6 ELECTRICITY AND THE NERVOUS SYSTEM

The nervous system of humans and animals and the control of muscle movement, for example, are both governed by electrical interactions.

The most remarkable use of electrical phenomena in living organisms is found in the nervous system. Specialized cells called neurons form a complex network within the body which receives, processes, and transmits information from one part of the body to another.

The centre of this network is located in the brain, which has the ability to store and analyse information. Based on this information, the nervous system controls various parts of the body.

The neurons, which are the basic units of the nervous system, can be divided into three classes: **sensory neurons**, **motor neurons**, and **interneurons**.

The **sensory neurons** receive stimuli from sensory organs that monitor the external and internal environment of the body. The sensory neurons convey messages about factors such as heat, light, pressure, muscle tension, and odor to higher centers in the nervous system for processing.

The **motor neurons** carry messages that control the muscle cells. These messages are based on information provided by the sensory neurons and by the central nervous system located in the brain. The **interneurons** transmit information between neurons.

6.1 ELECTRICAL TECHNOLOGY IN BIOLOGICAL RESEARCH

Electrical technology has provided tools for the observation of biological phenomena. It yielded most of the modern clinical and diagnostic equipment used in medicine. Electrical technology has provided the means for translating information from many areas into the domain of our senses. A schematic diagram (See Figure 11) shows this process.

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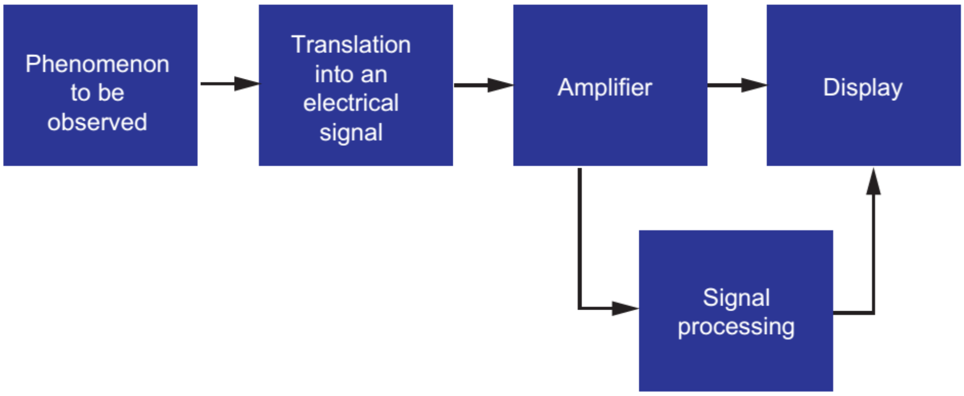

Figure 11: An experiment in biology.

6.2 DIAGNOSTIC EQUIPMENT

6.2.1 The Electrocardiograph

The electrocardiograph (ECG) is an instrument that records surface potentials associated with the electrical activity of the heart. The surface potentials are conducted to the instrument by metal contacts called electrodes which are fixed to various parts of the body. Usually the electrodes are attached to the four limbs and over the heart. Voltages are measured between two electrodes at a time.

A typical normal signal recorded between two electrodes is shown in Figure 12. **The main features of this waveform are identified by the letters *P*, *Q*, *R*, *S*, and *T*.**

The shape of these features varies with the location of the electrodes. A trained observer can diagnose **abnormalities** by recognizing deviations from normal patterns. The wave shape in Figure 12 is explained in terms of the pumping action of the heart. The rhythmic contraction of the heart is initiated by the **pacemaker**, which is a specialized group of muscle cells located near the top of the right atrium. Immediately after the pacemaker fires, the action potential propagates through the two atria. The P wave is associated with the electrical activity that results in the contraction of the atria. The QRS wave is produced by the action potential associated with the contraction of the ventricles. The T wave

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is caused by currents that bring about the recovery of the ventricle for the next cycle.

