How reflexes work

Bodily actions that can occur independently of conscious control are called reflexes. They are especially important when a rapid involuntary response is required.

The central nervous system is able to perform highly complex tasks, and not all of these require conscious thought. Those actions that are involuntary in nature are called reflexes, pre-programmed and predictable responses to a specific sensory stimulus.

SOMATIC REFLEXES

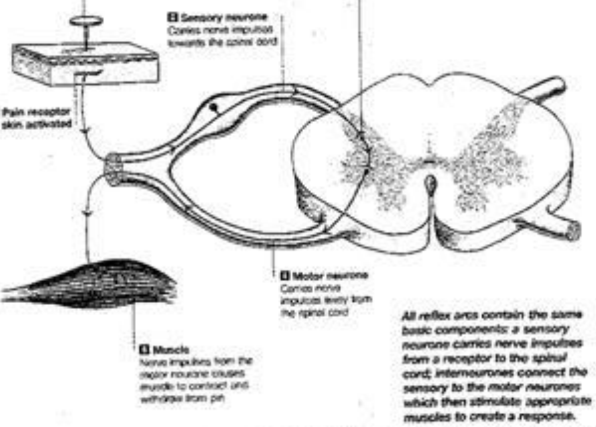
Somatic reflexes result in the movement of a muscle, or the secretion of a chemical from a gland.

For example, if you were to touch a hot oven, pain receptors in your hand would send nerve impulses to neurones in the spinal cord. These in turn would communicate with the appropriate muscles in your arm telling them to withdraw the hand instantly. Only after the hand was withdrawn, however, would your brain become aware of what had happened.

AUTONOMIC REFLEXES

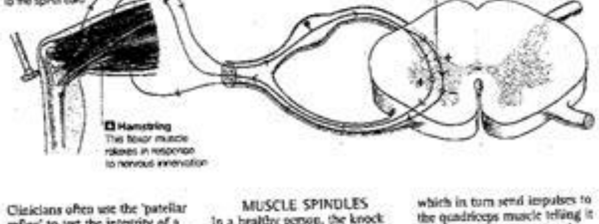
We are not conscious of the outcome of all the reflexes that occur in our bodies. For example, the baroreceptor reflex corrects a rise in arterial blood pressure without us being aware that it is doing so.

A simple reflex arc



All reflex arcs contain the same basic components: a sensory neurone carries nerve impulses from a receptor to the spinal cord; interneurones connect the sensory to the motor neurones which then stimulate appropriate muscles to create a response.

The patellar reflex



The patellar reflex is tested by doctors after a patient has suffered a traumatic injury to determine whether their lower spine has been damaged.

Babies up to about one year old exhibit the Babinski reflex when the sole of the foot is rubbed. This disappears as their nervous system develops.

Clinicians often use the 'patellar reflex' to test the integrity of a patient's lower spine. The patient sits high up so that the legs hang freely. The doctor then lightly taps the patellar tendon (situated just below the knee-cap) and looks for a response.

MUSCLE SPINDLES

In a healthy person, the knock to the tendon stretches the quadriceps muscle. This stretch is detected by structures in the muscle called muscle spindles. These send nervous signals to neurones in the spinal cord, which in turn send impulses to the quadriceps muscle telling it to contract (to counteract the initial stretch). This causes the foot to spring forward. At the same time the antagonistic muscle, the hamstrings, are inhibited.

Complex reflexes

Although some spinal reflexes, such as the patellar reflex, are relatively simple and involve only a few nerve cells, the spinal cord is capable of carrying out more complicated functions without needing to involve the brain.

If you were to step on a sharp object, such as a drawing pin, with your right foot, a complex reflex (the crossed extensor reflex) would be initiated in order to withdraw the foot and to shift the body's weight onto the left leg.

Initially, the drawing pin stimulates pain receptors in the skin of the right foot, causing them to send nerve impulses, via afferent nerve fibres (from the Latin 'afferre' – to carry towards), to the right hand side of the spinal cord. Neurones in this half of the spinal cord send nerve signals away from the cord via efferent nerve fibres to tell the extensor muscles to relax and the flexors to contract.

