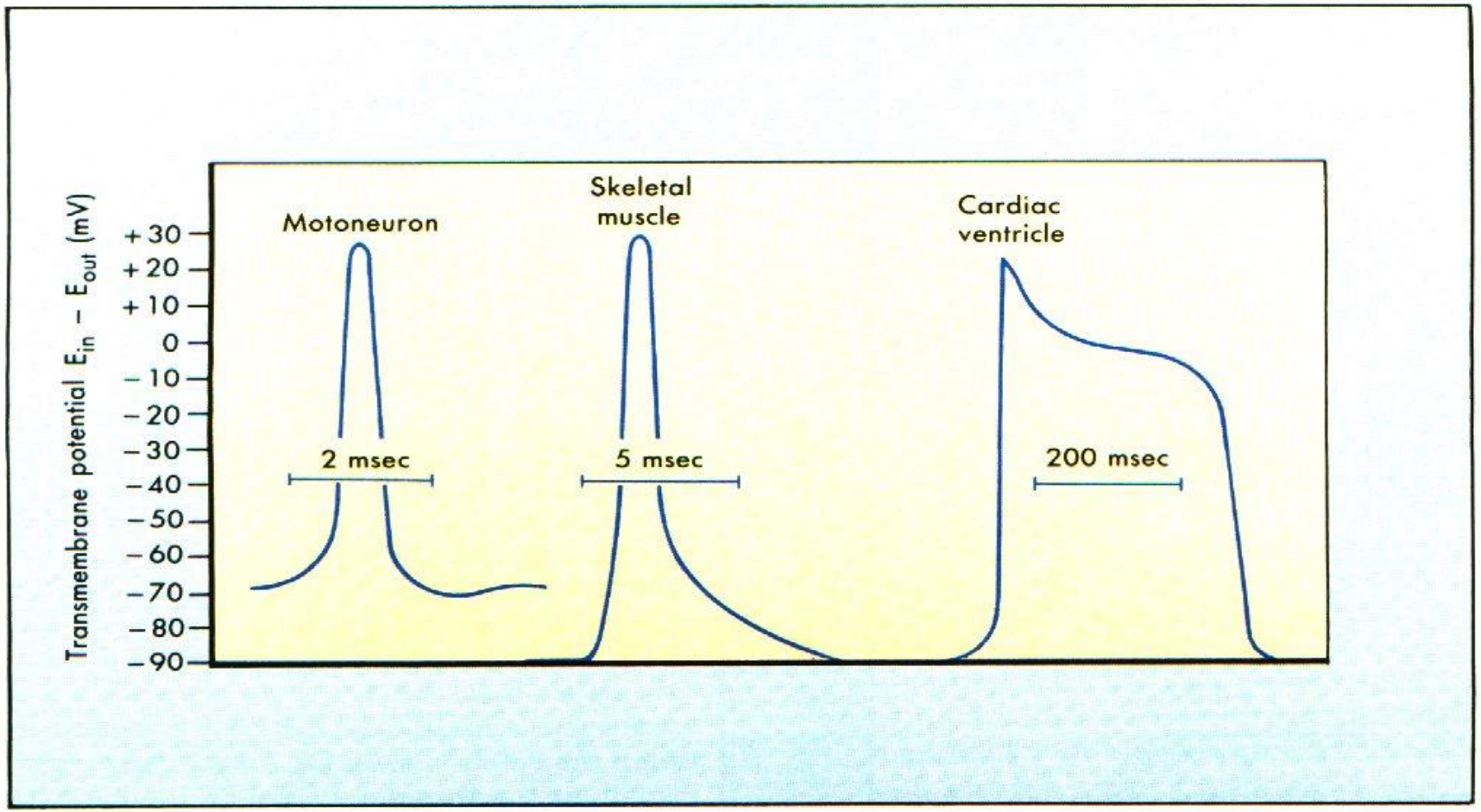


FIGURE 3-1 Action potentials from three vertebrate cell types. Note the different time scales. (Redrawn from Flickinger CJ et al: Medical cell biology, Philadelphia, 1979, WB Saunders Co.)