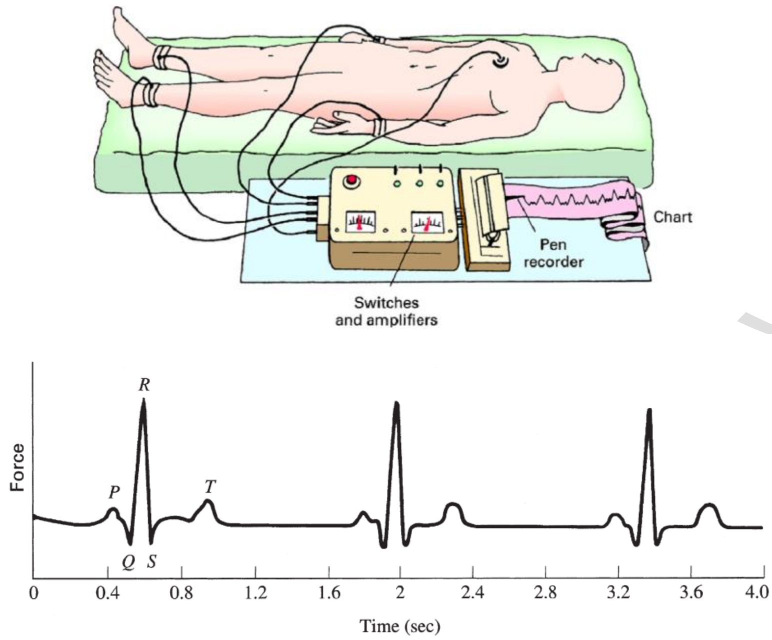

Figure 12: Electrocardiography and an electrocardiogram.

6.2.2 The Electroencephalograph

The electroencephalograph (EEG) measures potentials along the surface of the scalp. Here again electrodes are attached to the skin at various positions along the scalp. The instrument records the voltages between pairs of electrodes. The EEG signals are much more complex and difficult to interpret than those produced by the electrocardiograph. The EEG signals are certainly the result of collective neural activity in the brain. However, so far it has not been possible to relate unambiguously the EEG potentials to specific brain functions. Nevertheless, certain types of patterns are known to be related to specific activities, as illustrated in Figure 13. Electroencephalographs have been useful in diagnosing various brain disorders. Epileptic seizures, for example, are characterized by pronounced EEG abnormalities (see Figure 14). Brain tumors can often be located by a careful examination of EEG potentials along the whole contour of the scalp.

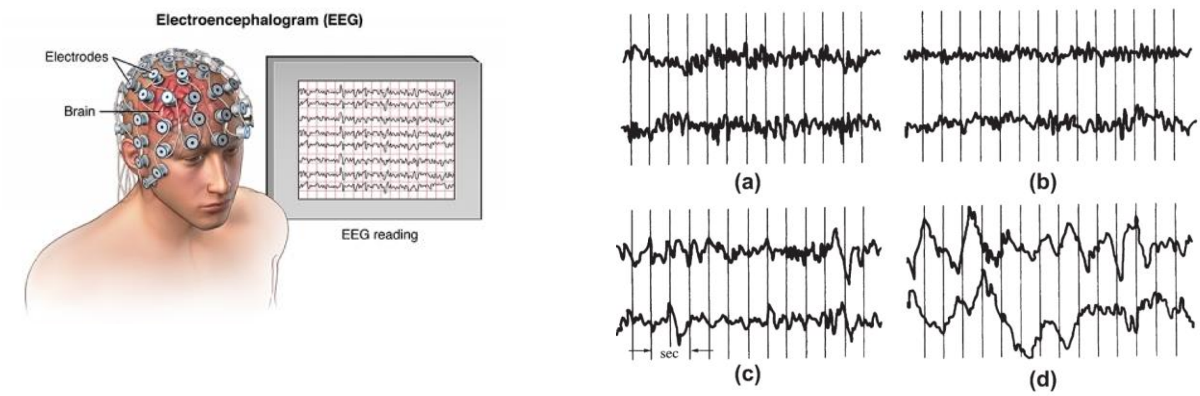

Figure 13: electroencephalogram and EEG potentials between two pairs of electrodes: (a) subject alert, (b) subject drowsy, (c) light sleep, (d) deep sleep.