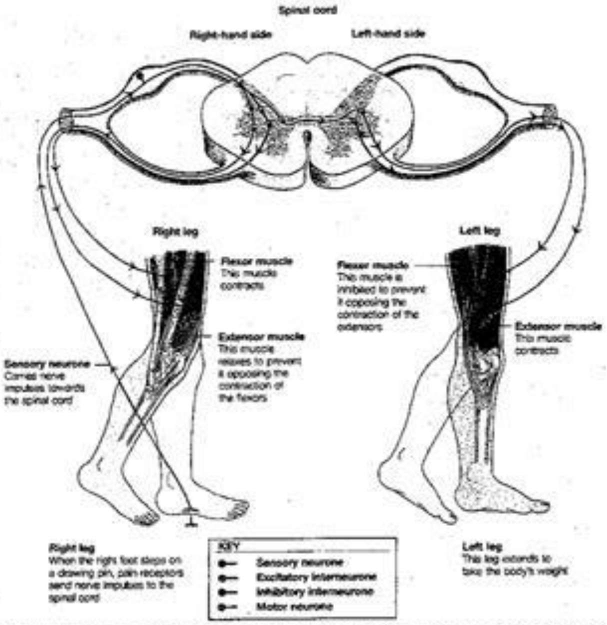
TRANSFER OF WEIGHT

These events result in the injured leg being moved away from the drawing pin. However, unless the body's weight is transferred to the other leg, you will fall over.

Thus neurones from the right-hand side of the spinal cord cross over to the left-hand side and synapse with motor neurones which innervate muscles in the left leg. These motor neurones inform the extensor muscles in the left leg to contract and the flexors to relax, causing the leg to be extended so that it can carry the body's weight.

When a bare foot treads on a sharp object, it is rapidly withdrawn and the body's weight is transferred to the other leg.

The crossed extensor reflex



Learned reflexes

The reflexes that have been discussed so far are 'hard-wired' into the nervous system.

However, while babies are born with the innate ability to learn how to walk, we have to make a conscious effort to learn to drive a car, ride a bicycle or play the piano.

With time, new movements can become as automatic as walking. For example, although learning to drive is a relatively difficult experience for most people, after a while the movements become automatic and the driver no longer has to consciously think what he or she is doing.

Similarly, touch-typists do not need to think where their fingers are on a keyboard, and as a result many can type at up to 80 words per minute. Assuming that the average word contains around six letters, a fast typist can make up to eight keystrokes every second!

It is thought that during the learning process the neurones involved in controlling the movement change the way that they are connected to each other. Important connections between cells are reinforced and unnecessary synapses are lost

Pianists are able to read music and then play the appropriate note without thinking about what they are doing. This is an example of a learned reflex.

Neurones

A neurone is a specialized cell of the nervous system.
The main function of neurones is to carry information in the form of electrical impulses from one part of the body to the other.

The tissues of the nervous system are made up of two types of cells: neurones, or nerve cells, which transmit information in the form of electrical signals; and the smaller supporting cells (glial cells) which surround them.

COMMON FEATURES

Neurones are the large, highly specialized cells of the nervous system, whose function is to receive information and transmit it throughout the body. Although variable in structure, neurones have some features in common:

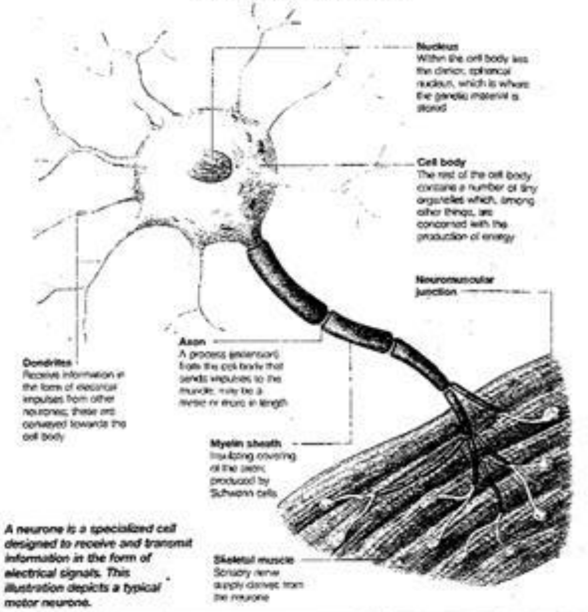
- **Cell body** – the neurone possesses a single cell body from which a variable number of branching processes emerge
- **Dendrites** – these are thin, branching processes of the neurone, which are in fact extensions of the cell body
- **Axon** – each neurone has an axon carrying electrical impulses away from the cell body.

