Neurones – their role in the nervous system.

Learning Objectives.

At the end of this module, you should be able to :

1. **describe the structure of the neurone;**
2. **understand the mechanisms of action potential generation;**
3. **appreciate the differing types of neurone, and how the differences in structure relate to their functions;**
4. **understand the mechanisms of synaptic transmission and neuromuscular transmission;**
5. **have a basic understanding of the range of sensory receptors throughout the body.**

Arrangement of the Nervous System

The nervous system can be divided into two parts: the central nervous system and the peripheral nervous system. The central nervous system includes the brain and spinal cord, enclosed in the cranium and the vertebral canal. The peripheral nervous system includes 12 pairs of cranial nerves and their branches and 31 pairs of spinal nerves and their branches. The peripheral nervous system provides input to the central nervous system from sensory receptors and output from it to effectors (muscles and glands). Communicating networks within the central nervous system and various brain centres which process incoming sensory information make possible the appropriate unconscious or conscious response to sensory input. For convenience,

peripheral efferent nerve fibers distributed to smooth muscle, cardiac muscle, and glands are usually referred to as the autonomic nervous system.

Types Of Cells In The Nervous System

The nervous system is composed of a special tissue containing two major types of cells: neurons, the active conducting elements, and neuroglia (glia, meaning 'glue'), the supporting elements.

Neurones

The basic unit of the nervous system is the neurone, or nerve cell, which conducts an electrical impulse from one part of the body to another. The neurone itself consists of a cell body containing a single nucleus, and processes which transmit impulses to and from the cell body.
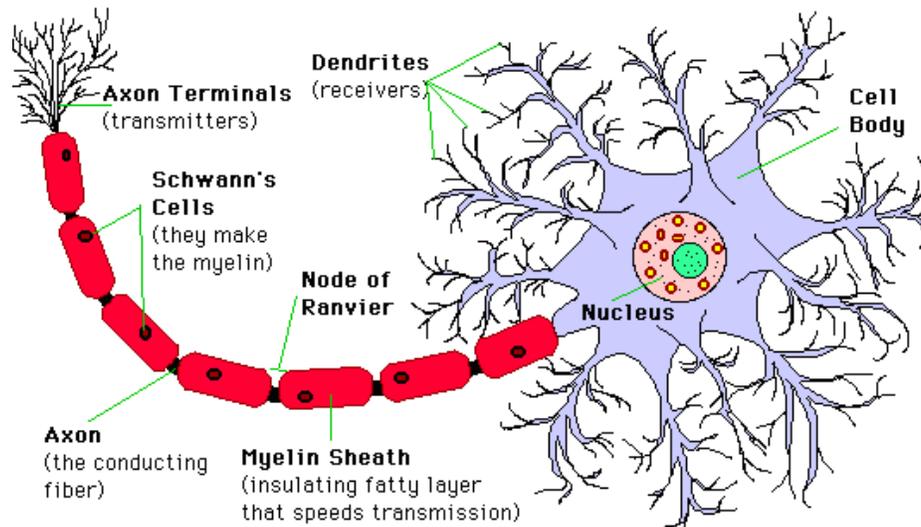
Neurones have two types of processes: axons and dendrites. An axon is a single, elongated, cytoplasmic extension carrying nerve impulses away from the cell body. The axon substance, or axoplasm, is jelly-like. The axon itself has a smooth outline, is of constant diameter, is sheathed, and terminates in more minute branches, which form junctions with effectors and other neurones. There is only one axon per neurone, but side branches, called collaterals, may arise along the course of an axon.

The dendrites are processes that carry impulses toward the cell body. The word dendrite describes the manner in which the processes appear in true dendrites - numerous, short, branching, and thickened at their point of origin. True dendrites are unsheathed and their surfaces have spine-like projections (dendrite spines) that are the principal sites of junctions between dendrites and axon terminals, where nerve impulses are transmitted from one to the other. Sensory neurones (those conducting sensory information to the central nervous system) have a single process that bifurcates a short distance from the cell body. One branch (the peripheral process) runs from a receptor to the cell body located just outside the central nervous system. The other (the central process, or axon) runs from the cell body to the central nervous system. The peripheral process has the smooth surface, is sheathed, and is in other respects similar to axons. Sensory neurons, therefore, do not have true dendrites, although the peripheral process is sometimes called a dendrite because it conducts impulses to the cell body.

Cytoplasmic Organelles.
Located in the cell body are the endoplasmic reticulum and associated ribosomes (collectively called Nissl bodies), the Golgi apparatus, mitochondria, and lysosomes. True dendrites have a similar organelle composition but lack the Golgi apparatus and have lesser amounts of endoplasmic reticulum. Ribosomes and the Golgi apparatus are not present in axons. Nissl bodies characteristically respond to injury of a nerve fiber by breaking up into a powder-like mass and dispersing with a loss of affinity to stains, a change called 'chromatolysis'. Also present throughout the neurone are microtubules, neurofilaments, and microfilaments. These organelles play a role in transporting neuronal substances, especially neurotransmitters or enzymes needed for their synthesis from the cell body to axon terminals. They also appear to be involved in nerve fiber growth.

