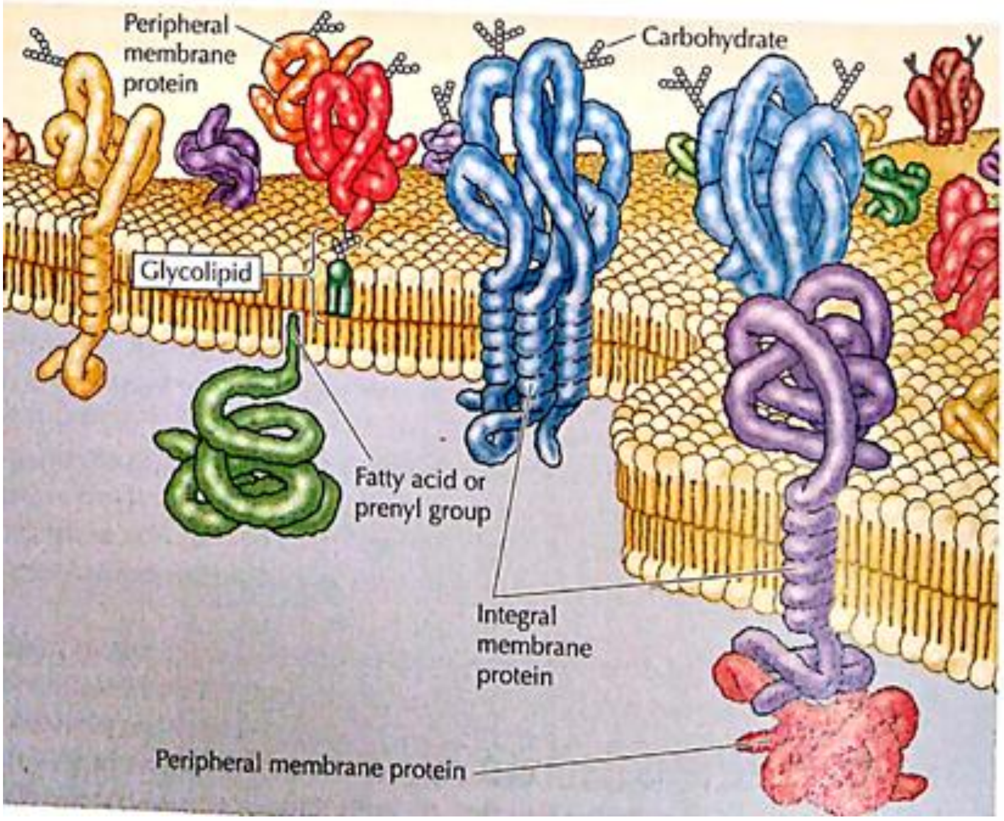

Bioelectrical phenomena

Prepared by

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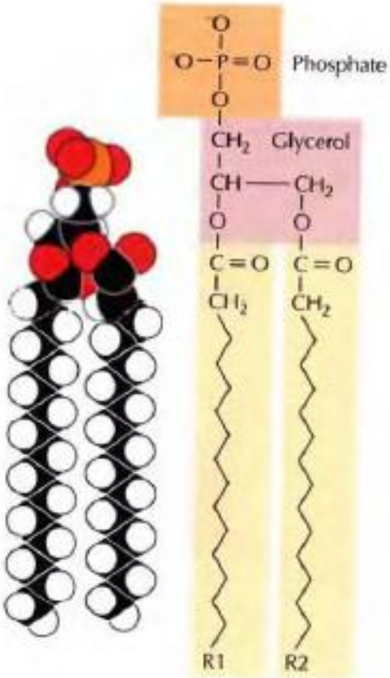
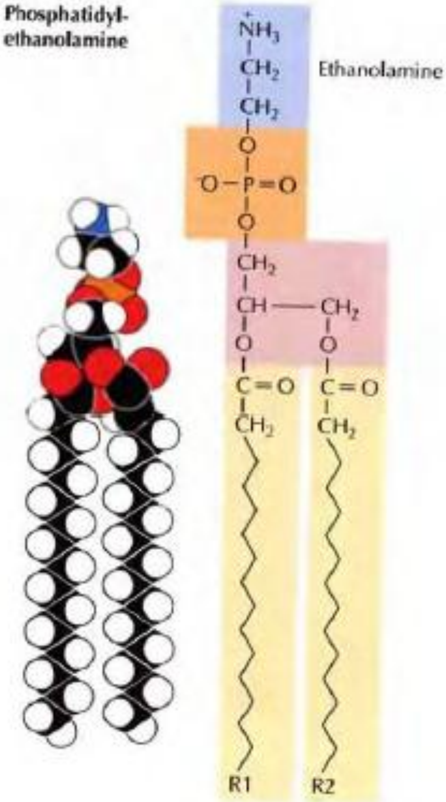
Physics department

