




COORDINATION

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S.6 BIOLOGY

12/28/2025

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LEARNING OUTCOMES.

- *Examine the role of plant hormones in tropisms, photoperiodism, and the application of these processes in agricultural practices. (u, s, gs, v/a)*
- *Analyze impulse transmission in relation to the structure of a neurone, a chemical synapse, and the factors that influence neural activity in response to environmental stimuli. (u, gs, v/a)*
- *Examine the properties and functions of sensory receptors, the role of the retina in visual perception, and the ear's organs of balance in relation to their response to environmental stimuli. (u, s, gs, v/a).*
- *Examine the adaptive significance of diverse animal behaviour in promoting survival and reproductive success. (u, s, gs, v/a)*

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COMMON TERMS USED IN COORDINATION



- **Irritability**: ability of an organism to detect and respond to stimulus in the environment.
- **Stimulus**; refers to a *change in the internal or external environment to which an organism responds*. Stimulus can be categorized as, *Chemical stimulus* e.g. smell & taste and *physical /mechanical stimulus* e.g. light, pressure, gravity, touch, & heat
- *External stimulus* i.e. *change in the conditions in the external environment* of an organism. e.g. sound, light, temperature, touch, smell etc.
- *Internal stimulus* i.e. *change in all conditions in fluids surrounding the living cells/ tissue fluid* e.g. internal body temperature, salt concentration, carbon dioxide concentration and blood sugar.



CONT.....



- **Receptors** ; cells or organs *that receive the stimulus/ detect change* in internal and external environments and *convert it into impulses*. e.g. ears, nose, skin , tongue etc.
- **Effectors** ; is a cell or organ or *body structure that produces a physiological response when stimulated*. e.g. muscles and glands.
- **Response**; change in activity of part or whole of an organism body as a result of the presence of a stimulus.

This can either be towards the direction of stimulus (Positive response) or away from the direction of stimulus (negative stimulus).



TYPES OF RESPONSES

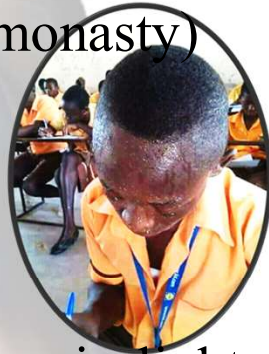


Nastic response.

- Is a *movement of part of a plant in response to a non directional stimulus*. i.e. independent of the direction of the stimulus . E.g.
- Folding and drooping of leaves of *Mimosa pudica* on slight touch. (thigmonastic)
- Closing of leaves in insectivorous plants such as venus fly trap, on landing of insects between its lobes.(haptonastic).
- Opening of crocus and tulip flowers in response to a rise in temperature(thermonasty)

Significance of nastic responses.

- The plant avoids losing a lot of water through transpiration.
- It enables the insectivorous plants to feed by capturing landing insects.
- Folding of leaves when light intensity decreases and spreading with increase in light intensity, allows maximum absorption of light for photosynthesis, more carbohydrate is made and faster.





Tactic responses.

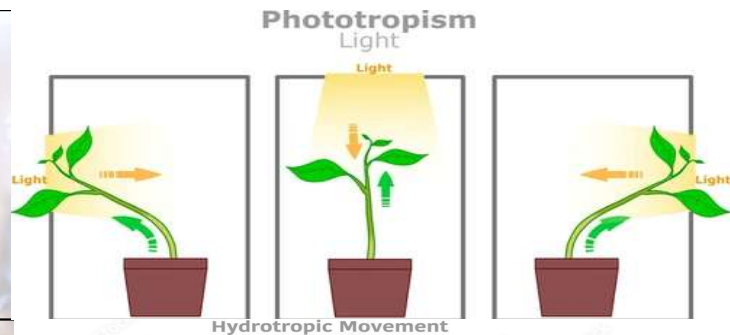
- A taxis is the *movement of a freely motile organism, or a freely motile part of an organism, in response to a directional stimulus*. The direction of the response is related to that of the stimulus. Taxes occur in both plants and animals and can be negative or positive.

Tropic response (tropism)

- Tropism is a *growth movement of part of the plant organ in response to an external unidirectional stimulus*. Tropic responses are **slow**, and are usually *caused by plant growth substance, auxins*
- *Growth movement towards* a stimulus is referred to as *positive tropism* while *growth movement away* from a stimulus is referred to as negative tropism.
- Tropic responses are classified depending on the nature of the stimulus and plants show 5 forms of tropism i.e.

Phototropism, growth movement of part of plant in response to a unidirectional light.

Plant shoots grow towards the direction of light(positive)
Plant roots grow away from the direction of light.



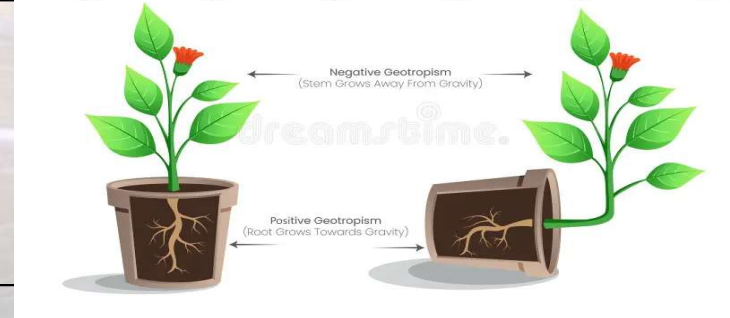
Hydrotropism, growth movement of part of a plant in response to a unidirectional source of water.

Plant roots grow towards a water source (positively hydrotropic)



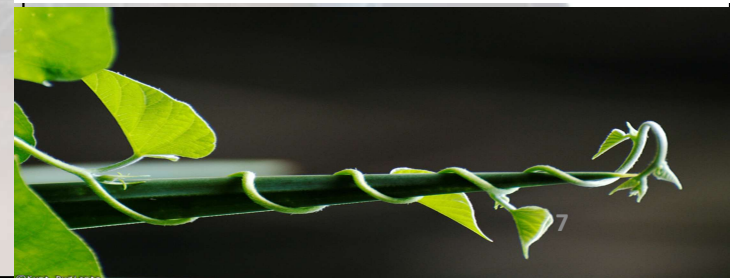
Geotropism, growth movement of part of a plant in response to gravity.

Plant roots grow downwards towards the gravitational pull (positive).
Plant shoots grows away from gravitational pull(negative)



Thigmotropism; is the growth movement part of plant in response to unidirectional touch.