The Nerve Fiber.
The term 'nerve fiber' refers to any long neurone process, such as an axon or peripheral process of a sensory neurone. All fibers of the peripheral nervous system

have a wrapping outside the cell membrane formed by accessory cells of the peripheral nervous system called Schwann cells. Fibers less than about one micrometer in diameter have a thin wrapping. In the case of the larger-diameter fibers, repeated wrappings form a thick sheath called myelin. When this sheath is formed, the bulk of the cytoplasm of the Schwann cell is expelled as it wraps around a segment of the nerve fiber, so that what remains is a tightly wound spiral of Schwann cell membrane with occasional clefts of cytoplasm.
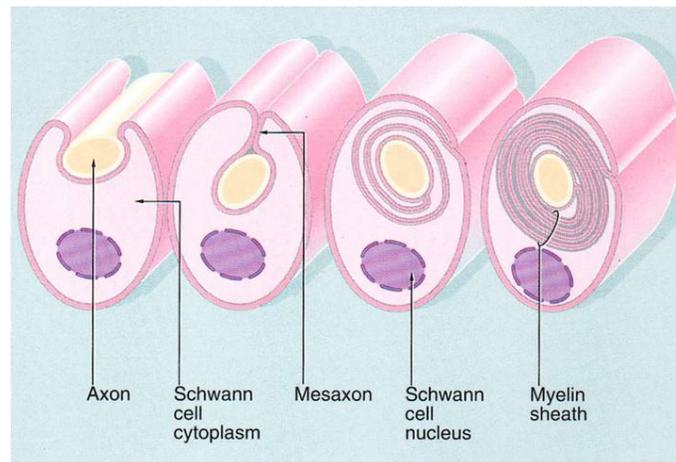
The outermost wrapping, containing the flattened nuclei of the Schwann cells and the greater part of their cytoplasm, is referred to as the neurilemma or sheath of Schwann. Myelin covers the entire fiber except at its termination, which is enveloped by the neurilemma, and at periodic gaps called nodes of Ranvier, where the neurilemma dips inward with finger-like processes to cover the fiber. Segments between nodes are called internodes, each formed by a single Schwann cell. Fibers wrapped in a myelin sheath are called myelinated fibers. The small-diameter fibers, which lack the multilayered myelin sheath, are called non-myelinated fibers.
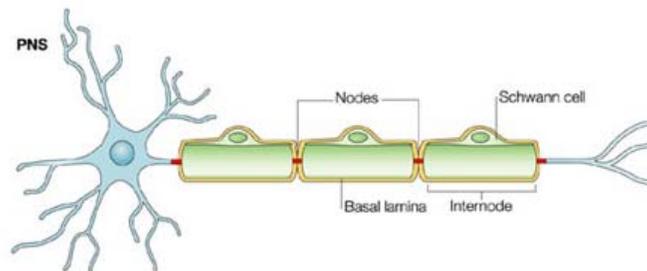
In the central nervous system, where Schwann cells are absent, the myelin sheath is formed by accessory cells called oligodendroglia. However, there is an important difference between myelin formed by oligodendroglia and Schwann cells. A whole oligodendroglial cell does not wrap itself around a segment of a neurone fiber; rather, it sends out processes (the average number may be as high as 40), each of which wraps around a segment of an adjacent fiber. Hence, these fibers lack an outer, nucleus -containing wrapping (neurilemma).

Myelin is about 80 per cent lipid and is an effective insulator. It increases the rate at which impulses are conducted along nerve fibers, a property described as saltatory conduction.

Schwann Cells and Nerve Fiber Regeneration.
Schwann cells play an essential role in nerve fiber regeneration. When a nerve fiber is damaged or cut, the part connected to the cell body sends out new sprouts, but the part distal to the cut undergoes degenerative changes (initially described by Augustus Volney Waller in 1852 and known as Wallerian degeneration). The axon swells and breaks into fragments, the myelin breaks up, and the disintegrating material is removed by macrophages. At the same time, Schwann cells proliferate, and a re-formed neurilemma joins the proximal end of the neuron to provide what has been called 'contact guidance' for the growing tip of the axon. When growth is completed, the Schwann cells form a new myelin sheath.

Damaged fibers of the central nervous system (as well as of the optic nerve, which also does not have Schwann cells) cannot repair themselves. The oligodendroglial cells do not regenerate after injury to the nerve fiber, and other glial cells in the damaged region, known as astrocytes, proliferate to form a dense tangle of processes that blocks regrowth of the fiber. Attempts have been made in experiments to overcome this blockage by replacing the damaged parts of spinal cords with grafts of peripheral nerve tissue containing Schwann cells. Only limited regrowth, however, has been observed.

Neurones Classified According To Structure.

Structurally, neurones are commonly described as unipolar, bipolar, and multipolar. This classification depends on the number of processes extending from the cell body. A unipolar neuron has only one process. True unipolar neurons, those with a single axon, are rare, except in the embryo. Sensory neurons that have one process which divides in two a short distance after leaving the cell body are also classified as unipolar, although some authors describe them as pseudounipolar, since they develop from embryological bipolar cells and function as bipolar cells. Bipolar neurons have only two processes, one conducting impulses to the cell body (not a true dendrite, although often called one), the other an axon; such cells are found in the retina of the eye and in the olfactory epithelium. Multipolar neurons have many true dendrites and a single axon. The majority of neurons in the brain and spinal cord are multipolar.

Bipolar   Unipolar   Multipolar
(Interneuron) (Sensory Neuron) (Motoneuron)
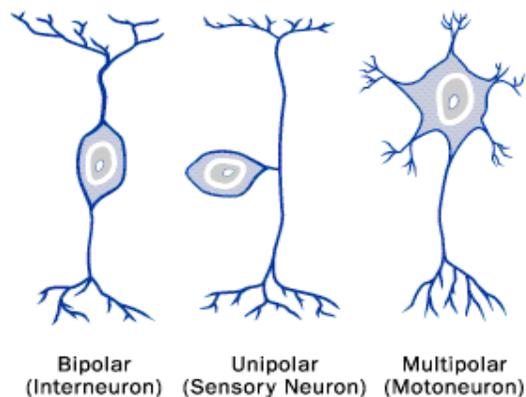
Neurones classified according to function.

There are three classes of neurones entering into the formation of nerve pathways. Sensory, or afferent (afferre, to carry to), neurones convey impulses from the skin or other sense organs to the central nervous system (spinal cord and brain). Motor, or efferent (efferre, to carry away), neurones carry impulses away from the central nervous system to muscles and glands. The third class consists of neurons which lie entirely within the central nervous system. These neurons receive input from sensory neurones and communicate with one another or with motor neurones. They are of

two types: those with long axons which form tracts connecting different parts of the nervous system, and those with short axons which form local circuits within a given region of the central nervous system. Some authors refer to all neurones located entirely within the central nervous system as inter-neurones or internuncial neurones. Others restrict these terms to the short-axon type. The short-axon neurons (also known as Golgi type II neurones, in distinction from the long-axon Golgi type I neurones) play important roles in information processing. Frequently this involves inhibitory processes. For example, in one kind of inhibitory interaction, lateral inhibition, which occurs in sensory pathways, maximally excited neurons may reduce the activity of less-excited adjacent neurons via inhibitory inter-neurones, thereby 'sharpening' sensory patterns.