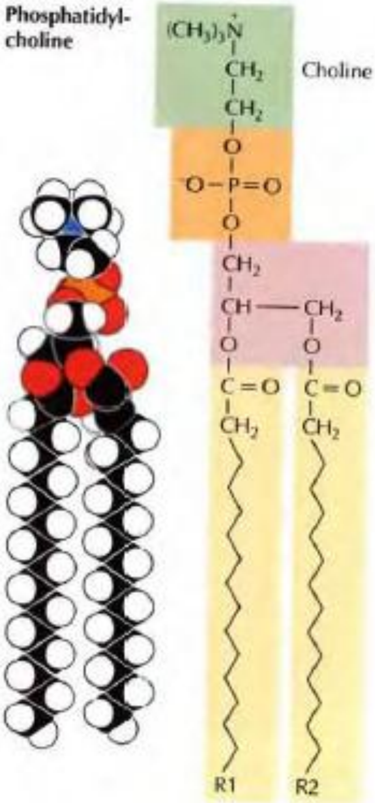
Phosphatidic acid



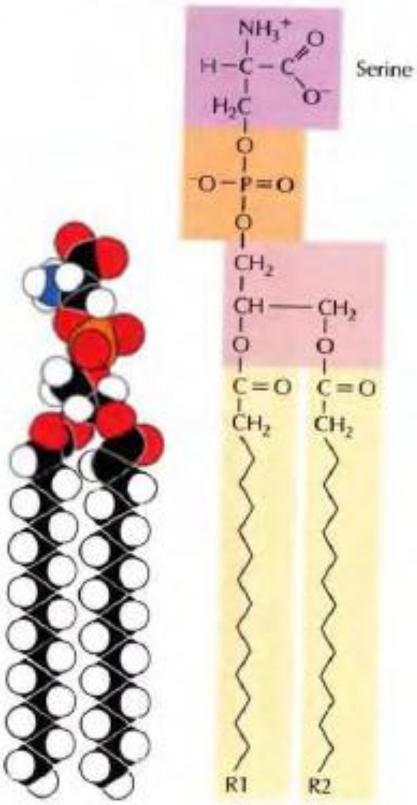
Phosphatidyl-ethanolamine



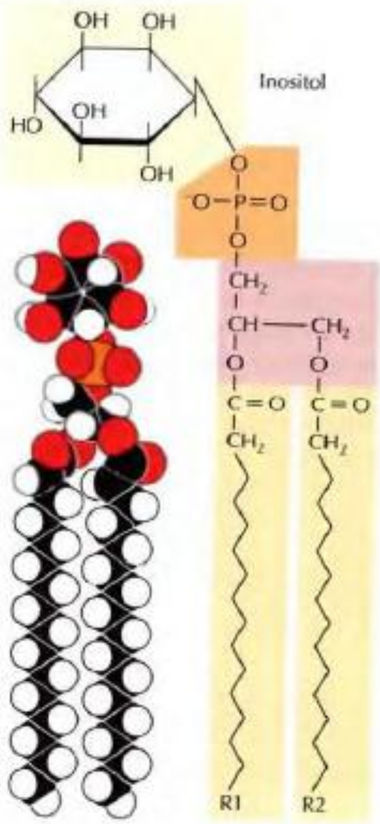
Phosphatidyl-choline



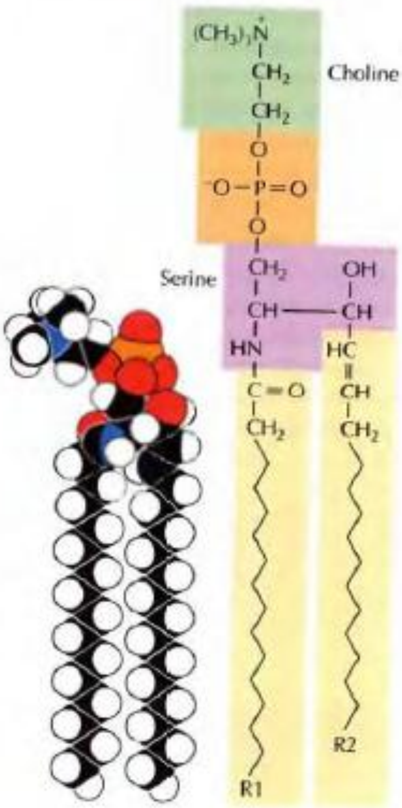
Phosphatidylserine



Phosphatidylinositol



Sphingomyelin



Cell's Electrical Properties

A cell derives its electrical properties mostly from	**A membrane, in turn, acquires its properties from**
the electrical properties of its membrane	**its lipids and proteins, such as ion channels and transporters**

Electrical Potentials

An electrical potential difference exists between the interior and exterior of cells. Electrical potential differences are usually denoted as V or ΔV and measured in volts; therefore, potential is also termed voltage.

Motion of charged ions

A charged object (ion) gains or loses energy as it moves between places of different electrical potential

Cell's Potential difference

The potential difference across a cell relates the potential of the cell's interior to that of the external solution, which, according to the commonly accepted convention, is zero.

Potential difference across the lipid bilayer

Potential differences between two points that are separated by an insulator are larger than the differences between these points separated by a conductor. Thus, the lipid membrane, which is a good insulator, has an electrical potential difference across it.

Transmembrane potential