CHARACTERISTICS

Neurones have several other special characteristics:

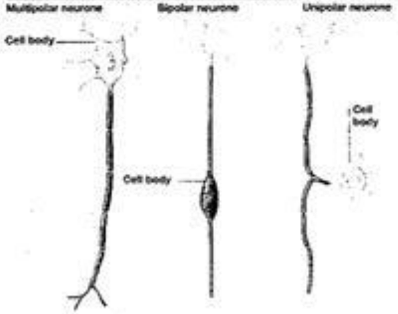
- Neurones cannot divide and so cannot replace themselves if damaged or lost
- Neurones live for a very long time; as they cannot replace themselves they need to last for a lifetime
- Neurones have very high energy requirements and so cannot survive for more than a few minutes without oxygen or glucose from the blood.

Structure of a motor neurone



A neurone is a specialized cell designed to receive and transmit information in the form of electrical signals. This illustration depicts a typical motor neurone.

Structural types of neurone



There are three major groups of neurones, based on the number of processes extending from their cell bodies:

- **Multipolar neurones** – have many processes extending from the cell body, all except one of which (the axon) are dendrites. This is the most common form of neurone, especially within the central nervous system (CNS). Sometimes the axon is absent
- **Bipolar neurones** – have only two processes: a single dendrite and an axon. This type of neurone is unusual within the body, and they are found in special sense organs, such as the retina of the eye
- **Unipolar neurones** – have a single process, which is divided into a peripheral process that receives information, often from a sense receptor, and a central process which enters the CNS.

The arrangement of cell processes from the cell body of a neurone fall into three categories. The structural type of the cell is related to function.

NEURONE FUNCTION

Neurones may also be classified according to their functions into sensory (or afferent) neurones and motor (or efferent) neurones. Most sensory neurones are unipolar while motor neurones are multipolar.

The myelin sheath

The speed of an electrical signal along a neurone's axon is increased by the presence of a myelin sheath – a layer of fatty insulation.

The myelin sheath is formed differently according to where it is located:

- In the peripheral nervous system (those nerves lying outside the brain and spinal cord), the myelin sheath is produced by specialized Schwann cells. These wrap themselves around the axon of a nerve cell to form a sheath of concentric circles of their cell membranes
- In the central nervous system, neurones are given their myelin sheath by cells known as oligodendrocytes, which can myelinate more than one nerve axon at a time.

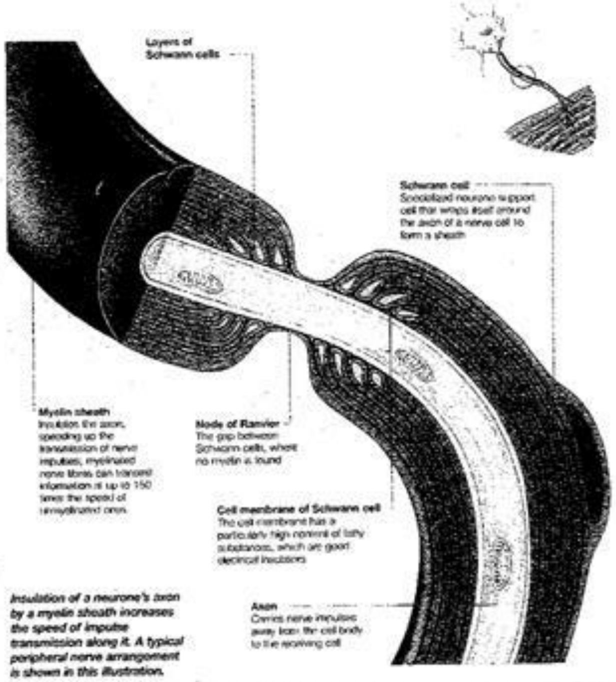
APPEARANCE

Nerve fibres with myelin sheaths tend to look whiter than unmyelinated ones, which have a grey tinge. The 'white matter' of the brain is composed of dense collections of myelinated nerve fibres, whereas the 'grey matter' is made up of nerve cell bodies and unmyelinated fibres.