Accessory Cells

The non-nervous elements consist of blood vessels, connective tissue, and supporting cells known collectively as neuroglia. Schwann cells, which form the myelin sheath and neurilemma of fibers of the peripheral nervous system, have already been described. Mention has also been made of oligodendroglia, which form the myelin sheath of fibers of the central nervous system. Other accessory cells of the central nervous system are astrocytes, microglia, and ependymal cells.

Astrocytes are so named because their processes are star shaped. Some of the processes have terminal expansions in contact with blood vessels. The capillaries of the central nervous system are relatively impermeable and constitute a so called blood:brain barrier. It has been suggested that astrocytes, which occupy the space between capillaries and neurons, control the transport of substances between the blood stream and neurones.
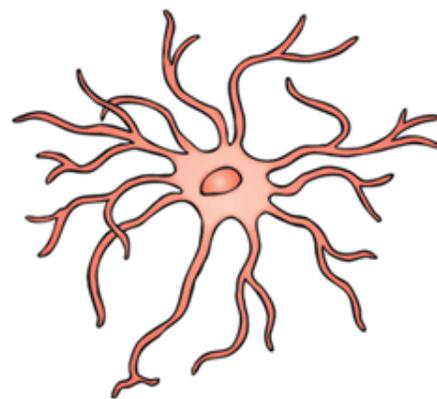
Microglia, unlike all other cells of the nervous system, develop from the embryonic mesoderm (which gives rise, among other things, to connective tissue, muscles, and the vascular system) rather than the ectoderm (from which the epidermis and neural tube develop). Microglia function as phagocytic cells.
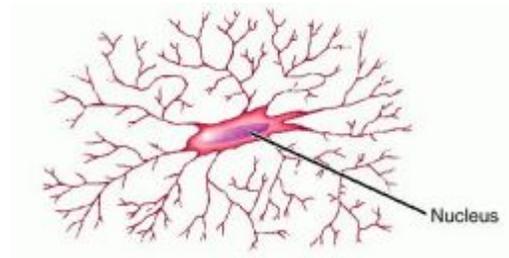
Ependymal cells line the ventricles (cavities) of the brain and the central canal of the spinal cord. In the embryo these cells are columnar and ciliated, but in the adult are cuboidal in shape with few cilia.
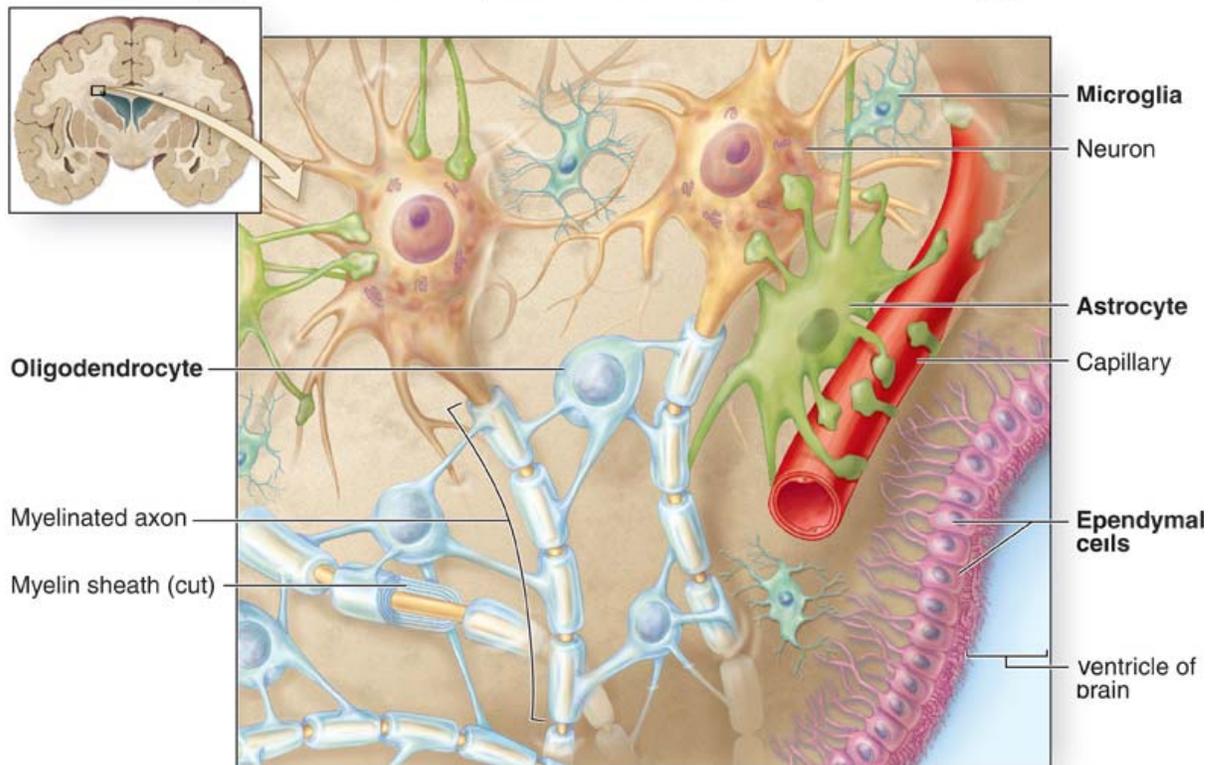
KEY LEARNING POINTS.

1. The basic cell of the nervous system is the neurone, consisting of a cell body, axons, and dendrites.
2. Dendrites carry impulses towards the cell body, whilst axons carry impulses away.
3. Schwann cells act to insulate the nerve, speeding up the rate of impulse transmission.
4. Sensory neurons carry information from the peripheral nervous system to the central nervous system, motor neurons transmit away from the central nervous system to effector organs.

