**THE NERVOUS SYSTEM**

**The nervous system** is the body’s control center. In humans, the nervous system serves three broad functions: sensory, integrative and motor. First, it senses changes within the body and the outside environment; this is its sensory function. Second, it interprets the changes; this is its integrative function. Third, it responds to the interpretation by initiating action in the form of muscular contractions or glandular secretions; this is its motor function.

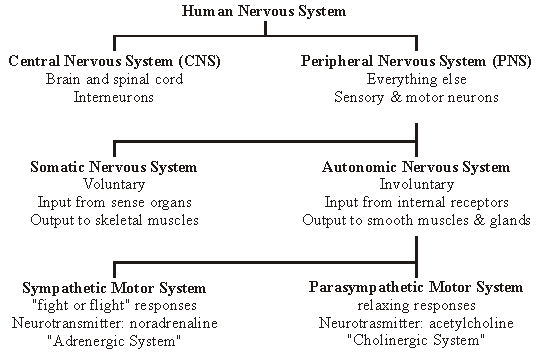
Through sensation, integration, and response the nervous system represents the body’s most rapid means of maintaining homeostasis. Its split-second reactions, carried out by nerve impulses, can normally make the adjustments necessary to keep the body functioning efficiently. The nervous system shares the maintenance of homeostasis with the endocrine system. Although the adjustments made by hormones secreted by endocrine glands are slower than those made by nerve impulses, they are no less effective.

The branch of medical science that deals with the normal functioning and disorders of the nervous system is called **neurology**.

**ORGANIZATION**

The nervous system may be divided into two principal divisions, the central nervous system and the peripheral nervous system, and several subdivisions.

**The central nervous system (CNS)** is the control center for the entire nervous system and consists of the brain and spinal cord. All body sensations must be relayed from receptors to the central nervous system if they are to be interpreted and acted on. The majority of nerve impulses that stimulate muscles to contract and glands to secrete must also originate in the central nervous system.



The various nerve processes that connect the brain and spinal cord with receptors, muscles and glands constitute the **peripheral** **nervous system** (PNS). The peripheral nervous system may be divided into an afferent system and an efferent system. **The** **afferent** system consists of nerve cells that convey information from receptors in the periphery of the body to the central nervous system. These nerve cells, called **afferent** (sensory) neurons, are the first cells to pick up incoming information. The efferent system consists of nerve cells that convey information from the central nervous system to muscles and glands. These nerve cells are called **efferent** (**motor**) **neurons**.

The efferent system is subdivided into a somatic nervous system and an autonomic nervous system. **The somatic** (*soma* = body) nervous system or ***SNS*** consists of efferent neurons that conduct impusles from the central nervous system to skeletal muscle tissue: Since the somatic nervous system produces movement only in skeletal muscle tissue, it is under conscious control and therefore voluntary. The autonomic nervous system or ***ANS***, by contrast, contains efferent neurons that convey impulses from the central nervous system to smooth muscle tissue, cardiac muscle tissue, and glands. Since it produces responses only in involuntary muscles and glands, it is usually considered to be involuntary.

With few exceptions, the viscera receive nerve fibers from the two divisions of the autonomic nervous system: the **sympathetic division and the parasympathetic division**. In general, the fibers of one division stimulate or increase an organ’s activity, while the fibers from the other inhibit or decrease activity.

**HISTOLOGY**

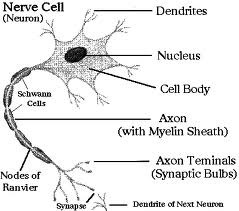
Despite the organizational complexity of the nervous system, it consists of only two principal kinds of cells: neurons and neuroglia. Neurons make up the nervous tissue that forms the structural and functional portion of the system. They are highly specialized for nerve impulse conduction and for all special functions attributed to the nervous system: thinking, controlling muscle activity, regulating glands. Neuroglia serves as a special supporting and protective component of the nervous system

**NEUROGLIA**

The cells of the nervous system that perform the functions of support and protection are called ***neurogila*** or ***glial*** ***cells***. Neuroglia are generally smaller than neurons and outnumber them by 5-10 times. Many of the glial cells form a supporting network by twining around nerve cells or lining certain structures in the brain and spinal cord. Others bind nervous tissue to supporting structures and attach the neurons to their blood vessels. A few types of glial cells also serve specialized functions. For example, some produce a phospholipid covering, called a myelin sheath, around nerve fibers in the central nervous system, which increases the speed of nerve impulse conduction and insulates the fibers. Certain small glial cells are phagocytic; they protect the central nervous system from disease by engulfing invading microbes and clearing away debris. Neuroglia are of clinical interest because they are a common source of tumors (gliomas) of the nervous system. It is estimated that gliomas account for 40 - 45 percent of brain tumors. Unfortunately, gliomas are very invasive.

**NEURONS**

Nerve cells, called ***neurons***, are responsible for conducting nerve impulses from one part of the body to another. They are the structural and functional units of the nervous system.



**Structure of a motor Neuron**

**Structure**

Most neurons consist of three distinct portions: (1) cell body, (2) dendrites, and (3) axon. The cell ***body***, ***soma*** or ***perikaryon*** contains a well-defined nucleus and nucleolus surrounded by a granular cytoplasm. Within the cytoplasm are typical organelles such as lysosomes, mitochondria, and Golgi complexes. Many neurons also contain cytoplasmic inclusions such as ***lipofuscin*** pigment that occurs as clumps of yellowish granules. Lipofuscin may be a by-product of lysosomal activity. Although its significance is unknown, lipofusin is related to aging; the amount of pigment increases with age. Also located in the cytoplasm are structures characteristic of neurons: chromatophilic substance and neurofibrils. The ***chromatophilic*** ***substance*** (***Nissl*** ***bodies***) is an orderly arrangement of granular (rough) endoplasmic reticulum whose function is protein synthesis. Newly synthesized proteins pass from the perikaryon into the neuronal processes, mainly the axon, at the rate of about 1 mm (0.04 in.) per day. These proteins replace those lost during metabolism and are used for growth of neurons and regeneration of peripheral nerve fibers. ***Neurofibrils*** are long, thin fibrils composed of rnicrotubules. They may assume a function in support and the transportation of nutrients. Mature neurons do not contain a mitotic apparatus .

Neurons have two kinds of cytoplasmic processes: dendrites and axons. ***Dendrites*** (dendro = tree) are usually highly branched, thick extensions of the cytoplasm of the cell body. They typically contain chromatophilic substance, mitochondria, and other cytoplasmic organelles. A neuron usually has several main dendrites. Their function is to conduct nerve impulses toward the cell body.

The second type of cytoplasmic process, called an ***axon*** (***axis*** ***cylinder***), is a single, highly specialized, usually long, thin process that conducts nerve impulses away from the cell body to another neuron or tissue. It usually originates from the cell body as a small conical elevation called the ***axon hillock***.

An ***axon*** contains mitochondria and neurofibrils but no chromatophilic substance; thus, it does not carry on protein synthesis. Its cytoplasm, called axoplasm, is surrounded by a plasma membrane known as the ***axolemma*** (lemma = sheath or husk). Axons vary in length from a few millimeters (1mm = 0.04 in.) in the brain to a meter (3.28 ft) or more between the spinal cord and toes. Along the length of an axon, there may be side branches called ***axon collaterals***. The axon and its collaterals terminate by branching into many fine filaments called ***axon terminal (telodendria)***. The distal ends of axon terminals are expanded into bulblike structures called ***synaptic*** **endbulbs**, which are important in nerve impulse conduction from one neuron to another and from a neuron to muscle or glandular tissue. They contain membrane-enclosed sacs called ***synaptic*** ***vesicles*** that store chemicals called neurotransmitters that determine whether or not nerve impulses pass from one neuron to another or from a neuron to another tissue (muscle or gland)

The cell body of a neuron is essential for the synthesis of many substances that sustain the life of the nerve cell. Neurons have two types of intracellular systems for transporting synthesized materials from the cell body. The slower one, called ***axoplasmic*** ***flow***, conveys axoplasm in one direction only—from the cell body toward axon terminals. This mechanism may occur by protoplasmic streaming and supplies new axoplasm for developing or regenerating axons and renews axoplasm in growing and mature axons. The faster type of intracellular transport is called ***axonal*** ***transport***. It conveys materials in both directions—away from the cell body and toward the cell body—possibly along tracks formed by microtubules and filaments. Axonal transport moves various organ and materials that form the membranes of the axolemma, synaptic end-bulbs, and synaptic vesicles. Materials returning to the cell body are degraded or recycled.

The terms ***nerve fiber*** may be applied to any process projecting from the cell body. More commonly, it refers to axon and its sheaths. Many axons, especially large ones outside the CNS, are surrounded by a multilayered, white, phosholipid, segmented covering called ***myelin sheath.*** Axons containing such a covering are ***myelinated,*** while those without it are ***unmyelinated***. The function of the myelin sheath is to increase the speed of nerve impulse conduction and insulate and maintain the axon. Myelin is responsible for the white in the nerves, brain and spinal cord.