FUNCTION

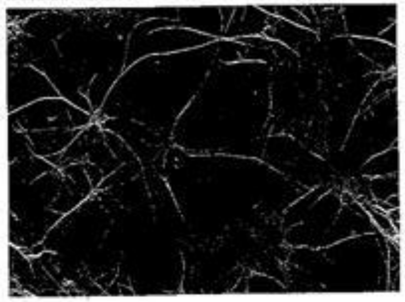
Each Schwann cell lies adjacent to, but not touching, the next. The gap between the cells, where there is no myelin, is known as the node of Ranvier. As an electrical signal passes down the nerve it must 'hop' from one node to the other, which makes it travel faster overall than if no myelin sheath were present.

Insulation of a peripheral nerve



Insulation of a neurone's axon by a myelin sheath increases the speed of impulse transmission along it. A typical peripheral nerve arrangement is shown in this illustration.

Supporting cells of the central nervous system



Neurones are surrounded by neuroglia, a collective name given to the group of small support cells which make up about half the bulk of the central nervous system.

Neuroglial cells outnumber neurones by about 10 to 1 and have a variety of functions:

- **Astrocytes** – the most abundant neuroglial cells; they are star-shaped. They anchor the neurones to their blood supply and determine what substances can pass between the blood and the brain (the so-called blood-brain barrier)
- **Microglia** – like similar cells in other parts of the body, these small oval cells are specialized to ingest, or phagocytose, any invading micro-organisms or dead tissue
- **Oligodendrocytes** – these cells provide the myelin sheath for neurones of the CNS
- **Ependymal cells** – lining the fluid-filled ventricles of the CNS, these cells may be of a variety of shapes, from flat to columnar. They have tiny brush-like cilia on their surfaces which beat to maintain circulation of the cerebrospinal fluid.

Astrocytes are star-shaped cells in the central nervous system. Their numerous branches of connective tissue provide support and nutrition for neurones.

How nerve cells work

Nerve cells generate nerve impulses, electrical messages which travel from one end of a nerve cell to the other. This ability is essential for us to interact successfully with the world around us.

The human central nervous system contains at least two hundred billion neurones (nerve cells); on average, each neurone communicates with thousands of other nerve cells. This complexity allows the brain to interpret the rich sensory input that it receives from the five senses and to react accordingly.

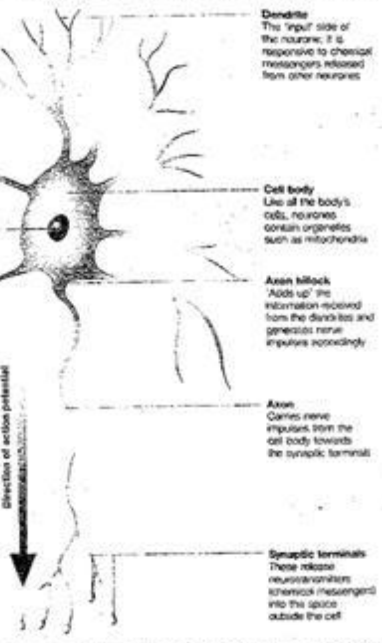
NEUROANATOMY

Although nerve cells from different regions of the nervous system can look very dissimilar, they all contain the same three basic elements: dendrites, a cell body and an axon:

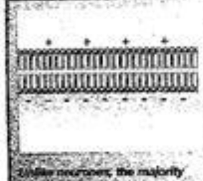
- Dendrites (from the Greek 'dendros', meaning tree) are branch-like protrusions of the cell membrane which provide a large surface area to receive neurotransmitters released from other neurones. The dendrites transduce (convert) this chemical information into small electrical impulses, which are then conveyed to the cell body.
- The greater part of a neurone is made up of the cell body which, like the majority of the body's cells, contains a nucleus. A region of the cell body called the axon hillock collates all the small nervous impulses generated by the many dendrites and initiates action potentials (nerve impulses) accordingly.
- The axon of a neurone carries nerve impulses from the cell body to the synaptic terminals – specialized endings which release neurotransmitters to communicate with other neurones.