The Nerve Impulse

Neurones function to conduct signals from one part of the body to another. The capacity for selective permeability to ions is a function of the cell membrane, and it is this property of the nerve cell which is involved in the transmission of the nerve impulse. In the resting state the interior of the nerve fiber is negative to the exterior by approximately 70 to 90 millivolts. This difference in potential across the membrane is called the resting membrane potential of the nerve fiber. In general terms, the origin of the resting membrane potential is accounted for as follows: the active transport of positively charged sodium ions to the outside of the cell (the so-called sodium pump) with the reciprocal transfer of positively charged potassium ions to the inside maintains a high concentration of sodium outside and a high concentration of potassium inside the cell.

Diffusion of sodium and potassium across the cell membrane in response to the concentration gradients created by the active transport mechanism results in the 'leaking' of sodium back into and potassium out of the cell. However, the cell membrane is much more permeable to potassium than to sodium. Very little inward diffusion of sodium occurs, and the greater outward diffusion of potassium creates a deficit of positive charges on the inner surface of the membrane that is responsible for the resting membrane potential. The relatively high permeability of the membrane to potassium is accounted for by the presence in the membrane of a class of permanently open channels selectively permeable to potassium.

When a stimulus is applied to a nerve cell, an impulse, a transient reversal of the membrane potential, is transmitted along the nerve fiber. This comes about as follows:

the stimulus causes changes in the conformation of membrane proteins functioning as sodium and potassium ion channels that are closed in the resting state. This results first in opening of the sodium channels and a rapid inflow of sodium, which changes the membrane potential locally from negative to positive. This is

followed by closing of the sodium channels and opening of the potassium channels. A rapid outflow of potassium returns the membrane potential to negative. These changes are known as the action potential. The local disturbance stimulates the adjacent regions of the nerve fiber, and the action potential sweeps along the fiber. In the body the stimulus is normally received at one end of the neuron and is propagated in one direction, but if a nerve fiber is artificially stimulated in the middle the action potential will be transmitted in both directions.

For a brief period following stimulation of a nerve fiber it will not respond to a new stimulus. The interval of complete unresponsiveness is called the absolute refractory period. The absolute refractory period is followed by a relative refractory period, during which time a stronger than minimum effective stimulus will lead to the transmission of a nerve impulse. For a large mammalian myelinated nerve fiber the absolute refractory period ranges from 0.4 to 1 millisecond. Excitability gradually returns to about 95 per cent of the resting level in 10 to 30 milliseconds.

The absolute refractory period corresponds to a period when the inflow of sodium ions is completely inactivated. The sodium channel protein apparently has three conformations. In the resting state the conformation is closed. A stimulus changes it to an open conformation. This change from a closed to an open conformation is terminated after a brief interval by a process called sodium inactivation. The closed conformation in the inactivated state is different from the resting state conformation, and until the channel returns to the resting state it will not respond to a new stimulus.

③ **Rising phase of the action potential**

④ **Falling phase of the action potential**

② **Depolarization**

Action potential

+50

0

Membrane potential (mV)

③

②

④

⑤

①

-50 Threshold ①

Resting potential

-100

Time

① **Refractory period**

Extracellular fluid   Na⁺   Potassium channel   Activation gates

Plasma membrane

Cytosol

Sodium channel   K⁺   Inactivation gate

① **Resting state**
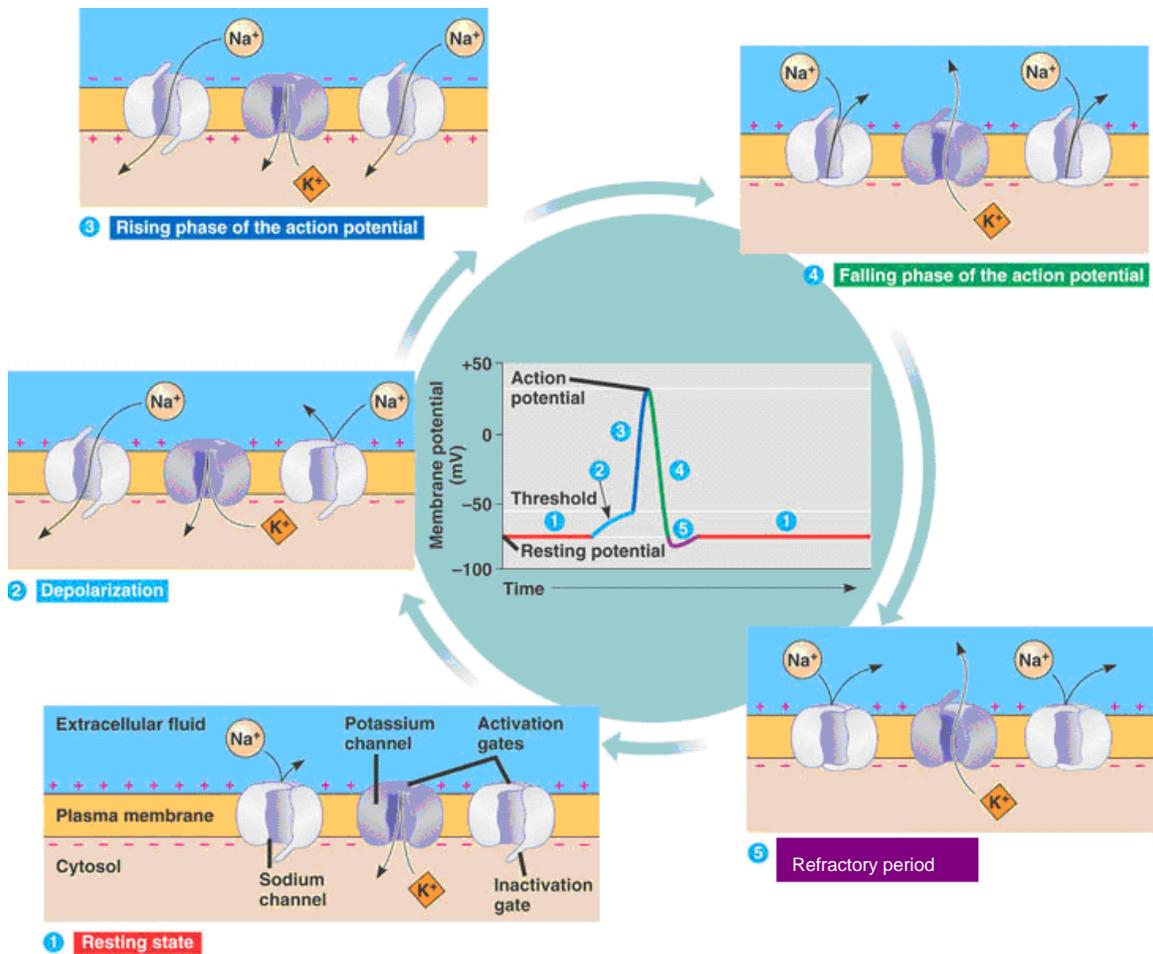
All-or-None Principle.