The myelin sheath of axons of the peripheral nervous system is produced by flattened cells, called ***neurolemmocytes*** (***Schwann*** ***cells)***, located along the axons. In the formation of a sheath, a developing neurolemmocyte encircles the axon until its ends meet at overlap. The cell then winds around the axon many times and, as it does so, the cytoplasm and nucleus are pushed to the outside layer. The inner portion, consisting of up to 20-30 Iayers of neurolemmocyte membrane, is the myelin sheath. The peripheral nucleated cytoplasmic layer of the neurolemmocyte (the outer layer that encloses the sheath) is called the ***neurolemma (sheath of Schwann).***

The neurolemma is found only fibers of the peripheral nervous system. Its function is to assist in the regeneration of injured axons by forming a tube in which a regenerating axon grows. Between the segments of the myelin sheath are unmyelinated gaps, called ***neurofibral*** ***nodes*** (***nodes*** ***of Ranvier*** unmyelinated fibers are also enclosed by neurolemmocytes, but without multiple wrappings.

Nerve fibers of the central nervous system may also be rnyelinated or unmyelinated. Myelination of central nervous system axons is accomplished by oligodendrocytes in somewhat the same manner that neurolemmocytes myelinate peripheral nervous system axons. Myelinated axons of the central nervous system also contain neurofibral nodes, but they are not so numerous.

Myelin sheaths are first laid down during the later part of fetal development and during the first year of life. The amount of myelin increases from birth to maturity and its presence greatly increases the rate of nerve impulse conduction. Since myelination is still in progress during infancy, an infant’s responses to stimuli are not as rapid or coordinated as those of an older child or an adult.

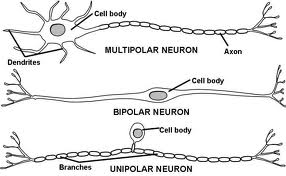
**Structural Variation**

Although all neurons conform to the general plan described, there are considerable differences in structure. For example, cell bodies range in diameter from 5  for the smallest cells to 135  for large motor neurons. The pattern of dendritic branching is varied and distinctive for neurons in different parts of the body. The axons of very small neurons are only a fraction of a millimeter in length and lack a rnyelin sheath, whereas axons of large neurons are over a meter long and are usually enclosed in a myelin sheath.

**CLASSIFICATION**

The different neurons in the body may be classified by structure and function.

The structural classification is based on the number of processes extending from the cell body.



***Multipolar neurons*** usually have several dendrites and one axon. Most neurons in the brain and spinal cord are of this type.

***Bipolar*** ***neurons*** have one dendrite and one axon and are found in the retina of the eye, inner ear, and olfactory area.

***Unipolar*** (***pseudounipolar***) neurons have only one process extending from the cell body. The single process divides into a central branch, which functions as an axon, and a peripheral branch, which functions as a dendrite.

Unipolar neurons originate in the embryo as bipolar neurons and, during development, the axon and dendrite fuse into a single process. Unipolar neurons are found in posterior (sensory) root ganglia of spinal nerves and the ganglia of cranial nerves that carry general somatic sensations.

**Functional classification**

The functional classification of neurons is based on the direction in which they transmit impulses.

***Sensory*** (***afferent***) ***neurons*** transmit impulses from receptors in the skin, sense organs, and viscera to the brain and spinal cord and from lower to higher centers of the CNS. They are usually unipolar.

***Motor (efferent) neurons*** convey impulses from the brain and spinal cords to effectors, which may be either muscles or glands and from higher to lower centers of the CNS.

Other neurons, called **association (connecting or interneuron) neurons,** carry impulses from sensory to motor neurons and are located in the brain and spinal cord. All are found in the cerebral cortex, the outer layer of the cerebrum. The granule cell and Purkinje cell are association neurons in the cortex of the cerebellum. Most neurons in the body, perhaps 90 percent, are association neurons.

The processes of afferent and efferent neurons are arranged into bundles called nerves if outside the CNS or tracts if inside the CNS. Since nerves lie outside the CNS, they belong to the peripheral nervous system. The functional components of nerves are the nerve fibers, which may be grouped according to the following scheme.

1. General somatic afferent fibers conduct nerve impulses from the skin, skeletal muscles, and joints to the central nervous system.
2. General somatic efferent fibers conduct nerve impulses from the central nervous system to skeletal muscles. Impulses over these fibers cause the contraction of skeletal muscles.
3. General visceral afferent fibers convey nerve impulses from the viscera and blood vessels to the central nervous system.
4. General visceral efferent fibers belong to the autonomic nervous system and are also called autonomic fibers. They convey nerve impulses from the central nervous system to cause contractions of smooth and cardiac muscle and secretion by glands.

In addition to being grouped as nerves, neural tissue is also organized into other structures such as ganglia, tracts, nuclei, and horns.

Two striking features of nervous tissue are (1) its highly developed ability to generate and conduct electrical messages called nerve impulses and (2) its limited ability to regenerate.

**NERVE IMPULSE**

Very simply, a ***nerve impulse (nerve action potential)*** is a wave of negativity that self-propagates along the surface of the membrane of a neuron. Among other things, a nerve impulse depends on the movement of sodium, potassium, and other ions between interstitial fluid and the inside of a neuron. For a nerve impulse to begin, a stimulus of adequate strength must be applied to the neuron. A stimulus is a change in the environment of the cell of sufficient strength to initiate a nerve impulse. The ability of a neuron to respond to a stimulus and convert it into a nerve impulse is known as excitability.

The nerve impulse is the most rapid way that the body can respond to environmental changes. It provides the quickest means for achieving homeostasis. The speed of a nerve impulse is determined by the size, type, and physiological condition of the nerve fiber. For example, myelinated fibers with the largest diameters can transmit impulses at speeds up to about 100 m (328 ft)/sec. Unmyelinated fibers with the smallest diameters can transmit impulses at the rate of about 0.5 m (1.5 ft)/sec.

In addition to excitability, neurons are also characterized by ***conductivity***, the ability to transmit a nerve impulse to another neuron or another tissue, such as a muscle or a gland. The junction between two neurons is called a synapse (synapse = to join). The synapse is essential for homeostasis because of its ability to transmit certain nerve impulses and inhibit others. Much of an organism’s ability to learn will probably be explained in terms of synapses. Moreover, most diseases of the brain and many psychiatric disorders result, from a disruption of synaptic communication.’ And synapses are the sites of action for most drugs that affect the brain, including therapeutic and addictive substances. Within a synapse is a minute gap, about 20 nm across, called the synaptic cleft. A ***presynaptic neuron*** is a neuron located before a synapse. A ***postsynaptic neuron*** is located after a synapse

Impulses are conducted from neuron to a muscle fiber (cell) across an area of contact; called a ***neuromuscular junction (NM. myoneural junction,*** or ***motor end-plate.*** The area of contact between a neuron and glandular cells is known as a ***neuroglandular junction***. Together, neuromuscular and neuroglandular junctions are known as ***neuroeffector junctions.***

Axon terminals of neurons end in expanded bulb structures referred to as synaptic end bulbs. The synaptic end-bulbs of a presynaptic neuron commonly synapse with the dendrites, cell body, or axon hillock of a postsynaptic neuron. Accordingly, synapses may be classified as ***axodendritic***, ***axosomatic***, and ***axoaxonic***. The synaptic end-bulbs from a single presynaptic neuron may synapse with several postsynaptic neurons. Such an arrangement, called ***divergence***, permits a single presynaptic neuron to influence several postsynaptic neurons or several muscle fibers or gland cells at the same time. In another arrangement, called ***convergence***, the synaptic end-bulbs of several presynaptic neurons synapse with a single post- synaptic neuron. This arrangement permits stimulation or inhibition of the postsynaptic neuron.

At a synapse there is only ***one-way impulse conduction***-from a pre synaptic axon to a postsynaptic dendrite, cell body, or axon hillock. Nerve impulses must move forward over their pathways. They cannot back up into another pre synaptic neuron. Such d mechanism is crucial in preventing impulse conduction along improper pathways, a situation that would severely disrupt homeostasis.

Whether a nerve impulse is conducted across a synapse, neuromuscular junction, or neuroglandular junction depends on the presence of chemicals called ***neurotransmitters*** (***transmitter*** ***substances***). These chemicals are made by the neuron, usually from amino acids. Following its production and transportation to the, synaptic end-bulbs, the neurotransmitter is stored in the bulbs in small membrane- enclosed sacs called synaptic vesicles. Each of the thousands of synaptic vesicles present may contain between 10,000 and 100,000 neurotransmitter molecules.

When a nerve impulse arrives at a synaptic end-bulb of a presynaptic neuron, it is believed that a small amount of calcium ions leaks into the bulb, attracts synaptic vesicles to the plasma membrane and helps liberate the neurotransmitter molecules from the vesicles. Some scientists believe that the synaptic vesicles fuse with the plasma membrane of the presynaptic neuron, form openings, and release the neurotransmitter through the openings into the synaptic cleft. Other scientists think that the neurotransmitter leaves through small channels to enter the synaptic cleft. In either case, the neurotransmitter enters the synaptic cleft and, depending on the chemical nature of the neurotransmitter and the interaction of the neurotransrnitter with receptors of the postsynaptic plasma membrane, several things can happen.

An ***excitatory transmitter—receptor interaction*** is one that generates a nerve impulse across a synapse, while an ***inhibitory transmitter—receptor interaction*** is one that inhibits a nerve impulse across a synapse. Many presynaptic neurons synapse with a single postsynaptic neuron. Some presynaptic end-bulbs produce excitation and some produce inhibition. The sum of all the effects, excitatory and inhibitory, determines the effect on the postsynaptic neuron. Thus, the postsynaptic neuron is an integrator. It receives signals, integrates them, and then responds accordingly. The post- synaptic neuron may respond in the following ways:

1. If the excitatory effect is greater than the inhibitory effect but less than the threshold (minimal) level of stimulation, the result is facilitation, that is, near excitation so that subsequent stimuli can generate a nerve impulse.
2. If the excitatory effect is greater than the inhibitory effect but equal to or higher than the threshold level of stimulation, the result is generation of a nerve impulse
3. If the inhibitory effect is greater than the excitatory effect, the result is inhibition of a nerve impulse.