This potential difference ("transmembrane potential") amounts to less than 0.1 V, typically 30 to 90 mV in most animal cells, but can be as much as 150 - 200 mV in plant cells.

Cytoplasm potential difference

On the other hand, the salt-rich solutions of the cytoplasm and blood are fairly good conductors, and there are usually very small differences at steady state (rarely more than a few millivolts) between any two points within a cell's cytoplasm or within the extracellular solution.

Measuring the electrical potential

Electrophysiological equipment enables researchers to measure potential (voltage) differences in biological systems.

Electrical Currents

The flow of electrical charge passing a point per unit of time. Current (I) is measured in amperes (A)

currents measured by electrophysiological equipment range from picoamperes to microamperes.

Forinstance, typically, 10^4 Na^+ ions cross the membrane each millisecond that a single Na^+ channel is open. This current equals 1.6 pA (1.6×10^{-19} coul/ion $\times 10^4$ ions/ms $\times 10^3$ ms/s).

Two hand rules of current

(1) current is conserved at a branch point (Figure 1-1); and

(2) current always flows in a complete circuit (Figure 1-2).

In electrophysiological measurements, currents can flow through capacitors, resistors, ion channels, amplifiers, electrodes and other entities, but they always flow in complete circuits.

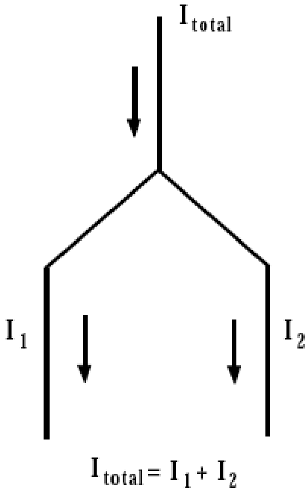


Figure 1-1. Conservation of Current
Current is conserved at a branch point.

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Current is conserved at a branch point.

