Biology from an EE perspective
Lecture 7

Electrically excitable tissue &
The Neuron

Rakesh K Lal

Lecture Overview

- A little info about the nervous system
- Type of electrically excitable tissue
- Nerve cells
- Potential in electrically active cells
- Nerve impulse
- Modeling of nerve impulse

Figure credits: Unless mentioned, all jpeg images are from the site of *Molecular Cell Biology* by Lodish et al., published by W H Freeman & Co

The neuron -1

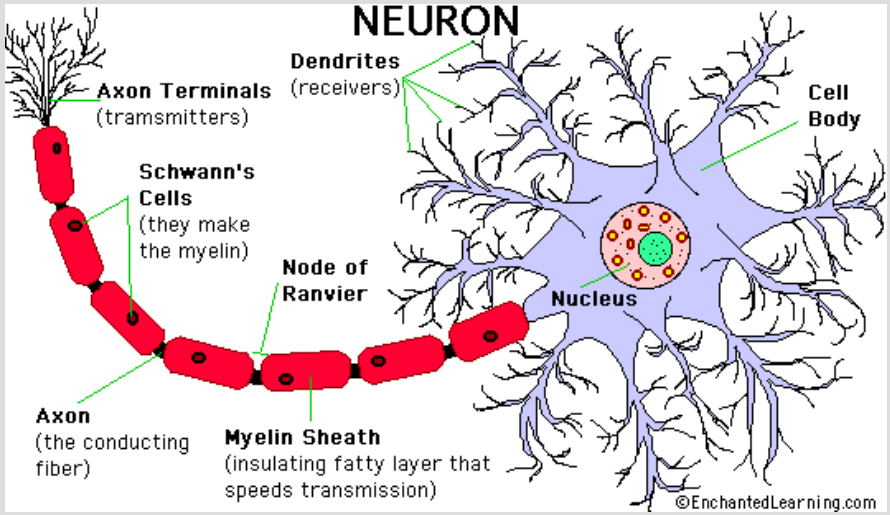
- The nervous system regulates all aspects of bodily function
- Allows signaling at speeds higher than what one could get with purely chemical
- Complex weighting, averaging and thresholding operation
  - These weighting and thresholding models used in artificial neural networks

The neuron -2

- Some numbers -- truly staggering:
  - Millions of nerve cells for sensing
  - These transmit to millions more for processing, storage and actuation
  - Plus the brain has about 10^12 nerve cells for info integration, storage, processing and transmission – each has a separate function and forms as much as a
- Thousands of connections with other cells
  - At least a 1000 different types of nerve cells identified

Cartoon of a neuron

- Cell body
- Dendrites
- Synapses
  - Chemical
  - Electrical
- Axon
  - Axon termini
  - Nerve cells have myelin sheath on axon



Cell body

- Cell body has all the molecular machinery for protein synthesis and degradation
- Proteins synthesized and distributed to regions where needed via intermediate fibers & microtubules – upto 10 meters in the case of a giraffe nerve cell (blue whale?)!
- Both orthograde & retrograde transport of chemicals possible
  - That is from the cell body to the axon termini & back

Dendrites

- Synapses in dendrites receive signals and depolarize if thresholds exceeded
- Potentials created spread passively and are summed near the axon hillock

Synapse -1

- Excitatory or inhibitory synapse
- Chemical synapse (more common)
  - Neurotransmitter (such as epinephrine or acetylcholine) in vesicles in axon termini or sense organs released in synaptic cleft
  - Diffuse to postsynaptic cell (~0.5 ms) and bind to receptor and trigger depolarization pulse
  - The management on chemicals at the synapse interesting: how is a synaptic signal turned of and how are neurotransmitters managed at the synapse?