Perhaps the best-studied neurotransmitter substance is ***acetylcholine*** or ***Ach.*** It is a neurotransmitter released by many neurons outside the brain and spinal cord and by some neurons inside the brain and cord. Following the arrival of a nerve impulse at an axon terminal, calcium (Ca2+) ions enter an axon terminal and cause the release of ACh from synaptic vesicles or the cytoplasm of the terminal. At neuromuscular junctions, ACh binds to receptor sites on the muscle fiber membrane: and increases the membrane’s permeability to Na+ ions. The acetylcholine receptor is an integral protein in the plasma membrane of the muscle fiber. When Ach molecules bind to the ACh receptor, a change occurs in the receptor, causing its channel to open. As a result, there is an inward movement of Na+ ions. In the absence of ACh, the receptor channel remains closed. The inward movement of Na+ ions leads to a sequence of events that generates a muscle action potential, causing the muscle fiber to contract. As long as ACh is present in the synaptic cleft, it can stimulate a muscle fiber almost indefinitely. The transmission of a continuous succession of impulses by ACh is normally prevented by an enzyme called ***acetyl cholinesterase(AChE)*** or simply ***cholinesterase.*** AChE is found on the surfaces of the subneural clefts of the membrane of muscle fibers. Within ¼oo sec AChE inactivates ACh. This action permits the membrane of the muscle fiber to discontinue action potential transmission immediately so that another action potential may be generated. When the next nerve impulse comes through, the synaptic vesicles release more ACh, a muscle action potential is generated, and AChE again inactivates ACh. This cycle is repeated over and over again.

ACh is released at some neuromuscular junctions that have cardiac and smooth muscle, as well as those that have skeletal muscle. It is also released at some neuroglandular junctions. Although ACh leads to excitation in many parts of the body, it is inhibitory with respect to the heart (vagus (X) nerve).

**Regeneration**

Unlike the cells of epithelial tissue, neurons have only limited powers for ***regeneration***, that is, a natural ability to renew themselves. Around 6 months of age, the cell bodies of most developing nerve cells lose their mitotic apparatus (centrioles and mitotic spindles) and their ability to reproduce. Thus when a neuron is damaged or destroyed, it cannot be replaced by the daughter cells of other neurons. A neuron destroyed is permanently lost, and only some types of damage may be repaired.

Damage to some types of myelinated axons or other processes often can be repaired if the cell body remains intact, if the cell that performs the myelination remains active, and if a completely severed nerve is surgically apposed. Axons in the peripheral nervous system are myelinated by neurolemmocytès (Schwann cells). They proliferate following axonal damage and their neurolemmas form a tube that assist in regeneration. Axons in the brain and spinal cord (central nervous system) are myelinated by oligodendroglial cells. These cells do not form neurolemmas to assist in regeneration and do not survive following axonal damage. An added complication in the central nervous system is that following axonal damage, astrocytes appear to stop axons from regenerating by activating a physiological pathway that inhibits axonal regeneration. This is the same pathway that stops axonal growth during development once a target cell has been reached. In addition, following axonal damage, the affected region is rapidly converted into a special form of scar tissue by astroglial proliferation. The scar tissue forms a physical barrier to regeneration. Thus, an injury to the brain or spinal cord is also permanent because axonal regeneration is blocked by a physiological stop pathway and rapid scar tissue formation. An injury to a nerve in the arm (peripheral nervous system) may repair itself before scar tissue forms, and so some nerve function may be restored.

**THE NEURON CHAIN**

A neuron chain is defined as a number of neurons associated with one another in series to form a functionally complete pathway. The numerous neurons comprising the nervous system are functionally and anatomically related to all the other tissues of the body and to one another.

A formally complete nerve pathway extends from the tissue in which the nerve impulse is aroused to the tissue in which a resultant reaction occurs. The simplest possible path involves a great number of neurons. The axon of one neuron bringing impulse from a peripheral tissue transfer the impulse to the dendrite or cell body of another by synapses and the axon of this in the same way transfer them to another and so on till the final or efferent neuron receives the impulse and the telodendria of it’s axon transfer them finally to the tissue elements that reacts in response to the stimulus brought.

Neurons are thus linked together in chains. The places where two neurons come into contact is known as a ***synapse***; the axon of one neuron terminate on the cell body or dendrite of another.

**RESTING STATE OF THE NEURON**

**Electrical properties of the cell membrane**

The nerve cell and its processes are bounded by a physiological membrane which regulates the interchange of materials between the inside of a cell and the outside. Such materials can pass through the membrane in either direction but the rate at which the particles move and their ability to penetrate the membrane vary considerably. As a consequence, the intracellular and extracellular fluid have quite different compositions.

The intracellular has a high concentration of K+ salt and the extracellular is largely a solution of NaCl. The respective solution are termed electrolyte because the particles they contain are electrically charged with positive or negative ions. Since particles of opposite charge are attracted to each order, there is always a tendency for positively charged ions (cations) to travel towards any point where there is a concentration of negatively charged ions (anions). Conversely, anions move in the opposite direction towards a positively pole. The movement of ions through the electrolytes set up a flow of current in both directions. If the current generated are equal and opposite, the net current flow will be zero. These simple facts endow the cell membrane with important electrical properties:

The electrical properties of the cell membrane are :

1. **Permeability**: the membrane is selectively permeable to different ions, usually less permeable to large molecules and more permeable to small molecules.
2. **Resistance:** The membrane does not permit the free movement of ions across it. The barrier to free movement is regarded electrically as a resistance.
3. **Conductance:** this is the inverse of resistance, it means that the membrane is a medium for current flow when charged particles are carried through it. The membrane can be visualized as a sieve with pores of varying sizes regulating the number and velocity of the particles moving into and out of the cell.
4. **capacitance:** the lipid component of the membrane structure has insulating properties. Without the existence of pores or protein channels for diffusion, a membrane will behave as a perfect insulator separating the two conducting solutions and for all practical purposes preventing penetration of ions. The semi-permeable nature of the resting nerve membrane means that certain ions are able to diffuse through it, while others are held back. The membrane does exhibit the features of a capacitor in which positively charged ions are held on one side and negatively charged ions on the other side.

**5. potential difference:** Any two points at the surface of a resting cell   
 are the same potential or electrically neutral. It follows that no current flows between

the two points. If one of the points is in contact with the interior of the cell, a Potential difference (PD) associated with a flow of current is obtained. The P.D is caused by unequal concentration of ions between the two points which had previously been kept by the insulating power of the membrane.In the resting state, the membrane is therefore said to be polarized.

**MOVEMENT OF IONS**

The transport of ions across surface membrane may occur passively by diffusion or actively by an electrochemical force. Ions diffuse from a region of high concentration to a region of low concentration i.e in a ‘downhill’ direction. When the concentrations are equal on the two sides of the membrane, the dissolved substance is in equilibrium and uniformly distributed. When the concentration are unequal, a gradient exists across the membrane. An electrochemical force derived from the metabolism of the cell actively transports ions from a region of low concentration to a region of high concentration i.e the ‘uphill direction’.Active transport is made possible when ions are coupled

with other molecules and carried across the membrane by means of a pumping process. The energy required for operating the pump may be provided by the conversion of glucose into glycogen or from the breakdown of adenosine triphosphate (ATP).

**RESTING MEMBRANE POTENTIAL (RMP)**

There is potential difference across the membrane of most cells with the inside of the cell negative to the outside. This resting membrane potential or steady potential is written with a minus (-) sign signifying that the inside is negative relative to the exterior. Its magnitude varies considerably from tissue to tissue ranging from – 9 to – 100mV. In neurons, it is usually -70mV.

The basic concept of how the membrane potential is generated depends on a number of factors including;

1. The distribution of Na+, K+ and Cl- ions
2. The activity of the Na+, K+ exchange pump.
3. The internal concentration of fixed protein anions

Each of these factors contributes to maintain a steady polarized state and to restore the membrane potential when it is displaced by processes that elicit the action potential. The steady state condition occurs when outward and inward ionic fluxes are of equal magnitude.

**Ionic basis of resting membrane potential**

The principal ions of the Extracellular fluid (ECF) are Na+ and Cl- ion which are derived from the plasma and exist is high concentration. The principal ions of the Intracellular fluid (ICF) K+. There is a different in concentration of Na+, K+ and Cl- at the resting state of the nerve membrane. In nerves as in other tissue, Na+ is actively transported out; K+ diffuses back out of the cell down its concentration gradient and Na+ diffuses back in, but since the permeability of the membrane to potassium is much greater than it is to Na+ at rest, the passive K+ efflux is much greater than the passive Na+ influx. Since the membrane is impermeable to most of the anions in the cells, the K+ efflux is not accompanied by an equal flux of anions and the membrane is maintained in a polarized state with the outside positive relative to the inside.