Tendrils of young passion fruits, and pumpkins twine around support. (positive).
Root tips grow away from stones and other obstacles. (negative)



SIGNIFICANCE OF TROPISM RESPONSES.

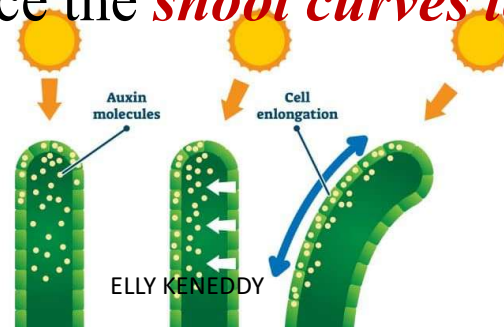
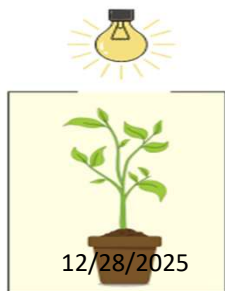


- Positive phototropism of shoots *allows plants to expose leaves to sunlight for maximum absorption hence efficient photosynthesis*
- Positive phototropism allows shoots to spread out *holding flowers and fruits in best positions*, enhancing *pollination and dispersal respectively*.
- Positive geotropism of roots *allows plants to absorb water and mineral salts from deep soil layers*.
- Positive geotropism provides *firm anchorage to the plant in the soil*, preventing physical destruction by wind.
- Negative geotropism of plant shoots, *allows upward growth exposing leaves in best positions* to absorb sun light for photosynthesis.
- Positive hydrotropism of roots, *allows plants to absorb water and mineral salts for photosynthesis and growth*.
- Thigmotropism *enables plants with weak stems to obtain support*.
- Positive chemotropism allows *growth of pollen tube, enhancing the process of fertilization in flowering plants*

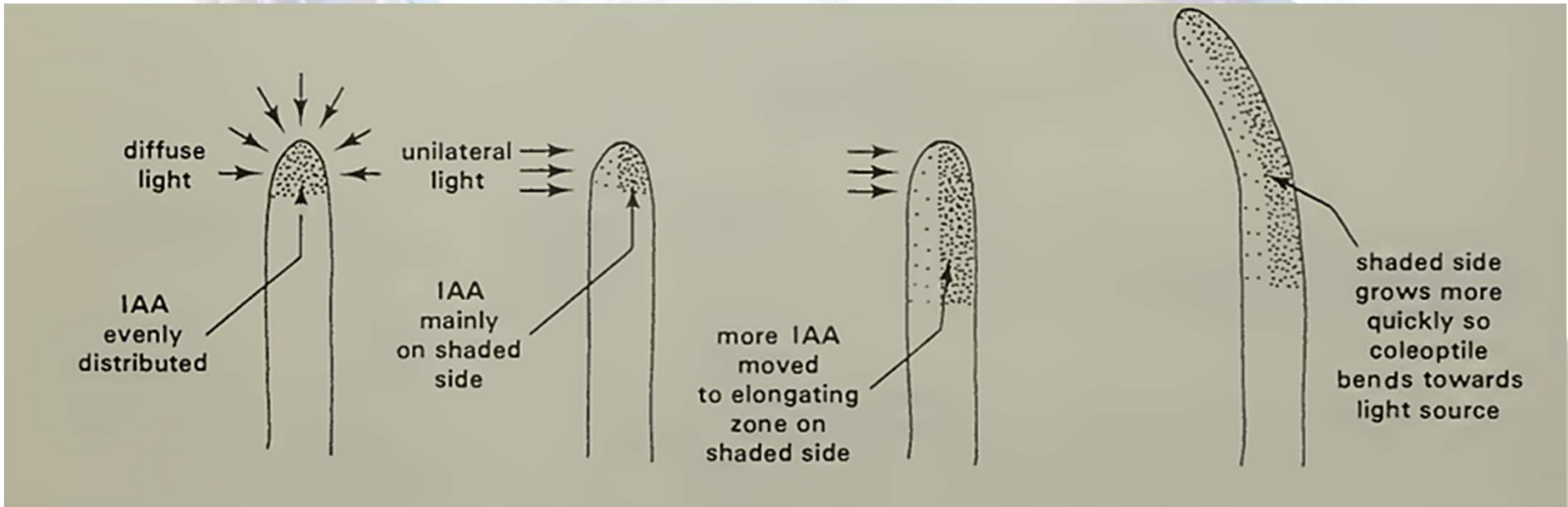


PHOTOTROPISM.

- This is the **growth movement of part of the plant in response to unidirectional light**. Plant shoots are **positively phototropic** that is, they **grow towards the direction of light** while the roots are **negatively phototropic** (they grow away from the direction of light).
- The shoot apex detects a light stimulus. **Blue light** of wavelength **440-460 nm** is **more effective than any other** in stimulating a phototropic response
- When a shoot apex is exposed to a unilateral source of light causes auxins, which are plant growth hormones produced at the shoot apex to **migrate to the shaded side**.
- The **higher concentration of auxins on the shaded side causes faster growth** than on the illuminated side, hence the **shoot curves towards the source of light**.



- The effect of unilateral light on a shoot apex is to *cause more auxin to migrate to the shaded side*. Thus more IAA is transported to the *elongating zone* on the shaded side of the shoot.
- The result is that *the shaded side grows more rapidly* and the shoot bends towards the source of light.
- Exactly how unilateral light effects a redistribution is not clear.

