# Introduction to PHYSIOLOGY

VOLUME 2
BASIC MECHANISMS
PART 2

HUGH DAVSON
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# PREFACE

We can think of two ways of composing an Introduction to Physiology. First we may take a large standard text and sieve the material contained in it to free it of as much experimental material, argument and other "extraneous matter" to reduce its bulk to about one third of the original. Alternatively one may compose something entirely new, expounding as simply as feasible the basic scientific principles governing the functioning of the animal. The former method has, we think, been employed before, and the result has been a *synopsis* of, rather than an *introduction* to, physiology. By memorizing it almost word-for-word the medical student probably passes muster at an undiscriminating examination, and completes his medical education with a very poor understanding of the basic principles of medicine.

Pursuing the latter method we found that the first draft was embarrassingly large, and in reviewing what had been written with a view to shortening the book, it became clear that any serious surgery would destroy its character since it was, in effect, rather more than an Introduction containing—to use a musical term—a great deal of "development" too. Rather than abandon the project of producing an Introduction that was both short and adequate, we carried out a different kind of surgery, namely the division into several volumes. Volumes 1 and 2, which we now present, are an introduction to the basic mechanisms whereby the animal absorbs, distributes and transforms its energy-giving materials; and whereby the energy thus made available is utilized in such fundamental activities as muscular contraction, the transmission of messages by both nerves and hormones, the defence mechanisms and in reproduction.

The difficulties in understanding physiology arise in the fundamental principles governing the activities of the animal's parts, such as the flow of fluids, the conduction of the nervous impulse, the elimination of secretions from a cell or epithelium and so on. If the student has a firm grasp of these principles, the way is clear for the understanding of the rest of physiology, which consists in the analysis of control mechanisms. The remaining volumes are designed to enable the student to take up where the first two left off; thus Volume 3 is devoted to visceral

control mechanisms and may be regarded as the "development" of the themes introduced mainly in Volume 1. Very arbitrarily the control of somatic motor activity and of reproduction have been put together to make Volume 4; this is only because their inclusion in Volume 3 would have made it too large for convenience. Volume 5 deals with sensory mechanisms and higher integrative processes, involving the cerebral cortex.

A few words on the way the volumes have been written. The present two volumes, being concerned largely with fundamentals, require little or no documentation, so that we have contented ourselves mostly with general references to reviews and texts at the end of each volume. This does not mean that the information has been culled only from these sources, and it is rare if we have quoted work that we have not read in the original. In the remaining volumes the subject matter has been treated in greater experimental depth, so that a more elaborate documentation, comparable with that found in Starling's *Principles of Human Physiology*, has been employed.

To conclude, we think that a study of the completed work will provide the student of physiology, taking this as part of a larger course, such as in medicine or dentistry, with knowledge of the subject sufficient for his requirements; for the student intending to make physiology his career the book will, we trust, be a proper "Introduction".

HUGH DAVSON
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*October 1974*

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# CHAPTER 1

# The Nervous System

## CONTROL MECHANISMS

In describing the basic principles of distribution of material in the body we have concentrated our attention on the mechanisms of the processes, showing how far the physiologist has been able to describe them in terms of concepts familiar to the physicist and chemist. We have, as far as possible, avoided touching on the mechanisms by which these physiological processes are brought into action and (of more importance) the mechanisms by which they are controlled to the point that the activities of the parts are smoothly integrated to ensure the adequate functioning of the whole organism.

### Autoregulation

To a small extent many of the physiological processes that we have already described have a built-in control system, in the sense that they control themselves; this phenomenon is given the general name of *autoregulation*. For example, in the formation of the extracellular fluid, an increased filtration at the arterial end of a capillary creates the condition for an increased absorption at the venous end; the loss of fluid tends to raise the concentration of proteins in the remaining plasma, and this results in an increased colloid osmotic pressure. Again, Starling's Law of the Heart is an expression of an autoregulatory activity in the sense that, as the load presented to the heart is increased, the force of contraction augments and results in a greater output. In considering the functioning of the kidney, we found a remarkable degree of autoregulation which ensures that the rate of flow of blood through the organ remains constant in spite of large variations in arterial pressure, a process that occurs when the kidney is removed from all possible central control.

