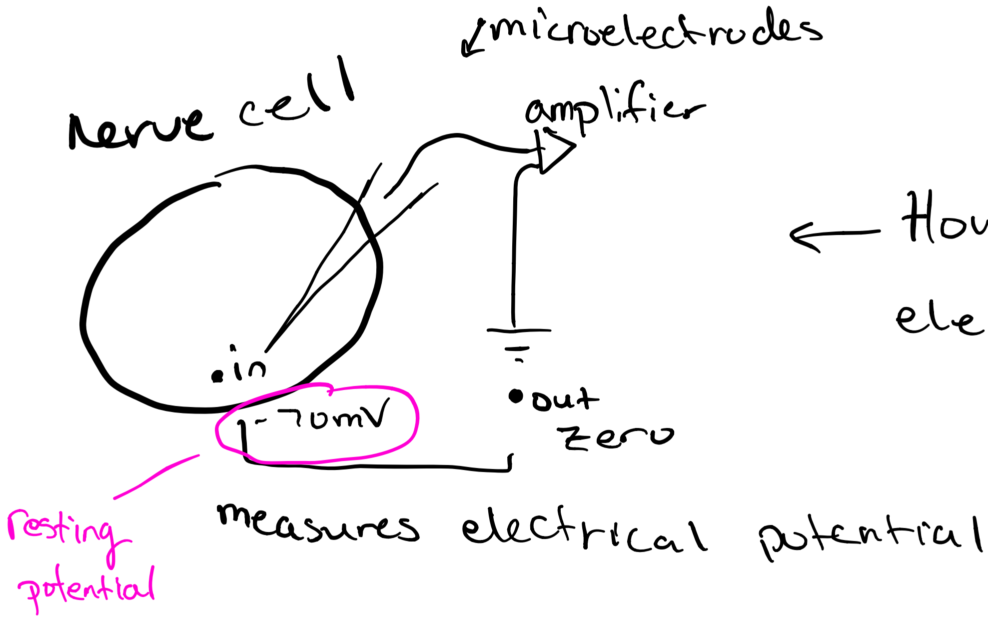
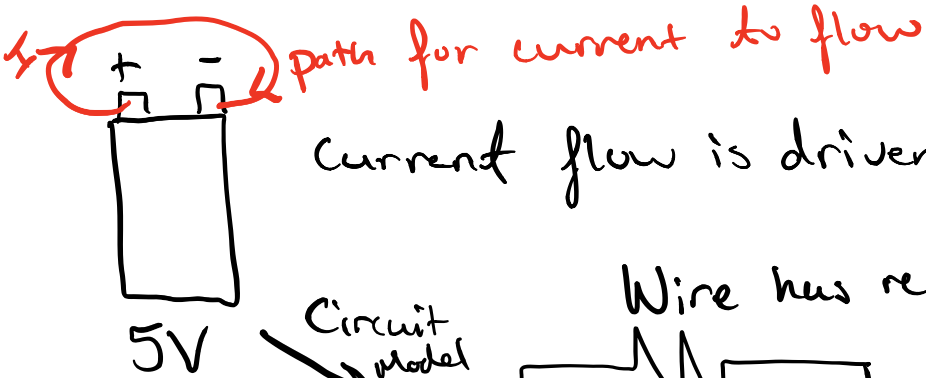
Pre-Lecture Video



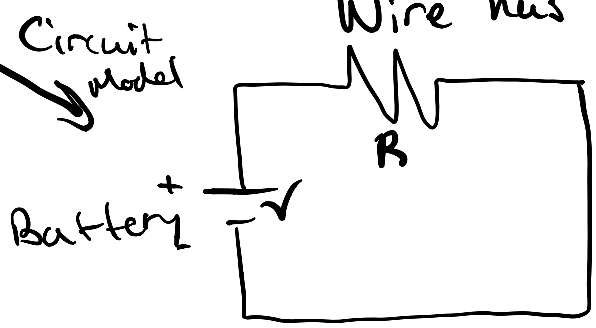
← How we measure electric potential

Potential difference



Current flow is driven by battery!