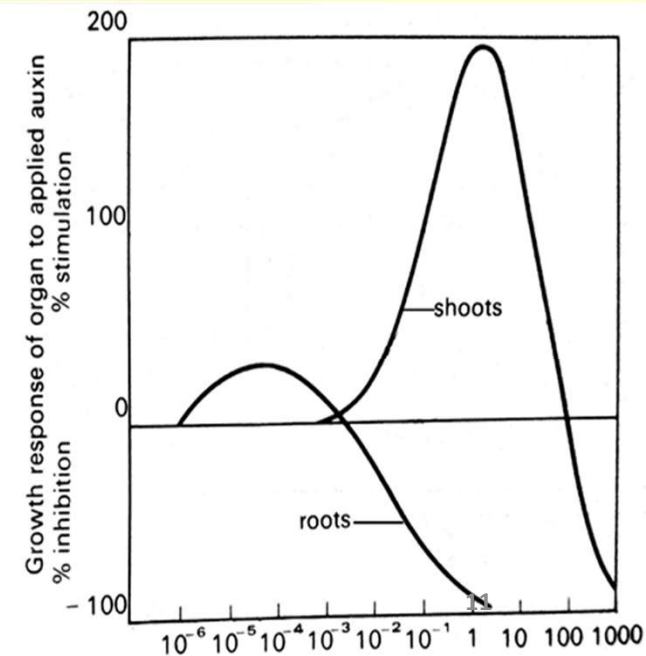
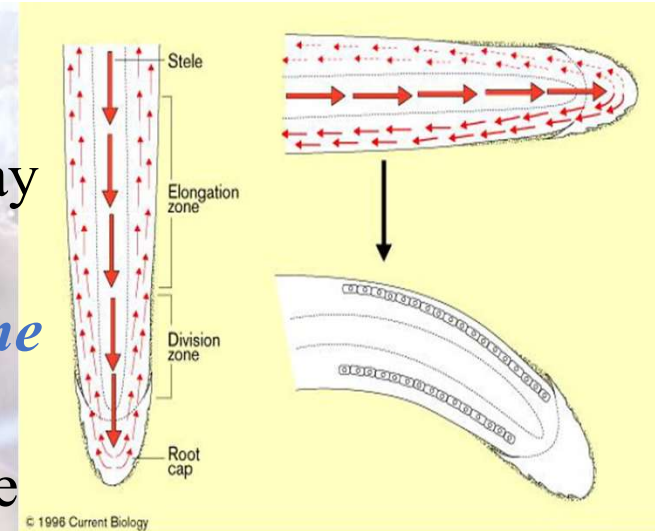


NOTE.

- Roots are usually *negatively phototropic* and grow away from a light source.
- The effect of unilateral light on *auxin distribution at the root apex is similar to that at a shoot apex*.
- Experiments have revealed that roots are more sensitive to auxin than stems, i.e. they respond to lower concentrations of auxins.
- *As the concentration of auxin increases*, the growth of roots, far from being stimulated, *becomes inhibited* causing the non illuminated side to grow more rapidly.
- At a concentration of auxin of 1 part per million, for example, the growth of roots is reduced while that of stems is considerably increased

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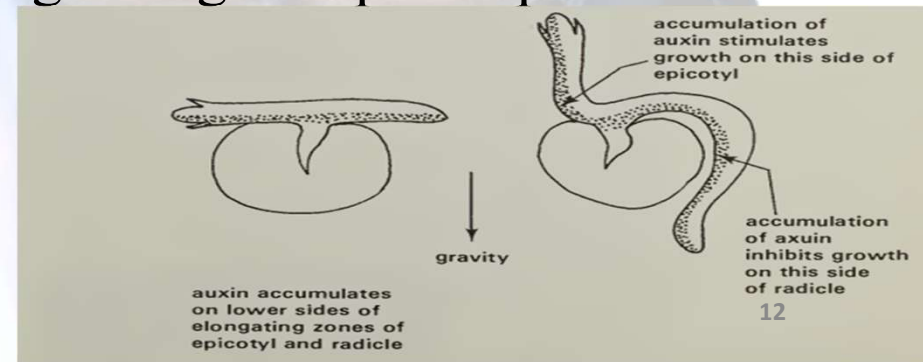
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GEOTROPISM.

- Roots and shoots also react to a unilateral stimulus of gravity. Shoots are usually **negatively geotropic**, growing away from a gravitational pull, while roots show **positive geotropism**.
- Changes in the normal pattern of auxin distribution are thought to account for the responses. It can be shown experimentally that a **higher concentration of auxin occurs on the underside of horizontal roots and shoots** which **move under the influence of gravity**.
- The **high concentrations inhibit root growth**, causing it to bend downwards, i.e. a positive geotropic response. The same concentrations **stimulate stem growth**, causing it to bend upwards, i.e. a negative geotropic response.



- However, the differences in concentration of auxin are small - smaller in fact than those of another plant hormone - gibberellin.
- One mechanism to explain these differences is the **statolith theory**. This suggests presence of that ***starch grains (or statoliths) which fall within the cytoplasm of a cell*** under the ***influence of gravity***. The statolith theory proposes that sedimentation of the starch grains through the cells occurs so that they come to rest on the lower sides
- Their accumulation on the ***lower side of the cell is responsible***. ***In some unknown way affects the distribution of growth substances*** which are produced sometimes in the root apex.
- Now it has been found that if temperature is raised, the time taken for statoliths to fall and presentation time both decrease.
- Further more if statoliths are destroyed, the root will no longer respond to gravity

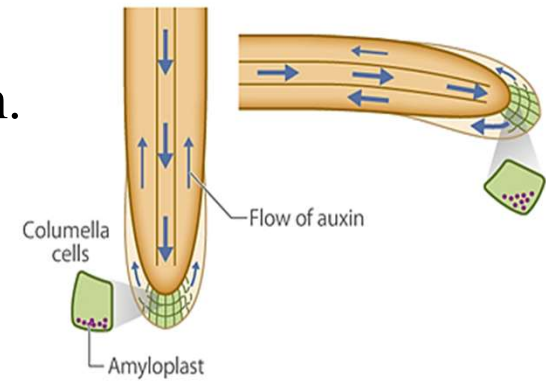
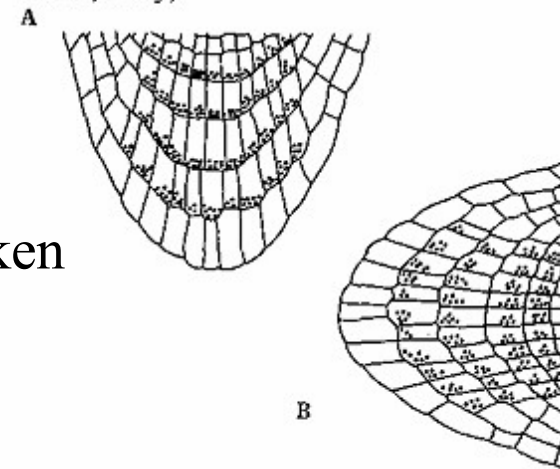


Figure 27.7 Positions of the starch grains (amyloplasts) in the root cap cells of a root orientated (A) vertically and (B) horizontally. See text for explanation. (After Esau, K., Anatomy of Seed Plants, Wiley)



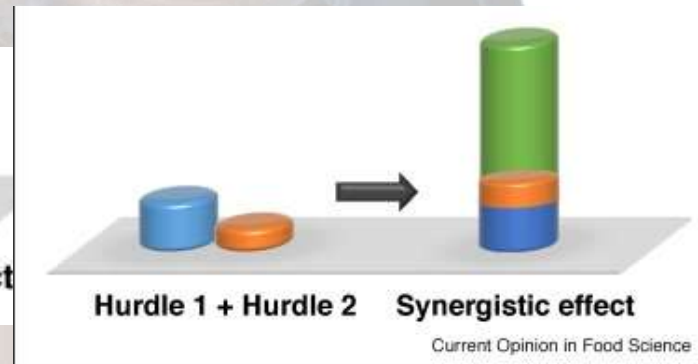
PLANT GROWTH SUBSTANCES.