**Feed-back**

With all physiological activities, however, we find additional control mechanisms that permit a fine adjustment of a given physiological process to the needs of the organism as a whole. The basis of this control may be illustrated by the well known principle of the thermostat, illustrated in Fig. 1.1. The sensor (S) is able to respond in some manner to a change in the feature that we wish to regulate, in this case the temperature; it does this by expanding, and the result of the expansion is to close an electrical switch, which operates a relay that

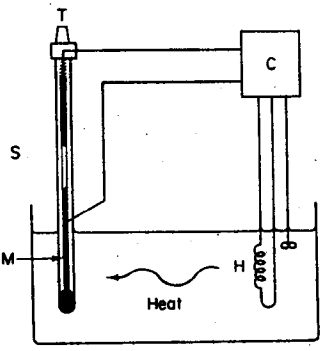


**Fig. 1.1.** The thermostat. The sensor (S) detects changes in temperature of the bath by changes in length of the column of mercury (M). If the bath temperature exceeds that set on the thermostat (T), the column of mercury rises and completes the circuit that switches off the current to the heating coil (H) by means of a relay in controller (C). Conversely, a fall in temperature opens the circuit and the heating coil now warms the bath to the preset temperature.

finally cuts off, or reduces, the supply of heat from an electrically heated source (H). We call the heater the *effector* in so far as it carries out the function that we are concerned with, namely keeping the bath warm. Between the sensor and the effector we have a communicating or *feed-back* system that carries the information regarding the temperature of the tank to the control centre and from the control centre to the effector; in the mechanical example considered this is contributed by the wires and relay. In living animals the sensor is called the *receptor*; the major communicating system is the *nervous system*, and the effectors are muscle fibres or other cells specialized to carry out specific functions, such as secreting enzymes in digestion.

### Hormone Control

Working alongside this nervous system of control we have a *hormonal* or *endocrine system*, in which the communication is carried out by transport of a chemical ejected into the blood-stream, through which it reaches its "target cells"—effector cells that respond to this blood-carried humoral agent. As we shall see, the distinction between the nervous and humoral mechanisms is often not as striking as at first thought; the transmission processes are indeed fundamentally different, in so far as, in the one case, the information is carried along nerve fibres and in the other, is carried in the blood-stream. However, in both cases the effectors are brought into action by a chemical agent, either a hormone such as secretin or adrenaline or a neurotransmitter like acetylcholine or noradrenaline.

## THE NERVOUS SYSTEM

### The Neurone

The basic unit in nervous control is the neurone, a cell that has become specialized to respond to a change in its environment—the *stimulus*—and to carry this response as a message to be transmitted either to another neurone or, more rarely, directly to an effector cell. According to their functions, the neurones have a wide variety of forms, as illustrated in Fig. 1.2 which shows several types. They have a common structure, in the sense that there is the cell body or *perikaryon* (also called the *soma*) containing the nucleus and most of the metabolic apparatus of the cell; there are also the *axon* and one or more processes called *dendrites*. The variability in form of neurones is largely caused by the wide variety of dendritic ramifications. It is along the axon that the neurone transmits its message, whilst it is along the dendrites that influences from other neurones are transmitted. Thus the message passes from the dendrites to the perikaryon, and away from the perikaryon along the axon. Where interconnections between neurones are concerned, the axon of the "transmitting" neurone may make its connections with the dendrite of the "receiving" neurone, or with its perikaryon (an "axo-somatic contact") or even with the initial part of its axon (an "axo-axonic contact").

### Grouping of Neurones

The processes from neurones are grouped together to form *nerves*, or *tracts*, many of these being visible to the naked eye. The perikarya,