Action potentials in heart

- There are two types of action potentials in the heart

Action potentials in heart

Cells in the heart are specific populations of cells that are specialized for different purposes

There is a division of labor between cells whose main job it is to contract and

Cells whose main job it is to conduct electricity.

Questions:

1. What is an equilibrium (Nernst) potential for an ion? What are typical values of Nernst potentials for Na^+, K^+, and Ca^{++}?
2. How does the opening of ion channels that are selective for a specific species of ion (e.g., Na^+, K^+, and Ca^{++}) affect membrane potential?
3. What is the resting membrane potential? Which ion channels typically stabilize the resting membrane potential?
4. Which types of ion channels can produce action potentials?
5. What is spike threshold?
6. Why does the opening of K channels hyperpolarize the membrane potential but the opening of Na channels or Ca channels depolarizes the membrane potential?

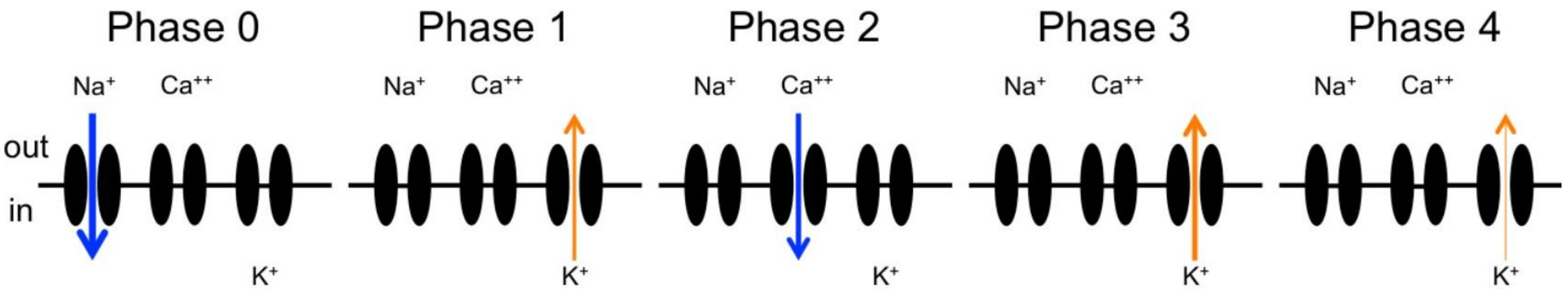
Action potentials in heart

- Fast/long action potentials are produced in working cells and Purkinje fibers.
  - Working cells do not exhibit automaticity, and they lack a spontaneous depolarization to threshold for producing an action potential. Purkinje fibers have a fast and long action potential, like the working cells, but they also have a small degree of automaticity, which we will discuss later.
  - The action potential is initiated by a very large Na^{+}current produced by the opening of voltage-gated Na channels.
  - The depolarization produced by the opening of the Na channels stimulates the opening of L-type Ca channels, which produces a long plateau in the action potential during which Ca^{++} enters the myocyte and contributes to contraction of the muscle.