- Coordination in plants is controlled by hormones.
- A hormone is a *chemical substance produced by glands* which **control physiological reactions** in the body
- Hormones *work at very low concentrations* at sites of action(target organs), some distance from where they are made.
- Plants are coordinated by chemicals which *do not necessarily move from their sites of synthesis* and hence, by definition, *should not always be termed hormones*.
- In view of this, because their effects are usually on some aspect of growth, they are called growth substances.
- Growth is divided into the three stages i.e. cell division, cell enlargement and cell differentiation.



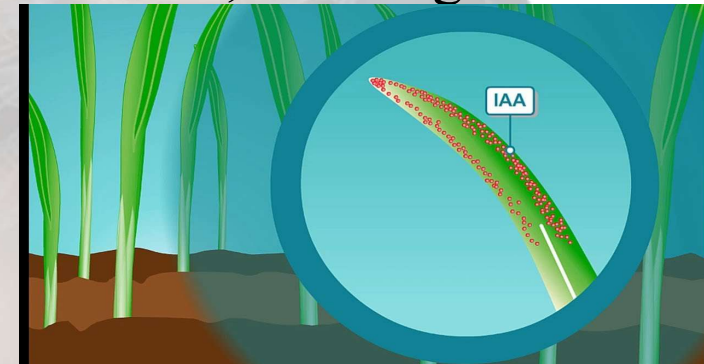
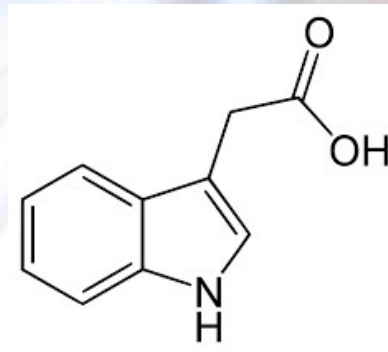
- There are five groups of growth substances generally recognized that is to say; **auxins**, **gibberellins**, **cytokinins**, **abscisic acid** (inhibitor) and **ethene** (ethylene).
- Sometimes *two hormones act together to reinforce an effect*, e.g. auxins and gibberellins both increase cell elongation. This is known as **Synergism**. Synergism is *where the combined effect of growth substances is much greater than the sum of their separate effects*.
- Alternatively, *two hormones may have opposing actions*, e.g. auxins induce apical dominance whereas cytokinins prevent it. This is known as **Antagonism**.
- Antagonism is where the two substances have opposite effects on the same process, one promoting and the other inhibiting.



AUXINS



- Auxins are a group of chemical substances of which *indoleacetic acid* (IAA) is the most common. Indoleacetic acid is *the main auxin made in plants* and have been isolated from a large number of plants.
- It is produced at *apices of shoots* from the amino acid tryptophan. IAA is *transported backwards to zones of elongation* in roots and shoots where it regulates *cell elongation* and *differentiation* of vascular tissues.
- Auxin transport is unidirectional or polar, in coeloptiles and is carried in parenchyma tissue but in mature roots and shoots, the main transporting tissue is the phloem.
- Short distance movement from cell to cell occurs by diffusion, but long distance transport is possible via phloem.



ROLES OF AUXINS.



- The IAA made by apical buds usually *inhibits lateral buds from growing* into side shoots, a phenomenon called *apical dominance*.
- *Leaf expansion is IAA-controlled* as well as *the growth of fruits and seeds* and sometimes cause *fruit setting in absence of pollination* (parthenocarpy)
- The positions of procambial strands at shoot apices too are determined by IAA made in leaf primordia.
- IAA released from the expanding buds of woody plants during spring *triggers the vascular cambium into activity*.
- IAA also stimulates translocation of organic substances in the phloem.
- IAA cause *tropisms*.
- IAA promote *formation and growth of adventitious roots* in stem cuttings.
- IAA stimulates cell division, help to *maintain the structure of cell walls* hence inhibits *abscission*, however high concentrations, inhibit growth.