The transmission of a nerve impulse by a nerve fiber is said to work on an all-or-none principle. This means that nerve fibers will not transmit an impulse unless the stimulus has a certain strength (the threshold of the nerve fiber). If the threshold is reached, the impulse is maximal. Each type of nerve fiber sends an impulse of only one strength - its characteristic impulse. A stronger stimulus does not lead to a larger impulse.

A stimulus just strong enough to lead to a propagated impulse is called a threshold stimulus. A subthreshold stimulus will cause the internal potential to become briefly less negative, deflecting the voltage upward. Only when the threshold voltage of the nerve fiber is reached will the sodium influx be of sufficient magnitude to cause the sharp spike potential and propagated impulse.

Different nerve fibers have different thresholds - some will fire only with very strong stimulation, others with very weak stimulation, but all fibers work characteristically and on the all-or-none firing principle.

Saltatory Conduction.

Myelin is resistant to the flow of ions, and the thick myelin sheath of myelinated fibers prevents continuous passage of impulses along the length of the fiber. Ion flow at nodes of Ranvier sets up potential differences between nodes, and the impulse jumps from one node to another. This process, called saltatory conduction, greatly increases the transmission velocity of nerve impulses.

KEY LEARNING POINTS.

1. **The diffusion of sodium and potassium ions across the neurone membrane bring about the production of an action potential.**
2. **The relative opening and closing of sodium channels, followed by potassium channels, controls the generation process.**
3. **the all-or-nothing principle means that a threshold change in charge across the membrane is required, but once this is reached, the maximum response is produced.**

Transmission of the Impulse at the Neuromuscular Junction

A motor neuron branches terminally and innervates from a few, to more than a thousand, muscle fibers depending upon the precision of the muscular action. The junction at which the axon branch and muscle fiber meet is known as the neuromuscular junction, also called the myoneural junction or motor end plate. In most muscles the junction is situated at the midpoint of the fiber and consists of several expanded endings of an axon branch arranged in a group. Each expanded ending contains mitochondria and vesicles that store a chemical mediator and projects into an invagination of the muscle fiber membrane (synaptic trough). The space between an ending and an invaginated muscle fiber membrane is called the synaptic cleft. Folds in the bottom of the muscle fiber membrane (subneural clefts) increase the surface area for stimulation.
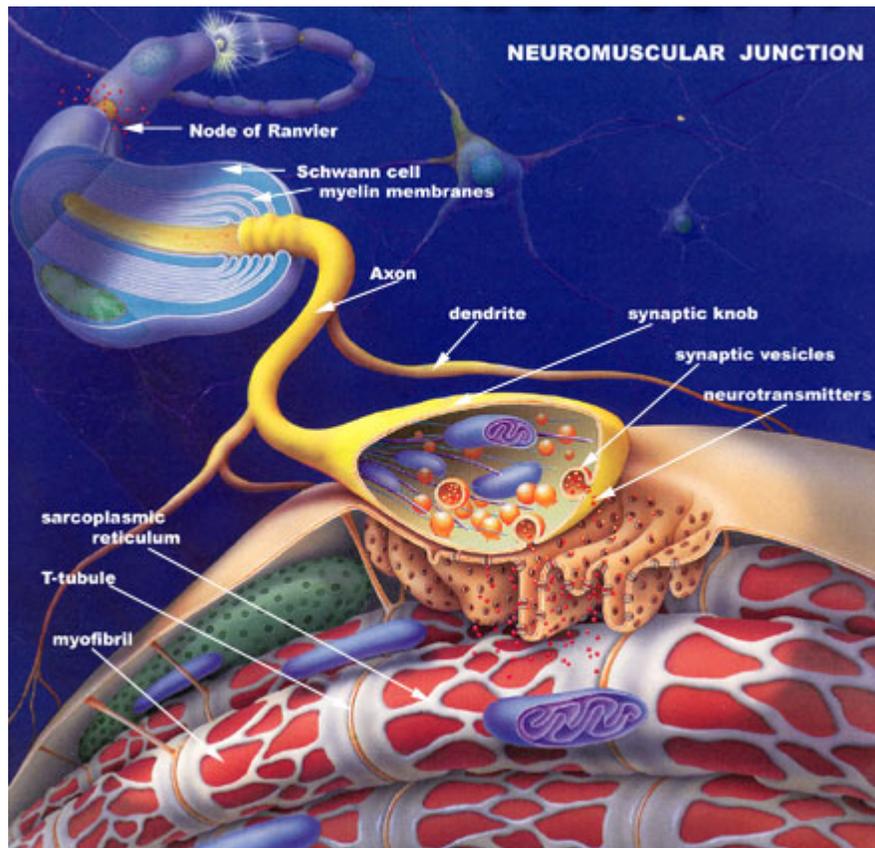
In the 1930's Sir Henry Dale and colleagues made the important discovery that the transmission of electrical impulses from nerve to muscle requires the intervention of a specific chemical mediator, acetylcholine. A nerve impulse causes the sudden release of a large amount of acetylcholine from vesicles in which it is stored in the axon branch endings into the synaptic clefts. The release of acetylcholine is apparently triggered by the influx of calcium into the axon branch endings. This leads to the fusion of the acetylcholine-containing vesicles with the membrane of the axon branch endings and discharge of acetylcholine (a process called exocytosis). Acetylcholine diffuses across the synaptic clefts and is bound by a receptor protein embedded in the membrane of the muscle fiber. According to recent research findings this receptor is an ion channel that is 'gated' by acetylcholine. Upon binding acetylcholine it undergoes a change in conformation that opens the channel to the passage of sodium and potassium ions. A sudden influx of sodium and outflow of potassium is associated with a reduction in the difference in potential across the cell membrane (making the membrane potential less negative). This change is called the end plate potential (EPP) and, when it reaches a critical level (the threshold of the muscle fiber), it is the stimulus for generating an action potential, which is propagated along a muscle fiber in the same way an action potential is propagated along a nerve fiber. The action of acetylcholine is halted by the enzyme acetylcholinesterase, located on the membrane of the muscle fiber, which splits acetylcholine into acetic acid and choline.