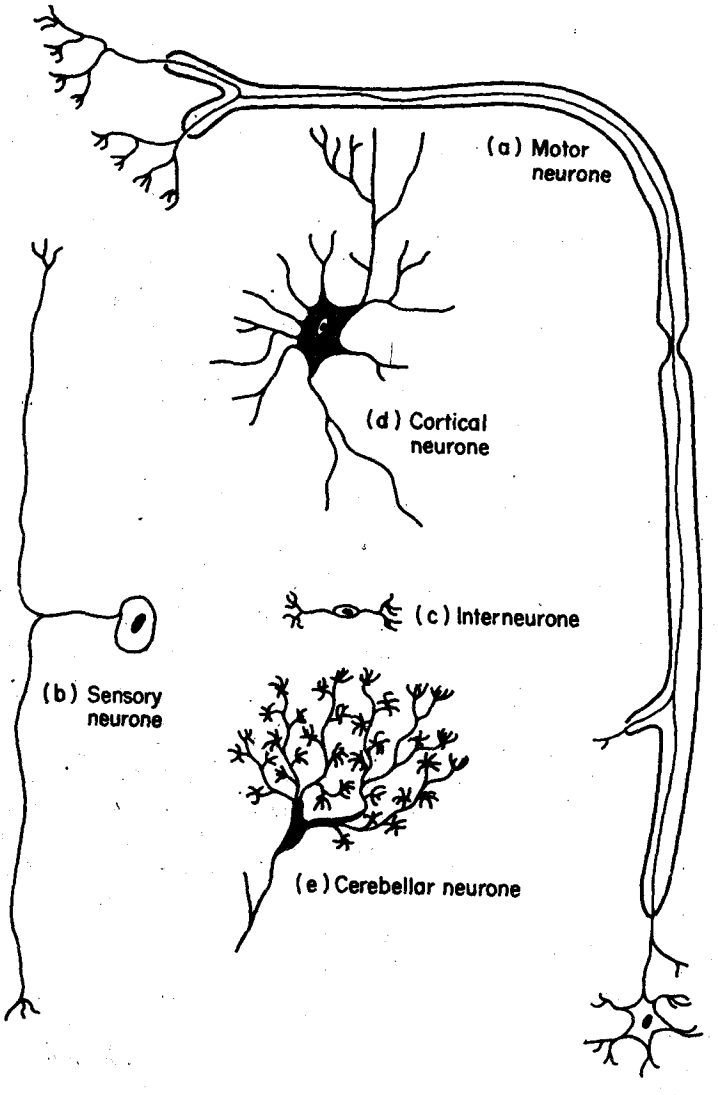


**Fig. 1.2.** Some of the types of neurone found in the nervous system. (a) motor; (b) bipolar sensory; (c) spinal interneurone; (d) cortical; (e) cerebellar.

or cell bodies, are likewise grouped together to form *nuclei* or *ganglia* which may be situated within or outside the *central nervous system*, the latter being defined as the brain and spinal cord.

**The Axon**

The basic organization of the nervous system can only be adequately appreciated with a knowledge of the nature of the messages a given neurone can transmit and the manner in which a stimulus, applied,

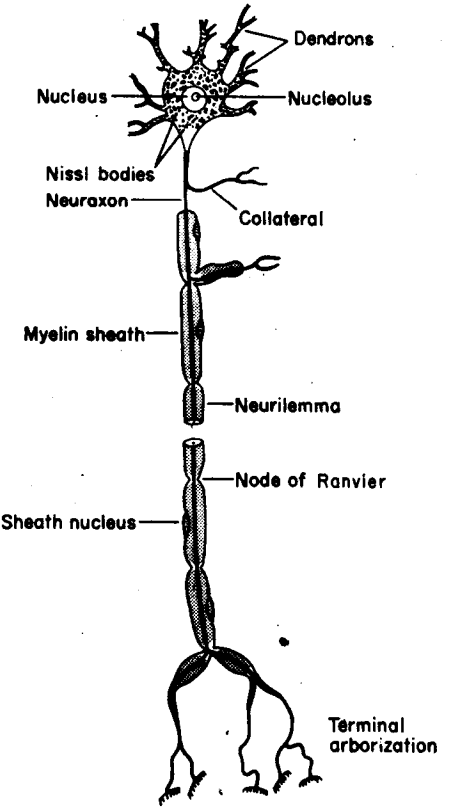


**Fig. 1.3.** A motor neurone and investing membranes. The neurone consists of a cell body with nucleus and cytoplasm. The cell body gives off projections, the dendrites, and the long axon in the case of the motor nerve. The axon is covered by a neurilemma or Schwann sheath, which encloses a layer of lipid or myelin, the electrical insulator of the axon. (Greep, "Histology", 1966, McGraw Hill.)

say, to the surface of the skin, can initiate the message that the nerve, with its endings in the skin, transmits to the brain. The neurone (Fig. 1.3) is a cell, and like all cells is separated from its environment by a plasma membrane which extends over its whole surface. The

axon consists, from without inwards, of an outermost cellular covering (the *neurilemma* or *Schwann sheath*); a myelin sheath of mainly lipoid material which acts as an electrical insulator—this may be thick in the typical *medullated* or *myelinated* axon, or very thin or non-existent in the *non-myelinated* axon; beneath the myelin sheath is the plasma membrane enclosing the *axoplasm*, the fluid or semi-fluid cytoplasm of the axon.

**Ultrastructure**

The endosplasmic reticulum of the neurone is concentrated in the perikaryon, where it was recognized by the light microscopists by virtue of its basophilia and described as *Nissl substance*; in the electron microscope its homology with that of other cells is easily recognized. Both perikaryon and the processes contain mitochondria. More recently two other structures have been identified, namely microtubules and microfilaments similar to those described in other cells (Vol. 1). The organization of these fine structures varies with the neurone and the particular process; thus in the dendrites of most neurones the filaments are rare, the major component being the microtubule, an inverse relation being found in the axon. Separation and analysis of the microtubules showed that they were built up of the protein, *tubulin*.