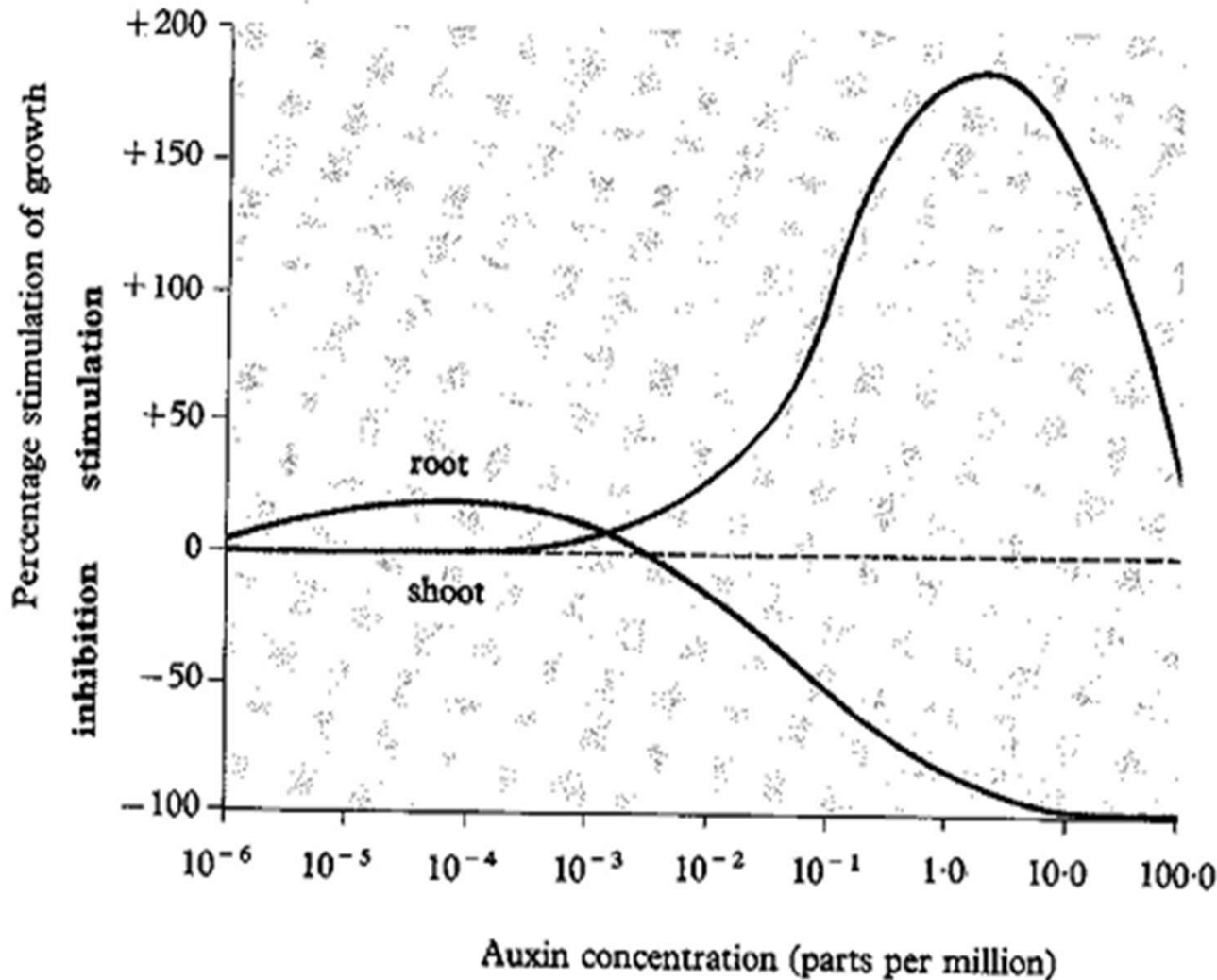
MECHANISM OF ACTION OF IAA. (OPTIONAL)

- The effect of auxins on **cell enlargement** is now reasonably well understood. Enlargement cell occurs by a combination of **osmotic swelling as water enters the cell** and by the **laying down of new wall cellulose material**. The orientation of the existing microfibrils probably helps to determine the direction of extension.
- During cell extension the **rigid cellulose framework of the cell wall must be loosened**. ‘Wall loosening’ is **induced by acid**.
- In the presence of auxins, **hydrogen ion secretion out of the cells and into the cell walls is stimulated**.
- This causes a **lowering of pH outside the cell** (increase in acidity) and hence **wall loosening**, possibly by **an enzyme with a low pH optimum** that **breaks bonds in cell wall polysaccharides**, thus **allowing the walls to stretch more easily**.

COMMERCIAL APPLICATIONS AND USES OF SYNTHETIC AUXINS



- Auxins are used to initiate rooting in stem cuttings.
- They are used to inhibit leaf fall when the leaf matures.
- They inhibit fruit fall, leaf fall and flower fall (abscission) by maintaining the structure of cell walls.
- They inhibit the development of lateral buds hence reducing branching in plants. Removal of the apical buds therefore leads to branching.
- Synthetic auxins kill broad leaf plants by disrupting their growth hence used as selective weed-killers. Explain why
- Synthetic auxins stimulate fruit growth and parthenocarpic fruit development. Parthenocarpy is fruit development without fertilization.



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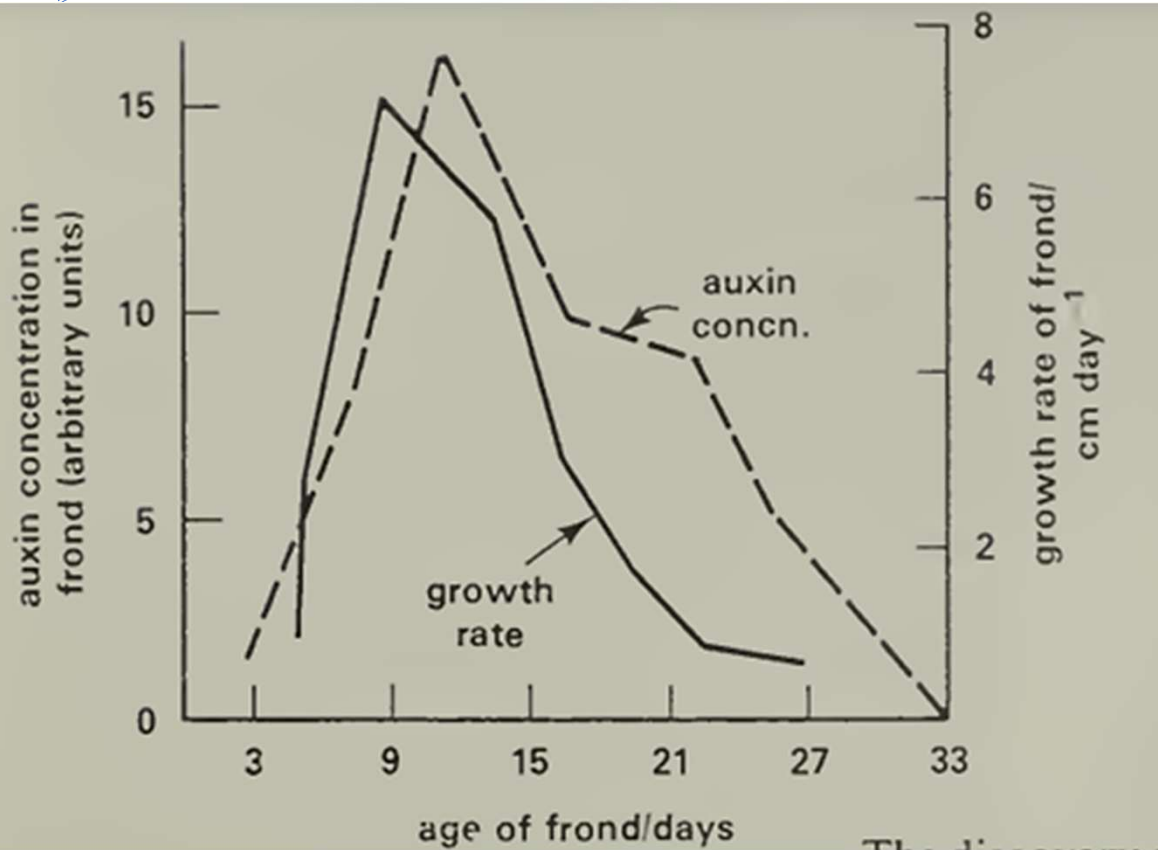
ACTIVITY.