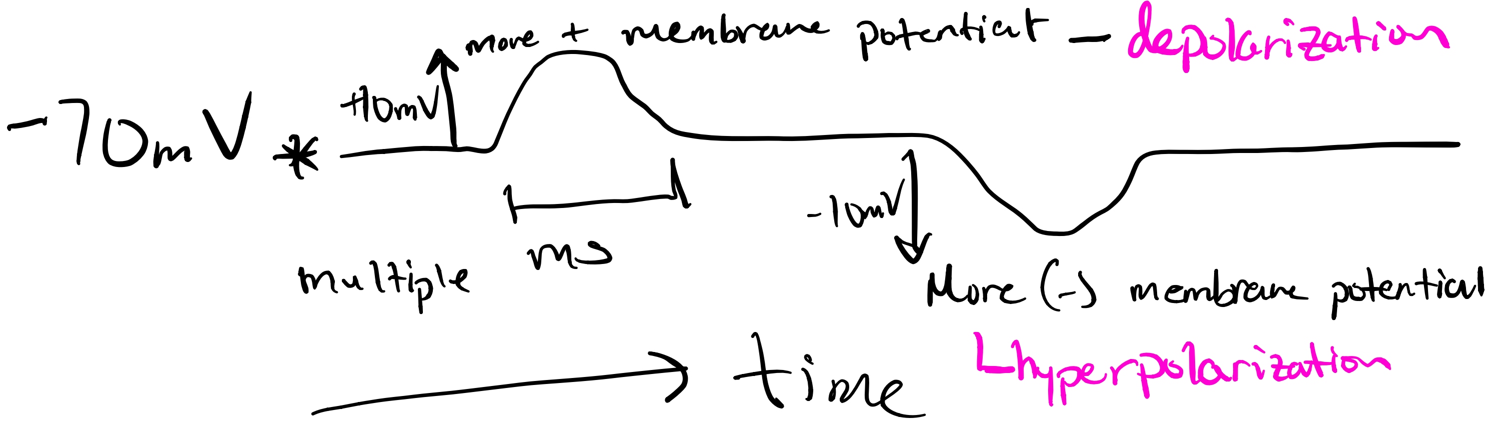
Wire has resistance



For a battery w/ voltage V, resistance R,

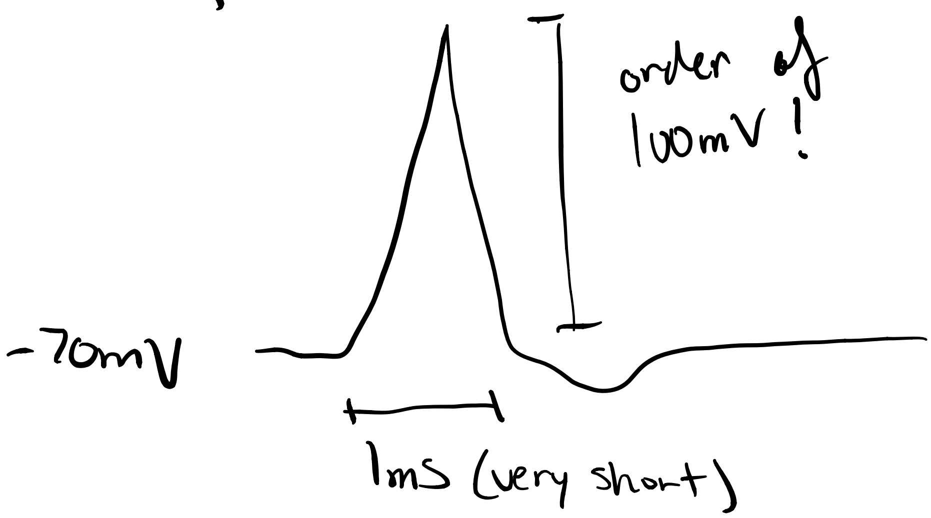
$V = IR$! (Ohms Law)

$$I = \frac{V}{R}$$



Postsynaptic potentials = inputs from other neurons

Action potential (quick change)



Lecture 03. Electrical Signaling in the Nervous System

Watch the Pre-class video!

Reading (less important than the pre-class video)

Relevant reading: Bear et al., pp. 59-70.

Learning Objectives

1. To understand the differences between resting potential, synaptic potentials and action potentials, the key electrical events in neurons that need to be explained at a cellular level.