**Schwann Sheath**

The Schwann sheath is made up of characteristically flattened cells which remain *in situ* as apparently permanently fixed elements. However, they have by no means lost the powers of movement or reproduction so that when the underlying axon and myelin degenerate, as when the nerve fibre is severed, the Schwann cells tend to become more spherical, exhibiting continuous changes in shape until they finally take up new positions on regenerating material. In order to be able to re-sheathe a growing axon-stump they must, of course, migrate, and they move at some 49–90 $\mu$ per 24 hr.

**Axon–Schwann Cell Relations.** The relations of the axon to the myelin sheath and Schwann cell have been indicated earlier (Vol. 1, Ch. 2) when discussing the origin of the myelin as a lamellar arrangement of plasma membrane derived from the enclosing Schwann cell. To recapitulate, the axon with its limiting plasma membrane is enveloped by the Schwann cell, whilst the myelin sheath is derived from the Schwann cell's own plasma membrane and is to be regarded as part of the Schwann cell (Fig. 2.13, Vol. 1). The non-myelinated axon is likewise enclosed in a Schwann sheath, being enveloped within the Schwann cell, as illustrated in Fig. 1.4, where it is called a *Remak*

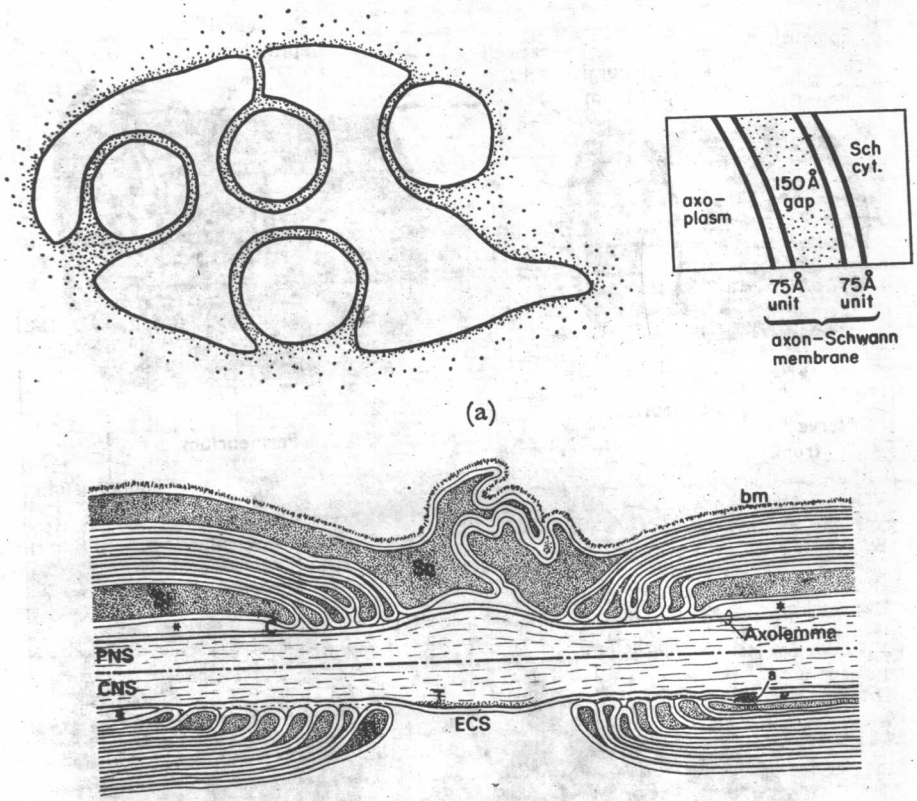


**Fig. 1.4.** (a) Illustrating Remak axons embedded to different extents in a single Schwann cell. (Courtesy J. D. Robertson.) (b) The node of Ranvier. The upper half of the diagram illustrates the structure found in peripheral myelinated nerve (PNS), and the lower half illustrates that found in the central nervous system (CNS). In the PNS the Schwann cell provides both an inner collar (Si) and an outer collar (So) of cytoplasm in addition to the compact myelin. Outer collar (So) is extended into the nodal region as a series of loosely interdigitating processes. Terminating loops of the compact myelin come into close apposition to the axolemma in region near the node apparently providing some barrier (arrow at a) for movement of materials into or out of the periaxonal space (marked by *). The Schwann cell is covered externally by a basement membrane. In the CNS the myelin ends similarly in terminal loops (Tl) near the node and there are periodic thickenings of the axolemma where the glial membrane is applied in the paranodal region. These may serve as diffusion barriers and thus confine the material in the periaxonal space (marked *) so that movement in the direction of the arrow at (a) would be restrained. At many CNS nodes there is considerable extracellular space (ECS). (Bunge, *Physiol. Rev.* 1968, **48**, 197.)