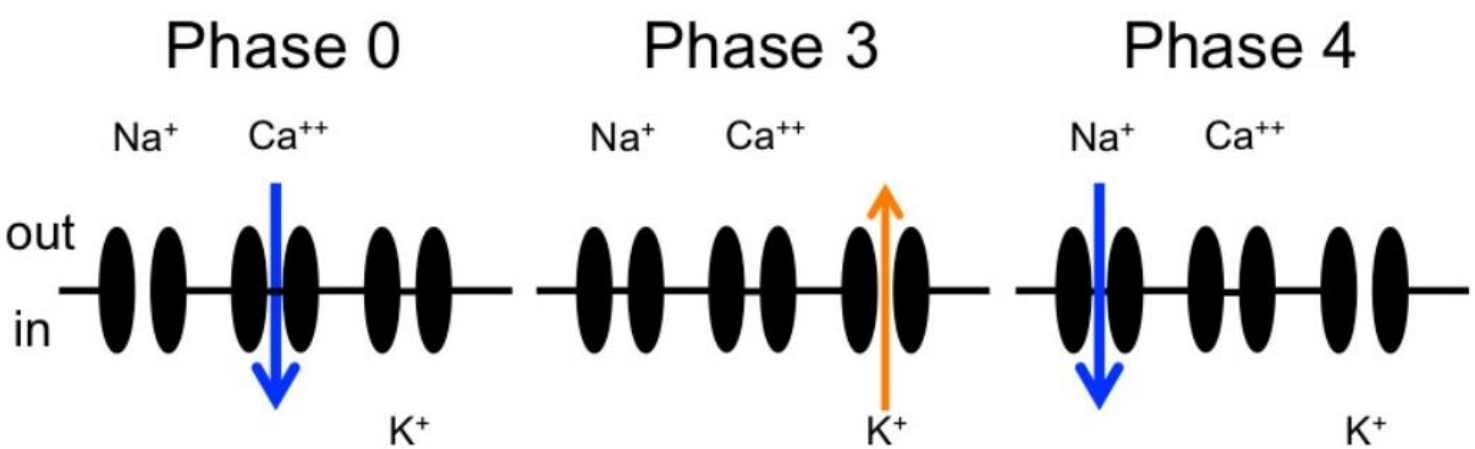
Action potentials in heart

- Slow/brief action potentials are produced in the SA & AV nodes.
  - These are the cells that exhibit automaticity. Their membrane potential is never constant, and they spontaneously depolarize towards threshold to produce an action potential.
  - The action potentials are produced by the opening of L-type Ca channels only, and the action potentials can be blocked by verapamil and diltiazem.
  - Voltage-gated Na channels are not involved in these action potentials

Fast Action Potential



Slow Action Potential



What is Autumaticity?

What is Autumaticity?

- **Automaticity**
  Automaticity is the ability of certain cells of the heart to regularly depolarize without an external stimulus telling them to do so.

- The rate of depolarization of SA node cells is faster than the rate of depolarization of AV node cells

How **does beta adrenergic receptor** and muscarinic M_2 receptors regulate the funny currents?

Responsiveness

- Responsiveness is the rate of depolarization of the membrane potential during phase 0. The working cells and Purkinje fibers have a very high responsiveness because of the presence of many voltage-gated Na channels. Note that responsiveness and automaticity are different.

Threshold

- The membrane potential at which an action potential is triggered. Increasing the threshold corresponds to making the threshold membrane potential more depolarized and more difficult to reach.

Conduction Velocity

- Conduction velocity is the rate of propagation of an action potential, which depends on the density of the channels carrying inward currents and on the spike threshold. Purkinje fibers have the highest conduction velocity. This is important because the regions of the ventricles near the apex of the heart must contract first, or at least no later than the regions closer to the aortic and pulmonary valves. Conduction through the bundles and branches of Purkinje fibers helps to coordinate this. Note that conduction velocity is different from responsiveness and from automaticity.

Refractory Period

- The refractory period is the period of time during which the threshold for producing an action potential is increased.

