Name:

Chapter 1

THE BRAIN is wider than the sky,
  For, put them side by side,
The one the other will include
  With ease, and you beside.

The brain is deeper than the sea,
  For, hold them, blue to blue,
The one the other will absorb,
  As sponges, buckets do.

The brain is just the weight of God,
  For, lift them, pound for pound,
And they will differ, if they do,
  As syllable from sound.

CXXVI, Emily Dickinson

Introduction

The human brain is the most complex object in the known universe. It is capable of understanding the universe around it, formulating complex models of how the world works. It is the seat of all feelings and thoughts, capable of creating and appreciating immortal works of art. It may even one day understand itself. How can a 3-pound mass of flesh with the consistency of a wet sponge do all that? This is the question at the heart of neuroscience, and this book intends to give you some of the tools to begin to answer it.

This chapter introduces the core concepts of neuroscience. Neuroscience is a multidisciplinary study. This is a complex way of saying that knowledge from many different areas is required to understand it. Biology, chemistry, physics, and math all contribute to a basic understanding of the brain and its components. In the following sections, we will explain the concept of electricity, how it is generated in the body, and how the brain uses it. We will then visit some basic examples of how neuroscientists use bioelectricity in experiments.

1.1 Bioelectricity

It is well known that electricity can be harmful to life. Young children are kept from playing with wall sockets. Adults are reminded to be careful with electrical appliances in the bathroom. Even a small shock can cause great pain. Yet at the same time, without electricity, life as we know it could not exist. Every cell is driven by electrical activity, and ceasing it (or overloading it) will inevitably result in the cell's death. In this chapter, we will learn the basics of electricity and its role in life, in particular the nervous system.

1.1.1 Electricity

Before we discuss bioelectricity, we need first to understand electricity itself. Electricity is the flow of particles that have electric charge, either electrons or ions. When most people think of electricity, they think of their smart phone or their car battery. In these cases, the flow of electrons "is" the electricity.

Electrons are negatively charged particles that can move through a variety of materials.

Scientists and engineers have discovered the rules that govern electron flow, and the understanding of these rules has given rise to modern society. Without a deep understanding of how electrons move and interact with other materials, it would be impossible to build a device as complicated as an iPhone.

However, no matter how complicated an iPhone is, a cell is much more complicated. Part of this has to do with the fact that biology does not use just electrons to move electric charge around. Instead, cells use ions.

The word "**ion**" comes from the Greek word for movement, and it means an atom that has an imbalance between protons and electrons.

Figure 1: Frankenstein being brought to life through the power of electricity. This would probably not actually work, but the story is based on real life experiments in bioelectricity at the time of the novel's writing.

This difference between numbers of protons and electrons gives rise to the electric charge of the ion, and the movement of ions constitutes the primary electrical activity in living things. Ions can be either positive or negative, depending on the direction of the imbalance.

It is important to note that, in most ways, ions and electrons act similarly. This is fortuitous for those who study bioelectricity. As I stated above, scientists and engineers have developed a deep understanding of the flow of electrons in order to understand the world and develop new technologies. Students of bioelectricity can use that understanding to learn new truths about how biology works. This is why, over the course of the next semester, we will be studying traditional electrical engineering (which deals primarily with electrons) alongside bioelectricity (which deals primarily with ions). In this way, ideas from electrical engineering will serve as *models* for processes involving bioelectricity, which are far more difficult to build in artificial environments.

1.1.2 Ions

An ion is an atom with an imbalance between the protons and electrons. This imbalance is called a charge, and is due to structural properties of an atom. In general, atoms try to avoid being in states where they are imbalanced. They group together in compounds to cancel out their imbalance. The simplest example of this is sodium chloride, or common table salt. Sodium chloride is a compound made of one positively charged sodium atom (i.e. it has one fewer electron than protons) and one negatively charged chlorine atom (i.e. it has one more electron than protons). Positively charged ions are called **cations**, while negatively charged ions are called **anions**. Cations and anions stick together in an **ionic bond**, and form a crystalline structure that has no charge, which means that there is the same number of electrons and protons in the crystal.

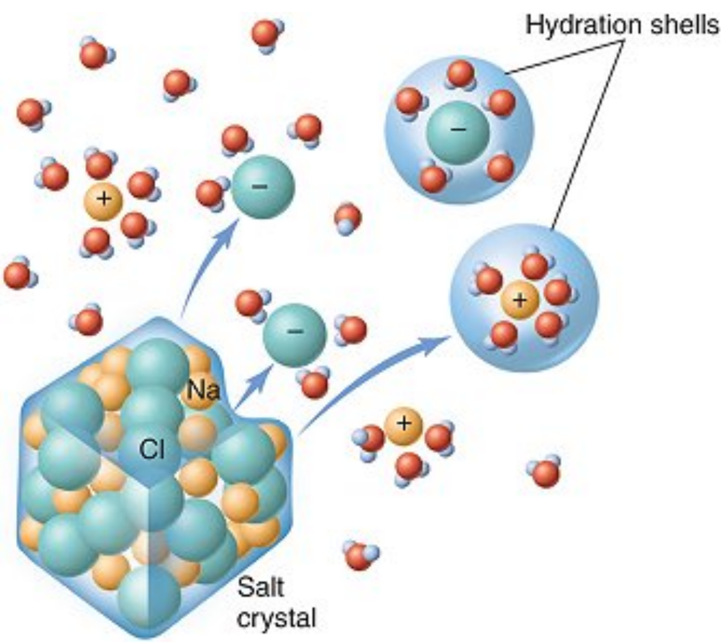

Figure 2: Blue spheres represent chlorine, while orange spheres represent sodium. The red and white molecules are water. Molecules of water tear apart salt molecules using electrical forces of attraction.