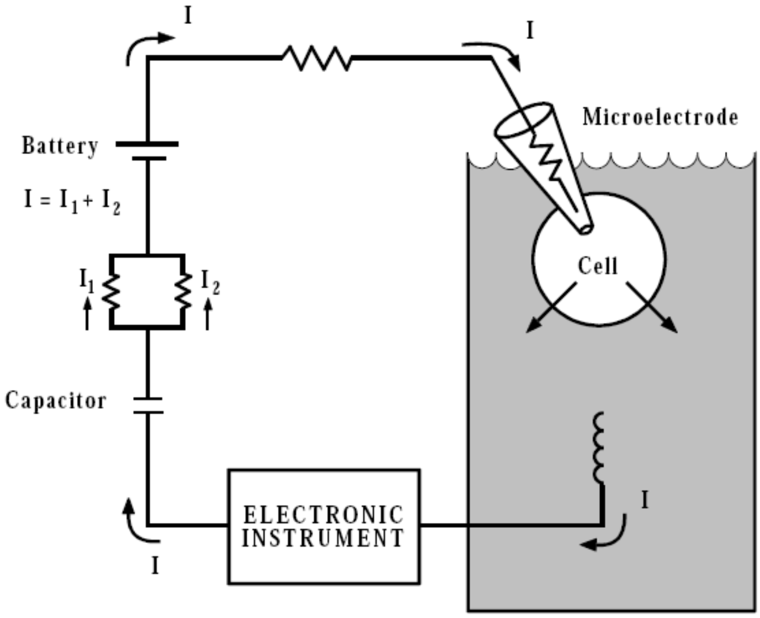


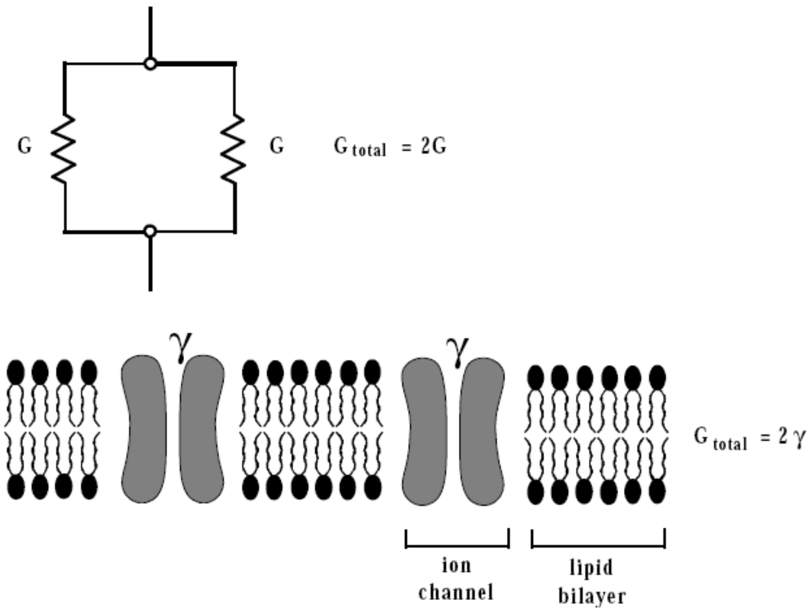
Figure 1-2. A Typical Electrical Circuit
Example of an electrical circuit with various parts. Current always flows in a complete circuit.

Resistors and Conductors

¾ the resistance emphasizes the barriers to current flow,	the conductor emphasizes the pathways for flow
R: (units: ohms (Ω))	G (units: siemens (S))
infinite resistance is zero conductance	
In electrophysiology, it is convenient to discuss currents in terms of conductance because side-by-side ("parallel") conductances simply summate	

Ion channels conductance

Parallel conductances involves ion channels. When several ion channels in a membrane are open simultaneously, the total conductance is simply the sum of the conductances of the individual open channels.



Equivalent circuit

A more accurate representation of an ion channel is a conductor in series with two additional circuit elements:

(1) a switch that represents the gate of the channel, which would be in its conducting position when the gate is open, and

(2) a battery that represents the reversal potential of the ionic current for that channel.

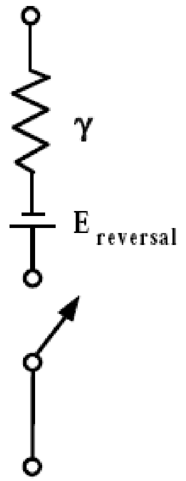


Figure 1-4. Equivalent Circuit for a Single-Membrane Channel
A more realistic equivalent circuit for a single-membrane channel.

Reversal potential

It is s defined operationally as the voltage at which the current changes its direction.