References

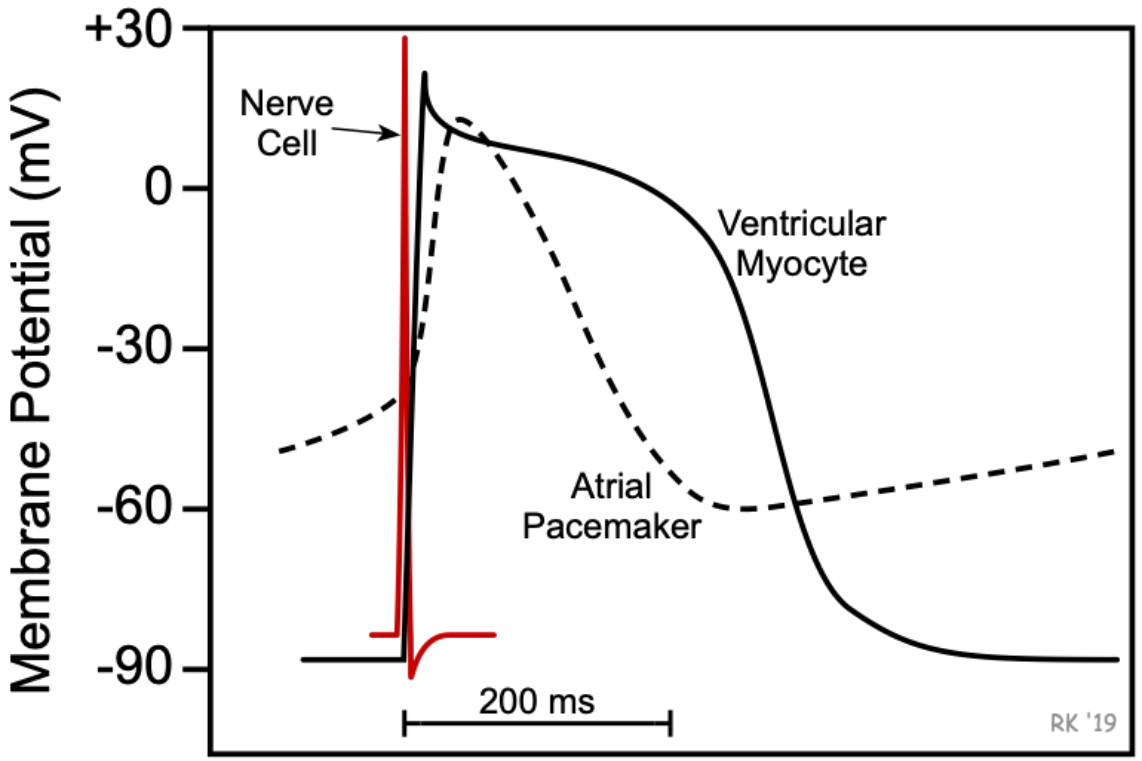
1. Boron, W. F., & Boulpaep, E. L. (2017). *Medical physiology* (3rd ed.). Philadelphia, PA: Elsevier/Saunders.
2. Lilly, L. S. (2016). *Pathophysiology of heart disease: A collaborative project of medical students and faculty* (6th ed.). Philadelphia, PA: Wolters Kluwer.