1. State the effect of increasing auxin concentration on percentage stimulation of growth in both root and shoot.
2. Account for the effect stated above



THE FIGURE BELOW SHOWS CORRELATION BETWEEN AUXIN CONCENTRATION AND THE GROWTH OF OSMUNDA FRONDS



- Describe the changes in the growth rate of osmunda fronds with time.
- Compare the curves above
- Account for the effect of auxin concentration on the growth rate in the figure.



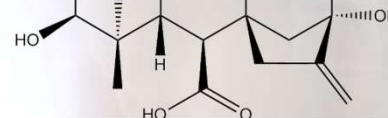
GIBBERELLINS

- Gibberellins take their name from the fungal parasite *Gibberella fujikuroi* which causes a disease of rice plants known as ‘*foolish seedling*’.
- Seedlings which are attacked by the fungus *develop very long internodes* so that the *shoot systems are much taller than* those of healthy plants.
- By the late 1920s Japanese workers showed that a growth-promoting substance called *gibberellin* was present. The best-known effect of gibberellic acid (GA) is to bring about *internode elongation*.
- The main influence of gibberellins on plants is to *promote cell elongation* leading to internode elongation and so increase length.
- Unlike auxins, gibberellins can stimulate growth in dwarf varieties, thus restoring them to normal size.

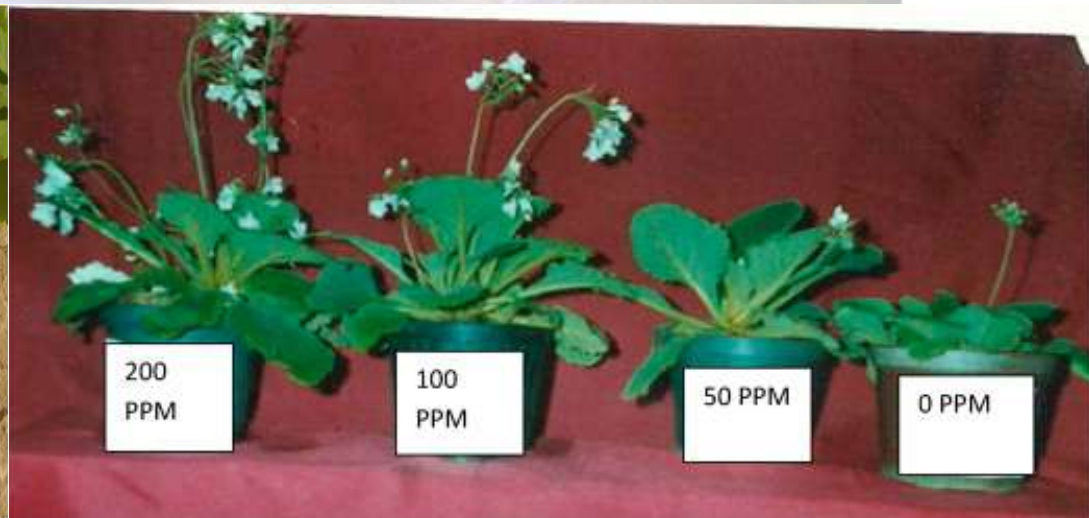
GAA on cabbage



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- These dwarf varieties are thought to *result from a genetic mutation* which *prevents them producing gibberellins* naturally.
- They therefore *require an external supply to make them grow* to normal size.
- The main effect of gibberellins is to cause elongation of the stem; they also influence *cell division* and cell differentiation to some extent.
- Their varied effects *sometimes complement those of auxins*, e.g. in promoting growth, but at *other times they have antagonistic effects*, e.g. while auxins promote the growth of adventitious roots, gibberellins inhibit their formation.



ROLES OF GIBBERELLINS.

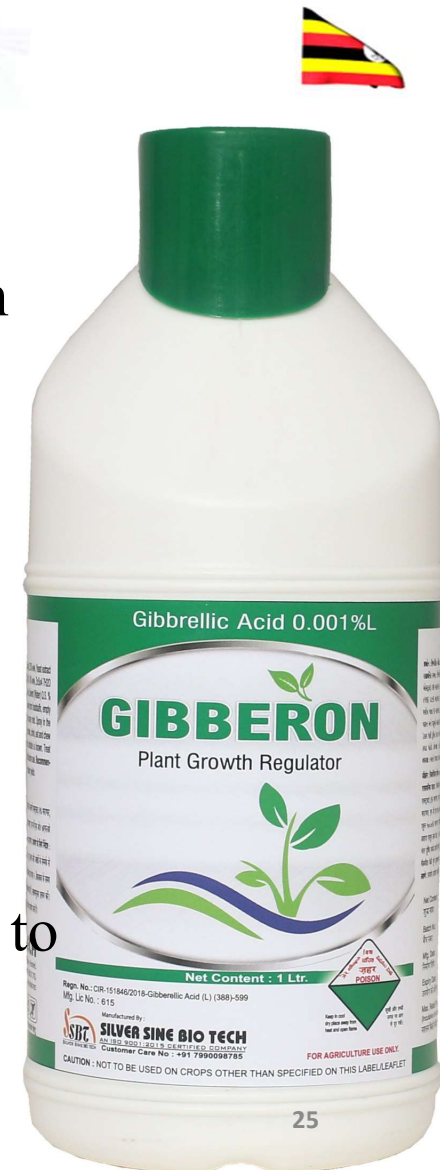


- Gibberellins play a role in *breaking dormancy in seeds* such as wheat and barley. GA also stimulates enzyme production during seed germination..
- When applied to woody stems GA *promotes division of the vascular cambium*, but the derivatives fail to differentiate into mature xylem elements unless IAA is added. However, GA on its own brings about differentiation of mature phloem elements.
- Promote cell enlargement in presence of auxin. Also promote cell division in apical meristem and cambium.
- Promote '*bolting*' of some rosette plants.
- Can sometimes induce *parthenocarpy*.
- Induce flowering in some plants substituting the effect of *photoperiodism*.
- GA delay leaf fall in some plants