For perfect selective channel

For a perfectly selective channel (i.e., a channel through which only a single type of ion can pass), the reversal potential equals the Nernst potential for the permeant ion.

Nernst potential

(Ea) The Nernst potential for ion A, can be calculated by the Nernst equation:

$$E_A = (RT/z_AF)\ln\{[A]_o/[A]_i\} = 2.303(RT/z_AF)\log_{10}\{[A]_o/[A]_i\} \quad \text{(units: volts)} \qquad (1)$$

where R is the gas constant (8.314 V C K^{-1} mol^{-1}), T is the absolute temperature (T = 273° + C°),
z_A is the charge of ion A, F is Faraday's constant (9.648×10^4 $Cmol^{-1}$), and $[A]_o$ and $[A]_i$ are the concentrations of ion A outside the cell and inside the cell, respectively. At 20°C ("room temperature"), $2.303(RT/z_AF)$=58 mV for a univalent ion.

Examples

For instance, at room temperature,.

a Na^+ channel facing intracellular Na^+ concentration that is ten-fold lower than the extracellular concentration of this ion would be represented by a battery of +58 mV	A K^+ channel, for which the concentration gradient is usually reversed, would be represented by a battery of -58 mV.

For other types of channels

Reversal potentials are not easily predicted for channels that are permeable to more than one ion. Nonspecific cation channels, such as nicotinic acetylcholine receptors, usually have reversal potentials near zero millivolts. Furthermore, many open channels have a nonlinear relation between current and voltage.

Consequently, representing channels as resistors is only an approximation.

Considerable biophysical research has been devoted to understanding the current-voltage relations of ion channels and how they are affected by the properties and concentrations of permeant ions.

Transmembrane potential

The transmembrane potential is defined as the potential at the inner side of the membrane relative to the potential at the outer side of the membrane.

Rest membrane potential

The resting membrane potential (E_{rp}) describes a steady-state condition with no net flow of electrical current across the membrane.
The resting membrane potential is **determined by** the intracellular and extracellular **concentrations** of ions to which the membrane is permeable and on their **permeabilities**.
If one ionic conductance is dominant, the resting potential is near the Nernst potential for that ion.
Since a typical cell membrane at rest has a much higher permeability to potassium (P_K) than to sodium, calcium or chloride (P_{Na}, P_{Ca} and P_{Cl}, respectively), the resting membrane potential is very close to E_K, the potassium reversal potential.

Ohm's Law

For electrophysiology, perhaps the most important law of electricity is Ohm's law. The potential difference between two points linked by a current path with a conductance G and a current I

$\Delta V = IR = I/G$ (units: volts)

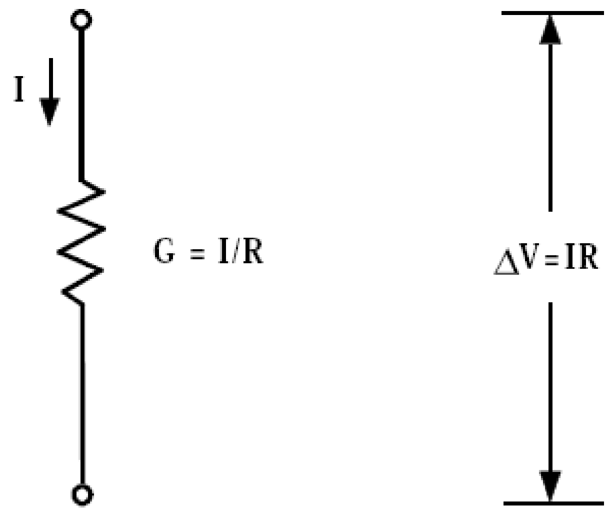


Figure 1-5. Ohm's Law

This concept applies to any electrophysiological measurement, as illustrated by the two following examples:

(1) In an extracellular recording experiment: the current I that flows between parts of a cell through the external resistance R produces a potential difference ΔV, which is usually less than 1 mV (Figure 1-6). As the impulse propagates, I changes and, therefore, ΔV changes as well.