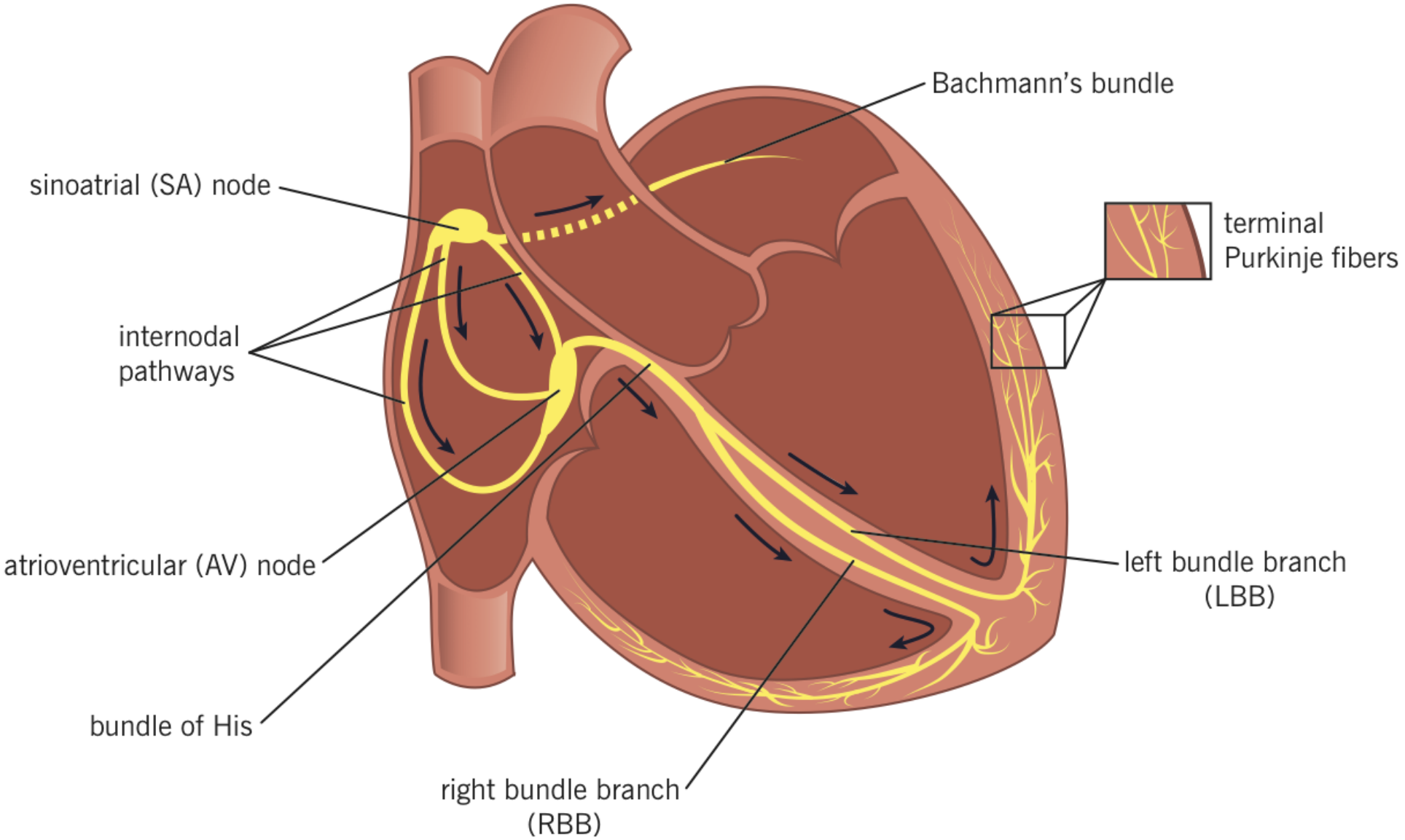
Action potentials in the heart

Cardiac action potentials in the heart differ considerably from action potentials found in neural and skeletal muscle cells. One major difference is in the duration of the action potentials.

In a typical nerve, the action potential duration is about 1 ms. In skeletal muscle cells, the action potential duration is approximately 2-5 ms. In contrast, the duration of cardiac action potentials ranges from 200 to 400 ms.