In the 1950's it was demonstrated by Bernard Katz and Paul Fatt that even in the absence of stimulation the end plate region is not entirely at rest. Randomly occurring subthreshold miniature end plate potentials (MEPP) resulting from the spontaneous, intermittent release of acetylcholine can be recorded. The effect of a stimulus is to greatly increase the release of acetylcholine. The amount released following a stimulus is sufficient to induce an action potential in the muscle fiber.

Certain drugs, such as methacholine, nicotine, and carbachol, mimic the effect of acetylcholine at the neuromuscular junction. However, because these drugs either are

not or are very slowly destroyed by acetylcholinesterase, their actions persist. Moderate doses induce a state of muscular spasm, but high doses cause paralysis because the receptor protein becomes unresponsive to chemical mediators.

Neuromuscular transmission can be blocked by curare, which has a greater affinity for the receptor protein than acetylcholine. Poisoning with this drug can cause death as a result of paralysis of the muscles of respiration.

Synaptic Transmission

Signals are passed from one neurone to another at specialized junctions called synapses. Most often transmission is from the axon terminal of one neurone to the dendrites or cell body of another, synapse occurring most frequently between axon terminals and dendrites. Other, less common, types of synapses involved in information transfer include axon on axon, dendrite on axon, dendrite on dendrite, and dendrite on cell body.
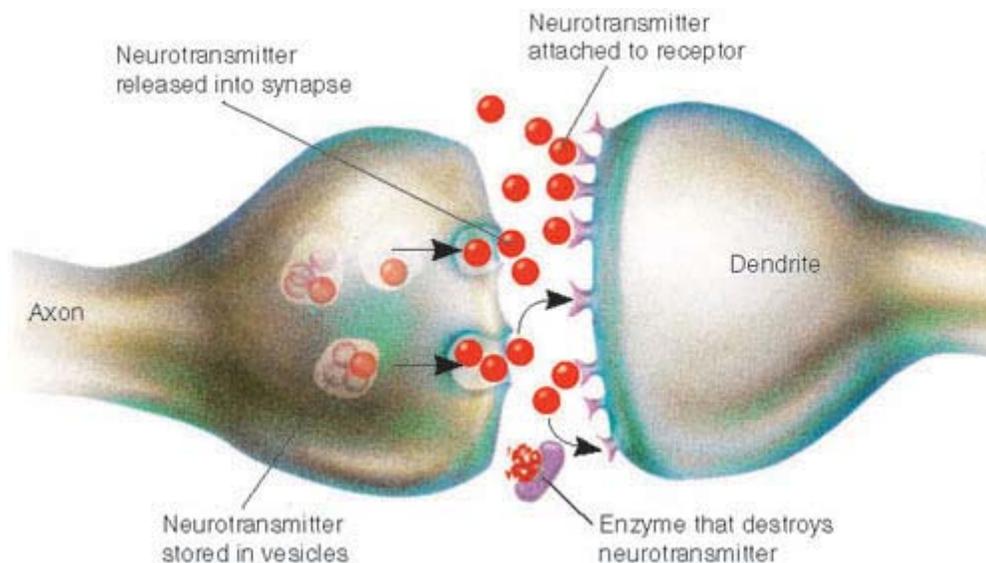
Before an axon makes synaptic connections, it gives rise to many branches, each of which ends in a knob-like expansion called a presynaptic knob, bouton, or presynaptic terminal. A presynaptic knob is separated from the membrane of a

postsynaptic neuron by a synaptic cleft and contains mitochondria and vesicles filled with a neurotransmitter, a chemical mediator that alters the permeability of the postsynaptic membrane. The arrival of a nerve impulse at the presynaptic terminal leads to the discharge of the neurotransmitter into the synaptic cleft just as it does at the axon branch endings at the neuromuscular junction. However, whereas the vesicles in the axon endings at the neuromuscular junction contain only acetylcholine, which always has an excitatory effect on the postsynaptic membrane, the vesicles of presynaptic knobs contain any one of a number of neurotransmitters which may exert either excitatory or inhibitory actions.

Furthermore, it is not unusual for the action of a given neurotransmitter to be excitatory at some synapses and inhibitory at others. When a neurotransmitter diffuses across the synapse, it is bound by a receptor protein in the membrane of the postsynaptic neuron. The receptor may, as is the case with the acetylcholine receptor at the neuromuscular junction, function as a chemically gated ion channel, assuming an open conformation when a specific neurotransmitter is bound. Some receptors, on the other hand, appear to function by a more elaborate mechanism, often involving the formation of cyclic AMP, functioning as a second messenger in mediating the action of the neurotransmitter.