The synapse -2

- Electrical synapse
  - Connected by gap junctions
  - Potential impulse passes directly
  - Fast

Axon

- Actively carries the depolarization signal along
  - Axons maybe myelinated
- Terminates at synapses in axon termini

Several types of neurons

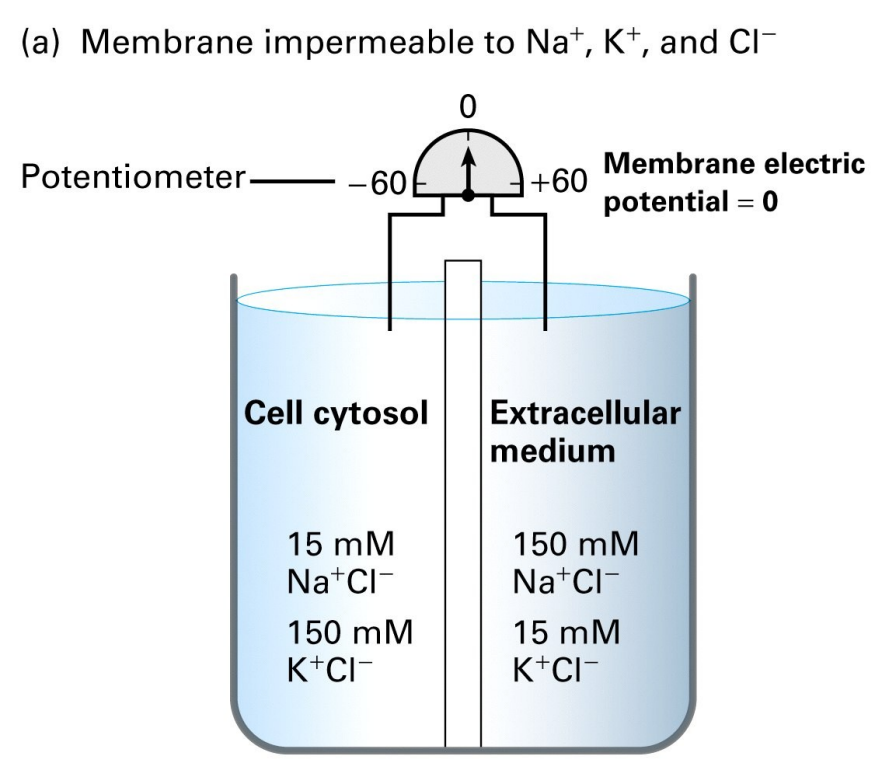
- Long dendrites & short axons
- Many dendrites & long axon
- Different branching patterns
- Myelinated axons
- Bipolar axons

Nerve action

- Signals from sense organs or upstream neurons excite synapses
- These create depolarization signals in dendrites
- Depolarization signals from different dendrites are summed at the axon hillock
- If it exceeds a certain threshold the depolarization signal is created and travels down the axon
- Synapses at axon termini excite other neurons or other effector cells such as muscle cells