Anatomy of a nerve cell (neurone)

Although neurones differ a great deal in shape, they all contain the same main elements: dendrites, a cell body containing a nucleus and an axon.



This neurone (a Purkinje cell from the cerebellum) has a large number of dendrites, allowing it to receive information from a large number of other neurones.



Unlike neurones, the majority of the body's cells do not have protein pores which can open and close in response to a pre-determined signal.

The chemical composition of the fluid inside a cell (called the cytosol) is different from the composition of the fluid outside the cell (extracellular fluid).

Compared to the extracellular fluid, the cytosol has fewer positive charges and more negative charges; this means that the inside of the cell is slightly negative compared to the outside of the cell. This electrical charge across the membrane is called the membrane potential, and in most cells is about minus 70 millivolts (thousandths of a volt).

What makes neurones so special is that they can alter the electrical charge across their membrane to generate nerve impulses. They can do this because their cell membrane contains gated protein pores which allow electrically charged ions (sodium, potassium, calcium or chloride ions) to cross it transiently, so altering the neurone's membrane potential. Other cells do not have these protein pores and so their membrane potential stays relatively constant.

Neurones are able to generate nerve impulses because their membrane contains gated channels that respond either to chemical messengers (left) or to a change in voltage (right).

How nerve impulses are generated

Neurones generate nerve impulses by altering the charge across their membrane. If this is reduced (e.g. by cooling) production of impulses is decreased.

A neurone can only generate an action potential when it has been adequately stimulated. Neurotransmitters (chemical messengers), released from nearby neurones, cause receptor proteins in the dendritic membrane to open. This allows positive sodium ions to flow into the dendrite, causing the membrane potential to become slightly less negative.

THE 'UPSHOOT' OF AN ACTION POTENTIAL

If sufficient sodium ions enter the neurone to raise the membrane potential to the 'threshold potential', other voltage-dependent protein pores open, which allows even more positive sodium ions to enter the neurone.

An electroencephalogram (EEG) records the electric fields generated by the billions of action potentials that the brain generates every second.

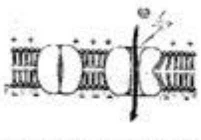
Action potentials are not graded in amplitude (that is, they do not vary in 'strength'). Rather, when the threshold potential is reached the membrane potential suddenly rockets to its maximum level.

By analogy, in order to flush a toilet, sufficient pressure has to be applied to the handle to open the valve that connects the cistern with the toilet bowl. However, once the water starts flowing, it is not possible to stop the cistern emptying.

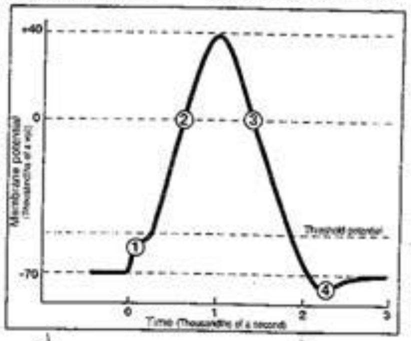
ACTION POTENTIAL RECOVERY

When the membrane potential reaches its maximum level, the sodium channels close and other channels, which are permeable to positive potassium ions, open in response to the high membrane potential (the potassium channels only open in response to a high voltage). The positive potassium ions flow out of the cell, bringing the membrane potential back towards its resting value.