The effect of an excitatory neurotransmitter is to bring about ion flows that make the membrane potential less negative, producing what is called the excitatory postsynaptic potential (EPSP). An excitatory postsynaptic potential produced by discharge of the neurotransmitter from a single presynaptic knob will not reach the threshold for initiating an action potential in the postsynaptic neuron. To reach the threshold a summing of many excitatory postsynaptic potentials must occur. This may be accomplished by the discharge of the neurotransmitter from a number of presynaptic knobs simultaneously, a process called spatial summation. Converging neural pathways, which result in the innervation of a single neuron by the terminal branches of many neurons, make possible spatial summation by input from many presynaptic neurons. A summing of excitatory postsynaptic potentials may also be

brought about by the discharge of the neurotransmitter from presynaptic knobs in rapid succession, a process called temporal summation.

When the membrane potential of the postsynaptic neurone is made less negative than the resting membrane potential, but not sufficiently so to reach the threshold for firing, the neurone is said to be facilitated. In this state the neurone is more responsive to weak input signals than it would otherwise be.

The effect of inhibitory neurotransmitters on the postsynaptic membrane is the reverse of excitatory neurotransmitters. They cause ion flows (usually an outflow of potassium ions or inflow of chloride ions) that make the membrane potential more negative (hyperpolarized). This change is called the inhibitory postsynaptic potential (IPSP).

Synaptic inhibition can also be caused by a reduction in the release of an excitatory neurotransmitter from presynaptic terminals, an action called presynaptic inhibition. Interneurone terminals overlying excitatory presynaptic terminals apparently release a neurotransmitter that acts on these terminals (an example of an axon on axon synapse).

Synaptic response is influenced by diverging and converging neural pathways. Divergence refers to the innervation of many neurons by the terminal branches of a single neuron. Convergence is the innervation of a single neuron by the terminal branches of many neurons. In diverging pathways the signals may be amplified or sent to separate parts of the nervous system. A significant consequence of convergence is that a single neurone can receive input from widely scattered regions of the nervous system. What a neurone will do in response to its various inputs is determined by the summing of excitatory and inhibitory signals converging upon it. It is perhaps apparent that convergence provides an important mechanism for the correlation and evaluation of information by the central nervous system.

Although a number of substances have been tentatively identified as neurotransmitters, only two, acetylcholine and noradrenaline, meet all of the criteria used by researchers for classification as such. These criteria are the presence of enzymes for its synthesis, a mechanism for termination of its action, reaction with a receptor site upon release, and identification of a response.

Among the substances that do not meet all of these criteria but that are commonly accepted as neurotransmitters are dopamine, serotonin, gamma aminobutyric acid (regarded as the most common inhibitory neurotransmitter in the brain), glycine (concentrated in certain parts of the spinal cord, where it is inhibitory), glutamic acid, and aspartic acid.

All of the substances listed above are either simple compounds or individual amino acids. In recent years a new class of compounds, the neuropeptides, has become a neurotransmitter candidate. As a rule these peptides are also found in the intestinal tract or pituitary gland. Some are well-known hormones, such as secretin, gastrin, cholecystokinin (gastrointestinal hormones), ACTH, vasopressin (pituitary hormones), thyrotropin-releasing hormone, and luteinizing hormone-releasing hormone (hypothalamic hormones). Another, substance P, has a long history (it was isolated from the brain and intestines more than 50 years ago) and in recent years has been intensively studied as a transmitter of pain signals in the spinal cord. Two others, the enkephalins and endorphins, have aroused a great deal of excitement because of their morphine-like properties. Studies with some of these neuropeptides suggest that they do not function as neurotransmitters in the usual sense, but as neuromodulators, altering a neurone's response to a neurotransmitter. It has been observed that some neurones contain one or more neuropeptides in addition to a traditional small-molecule neurotransmitter. This appears to violate the rule, generally accepted for many years, that any given neurone releases only one neurotransmitter. It is possible, however, that the rule is one neurotransmitter per neurone plus one or more neuromodulators.

Neurotransmitters are continuously synthesized in synaptic knobs or the neuronal cell body. The neurotransmitters or enzymes required for their synthesis are transported from the cell body along the fiber to the knobs. Excessive neuronal stimulation will eventually deplete the store of transmitter substance, thereby causing cessation of synaptic transmission. This fatigue serves as a protective device, as in limiting the duration of an epileptic seizure.

There is evidence that the number of presynaptic terminals may actually increase with prolonged repetitive stimulation. It has been postulated that these physical changes may in part form the basis of memory.

Acidosis and alkalosis affect synaptic transmission by decreasing or increasing excitability. A decrease in pH from the normal of 7.4 to 7.0 depresses neuronal activity, as in severe diabetic coma. An increase in pH from 7.4 to 7.8 often results in convulsions owing to increased excitability.

KEY LEARNING POINTS.

1. **The neuromuscular junction is where the motor nerve transmits its impulse to the muscle fibres.**
2. **Acetylcholine is the neurotransmitter involved in this.**
3. **Synaptic transmission is where the action potential is passed from one neurone to another.**
4. **Some neurotransmitters are excitatory, whereas some inhibit transmission across the synapse.**
5. **A change in pH can affect synaptic transmission.**

Sensory Receptors

Input by sensory neurones to the central nervous system providing information about changes in the external and internal environment depends upon the existence of receptors. A receptor is a peripheral ending of a sensory neurone, or a structure or organ innervated by a sensory neurone, that is especially sensitive (but not exclusively) to a given kind of stimulus (called the adequate stimulus). Receptors vary in complexity from the free nerve endings sensitive chiefly to pain to the highly complicated organs for vision and hearing. Stimulation of a receptor causes changes that induce a localized potential in sensory neurones, called the generator potential, which, if it reaches a critical (threshold) amplitude, generates a propagated action potential.

Each sensory neurone transmits impulses to the central nervous system that will be identified as a specific kind of sensation, such as pain, touch, and sound. Since each sensory neurone functions simply as a transmitter of nerve impulses, it is perhaps apparent that the identification of the sensation depends upon the connections made by the sensory pathways in the brain. From this it also follows that no matter how the sensory neurone is stimulated (by the adequate stimulus or otherwise) the sensation perceived will be the same. A greater than threshold stimulus to a receptor will not increase the magnitude of the propagated action potential (all-or-none law), but it will increase the frequency of the impulses. Increasing the intensity of the stimulus also excites more receptors (partly because of different receptor thresholds).