**Active transport of Na+ and K+ through the membrane**

The cell membrane of the body has a powerful Na+- K+ pump that continually pumps Na+ to the outside of the cell and K+ to the inside. This is an electrogenic pump because more positive charges are pumped to the outside than to the inside (3 Na+ to the outside for 2 K+ to the inside) leaving a net deficit of positive ions on the inside this is the same as causing a negative charge inside the cell membrane. The Na+- K+ pump also cause the tremendous concentration gradient for Na+ and K+ across the resting nerve membrane, these gradient are as follows:

1. Na+ outside = 142 mEq/L
2. Na+ inside = 14mEq/L
3. K+ outside = 4mEq/L
4. K+ inside = 140mEq/L

**ACTIVE STATE OF THE NEURON**

When the membrane potential is displaced from the resting to the active state, the sequence of electrical changes that occurs is known as the **ACTION POTENTIAL (AP).**

The AP is a reversal of RMP, it occurs when there is an increased permeability to Na+ ion which carry their positive charge across the membrane to the interior. A slight increase in permeability will merely displace the membrane potential without initiating an impulse. If however, the resting potential is suddenly lowered about 15mV (that is from its normal value of about -70mV to -55mV) the changes observed are out of proportion of the applied stimulus.

Depolarization of the membrane below a critical level causes a high rate of sodium entry with the result that the membrane potential changes from the inside negative to inside positive. The increase of sodium permeability lasts for about 0.5msecs when the inside may become up to 60 millivolts positive relative to the outside that is approaching the equillibrum potential for sodium. The reason for the short duration of the Na flux is that an increase of K potassium permeability occurs almost simultaneously and the outward movement of K+ ions tends to return the membrane potential towards its resting level.

When the AP has reached its peak, Na permeability falls, K permeability rises and the potential different across the membrane approaches the equilibrium potential for potassium.

**REPOLARIZATION**

Under normal conditions, restoration of the membrane potential begins almost as soon as the membrane is depolarized. First the flow of current associated with the inward movement of Na+ ions is reduced by inactivation of Na+ conductance. Second, the outward current due to efflux of potassium ions greatly exceeds the inward current flow which raises the membrane potential to a level near that of the resting potential. Third, restoration of the original ionic concentrations and regain of K by the axon are brought about by the activity of metabolic pump or Na+ -K+ pump.

**INITIATION OF THE NERVE IMPULSE**

Impulse may be initiated by electrical stimulation of the nerve. The stimulating current tends to reduce or abolish the PD across the membrane. The impulse starts off from the stimulating region but is thereafter self-propagating and independent of the applied current. Once this has been accomplished, the membrane rapidly reverts to its original polarized state. Current flow through the membrane must be sufficient to lower the resting potential to a critical level. If the stimulating current is below threshold, excitability of the nerve fibre is raised, then rapidly declines without initiating an impulse. The decline of excitability following sub threshold stimulus is known as accommodation and is due partly to inactivation of Na conductance and partly by outward movement of K which tends to raise the threshold.

The intensity of the second stimulus required to initiate an impulse is a measure of the original excitability change in the nerve. Once the critical level of depolarization is reached the ionic changes evoked give rise to the action potential. If the level is below threshold, there can be no action potential. For this reason the action potential is considered to be an “ALL OR NONE RESPONSE”.

**THRESHOLD FOR INITIATION OF ACTION POTENTIAL**

An action potential will not occur until the initial rise in membrane potential is great enough to cause all the voltage gated Na channels to become totally activated and usually, a sudden rise in membrane potential of 15-30 millivolts is required. Therefore, a sudden increase in the membrane potential in a large nerve fibre of -90mV up to -65mV will usually cause the explosive development of the action potential. This level of -65mv therefore is said to be the threshold for stimulation.

Threshold for stimulation is therefore a critical level of depolarization that is a voltage required to convert a membrane potential into action potential.

Threshold is influenced by the following factors.

1. Type of current: a slowly rising constant current or an alternating current of very low or very high frequency may not reach the required intensity to be effective.
2. strength of current: a minimum strength of current is needed to excite a single nerve axon. A larger amount of current is needed during the relative refractory period or when the whole nerve is excited.
3. size of the nerve fibre: as the diameter of a nerve fibre increases, the resistance to current flow diminishes. Therefore, the threshold level of depolarization and excitation time are reduced in large fibres and increased in small fibres. Myelinated fibres have relatively low thresholds, unmyelinated fibres have high threshold.

**PROPAGATION OF THE IMPULSE**

When a current of threshold strength is applied to a nerve fibre, an action potential is initiated in the vicinity of the stimulating electrode. This is the response of the fibre to lowering of the membrane potential and sudden influx of Na ions, the sequence of changes that now give rise to the action potential results in a spread of current along the axon to adjacent parts of the membrane while the part stimulated is rapidly restored to its resting level. Current can spread along the axon in either direction from the stimulated region. Once an action potential has been initiated, the inside of the membrane becomes positive as the membrane approaches the equilibrium potential for Na ions. This means that a potential difference is produced between the active region and the adjacent inactive membrane. Consequently current flows along the inside of the axon and out again through the adjacent resting parts of the membrane and extacellular fluid to complete a circuit. As the current flows out, it discharges the membrane in the inactive region with the result that this region becomes active and as soon as threshold is reached another action potential is generated. A local circuit is once again produced and the sequence is continued as a wave of depolarization.

During the passage of an impulse, the nerve fibre is refractory and therefore the action potential cannot travel backward to the original point of stimulation. Under experimental conditions, propagation occurs in both direction away from a central refractory region, but under natural conditions in which the action potential is generated at one end of the axon, propagation must be unidirectional.

**CONDUCTION OF THE IMPULSE**

When a peripheral nerve is dissected away from the body, it can be easily demonstrated that impulses are conducted equally well in either directions.

In the intact body, conduction is in only one direction depending upon the origin of the impulse. Thus afferent fibres arising from receptors normally conduct impulses towards the CNS and motor fibres supplying the muscles and gland conducts impulses away from the CNS. This functional direction is called **ORTHODROMIC** conduction under experimental conditions in the intact body, it is possible to drive the impulse in the wrong direction and this is called **ANTIDROMIC CONDUCTION .**

**CONDUCTION VELOCITY**

This is the speed at which the wave of depolarization spreads along the axon or the time taken for an active region to depolarize an inactive region. The rate of current flow in a local circuit is determined by the passive electrical properties of the axon including its resistance and diameter. Larger fibres have a lower internal resistance than small fibres, hence they tend to conduct impulses at a faster speed. In unmyelinated fibres, conduction is impeded by a high resistance of the axoplasm and the large capacity of the membrane. As a result, conduction velocity in the smallest axons may be as low as 0.3secs-1. The myelinated fibre has a relatively larger diameter, lower resistance and smaller membrane capacity.

High conduction speed (up to 120msecs) are therefore possible. Myelin is an insulating material formed by schwann cells situated along the length of the axon. Since myelin is a good insulator and prevents the spread of current, action potential in myelinated nerves can be generated only at the nodes. When a fibre is depoarised, the local circuit flow is from one node through the axon to the next node and the action potential is said to jump from node to node, this is called sultatory conduction. Myelination makes possible the fast conduction of nerve impulses. The rate of conduction depends on the thickness of the sheath relative to the diameter of the axon and to some extent on the internodal distance.

**TRANSMISSION**

Nerve impulses do not pass directly from one neuron to another or from nerve endings to effectors organ. The information carried by nerve impulses is transmitted by the release from the axon terminal of chemical substances that may be either excitatory or inhibitory in nature. Since the process of transmission occurs at synaptic junction, the whole pattern of nervous activity is really determined by prevailing conditions at different synapses.

Excitatory action is evident when a neuron which was previously silent discharges at least one nerve impulse. Inhibitory actions may be regarded as a reduction in firing frequency up to the part of complete silence.

Transmitter substance are released from vesicle in the presynaptic fibre or axon terminal soon after the arrival of the nerve impulse. A potential change is then generated at the synaptic junction in the region of the closest contact between the terminal and sub-synaptic element, thus transmission is achieved by both chemical and electrical means in most vertebrates.

**Excitatory actions**

The electrical activity of a neuron depends upon the physicochemical properties of the surface membrane. This is an extremely important structure investing the entire neuron that is cell body, dendrites and axons.

All neuronal membranes have certain properties in common the most important being the membrane capacity to alter its permeability to the movement of ions and therefore to permit the flow of electrical current across it. Excitatory actions evoke a discharge or depolarization of the surface membrane. When this occurs at the receptor within the axon, a nerve impulse is generated. At synaptic junctions excitatory action is mediated by a chemical transmitter which acts on the sub-synaptic element causing increased permeability of the post synaptic membrane for certain ions. The resultant flow of ions causes an electric current to be generated between the synaptic knob and the cell producing an excitatory post synaptic potential (EPSP). The cell will discharge an impulse when depolarization of postsynaptic membrane reaches a critical level.

**Inhibitory actions**

These also depend upon a change in the permeability of the resting cell membrane with consequent movement of ions. At the synaptic junctions, inhibitory action is mediated by a specific transmitter substance which changes the ionic permeability of the sub synaptic membrane, as a result, the membrane becomes hyper-polarized and an inhibitory post synaptic potential (IPSP) is produced. The change in membrane potential depresses the excitability of the cell below the threshold level for impulse discharge.

