Animal Nerve Chapter

Experiments

Advanced Level Difficulty Rating: Can Be Done With:

AN-1: Membrane Potentials

AN-2: Compound Action Potentials

AN-3: Neuromuscular Studies

AN-4: Action Potential in Earthworms

AN-5: Cockroach Leg Mechanoreceptors

AN-6: Cockroach Cercal Sense Organs

AN-8: Frog Sciatic Nerve Compound Action Potential

Overview

Most cells have a potential difference across their membrane, and the potential inside the cell is negative relative to the potential outside. The magnitude of the potential difference is between 40mV and 100mV, and it is dependent upon the cell and its surrounding environment. Generally, the membrane potential is produced by three factors:

- The sodium-potassium pump.
- The membrane's greater permeability to potassium than to sodium.
- Negatively charged proteins inside the cell (and not outside the cell).

The sodium-potassium pump utilizes energy from ATP hydrolysis to transport three sodium ions out of the cell in exchange for two potassium ions being moved into the cell. This exchange of potassium and sodium ions helps produce an asymmetric distribution of ions across the membrane, so that sodium is at a higher concentration outside the cell while potassium concentration is higher inside the cell (Table AN-0-I1). These ions should tend to diffuse down their concentration gradients, and then be returned to their original location by the pump. However, the diffusion of these ions does not take place freely because the membrane is not equally permeable to all ions; and, there are negatively charged proteins inside the cell acting on the ions, as well.

The proteins inside the cell are negatively charged because they contain large proportions of negatively charged amino acids. Because these proteins are large and incapable of moving across the cell membrane, they attract cations into the cell. In the case of sodium, it wants to move into the cell along two gradients: its concentration gradient from outside to inside the cell and the electrostatic gradient that attracts this positively charged ion towards the negatively charged proteins inside the cell. However, a resting cell membrane has a low permeability for sodium ions, and only a few can enter the cell. On the other hand, the gradients for potassium ions work against each other: the concentration gradient pushes potassium from inside to outside the cell, but, the electrostatic gradient attracts potassium into the cell. In a resting cell, the relatively high permeability of the cell membrane to potassium causes these ions to leave the cell. In the resting cell, these displaced ions are picked up by the sodium-potassium pump and transported back across the membrane to maintain status quo. Thus, there is a constant flux of cations across the membrane.

Table AN-0-I1: The Distribution of Ions and Charged Proteins across the Membrane of the Squid Giant Axon, and the Equilibrium and Membrane Potentials.

Ion	Intracellular [mM]	Extracellular [mM]	Equilibrium Potential
Sodium	50	440	+55mV
Potassium	400	20	-76mV
A- Proteins	345	0	
		E_m= -65mV	

A passing knowledge of Ohm's Law (voltage = current x resistance) tells you that the movement of ions (current) across the membrane (resistance) produces a voltage. The voltage produced by the flow of a particular ion is called its equilibrium potential and can be determined by the Nernst Equation. For potassium, the equilibrium potential (at 20 degrees Celsius) is:

$$E_{K+} = 57.7 \log10 ([K+]_{out}/[K+]_{in})$$

While this equation can be used to derive the equilibrium potential for any specific ion, the values cannot be used to predict a cell's membrane potential. Since living cells have multiple ions affecting their potentials, the constant field or Goldman equation must be used to predict the resting membrane potential:

$$E_M = 57.7 \log10 \frac{(PK_{[K+]out} + PNa_{[Na+]out} + PCl_{[Cl-]in})}{(PK_{[K+]in} + PNa_{[Na+]in} + PCl_{[Cl-]out})}$$

This equation assumes that the membrane potential is produced by the combined effect of all ions and that the contribution of each ion is determined by its relative permeability across the membrane. In most resting membranes, the permeability of the membrane is highest to potassium, so the membrane potential is close to (but not the same as) the equilibrium potential for potassium.