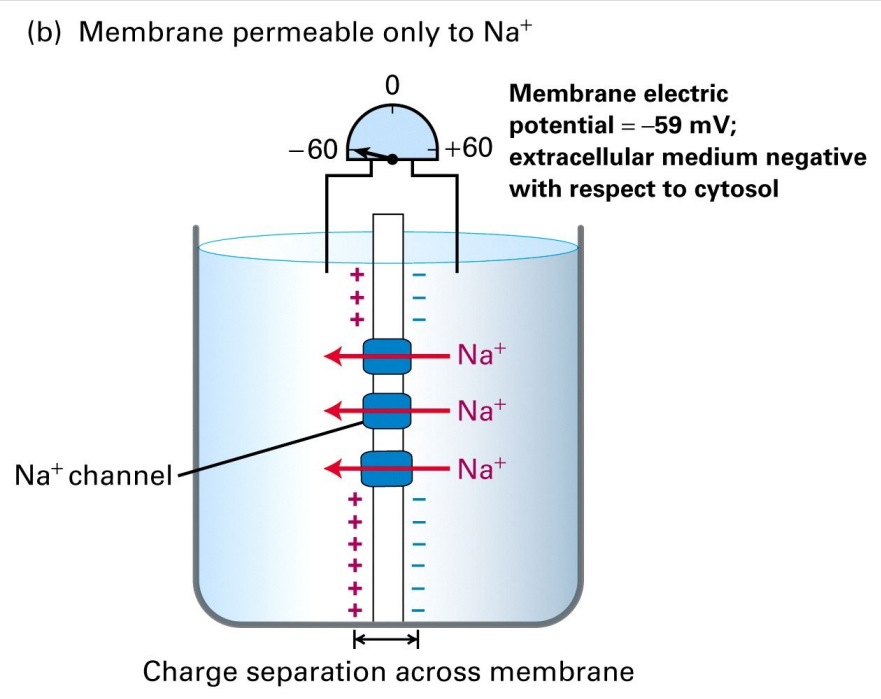
Membrane potential -1

- Two concentrations across a membrane no permeability
  - Can one use the Boltzmann relation as one does for a PN junction in equilibrium



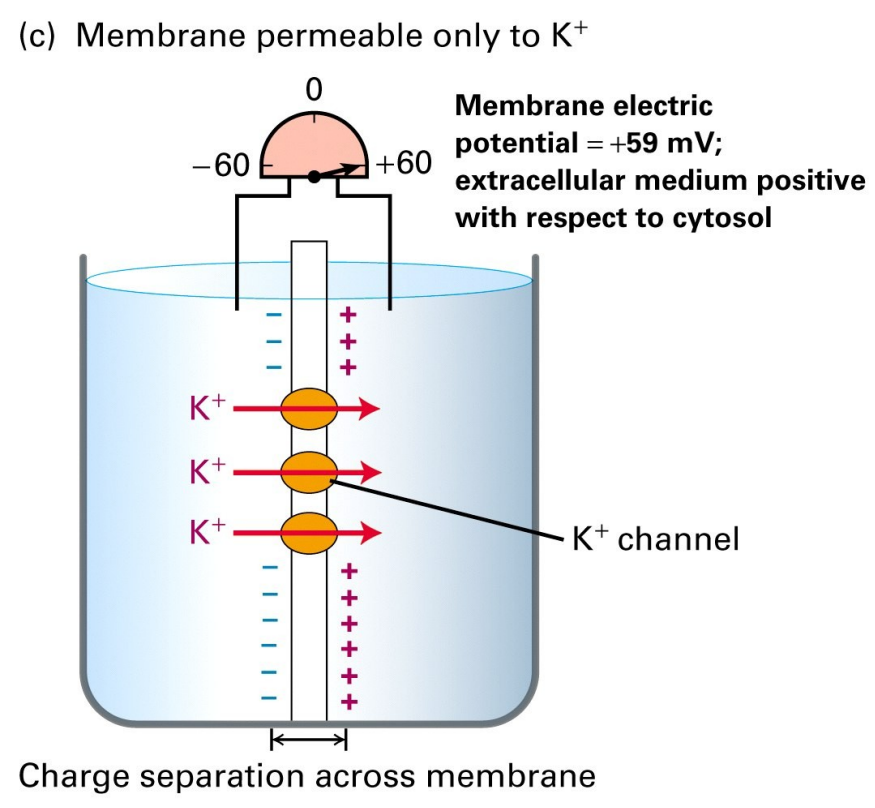
Membrane potential -2

- High Na permeability
- Note the voltage measured has changed with change of permeability, concentrations not yet altered after switch of permeability



Membrane potential -3

- High K permeability
- Direction of voltage has changed
- The direction of voltage measured can be figured out from the direction of current but estimating the magnitude more difficult



Discuss action potential & techniques

- The Boltzmann relation and getting the built-in voltage by balancing the diffusion and drift currents
- The Nernst potential in electrochemistry
- The use of a Nernst-like relation with permeability included for cell potentials
- Creation and propagation of the nerve impulse
- The role of myelination in speeding up nerve impulses
- Measurement of cell potentials
- The patch clamp technique

Summary

- The neuron is a mammalian cell type that is electrically active
- Signals are picked up at dendrites, passively transmitted across the cell body, summed at the axon hillock and an impulse created if a threshold is exceeded
- Once an action potential is created it moves along the axon with a certain refractory period created for each segment
- The action potential at axon termini either releases neurotransmitters or the potential change transmitted via ionic currents