Receptors are difficult to classify, and several somewhat conflicting classification schemes have arisen. The broadest classification distinguishes two principle types, receptors for the general senses distributed throughout the body and receptors for the special senses in the head region, namely, sight, hearing, taste, smell, and equilibrium (receptors for the last-named sense are located in the inner ear). The general senses include pain, touch, pressure, cold, warmth, and the kinesthetic sense (the perception of the position and movement of parts of the body made possible by

receptors in tendons and tissues in and around joints, also known as proprioreception). All of the foregoing receptors provide input that is consciously perceived. Other general receptors can detect bodily changes that are not consciously perceived but that play vital roles in maintaining homeostasis. These include receptors for arterial pressure (in the aorta and the carotid sinus), arterial oxygen (in the aortic and carotid bodies), arterial carbon dioxide (in the medulla of the brain and the aortic and carotid bodies), blood temperature, osmotic pressure, and glucose concentration (in the hypothalamus).

Among other terms frequently encountered in descriptions of sensory receptors are the following:

- Proprioceptors - receptors of vital importance for locomotor and postural responses, including kinesthetic receptors, the muscle spindle, and equilibrium receptors in the inner ear.
- Somesthetic receptors - frequently used to describe general body receptors for consciously perceived sensations.
- Exteroceptors - receptors responding to stimuli from the external environment, from a distance or on the body surface.
- Interoceptors - receptors responding to stimuli from the internal environment, excluding muscles, tendons, and joints.

The simplest sensory receptors are free nerve endings - undifferentiated peripheral endings of sensory nerve fibers. All pain receptors are of this type. Although the largest proportion of free nerve endings are receptors for pain, functionally different free nerve endings apparently exist, not distinguishable anatomically, which are sensitive to crude touch, pressure, itch, and temperature. Meissner's corpuscles, receptors for discreet touch, are especially numerous in the upper dermis of the hands, feet, lips, and nipples, and in the mucous membrane of the tip of the tongue. Other touch receptors include Merkel's discs, found in great numbers in the deepest epidermal layer of fingertips, and the end organs of hair (basketlike arrangements of nerve fibers around hair follicles). Pacinian corpuscles are very large receptors sensitive to deep

pressure. They are widely distributed in such areas as the deep layers of the skin and under mucous and serous membranes. Krause's end-bulbs, found in the upper dermis, and Ruffini's end organs, found deep in the dermis and other connective tissues, have traditionally been described as cold and warmth receptors, respectively. However, careful examination of regions of the skin where response to cold or warmth has been aroused does not reveal specific receptors of this kind. These structures, especially Ruffini's end organs, may function as receptors for touch and pressure. Ruffini's end organs are also located in joint capsules, where they are kinesthetic receptors. Other kinesthetic receptors are the Golgi tendon receptors and Pacinian corpuscles in tissues in and around joints.

A characteristic property of receptors is their adaptation to stimulation. This means that the frequency of impulses declines with the continued application of a stimulus of constant strength. Consequently, the sensation decreases in intensity and may disappear. In the case of rapidly adapting receptors, such as the Pacinian corpuscle and some of the touch receptors, namely, the hair receptors and Meissner's corpuscles, the impulses are extinguished within a second or less. Such receptors can provide information about changes in or movement of stimuli. Pacinian corpuscles, for example, which adapt to extinction within a few hundredths of a second, can detect high frequency vibrations. Poorly adapting receptors adapt slowly and not to extinction. Pain receptors are an example of poorly adapting receptors that continue to transmit impulses as long as they are stimulated. Other poorly adapting receptors are the muscle spindle, Ruffini's end organs, Merkel's discs and the receptors for blood pressure, oxygen, and carbon dioxide.

Classification of Nerve Fibers

Nerve fibers can be classified according to diameter (including the myelin sheath) and velocity of conduction. Type A fibers are myelinated and are subclassified (from the largest and fastest conductors to the smallest and slowest conductors) as A-α, A-β, A-γ and A-δ. Type B fibers are also myelinated but are slightly smaller than the A-

δ fibers, and are the preganglionic fibers of the autonomic nervous system. Type C fibers are very small, nonmyelinated fibers with the slowest conduction rates.

Impulses from the primary sensory endings of muscle spindles are transmitted by A-α fibers (velocity, 70120 meters/sec.). Receptors for discrete touch (Meissner's corpuscles and Merkel's discs), deep pressure, and kinesthesia are innervated by A-β fibers (velocity, 40-70 meters/sec.). Reception for cold is associated with A-δ fibers (velocity, 5-15 meters/sec.) and for warmth with C fibers (velocity, 0.5-1.5 meters/sec.). Pain is transmitted by two kinds of fibers: A-δ fibers, which transmit fast pain, and C fibers, which transmit slow pain. Pain is frequently sensed in two phases - an immediate, sharp, localized, painful sensation followed by a more diffuse burning sensation that may persist and become unbearable. The former is associated with A-δ fibers, the latter with C fibers. Aching pain, arising from deep structures and the viscera (often felt on the body surface), is also transmitted by C fibers.

Motorneurone fibers, whose branches terminate at the neuromuscular junction, are type A-α. Efferent fibers innervating the muscle spindle are A-γ. These fibers (so-called gamma efferents) control the sensitivity of the muscle spindle. As mentioned, preganglionic fibers of the autonomic nervous system are type B. Postganglionic autonomic fibers are type C.

KEY LEARNING POINTS.

1. **Sensory neurons receive their input from specialised sensory receptors.**
2. **There are specific receptors for different types of stimulus.**
3. **Nerve fibers transmit impulses at varying speeds, depending on their physical characteristics. Highly myelinated fibres transmit rapidly, whereas unmyelinated fibres transmit relatively slowly.**