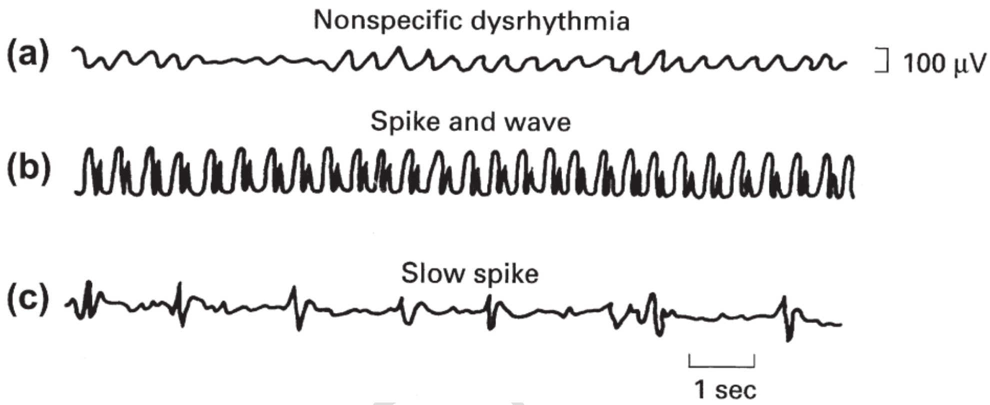

Figure 14: Abnormal EEG patterns. Pattern b is typical of petit mal seizures.

6.3 PHYSIOLOGICAL EFFECTS OF ELECTRICITY

The painful shock produced by electricity is well known to most people. The brain, the respiratory muscles, and the heart are all very seriously affected by larger electric currents.

An electrical current has two effects on body tissue:

1. The current stimulates nerves and muscle fibres, which produces pain and a contraction of muscles,
2. The current heats the tissue through dissipation of electrical energy.

Both of these effects, if sufficiently intense, can cause severe injury or death. But if the electrical current is applied in a controlled way, both the heating and the muscle stimulation can be beneficial.

- Most people begin to feel an electrical current when it reaches a magnitude of about **500 μA**.
- Currents in the range of a **few milliamperes** cause pain, and produce sustained tetanizing contraction of some muscles.
- Currents in the range of a **few hundred milliamperes** flowing across the head produce convulsions resembling epilepsy.
- Currents in the range of a **few amperes** flowing in the region of the heart can cause death within a few minutes.

In this connection, **a large current** of about 10 A is often **less dangerous** than a **1-A current.** This can be explained as following:

1. When the ***small current*** passes through the heart, it causes a **desynchronization of the heart action**; or **fibrillation**. Usually fibrillation **does not stop** when the current source is removed.
2. A ***large current*** **tetanizes** the **whole heart**, and when the current is discontinued the heart may **resume** its normal rhythmic activity.

There are two important applications of the electricity flow through the body:

1. **Defibrillator** is a clinical device designed to synchronize the heart. A capacitor in this device is charged to about 6000 V and stores about 200 J of energy. Two electrodes connected to the capacitor through a switch are placed on the chest. The current pulse lasts about 5 msec, during which the heart is tetanized. After the pulse, the heart may resume its normal beat. Often the heart must be shocked a few times before it re-synchronizes.

2. **The electronic pacemaker** is basically a pulse generator that produces short periodic pulses that initiate and control the frequency of the heartbeat. The device can be made small enough for surgical implantation.

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Unfortunately, the battery that powers the pacemaker has a finite lifetime and must be replaced every few years.

6.4 SENSORY AIDS

Electrical technology has led to the development of devices that greatly enhance hearing and, in some cases, even restore hearing. Examples of these devices such as hearing aids and cochlear implants.

6.4.1 Hearing Aids

A microphone converts sound to an electrical signal. The electrical signal is amplified and converted back into sound using a speaker-type device. The net result is an amplification of the sound that enters the ear.

6.4.2 Cochlear Implant

A cochlear implant functions **differently** from a hearing aid. A hearing aid simply amplifies incoming sound compensating for the diminished functioning of the ear. A cochlear implant converts sound to electrical signals of the type produced by the inner ear in response to sound that enters the ear.

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