2. To learn the concept of an ion gradient across a semipermeable membrane and how it can give rise to potential differences across membranes.

3. To learn the Nernst equation, which describes the potential difference in a case where only one ion is permeable.

Lecture Outline

1. Introduction: much of the function of the nervous system depends upon electrical signaling.

2. Electrical recordings from nerve cells reveal resting membrane potentials, synaptic potentials, and fast, large action potentials. Two fundamental questions that can be asked about these properties are:

3. The structure of neurons (really of cells in general) is important for electrical properties.

A. *Lipid bilayer* separating internal contents from external ones.

B. *Protein channels* that allow for some things (often ions such as sodium, potassium, and chloride) to move from outside in and vice versa.

C. *Protein pumps* that actively move ions or molecules from one side to the other.

These allow for the maintenance of different chemical compositions inside the cell (intracellular) versus outside the cell (extracellular) and this is key to generating electrical potential differences and producing rapid electrical events.

4. **How does a difference in the composition of the solutions inside and outside a neuron lead to the recorded potential difference between the inside and outside?**

A. *First consider a simple case in which there are two different concentrations of an uncharged molecule on either side of a membrane that is somewhat permeable to the molecule.*

The uncharged molecule will tend to move from highest concentration to lowest until concentrations are equal on both sides.

B. *What if the permeable particle is charged?* Suppose that we do the same experiment as in A, but with a high concentration of potassium chloride on one side and none on the other and a membrane that is permeable to K^+, but not to chloride.

K^+ moves down its concentration gradient, but this leads to the development of an electrical potential difference that opposes the force of the concentration gradient. When the potential difference is big enough, the electrical force balances the chemical concentration gradient and an equilibrium is established at which there is no net flow of K across the membrane. In other words, the chance that an ion will flow from higher concentration to lower due to the chemical force is exactly balanced by the chance that one will move from the more positive side of the membrane to the less positive side because of the electrical force.

5. **This is what happens in nerve cells because the ionic compositions are different inside and outside the cell and the membrane differs in its permeability to the different ions.**

A. *"Typical" major contributors to chemical composition of fluids inside and outside a mammalian neuron:*

	Internal (mM)	External (mM)	Permeable?
Potassium(K^+)	125	5	Y
Sodium (Na^+)	12	120	sometimes
Chloride (Cl^-)	5	125	Y
Large anions($A^{-1.2}$)	108	0	N
Also important:			
Calcium (Ca^{2+})	.0001	1	sometimes

B. *At rest, the membrane is mostly permeable to* K^+. The situation is then similar to the previous example with the higher concentration of K^+ inside cell. The inside of the cell will become more negative relative to the outside as K^+ moves out.

C. *The equation used to calculate the electrical potential (E) at equilibrium in a situation in which one ion (X) is permeable is the Nernst equation.*

$E_x = RT/zF$ (ln ($[X]_{out}$/($[X]_{in}$)

Where R= universal gas constant
T=temperature in Kelvin
z = valence (electrical charge of the ion)
F=Faradays constant

At room temperature in base 10
E_x (in millivolts)= 58/z log ($[X]_{out}$/($[X]_{in}$

D. *Equilibrium potentials for the permeant ions K, Na, and Cl.*

Study Questions

1. What are the different sorts of potential changes one would observe in a neuron when recording the potential difference across its membrane in an intact animal?

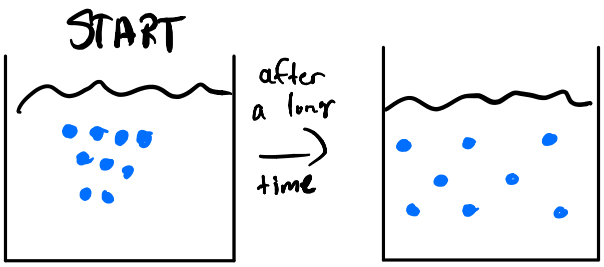
2. Describe clearly in words, not using an equation, how an electrical and a chemical force come into balance to form a potential difference across a membrane when only one ion is permeable and is present in different concentrations on the two sides of the membrane.

3. What is the Nernst equation? What does each of the terms in the equation represent and why are they important in determining the electrical potential described by the equation?