1 *Some neurotransmitters open sodium channels in the dendritic membrane, thereby allowing positive sodium ions to flow into the cell.*



2 *When the voltage reaches a threshold value, voltage-activated sodium channels open, allowing even more positive ions to enter the cell.*



3 *Sodium channels close and potassium channels open, allowing positive potassium ions to leave the cell; both these events act to lower the voltage.*

4 *Eventually, both the sodium and potassium channels inactivate – at this point the neurone is at rest and no further action potentials can occur.*

Speed of nerve impulses

Each axon transmits nerve impulses at a constant speed. However, there is a wide degree of variability in the speed at which different axons conduct action potentials.

NERVE DIAMETER

For example, conduction speeds can vary between about 0.5 and 120 metres per second. The speed depends on the diameter of the nerve (nerves with large diameters conduct quicker than nerves with small diameters) as well as the degree to which the nerve is insulated: conduction

nerve fibres that are wrapped in a fatty insulating substance called myelin.

EFFECT OF TEMPERATURE

Furthermore, the speed of nerve impulse transmission varies according to temperature. For example, cooling a twisted ankle with an ice pack dulls the pain because it reduces the number of action potentials along the nerve.

Placing an ice pack on a swollen ankle eases the pain by slowing down the transmission of the

How nerve cells communicate

Nerve cells communicate with each other by releasing chemical messengers called neurotransmitters. Both therapeutic and illicit drugs act by altering the effectiveness of these transmitter molecules.

Nerve cells do *not* make direct contact with each other. Rather, there is a very small gap, called the synaptic gap, which separates the nerve cell sending the information (the pre-synaptic neurone) from the neurone receiving the information (the post-synaptic neurone).

This gap means that an electrical nerve impulse cannot flow directly from one neurone to the next. Instead, when a nerve impulse reaches the synaptic terminals, the sudden change in voltage causes calcium ions to flow into the pre-synaptic cell.

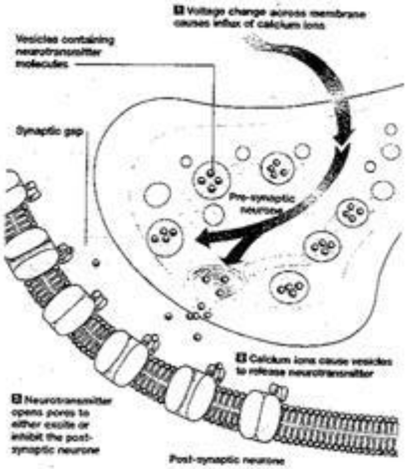
This transmission electron micrograph shows a presynaptic neurone (left) containing vesicles (blue) in synaptic contact with a post-synaptic neurone (right).

RELEASE OF NEUROTRANSMITTERS

Calcium ions cause vesicles (small membrane-bound sacs containing chemical messengers called neurotransmitters) to move towards, and dock with, the pre-synaptic cell membrane, releasing their contents into the synaptic gap.

The neurotransmitter molecules diffuse across to the post-synaptic cell and activate receptor proteins located within its membrane. This can have the effect of either exciting or inhibiting the post-synaptic cell (depending on the neurotransmitter and its associated receptor), increasing or decreasing the likelihood of an action potential being generated respectively.

Neurotransmitter molecules diffuse across the synaptic gap and bind to receptors in the post-synaptic membrane.



Some nerves project from the spinal cord to serve muscle. When a nerve impulse arrives at a 'neuromuscular junction' it causes a neurotransmitter called acetylcholine to be released from the nerve endings.

Acetylcholine diffuses across the synaptic gap and binds with receptors in the muscle tissue. This initiates a sequence of events that results in the contraction of the muscle fibres.

In this way, the central nervous system controls which muscles contract at a given moment. This is essential for complicated movements such as walking.

A micrograph showing a neuromuscular junction. The nerve (black) can be seen innervating the pink muscle.

Neurotransmitter effects .

After a neurotransmitter has bound with, and activated, its receptor on the post-synaptic membrane, it rapidly disengages and is either broken down by enzymes floating in the synaptic gap, or is taken up into the pre-synaptic terminal, where it is repackaged into another vesicle. This ensures that the effect of the neurotransmitter on a receptor molecule is short-lived.

Some illegal drugs, such as cocaine, as well as some prescription drugs, work by preventing the neurotransmitter (dopamine in the case of cocaine) from being reabsorbed; this prolongs the time that the neurotransmitter can activate receptors in the post-synaptic membrane leading to a much greater stimulatory effect.