COMMERCIAL APPLICATIONS OF GA

- They **promote fruit setting** and are used for growing seedless grapes. The development of seedless fruits occur if fertilization does not take place and is known as **parthenocarpy**.
- GA; is **used in the brewing industry** to stimulate a-amylase production in barley, and hence **promote 'malting'**.
- A number of synthetic growth retardants act as 'anti-gibberellins', that is they inhibit the action of gibberellins. Application of these often results in short (dwarf) plants with **deep green leaves**, sometimes **greater pest and disease resistance**. These take up less space and may in the future lead to higher yields per acre



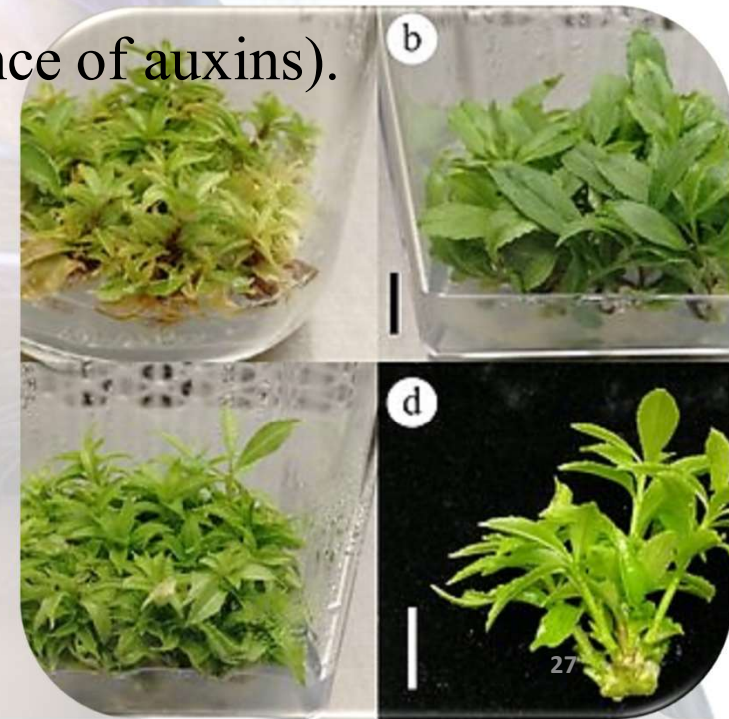
CYTOKININ.



- Cytokinins are **most abundant where rapid cell division** is occurring, particularly in **fruits** and **seeds** where they are **associated with embryo growth**
- Plant cells grown in synthetic nutrient media were **found to remain alive but did not undergo cell division**. Division only occurred if malt extract or coconut milk was added to the culture.
- It was later found that autoclaved samples of DNA also induced cell division and from these **kinetin**, a substance similar to adenine, was isolated.
- Partly as a consequence of their effects in promoting **cytokinesis** during cell division, substances like kinetin were termed **cytokinins**.
- A number of cytokinins are **produced naturally by many plants**; all are derivatives of **adenine**. This suggests that they operate through some role in nucleic acid metabolism, most probably being involved in tRNA synthesis.

- They are found ***largely in actively dividing tissues***, especially fruits and seeds, where they ***promote cell division in the presence of auxins***. Cytokinins exert the following effects.

- One interesting effect of cytokinins is In the presence of cytokinins, leaves removed from a plant remain green and active, rather than turning yellow and dying.
- They increase the rate of cell division (in the presence of auxins).
- They stimulate bud development.
- Promote leaf growth and fruit growth.
- Promote apical dominance.
- Promote stomatal opening.
- Breaks dormancy in some





COMMERCIAL APPLICATIONS OF CYTOKININS

- Cytokinins prolong the life of fresh leaf crops such as cabbage and lettuce (delay of senescence)
- Cytokinins are well as used in keeping flowers fresh.
- They can also be used to break the dormancy of some seeds.



ABSCISIC ACID



- It had long been suspected that dormancy was caused by inhibitors. ***Abscisic acid inhibits growth*** and so ***works antagonistically*** to *auxins, gibberellins and cytokinins*.
- Its main effect, as its name suggests, is ***on abscission*** (*leaf and fruit fall*). The process results from a balance between the production of auxin and abscisic acid.
- The quantity of ABA in the leaves of deciduous trees ***increases in the shorter days of autumn***. The accumulation of ABA ***slows down the growth rate of shoots*** and ***stimulates the formation of dormant winter buds***. Soon leaf fall, abscission, occurs.
- As a fruit ripens, ***the level of auxin (which inhibits abscission) falls***, while that of abscisic acid (which promotes abscission) increases. This leads to the ***formation of an abscission layer*** which causes the fruit to fall.

EFFECTS OF ABSCISIC ACID.

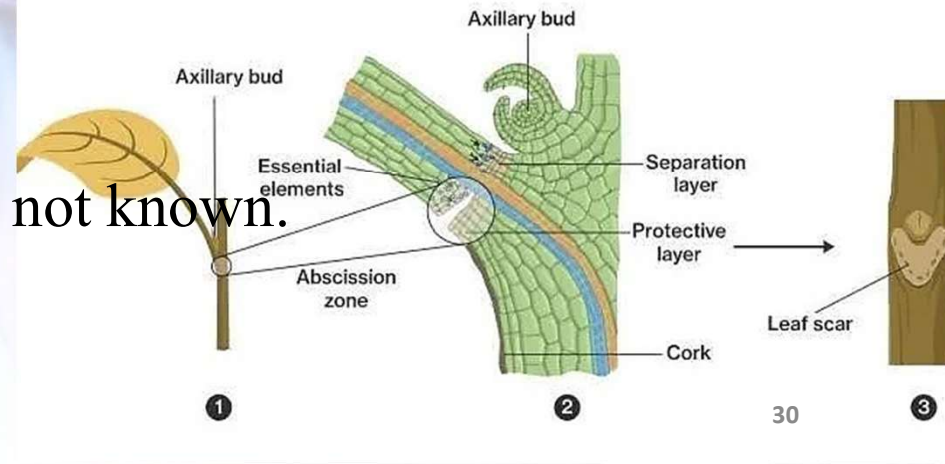
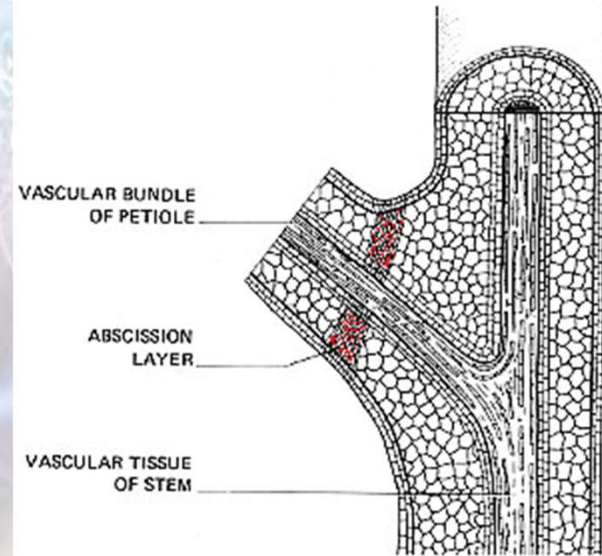
- Inhibits growth.
- Promotes bud and seed dormancy.
- Promotes abscission and leaf senescence.
- It induces stomatal closure in response to water stress.