However, if we place salt crystals in water, what happens? They dissolve. As we can see in Figure 2, the water molecules move in-between the atoms in the salt, and pull the ions apart. As a whole, the salt-water solution still has a neutral charge, but these individual atoms of sodium and chloride have positive and negative charges, respectively. Dissolved sodium and chlorine are vital ions for our body, but there are several more. Potassium and calcium are both cations that our bodies need to survive. Potassium is like sodium, in that it is only missing one electron. Calcium is different though; it has two missing electrons. For the rest of the text, we will be using common shorthand to describe these ions: Sodium is Na^+, potassium is K^+, calcium is Ca^{2+} (representing its double positive charge), and chlorine is Cl^- (representing its negative charge).

These four ionic species are crucial players in the normal functioning of all muscles and nerves. Cells need to keep the proper amounts of each ion on their inside and outside. As such, the body expends a large amount of its energy in maintaining specific imbalances between the intracellular (inside the cell) and extracellular (outside the cell) concentrations of these four ions. These imbalances are called **ionic gradients**, and if they falter, serious problems occur inside the body. For example, many athletes have issues with maintaining their K^+ gradient while doing extreme training. As the body sweats, it loses ions, and potassium is the hardest to replace. Without it, neurons and muscles don't function correctly, leading to severe cramps, nausea, fainting, and even death. Sports drinks like Gatorade have the right concentrations of the above ions to keep an athlete healthy during intense training.

1.1.3 Potential Energy

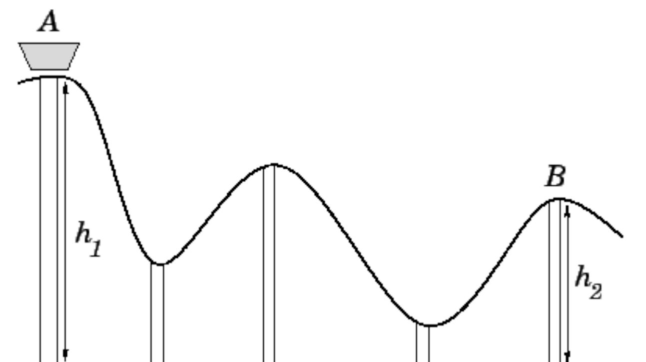

Figure 3: A demonstration of a rollercoaster, and how its height from the ground affects the potential energy

Potential is the term scientists use to describe the energy difference between two points. A rollercoaster at the top of the tracks has potential energy. As it rolls down the track, its potential energy is converted into movement. When it reaches the bottom of the tracks, it has no potential energy, having converted it all into movement. We can describe the potential energy of a rollercoaster in terms of how far it is from the bottom of the track and how much it weighs. With that knowledge, we can use math to determine how fast it will go.

What does this have to do with ions? Similar to how the earth and the rollercoaster attract each other with gravity, ions can attract one another with electric charge. They can also repel each other. Ions of the same charge (negative-negative or positive-positive) want to move away from each other. Ions with different charges (positive-negative) attract each other. Knowing this, imagine if we had container filled with a liquid containing anions and cations. Left to themselves, anions and cations intermingle evenly (Figure 4A).

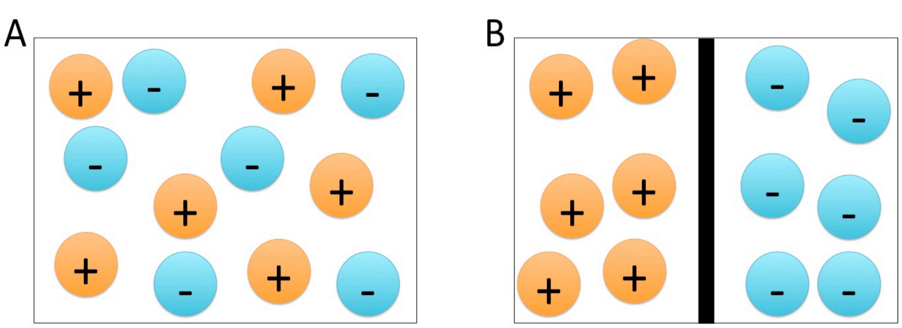

Figure 4: A) Has evenly mixed anions and cations, and no electric potential. B) Has separated anions and cations, and electric potential

However, we could place a barrier separating the liquid in the container into two compartments. If we were to force anions to one side and cations to the other, we would now have an ionic gradient and an **electric potential**. The anions and cations would want to flow through the barrier to mix with the other side. Unless there are holes in the barrier, they would be unable to do so, and the electric potential would be conserved. This would be like the rollercoaster suspended at the top of its tracks. If we do poke a hole in the membrane, this potential energy would be converted into *current*, or the flow of ions. The anions and the cations would flow to the opposite side of the barrier like the rollercoaster rolls down the track, turning potential energy into motion. In this case, that motion would be electricity, and it can be used to do important work. After the ions have mixed on both sides, with no side having surplus charge, there will be no more directed motion of ions. This is like the rollercoaster having expended all of its energy at the bottom of the track.

Student Note Space