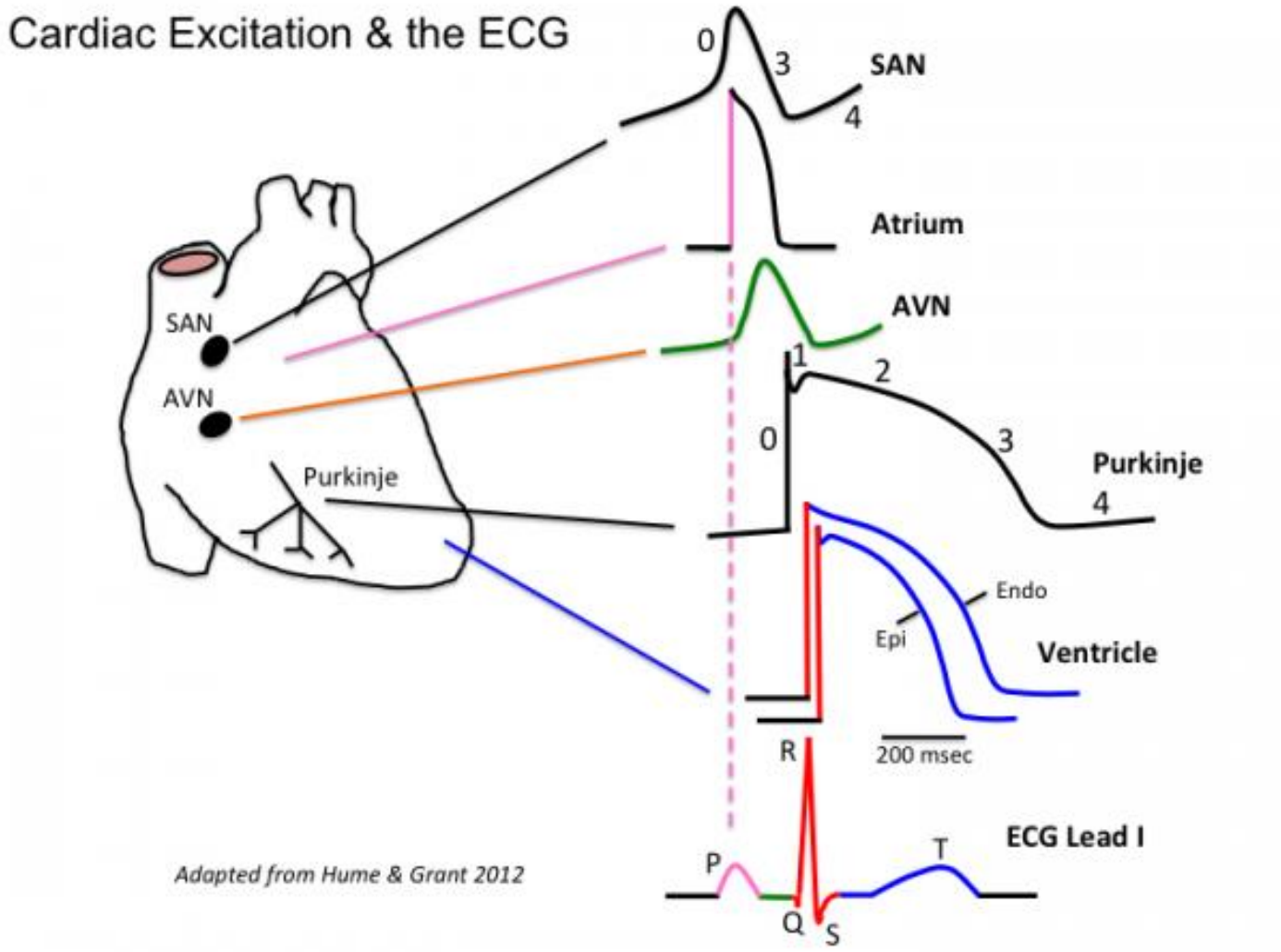
Another difference between cardiac and nerve and muscle action potentials is the role of calcium ions in depolarization.