**INFORMATION PROCESSING IN NEURONS**

The basic mode of processing information is similar for either the internal or external environment. Information is collected by a sensor (such as the eye) using sensory neurons, and then carried to the central nervous system (CNS), where it is processed. The response determined by the CNS is transmitted via motor neurons to the effector organ (a muscle or gland), which carries out the response. Internal information (such as the blood levels of gases or hormones) is processed by the autonomic nervous system, which reacts automatically. Information from the external environment is processed by the sensory-somatic nervous system, which requires voluntary responses.

**Components of information processing**

Information processing comprises three parts:

1. sensory input,
2. integration,
3. and motor output.

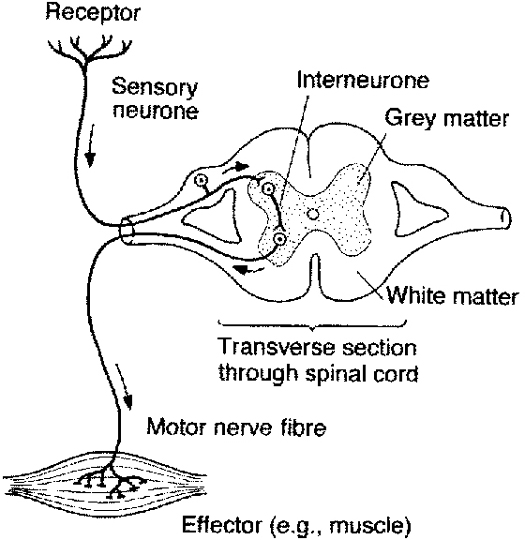
The Central nervous system (CNS) is involved in the integration process, while the peripheral nervous system (PNS) controls the neurons involved in sensory input and motor output.

Every piece of information is handled by a specific group of neurons.

* Information transmitted from the eye, nose and mouth (sensors responding to stimulus such as light, taste, smell etc.) is handled by sensory neurons, which also detect internal conditions such as blood  pressure, muscle tension, and blood carbon dioxide level.
* Sensory neurons carry information to the central processing unit, the  brain. Information in the brain is analyzed and interpreted. Neurons convey information from the brain to motor neurons, which in turn induce a response, such as muscle contraction.
* Inter neurons are found in great numbers within the  brain. They form local connections among neurons in the brain.

A **reflex** is a response to a perturbing stimulus that acts to return the body to homeostasis. This may be subconscious as in the regulation of blood sugar by the pancreatic hormones, may be somewhat noticeable as in shivering in response to a drop in body temperature; or may be quite obvious as in stepping on a nail and immediately withdrawing your foot.

**REFLEX ARC**

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A**reflex arc** refers to the neural pathway that a nerve impulse follows. The reflex arc typically consists of five components:

1. The **receptor** at the end of a sensory neuron reacts to a stimulus.

2. The **sensory (afferent) neuron** conducts nerve impulses along an afferent pathway towards the central nervous system (CNS).

3. The **integration center**consists of one or more synapses in the CNS.

4. A **motor (efferent) neuron** conducts a nerve impulse along an efferent pathway from the integration center to an effector.

5. An **effector** responds to the efferent impulses by contracting (if the effector is a muscle fiber) or secreting a product (if the effector is a gland).

Reflexes require a minimum of two neurons, a **sensory** neuron (input) and a **motor** neuron (output) (see Figure 1) The sensory neuron (such as a pain receptor in the skin) detects the stimuli and sends a signal towards the CNS. This sensory neuron synapses with a motor neuron which innervates the effector tissue (such as skeletal muscle to pull away from the painful stimuli). This type of reflex is the "withdrawal" reflex and is **monosynaptic**, meaning only one synapse has to be crossed between the sensory neuron and the motor neuron. It is the simplest reflex arc and the integration center is the synapse itself.

Polysynaptic reflexes are more complex and more common. They involve interneurons which are found in the CNS. In **polysynaptic** reflex pathways, one or more interneurons connect [afferent](http://en.wikipedia.org/wiki/Afferent_nerve) ([sensory](http://en.wikipedia.org/wiki/Sensory_system)) and [efferent](http://en.wikipedia.org/wiki/Efferent_nerve) ([motor](http://en.wikipedia.org/wiki/Motor_system)) signals. All but the most simple reflexes are polysynaptic, allowing processing or inhibition of polysynaptic reflexes within the brain.

More complex reflexes may have their integration center in the spinal cord, in the brainstem, or in the cerebrum where conscious thoughts are initiated.

A reflex arc represents a mechanism by which a physiological function is automatically managed or regulated. Reflex arcs can be found throughout the body, ranging from [skeletal muscles](http://en.wikivet.net/Muscles_-_Anatomy_%26_Physiology#Skeletal_Muscle) to [smooth muscle](http://en.wikivet.net/Muscles_-_Anatomy_%26_Physiology#Smooth_Muscle) in glands. Reflex arcs are initiated via the excitation or stimulation of specific sensory cells that are directly connected to motor neurons thus enabling [motor nerve](http://en.wikivet.net/Spinal_Cord_-_Anatomy_%26_Physiology#Upper_and_Lower_Motor_Neurons) impulses to be automatically passed on to that particular muscle or gland.

A number of different sensory inputs are utilised by reflex arcs, including; skin receptors, muscle spindles, the retina, the [organ of Corti](http://en.wikivet.net/Ear_-_Anatomy_%26_Physiology#Inner_Ear) and the olfactory mucosa. These sensory aspects of reflex arcs feed into two main types of reflex systems in the body; **autonomic** reflexes and **somatic** reflexes.

## Autonomic Reflexes

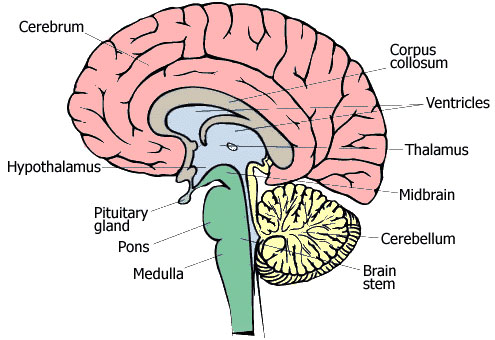
Autonomic reflexes control and regulate **smooth muscle cells, cardiac muscle cells** and **glands**. In general these reflexes contain the same basic components as somatic reflexes but a key difference is that autonomic reflexes have the ability to both stimulate or inhibit the smooth muscle/gland.   
**Somatic Reflexes**

Somatic reflexes are involved in the reflex control of **skeletal muscles** and as such there are many different types of somatic reflexes including **scratching reflexes**, **withdrawal reflexes** and **stretch reflexes** and **tendon reflexes**.

**THE BRAIN**

The brain is the enlarged anterior portion of the central nervous system (CNS). It is surrounded by three protective membranes or meninges and enclosed within the cranial cavity of the skull. It constitutes about 95% of the entire CNS. The brain is mushroom shaped and divided into four principal parts:

**Regions of the brain**



1. Cerebrum
2. Brain stem
3. Diencephalon
4. Cerebellum

**Cerebrum:** This spreads over the diencephalon and constitutes 7/8th total weight of the brain. It occupies most of the cranium.

**The brain stem:**

The brain stem is the stalk of the mushroom. It consists of the medulla oblongata, pons and midbrain (mesencephalon). The lower end of the brain stem is the continuation of the spinal cord.

**Diencephalon:**

This is above the brain stem and consists primarily of the thalamus and hypothalamus.

**Cerebellum:** This is inferior to the cerebrum and posterior to the brain stem.

**Development of the brain vesicles**

**10 Brain vesicle 20 brain vesicle Part of the brains**

**(1-4th wk) (5th wk) Formed**

1. Procencephalon Diencephalon Thalamus & Hypothalamus

(forebrain) Telencephalon Cerebrum

1. Mesencephalon Mesencephalon Midbrain

(midbrain)

1. Rhombencephalon Myelencephalon Medulla oblongata

(hindbrain) Metencephalon Pons and cerebellum

**BLOOD SUPPLY**

The brain is well supplied with oxygen and nutrients by blood vessels that form the cerebral arterial circle (circle of Willis).

Although the brain composes only about 2 percent of total body weight, it utilizes about 20% of the oxygen used by the entire body. The brain is one of the most metabolically active organs of the body, and the amount of oxygen it uses varies with the degree of mental activity. If the blood flow to the brain is interrupted even briefly, unconsciousness may result. One or two minutes interruption may weaken the brain cells by starving them of oxygen, and if cells are totally deprived of oxygen for 4 minutes, many are permanently injured. Blood supplying the brain also contains glucose, the principal source of energy for brain cells. Because carbohydrate storage in the brain is limited, the supply of glucose must be continuous . If blood entering the brain has a low glucose level, mental confusion, dizziness, convulsion, and loss of consciousness may occur. Glucose, oxygen and certain ions pass rapidly from the circulating blood into brain cells. Other substances, such as creatinine, urea, chloride, insulin and sucrose, enter quite slowly. Still other substances proteins and most antibiotics do not pass at all from the blood into brain cells. The different rate of passage of certain materials from the blood into most parts of the brain are based upon the concept called the BLOOD-BRAIN BARRIER (BBB).

The BBB functions as a selective barrier to protect the brain cells from harmful substances. An injury to the brain due to trauma, inflammation or toxins causes a breakdown of the BBB, permit the passage of normally restricted substances into brain tissue.

**Protection and covering of the brain**

The brain is protected by the cranial bones and the spinal cord. The brain is also protected by the cranial meninges namely: dura mater, arachnoid and pia mater (inner layer).