Cocaine works by inhibiting the uptake of the neurotransmitter dopamine. This allows the dopamine molecules to activate their receptors for longer.

Neural processing

The brain is an incredibly complex structure; each of its neurones is connected to thousands of others located throughout the nervous system.

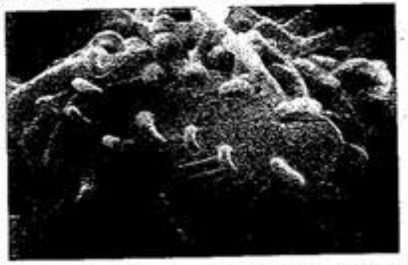
Since nerve impulses do not vary in strength, information is encoded in the frequency of nerve impulses (that is, the number of action potentials that a neurone generates per second), in a similar way to Morse code.

One of the big problems that neuroscientists face today is to try to understand how this relatively simple encoding system produces: for example, the emotional responses that we feel when a friend or relative dies, or the ability to throw a ball with such accuracy that it hits a target 20 metres away.

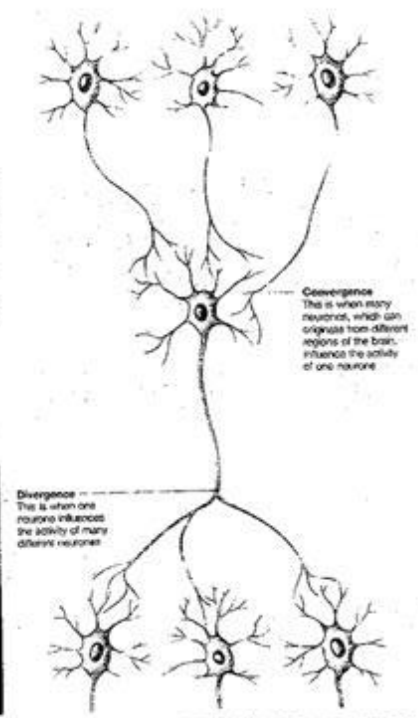
In this regard, it is clear that information is not transmitted from one neurone to another in a linear fashion. Rather, a single neurone is likely to receive synaptic inputs from many other neurones (called convergence) and be able to influence a large number (up to 100,000) of other neurones (called divergence).

Indeed, it has been calculated that the number of possible routes for nerve impulses to take through this vast neural network is greater than the number of sub-atomic particles contained in the entire universe!

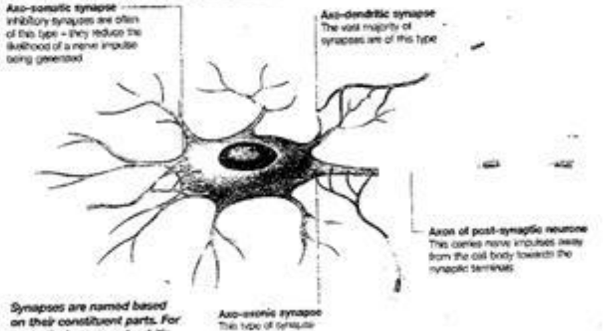
This scanning electron micrograph shows many pre-synaptic neurones (blue) synapsing with a post-synaptic neurone (orange).



Information transfer does not occur in a linear fashion. A single neurone can thus influence and be influenced by thousands of other such cells.



Types of synapse



Synapses are named based on their constituent parts. For example, in an axo-dendritic synapse an axon makes synaptic contact with a dendrite.

There are two main types of synapse: those that cause the post-synaptic neurone to become excited, and those that cause it to become inhibited (this depends to a large degree on the type of neurotransmitter that is released). A neurone will only fire a nerve impulse when the excitatory inputs outweigh the inhibitory ones.

STRENGTH OF SYNAPSES

Each neurone receives a large number of both excitatory and inhibitory inputs. Each of the synapses present will have a greater or lesser effect in determining whether an action potential is initiated.

For example, synapses that have the most powerful effect are generally those close to the nerve impulse-initiating zone in the cell body (soma).