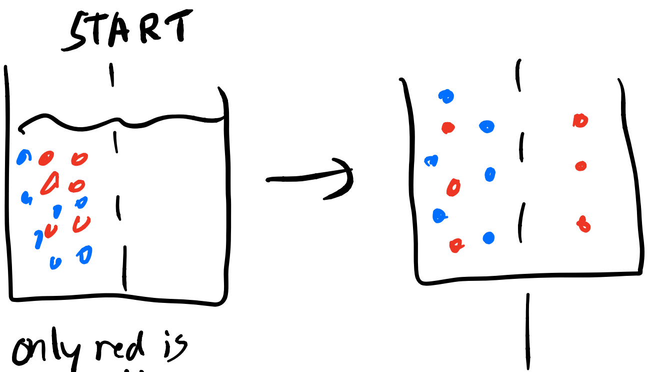
IN-CLASS

Resting Potential

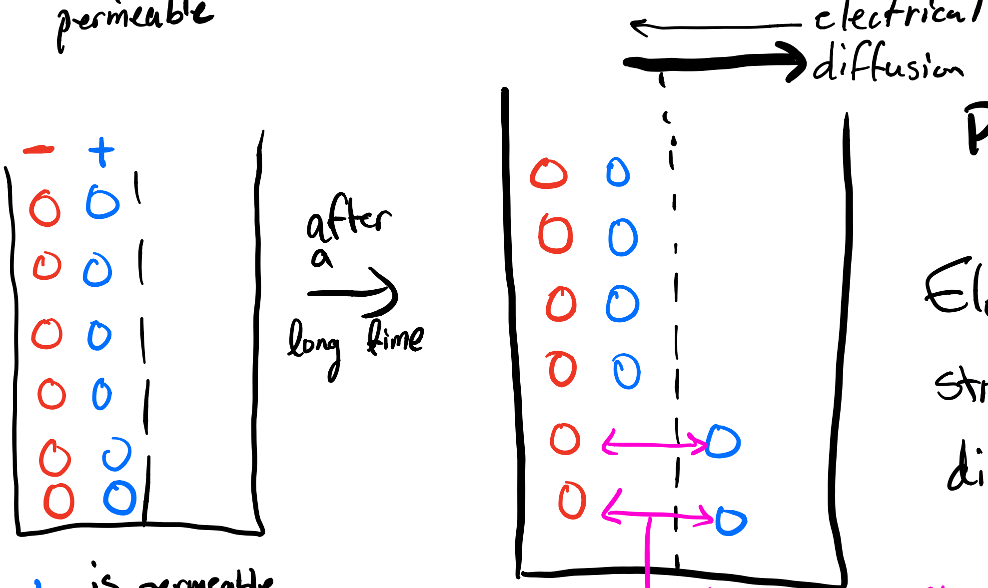
All brain function depends on flow of charged ions such as potassium and sodium.



Particles move from high → low concentration



only red is permeable



+ is permeable

attract eachother, but NOT strong enough

Plus attracts Minus

Electric force is NOT strong enough to prevent diffusion.

There is a diffusion force on blue.

There is electrical force on blue

Now there is a potential difference across the membrane

*When a single type of charged particle is permeable, a **POTENTIAL DIFFERENCE** across the membrane

⋮

	Internal (mM)	External (mM)	Permeable
Potassium (K^+)	125	5	Y
Sodium (Na^+)	12	120	M
Chloride (Cl^-)	5	125	Y
Anions (A^-)	108	0	N
Calcium (Ca^{2+})	.001	1	M

NERNST EQUATION

- Describes the potential at which the two forces are in balance across a membrane that is pereneable to ONLY ONE charged particle type (ion)

Temp in Kelvin

$$E_x = \frac{RT}{zF} \ln \frac{[X_{out}]}{[X_{in}]}$$

Concentration of ion outside

concentration of ion inside

Faraday's Constant

equilibrium potential of ion

Gas Constant (8.314 J/mol)

valence of ion

At 20°C,

$$E_x = \frac{58\,mV}{z} \log \frac{[X_{out}]}{[X_{in}]}$$

So for ions from table above,

$$E_{K^+} = \frac{58mV}{1} \log \frac{5}{125} = -81mV$$

$$E_{Na} = +58mV$$

$$E_{Cl} = -81mV$$