**Cerebrospinal fluid (CSF):** The brain as well as the rest of the CNS is further protected against injuries by CSF. This fluid circulates through the sub arachnoid space around the brain and spinal cord and the ventricles of the brain. The subarachnoid space is the space between the arachnoid and pia matters. The entire CNS contains between 80-150 ml of CSF. CSF is a clear colourless fluid of watery consistency. Chemically it contains proteins, glucose, urea and salts. It also contains some lymphocytes. It has two principal functions related to homeostasis: (1) Protection (2) circulation.

**Protection:**The fluid serves as a shock absorbing medium to protect the brain and spinal cord from jolts that would otherwise cause them to crash against the bony wall of the cranial and vertebral cavities. The fluid also allows the brain to float in the cranial cavity.

**Circulation:** It delivers nutritive substances filtered from the blood to the brain and the spinal cord and removes waste and toxic substances produced by the brain and spinal cord cells.

**Ventricles**

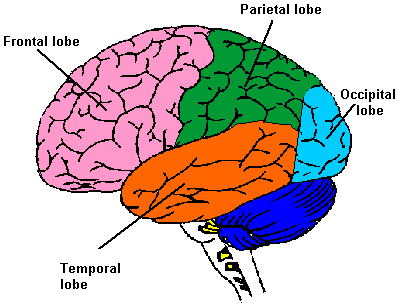
Ventricles are cavities in the brain that communicate with each other, with the central canal of the spinal cord, and with the sub arachnoid space.

1. **Two lateral ventricles:** Located in a hemisphere of the cerebrum under the corpus callosum.
2. **The third ventricle:** Vertical slit between the lateral ventricles
3. **The fourth ventricle:** Between inferior brain stem and cerebellum

**Cerebrum**

The cerebrum forms the bulk of the brain. The surface of the cerebrum is composed of grey matter 2-4mm thick and is referred to as cerebral cortex. The grey matter of the cortex containing billions of cells consists of six layers of nerve cell bodies. In most areas beneath the cortex lies the cerebral white matter. During embryonic development the grey matter of the cortex enlarges out of proportion to the underlying white matter, as a result, the cortical region rolls and folds upon itself. The folds are called gyri or convolutions. The deep grooves between folds are called fissures. The shallow grooves between folds are sulci. The most prominent fissure, the longitudinal fissure separates the cerebrum into right and left hemispheres. The hemispheres are connected histological by a large bundle of transverse fibres composed of white matter called the corpus callosum.

**Lobes of the cerebrum**

**Lobes of the cerebrum**

Each cerebral hemisphere is further subdivided into four (4) lobes by deep sulci or fissures:

1. Frontal lobe
2. Parietal lobe
3. Occipital lobe
4. Temporal lobe.
5. **Frontal lobe:** Extends from the frontal portion to the frontal sulcus. The frontal lobe contains pre-central sulcus, central sulcus, superior middle and inferior frontal gyri which also contains orbital sulci & gyri, olfactory sulcus, straight gyrus, the cingulate gyrus and para central lobule.
6. **Parietal lobe:** Parietal lobe extends from the central sulcus to the parieto-occipital fissure and laterally to the level of the lateral cerebral fissure.
7. **Occipital lobe:** It is the pyramid shaped posterior lobe situated behind the cerebral fissure. The calcarine fissure divides the medial surface of the occipital lobe into the cuneous and the lingual gyrus.
8. **Temporal lobe:** Lies inferior to the lateral cerebral fissure and extends back to the level of the parieto-occipital fissure.

**White substance**

Each cerebral hemisphere contains inner mass of white fibres. White matter forms the bulk of the deep parts of the brain and the superficial parts of the [spinal cord](https://en.wikipedia.org/wiki/Spinal_cord). The white substance of the cerebral hemisphere contains myelinated fibres of many sizes as well as neuroglia. White matter is the tissue through which messages pass between different areas of gray matter within the central nervous system. The white matter is white because of the fatty substance (myelin) that surrounds the nerve fibers (axons).

Three types of myelinated nerve fibres make up centre of the cerebral hemisphere.

1. Transverse fibres
2. Projection fibres
3. Association fibres
4. **Transverse fibres:** Also known as commissural fibres. These fibres interconnect the two cerebral hemisphere (laterally). Commissural tracts cross from one cerebral hemisphere to the other through bridges called commissures. The corpus callosum is the largest and most of its fibres arise from the various parts of the cerebral hemisphere and terminate in the symmetric area of the opposite cerebral hemisphere. Commissural tracts enable the left and right sides of the cerebrum to communicate with each other.
5. **Projection fibres:** Projection tracts extend vertically between higher and lower brain and spinal cord centers, and carry information between the cerebrum and the rest of the body.
6. **The afferent fibres:** This includes the geniculocalcarine tract from the lateral geniculate body (LGB) to the calcarine cortex. The auditory radiation from the medial geniculate body (MGB) to the auditory cortex, and thalamic radiation from the thalamic nuclei to specific cerebrocortical areas. Projection fibres form the ascending and descending tracts that transmit nerve impulses from the cerebrum to other parts of the brain & spinal cord
7. **The efferent fibres:** These proceed from the cerebral cortex to the thalamus, brain stem and spinal cord.
8. **Association fibres:** Association tracts connect different regions within the same hemisphere of the brain. Long association fibers connect different lobes of a hemisphere to each other whereas short association fibers connect different gyri within a single lobe.

Amongst short association fibres, those located in the deeper portions of the cortex are known as intra-cortical fibres where as those just beneath the cortex are called subcortical fibres.

**Basal ganglia (cerebral nuclei)**

These are paired masses of gray matter in each cerebral hemisphere. The largest of the basal ganglia in each hemisphere is the corpus striatum. It consists of the caudate nucleus and lentiform nucleus, the lentiform nucleus is subdivided into putamen and globus pallidus. Other structures frequently considered as part of the basal ganglia are substantia nigra, subthalamic nucleus and the red nucleus. The caudate nucleus and putamen control large sub-conscious movements of skeletal muscles such as swinging the arms while walking.

The globus pallidus controls the muscle tone required for specific movements. Damage to the basal ganglia results in abnormal body movement such as uncontrollable shaking called TREMOR and involuntary movements of skeletal muscles. The caudate nucleus is an area often affected by a stroke.

**LIMBIC SYSTEM**

The limbic system is a group of structures that encircles the brain stem and function in emotional aspect of behavior related to survival. It contains component of cerebral hemisphere and diencephalon. Among its components are the following regions of grey matter:

1. Limbic lobe
2. Hippocampus
3. Amygdaloid nucleus
4. Mamillary bodies of the hypothalamus
5. Anterior nucleus of the thalamus

The hippocampus, together with portions of cerebrum functions in memory. Memory impairment results from lesions in the limbic system. People with such damage forget recent events and cannot commit anything to memory.

**CEREBRAL CORTEX**

The cerebral hemisphere consists of an outer layer of grey matter termed the cerebral cortex.

The thickness of the cerebral cortex vary from 2-4mm and it is always greater on the exposed surfaces of the gyri than in the depth of the sulci. About 2/3rd of the cortex is buried in the sulci. Microscopically, like grey matter elsewhere the cortex consists of nerve cells intermingled with nerve fibres, neuroglia and blood vessels. The cells are everywhere arranged in strata parallel with the surface. The cells show wide variation in size, shape and arrangements of their processes. It can be classified into 3 groups.

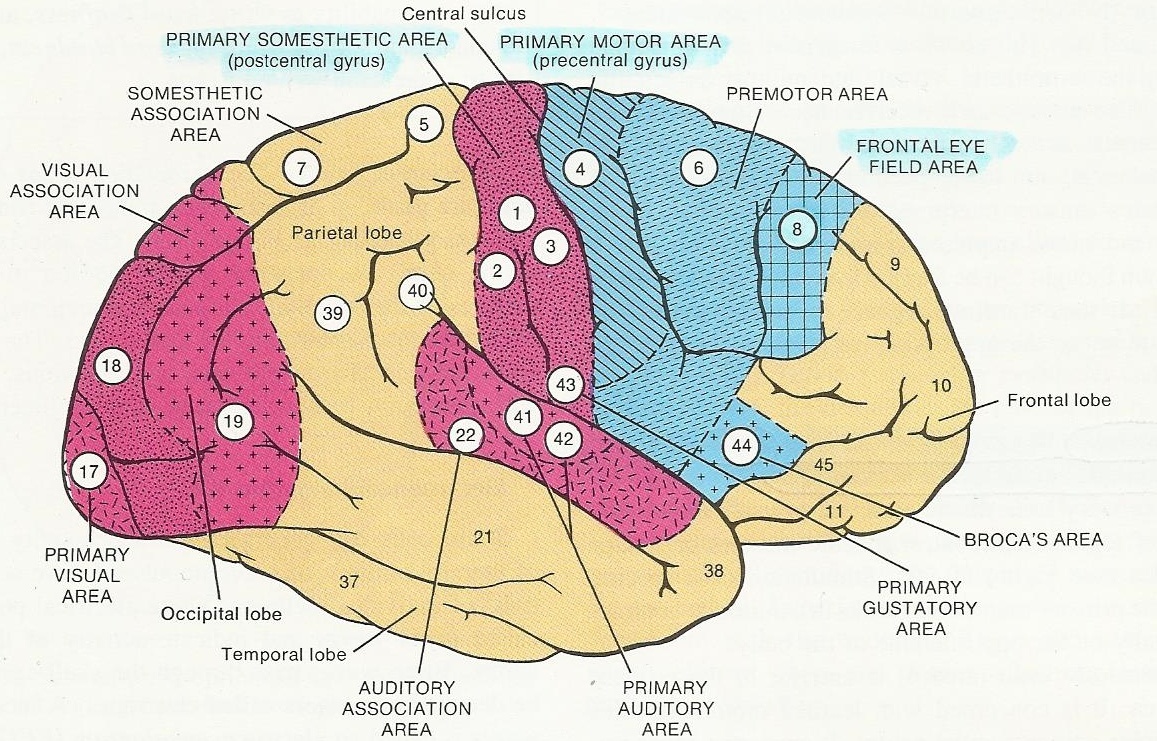
1. Pyramidal cells
2. Granular cells
3. Pleomorphic cells

* **Pyramidal cells:** They are present in all parts of the cortex and are pyramidal in shape with the apex directed towards the surface of the cortex.
* **Granular cells:** They are found in every stratum of the cortex, they are small cells averagely 8 -10mm diameter. They have short branching processes giving them their stellate appearance.
* **Pleomorphic cells:** They occur in all layers particularly the 1st layer. These cells may be pyramid or ovoid in shape.