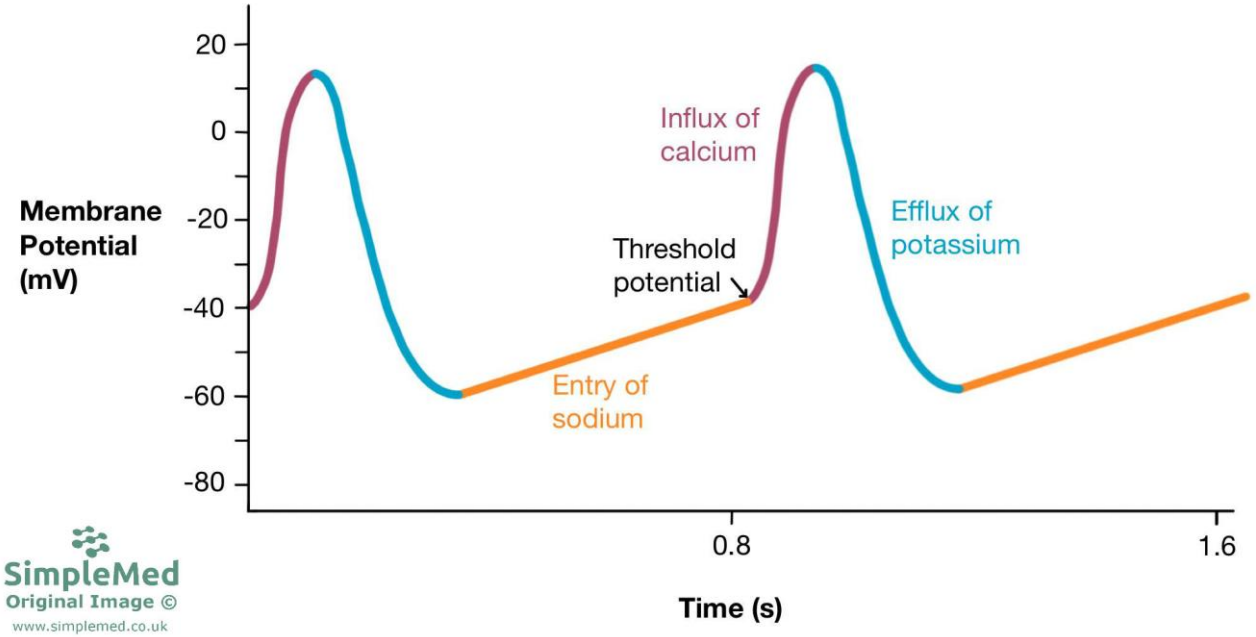
http://www.pathophys.org/physiology-of-cardiac-conduction-and-contractility/

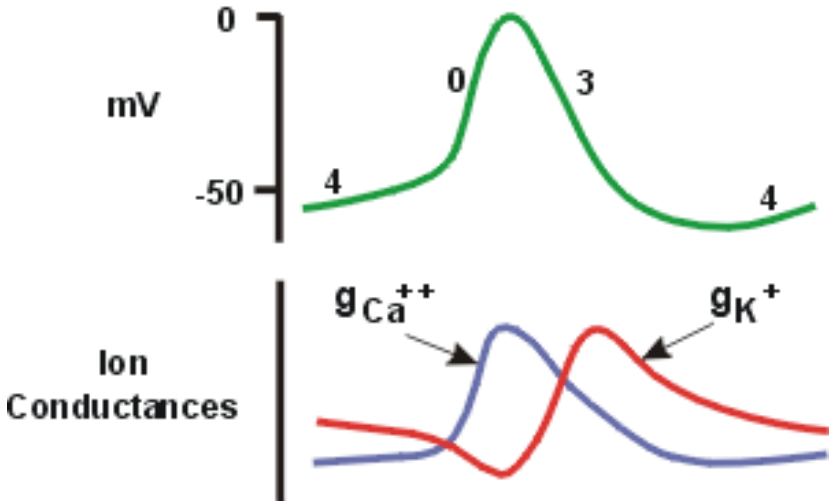
Action potentials in the heart



- Depolarization starts in the SA node, travels through the atrial internodal fibers, then through the AV node and subsequent Purkinje fibers, and finally out through the working cells in the ventricles.
- There are variability in the shape of the action potential at each location. Those action potentials can be fast and long, or slow and brief.
  - Fast/long action potentials are produced in working cells and Purkinje fibers.
  - Slow/brief action potentials are produced in the SA & AV nodes.

Sinoatrial Node Action Potentials





Summary

- Membrane potentials in cells are determined primarily by three factors
- Ionic mechanisms of action potentials
- Membrane and action potential difference between neuronal, skeletal and heart muscle