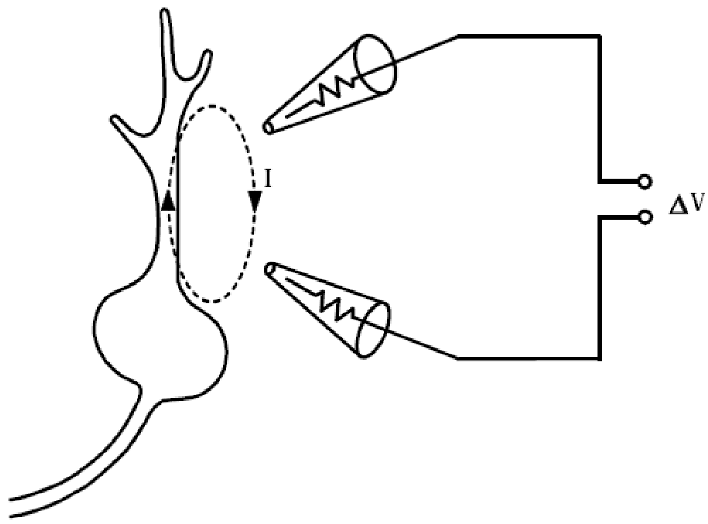


Figure 1-6. IR Drop

In extracellular recording, current I that flows between points of a cell is measured as the potential difference ("IR drop") across the resistance R of the fluid between the two electrodes.

(2) In a voltage-clamp experiment: when N channels, each of conductance g, are open, the total conductance is Ng. The electrochemical driving force ΔV (membrane potential minus reversal potential) produces a current NgΔV. As channels open and close, N changes and so does the voltage-clamp current I. Hence, the voltage-clamp current is simply proportional to the number of open channels at any given time. Each channel can be considered as a g conductance increment.

The Voltage Divider

Figure 1-7 describes a simple circuit called a voltage divider in which two resistors are connected in series:

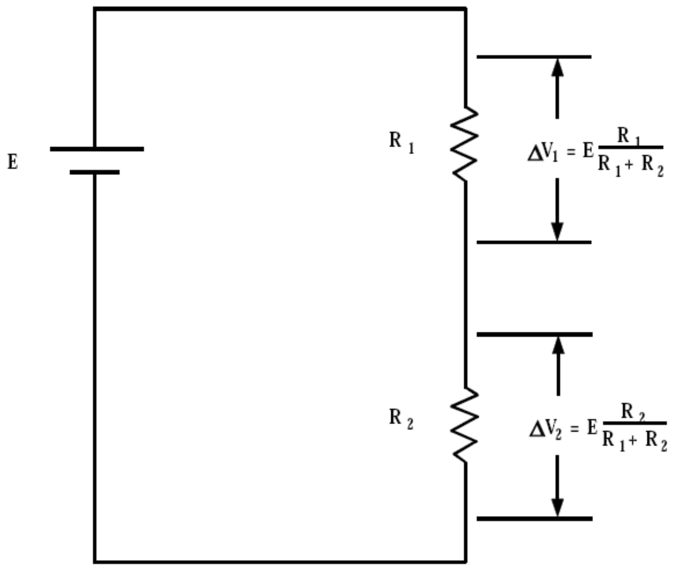


Figure 1-7. A Voltage Divider

The total potential difference provided by the battery is E; a portion of this voltage appears across each resistor.

When two resistors are connected in series, the same current passes through each of them.

Therefore the circuit is described by

$$\Delta V_1 = E\frac{R_1}{R_1 + R_2} \quad ; \quad \Delta V_2 = E\frac{R_2}{R_1 + R_2}$$

$$\Delta V_1 + \Delta V_2 = E$$

where E is the value of the battery, which equals the total potential difference across both resistors.

As a result, the potential difference is divided in proportion to the two resistance values.

Complete the following

1. **The cell drives its electrical properties from …………… which in turns acquire its electrical properties from …………… and ………… such as ……………. And …………**
2. **An electrical potential difference exists between the interior and exterior of cells.**
3. **A charged object (ion) gains or loses energy as it moves between places of different electrical potential**
4. **Two hand rules of current are**

   (1)………………………………………………………………………… ……………………

   (2)

   ……………………………………………………………………………… ……………..

5. **The salt-rich solutions of the …………… and ………… are fairly good conductors, and there are usually very small differences at steady state between any two points within a ……………………… or within the ………………………**