The cortex has about six layers of cells, from the surface inwards, the layers consists of:

1. Molecular layer
2. External granular layer
3. Layer of pyramidal cells
4. Internal granular layer
5. Large pyramidal cell layer/ ganglionic layer
6. Layer of fusiform or polymorphic cells

**BRODMANNS CLASSIFICATION OF THE CEREBRAL CORTEX**

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**Functional areas of the cerebrum**

Division and classification of cortex have been attempted by various scientists on the basis of cyto-architecture and inferences concerning the structure and function are drawn largely from observations of animals. The most commonly employed system are from von Economos and Brodmann. Brodmann sub-divided the cortex into fifty areas of which is identified by a number. He labeled individual area which he believed were different from other layers. These areas have been used as reference stage for classification of physiological and pathological processes. Some of the principal areas are as follows:

**Frontal lobe:** It is sub-divided into areas 4,6,8,9,10,11 & 12. Area 4 is the principal motor area, Area 6 is a part of the extra pyramidal tract circuit. Area 8 is concerned with eye movements and pupillary changes. Areas 9, 10, 11 & 12 are frontal association areas.

**Parietal lobe:** Areas 1, 2, 3, 5, & 7. Area 1, 2, & 3 consists of the posterior central principal sensory area. Area 5&7 are sensory association areas.

**Temporal lobe:** Areas 20, 21, 22, 38, 40, 41 and 42

Area 41 is the primary auditory cortex. Area 42 is the associative auditory cortex area 38, 40, 20,21 & 22 are association area.

**Occipital lobe:** Area 17, 18 & 19. Area 17 is the striate cortex and is the principal visual cortex.

Area 18 & 19 are visual assocation areas.

**FUNCTIONAL AREAS IN CEREBRAL CORTEX**

The functions of the cerebrum are numerous and complex. In a general way the cerebral cortex is divided into sensory, motor and association areas.

**Sensory areas**

**Primary somesthetic area**

Aka: The general sensory area: This is located directly posterior to the central sulcus of the cerebrum. The general sensory area is designated areas 1,2,3. The primary somesthic area receives sensation from cutaneous, muscular and visceral receptors in various parts of the body.

The secondary somesthetic area is a small region in the posterior wall of the lateral sulcus. It is involves mainly in less discriminative aspect of sensation. Posterior to the primary somesthetic area is the association area. It corresponds to the areas 5& 7

**Primary visual areas:** This is area 17 that is located on the medial surface of the occipital lobe. it receives sensory impulses from the eyes and interprets shape, colour and movement.

**Vision association areas**: Areas 18 & 19 also located on the occipital lobe. They receive sensory impulses from the primary visual area and the thalamus. It relates present to past visual experiences with recognition and evaluation of what is seen.

**Primary auditory area:** Area 41 & 42 Located in the superior part of the temporal lobe near the lateral cerebral sulcus. It interprets the basic characteristics of sound such as pitch and rhythm. Whereas the anterior lateral portion of the auditory area responds to low pitches the posterior lateral responds to high pitches.

**Auditory association area “Wernicke’s area”**

Basically, this is area 22. This is inferior to the primary auditory area in the temporal cortex. It determines if a sound is speech, noise or music, it also interprets the meaning of speech by translating words into thoughts.

**Primary gustatory area, Area43:** It is located at the base of the posterior central gyrus in the parietal lobe. It interprets sensation related to taste.

**Primary olfactory area:** It is located in the temporal lobe of the medial cortex, it interprets sensation related to smell.

**Gnostic area (Knowledge) Area 5,7, 39 & 40**: This common integrative area is located among the somesthetic, olfactory, visual and auditory association areas. The Gnostic area receives nerve impulses from these areas as well as from taste and smell areas, the thalamus and lower portions of the brain stem. It integrate sensatory interpretation from the association areas and nerve impulses from other areas so that a common thought can be formed from the various sensory inputs. It then transmits signals to other parts of the brain to cause appropriate response to the sensory signal.

Note: The sensory area interpretes sensory impulses, the motor area control muscular movement and association areas are concerned with emotional and intellectual processes.

**Motor areas**

**Primary motor area: “Area 4”:** It is located in the precentral gyrus of the frontal lobe. Primary motor area consists of regions that consist of specific muscle or root of muscles, stimulation of the specific point of a primary motor area results in muscular contraction usually on the opposite side of the muscle.

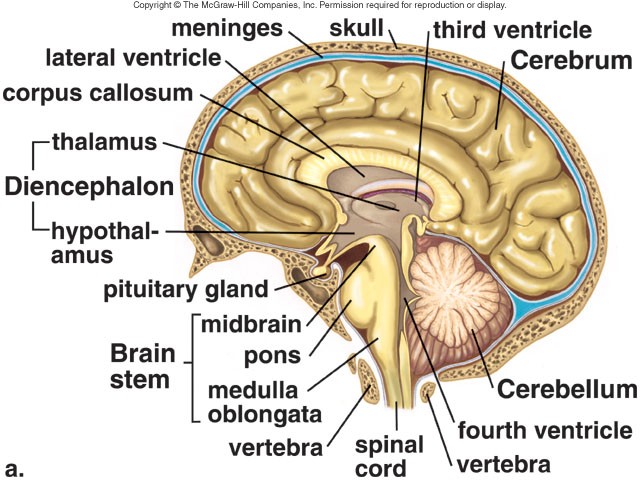
**Premotor Area:** “Area 6”. It is anterior to the primary motor area. It is concerned with learned motor activity that is complex and sequential in nature. It generates nerve impulses that cause a specific group of muscles to contract in a specific sequence e.g. writing. The premotor area controls skilled movement.

**Frontal eyefield area:** “Area 8”. This is the frontal cortex and sometimes included with premotor area. This area controls voluntary scanning movement of the eyes e.g. searching for a word in the dictionary.

**Language area:** These are significant portions of the motor cortex. The translation of speech or written words into thoughts involves primary auditory, auditory association, primary visual, visual association and gnostic areas. The translation of thoughts to speech involves the motor speech area of the language area “Area 44” known as BROCA’S area: It is located in the frontal lobe, from this area, there is a sequence of nerve impulses from the premotor region that control muscles of the pharynx, larynx, and mouth. The nerve impulses from the premotor area to the muscle result in specific co-ordinated contraction that helps one to speak simultaneously. Nerve impulses are sent from Broca’s area to the primary area.

**Association areas**

The association areas of the cerebrum are made of association tracts that connect motor and sensory areas. The association region of the cortex occupy a greater portion of the lateral surfaces of the occipital, parietal, temporal and frontal lobes anterior to the motor areas. Association areas are concerned with memory, emotions, reasoning, will, judgment, personality traits and intelligence.

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**Parts of the brain**

**BRAINSTEM**

The brainstem is a region of the brain that connects the cerebrum with the spinal cord. Located at the junction of the cerebrum and spinal cord, and lying anterior to the cerebellum. It consists of; Midbrain (mescencephalon), pons and medulla oblongata.

The brainstem generally has the following functions;

1. Conducts information from body to cerebrum and cerebellum.
2. Some cranial nerves like CNIII, XII, emerge from here
3. Integrative function – respiratory control, pain sensitivity control, alertness, awareness and consciousness, temperature regulation.

**MIDBRAIN**

This is the most superior part of the brain stem, which measures about 2.5cm in length. It is divided into an anterior and posterior section by the cerebral aqueduct or aqueduct of Sylvius which connects the 3rd and the 4th ventricle. The midbrain contains: cerebral peduncle, tectum, tegmentum, and some nuclei.

The cerebral peduncles are paired structures present on the ventral side of the cerebral aqueduct, they carry the tegmentum on the dorsal side. The cerebral peduncles constitute the main connection tract between upper part of the brain and the lower part and spinal cord. It contains motor fibers that carry nerve impulses from the cerebral cortex to the pons and spinal cord, while sensory fibers pass from the spinal cord to the thalamus.

The tegmentum forms the floor of the midbrain. It is involved in homeostasis.