Ion channels

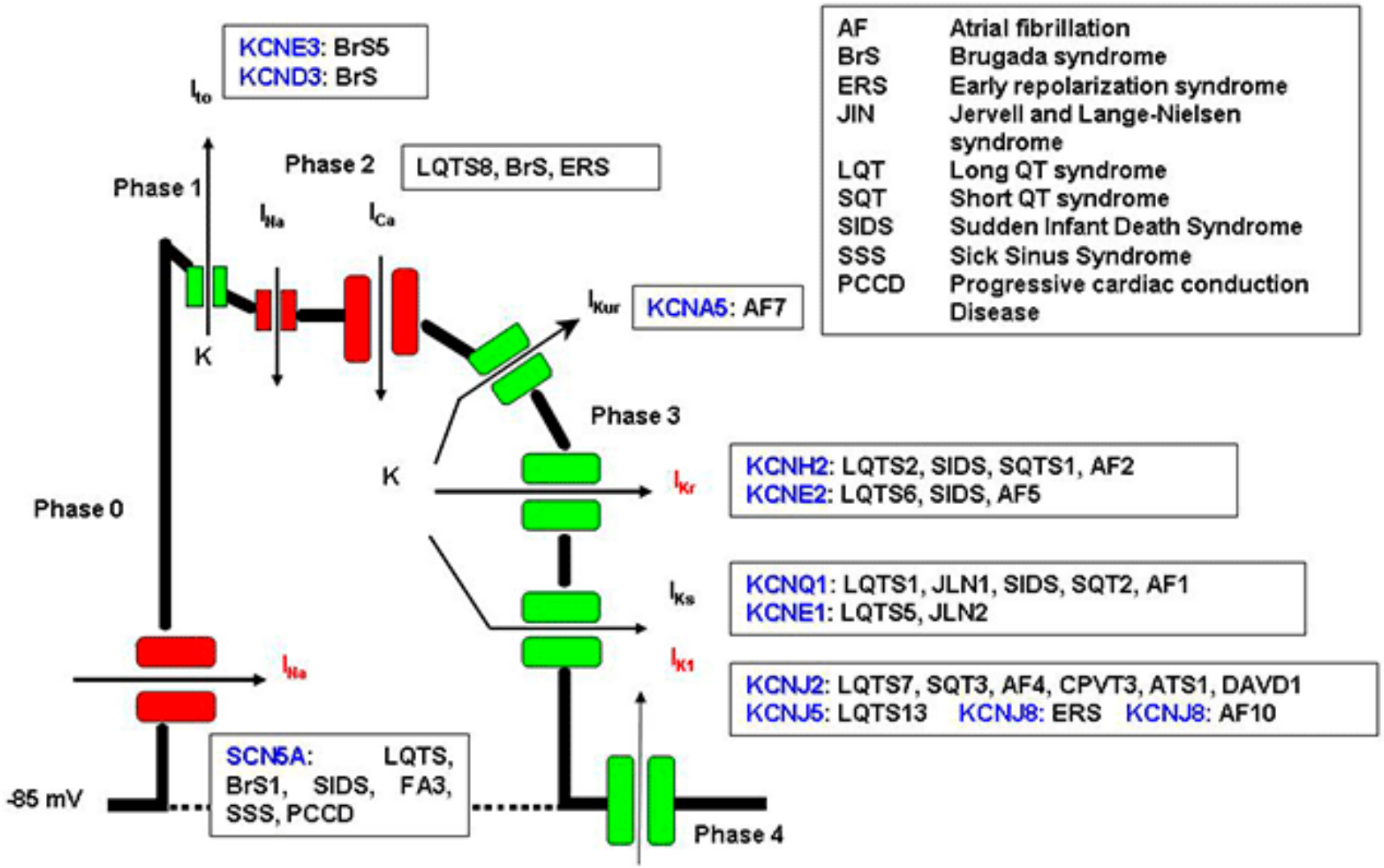
- The rate and direction of ion movement is governed by the electrochemical gradient.
- The rate of ion transport through the channel is very high 10^7 ions/sec. Transport is always down the gradient

Ion channels

- The rate and direction of ion movement is governed by the electrochemical gradient.
- The rate of ion transport through the channel is very high 10^7 ions/sec. Transport is always down the gradient

PHYSIOLOGY OF CARDIAC CONDUCTION AND CONTRACTILITY

Cardiac channelopathies



https://www.itaca.edu.es/cardiac-action-potential.htm