The dorsal part of the midbrain called the tectum contains 4 rounded eminence called the **corpora quadrigemina,** it is composed of two superior colliculi and two inferior colliculi. The superior colliculus are part of the visual system relaying input from the optic tract to the lateral geniculate body of the thalamus. The inferior colliculi are part of the auditory pathway and sends information to the medial geniculate bodies of the thalamus.

The important nuclei located in the midbrain include the **red nuclei, substantia nigra and the nuclei of the III and IV CN**. The red nuclei is an ovoid large mass in the anterior part of the tegmentum at the level of the superior colliculi, it connects the midbrain to the cerebellum and inner ear. The cerebellum relays motor adjustment to the cortex through the red nucleus and thalamus. The substantia Nigra is a group of dark colored cells found in the middle part of the cerebral peduncle, it is the only part of the brain that has melanin. The nucleus of the IV CN is situated in the ventral part of the substantia nigra. Lesions here cause **Parkinsons disease.**

**PONS**

Pons means bridge. The pons transfers information to and between the cerebellar hemispheres. It lies directly above the medulla, anterior to the cerebellum. It measures about 2.5cm in length. Its posterior border is separated from cerebellum by the cerebral aqueduct and more inferiorly by the 4th ventricle. Motor and sensory tract traverse the anterior surface of the pons with sensory fibers located behind the motor fibers. The nuclei of certain CNs are located here they include; CN V, VI, VII and the vestibular branches of VIII.

The pons plays a key role in sleep and dreaming. REM (rapid eye movement) sleep, which is a sleeping state where dreaming most likely occurs, has been proven to originate here.

**MEDULLA OBLONGATA**

This part of the brain is a continuation of the upper portion of the spinal cord, it is the inferior part of the brain stem measuring 3cm. On the ventral side of the medulla are two roughly triangular structures called **pyramids.** They are made of large motor tracts that pass from outer region of cerebrum to the spinal cord. There is decussation of fibers of the pyramids just above junction of the medulla with the spinal cord, this explains why motor areas of one side of the cerebral cortex controls muscular movements on opposite side of the body. Two nuclei present: **Gracilic and Cuneatus nuclei** aid in conducting sensory fibers from ascending tract of spinal cord and relay sensory info to opposite side of the medulla.

The medulla also contains an area called the **recticular formation.** It is a set of interconnected nuclei located throughout the brain stem and diencephalon. Its central and inferior nuclei are found in the medulla. The ascending recticular formation is responsible for sleep-wake cycles thus mediating various levels of alertness while the descending recticular formation is involved in posture and equilibrium as well as ANS activity. Interneurons of the recticular formation receive some of the corticobulbar fibres from the motor cortex, it is those fibers that innervate the CNIII involved in eye movement.

The medulla also contains nuclei of origin for several CNs, CN VIII, IX, X, XI and XII. Also associated in the medulla is a greater part of the vestibular nuclei complex. This nuclei assumes an important role in helping the body maintain a sense of equilibrium.

**Functions of the medulla**

As part of the brain stem, the medulla helps transmit neural messages from higher levels of brain to spinal cord and other parts of the brain. The medulla controls involuntary and crucial tasks in the body as result of reflex centers present there (a reflex centre is a collection of neurons in the CNS connected with performance of a particular function).

The three vital reflex centers within the medulla are;

1. Cardiac centre: Regulates heart beat and force of contraction.
2. Medullary rhythmicity centre: Adjusts basic rhythms of breathing (use chemoreceptors)
3. Vasomotor centre or vasoconstrictor centre: regulates diameter of blood vessels (use baroreceptors).

The medulla also regulates and includes the sense of touch, pressure, temperature, taste, chewing, swallowing, salivation, vomiting, coughing, sneezing, sweating, speech and pain.

In view of the many vital activities of the medulla, it is not surprising how a blow at the base of the skull can be very fatal.

**DIENCEPHALON**

This is the region of the brain that sits above the brainstem. It is deeply embedded within the brain. The Diencephalon is broadly divided into the thalamus and the hypothalamus. However two glands namely the pineal gland and pituitary gland are also located in this part of the brain. The four regions of the diencephalon are therefore: thalamus, hypothalamus, pineal gland and pituitary gland.

**THALAMUS**

A large oval shaped pile of grey matter on each side of the brain. It measures 3cm in length, making up about 4/5th of the diencephalon. The main information relayed here is sensory information (excluding sensory olfactory info). All sensory information going to the brain makes a stop at the thalamus in order to be relayed appropriately. By having all sensory info pass through this region, unnecessary info can be filtered while the necessary ones are synchronized. In addition to being the principal relay station for sensory impulse it also functions as an interpretation centre for some sensory impulse such as pain, temperature, light touch and pressure.

All visual information enter the brain at this level of the diencephalon.

**HYPOTHALAMUS**

A small portion lying below the thalamus. It forms the floor and part of the lateral walls of the 3rd ventricle. Info from the external environment comes to the hypothalamus via afferent pathways originating in the peripheral sense organs. Afferent impulses monitoring the internal environment arise from the internal visceral organs and reach the hypothalamus. The hypothalamus is an extremely important brain region because it helps control all autonomic and endocrine functions.

**Functions of the hypothalamus include:**

1. Controls and integrate the autonomic nervous system.
2. Receives sensory impulse from visceral organs and integrate them.
3. Articulates with the pituitary gland.
4. Centre for mind over body phenomenon (body is neutral and malleable in itself and can change as instantly as the consciousness that inhabits the body. *Multiple personality disorder* and *placebo effect: placebo effect based not on drug effectiveness but solely on therapeutic intention and expectations.*
5. Functions in rage and aggression.
6. Control normal body temperature, food intake and thirst.
7. Controls hormonal output.
8. Regulates sleep wake circle (circadian rhythm) *the body conforms to a 24hour day and night cycle regulated by an internal clock that lies in the hypothalamus.*
9. Acts as a pacemaker to drive many biological functions.

**Pineal gland**

The pineal gland is a very tiny gland that seats just behind the eyes, also known as “third eye”. It is thought to reset (adjust) the circadian rhythm to the day/night cycle. (e.g when you travel to a different time zone). It produces melatonin which helps to control sleep and wake cycles.

**Pituitary gland**

One half of this gland is diencephalic and the other half is made from tissues that make up the roof of the mouth. It hangs down like a ball on a string. It is an important part of the endocrine (hormonal) system that produces hormones for major body functions.

**CEREBELLUM**

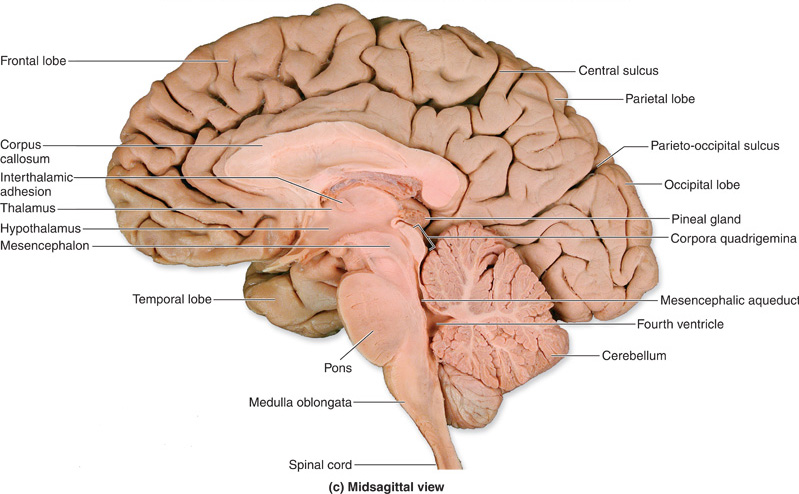
The cerebellum is known as “little brain”, it is shaped like a butterfly. It is the second largest portion of the brain. Located posterior to the medulla and pons, and below the occipital lobes of the cerebrum. Separated by the aqueduct of sylvius and the 4th ventricle. Like the cerebrum, it is covered by cortex and consists of two hemispheres each of which is divided into lobes. The hemispheres are separated from one another by a thin structure called the **vermis.** The flocculonodular node, the narrowest and most inferior part of the vermis is involved with maintenance of equilibrium.

The anterior lobe or paleocerebellum receives proprioceptive input from spinal cord and controls anti-gravity muscles of the body thus regulating posture.

The posterior lobe or neocerebellum is involved in co-ordination of muscles movement via inhibition of involuntary movement. It plays an important role in fine motor co-ordination.

In addition to the previous knowledge of cerebellum controlling motor function in the body, recent research has found a connection with autism.

The cerebellum contains 3 pairs of major projections called cerebellar peduncle (superior, middle and inferior cerebellar peduncle). A cerebellar peduncle is a nerve tract that permits communication between the cerebellum and the other parts of the central nervous system. The inferior peduncles bring sensory information about the actual position of body parts such as limbs and joints. The middle peduncles transmit information about the desired position of these parts. After integrating and analyzing the information from these two sources, the cerebellum sends impulses through the superior peduncles to the midbrain. In response, motor impulses are transmitted down through the pons, medulla oblongata, and spinal cord to stimulate or inhibit skeletal muscles at appropriate times and cause movements of body parts into the desired positions. This activity makes rapid and complex muscular movements possible.



**Functions of the Cerebellum**

* The cerebellum receives information from the **sensory systems**, the **spinal cord**, and other parts of **the brain** and then regulates motor movements.
* The cerebellum coordinates voluntary movements such as posture, balance, coordination, and speech, resulting in smooth and balanced muscular activity.