Commercial applications of ABA

- ABA can be sprayed on tree crops to regulate fruit drop at the end of the season. This removes the need for picking over a long time-span.

NOTE.

The mechanism of action of abscisic acid is not known.

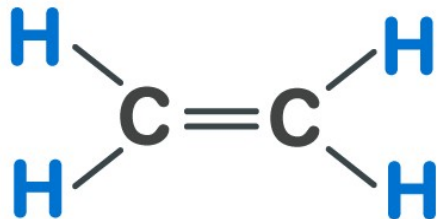


ETHENE/ETHYLENE.



- Ethene is **made by most or all plant organs** as a **metabolic by-products**, especially fruits. Ethene (ethylene) has a relatively **simple chemical structure** and **exists as a gas at room temperature**. Despite being a gas, it **does not generally move freely** through the stem of air spaces in the plant because **it tends to escape more easily** from the plant surface.
- However, movement of the water-soluble precursor of ethene from waterlogged roots to shoots in the xylem has been demonstrated.
- Its main effect is in stimulating the ripening of fruits but it also influences many auxin-induced responses.

ETHYLENE STRUCTURE



EFFECTS OF ETHENE AND COMMERCIAL APPLICATIONS.

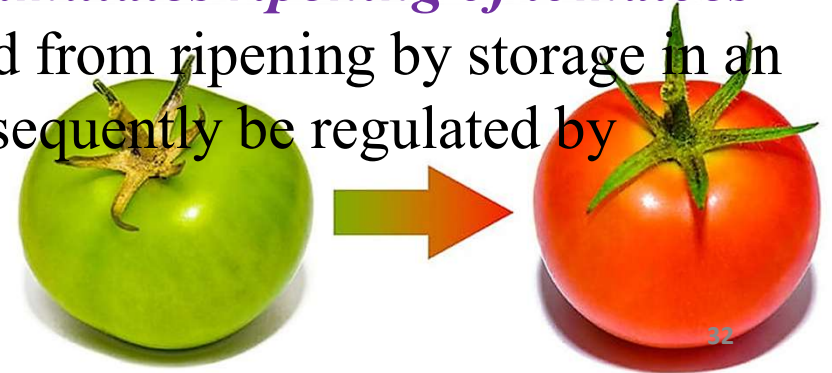


- Inhibits stem growth and root growth.
- Promotes flowering e.g. in pine apples.
- Ripens fruits.
- It also breaks dormancy in buds of some plants.



Commercial application.

- Ethene *induces flowering in pineapple* and *stimulates ripening of tomatoes and citrus fruits*. Fruits can often be prevented from ripening by storage in an atmosphere lacking oxygen; ripening can subsequently be regulated by application of ethene with oxygen.



PHOTOPERIODISM.



- Photoperiodism refers to *plant responses to varying durations of illumination\ exposure to light*. The relative length of day and night varies with the time of year and is called the *photoperiod*.
- These responses are mainly observed in promotion of *flowering* and *germination*. The effects of the photoperiod on flowering differ from species to species but plants fall into three basic categories:
- *Long-day plants* (LDP) ; These only flower when the *period of daylight exceeds a critical minimum length*. Examples include radish, clover, barley and petunia.
- *Short-day plants* (SDP) ;These only flower when the *period of daylight is shorter than a critical maximum length*. Examples include chrysanthemum, poinsettia, cocklebur and tobacco.
- *Day-neutral plants* ;These plants flower *regardless of the length of daylight*. Examples include cucumber, tomatoes, begonia, and carrot.



- **Note.**
- **Intermediate varieties exist.** For example, short-long-day plants only flower after a *sequence of short days is followed by long days*. These plants will flower naturally in *mid-summer* when the days are long following the shorter days of spring.
- Long- short-day plants flower after a sequence of *long days is followed by short days*. These will flower naturally in the autumn after the long days of summer are followed by the shorter days of *early autumn*.

Characteristics of long day plants



- They flower only when the light period exceeds the critical length of the day (12 hours).
- Short nights are more essential than the length of the day. Thus, they are commonly known as short night plants.
- They flower even when the short night is interrupted by flashes of light
- They also show flowering even when the long day is interrupted by short dark periods.
- They flower during summer when the days are longer than the night, like wheat.

Characteristics of short-day plants

- ✓ They flower only when day length become shorter than the critical day length.
- ✓ They need an uninterrupted period of darkness.
- ✓ They do not flower if given short days and long nights interrupted by flashes of light.
- ✓ If the short days are interrupted by intervals of darkness but left with an interrupted long night they flower. Such plants flower during autumn and winter.

PHYTOCHROME AND THE DETECTION OF NIGHT LENGTH

- Photoperiodism *requires a mechanism for detecting the length of darkness and day*. The best-known mechanism is a *pale-blue light-sensitive protein* called *phytochrome*.
- It exists in two interconvertible forms: *Phytochrome red* (P_r), which *absorbs red light* (wavelength of 660 nm), and *Phytochrome far-red* (P_{fr}), which *absorbs far-red light* (wavelength of 730 nm).
- Phytochrome is synthesized in its *P_r form*. Experiments with specific wavelengths of light show that P_r *is converted into P_{fr}* when *exposed to red light during day*, and that P_{fr} *is converted back into P_r* when *exposed to far-red light or when in darkness*.



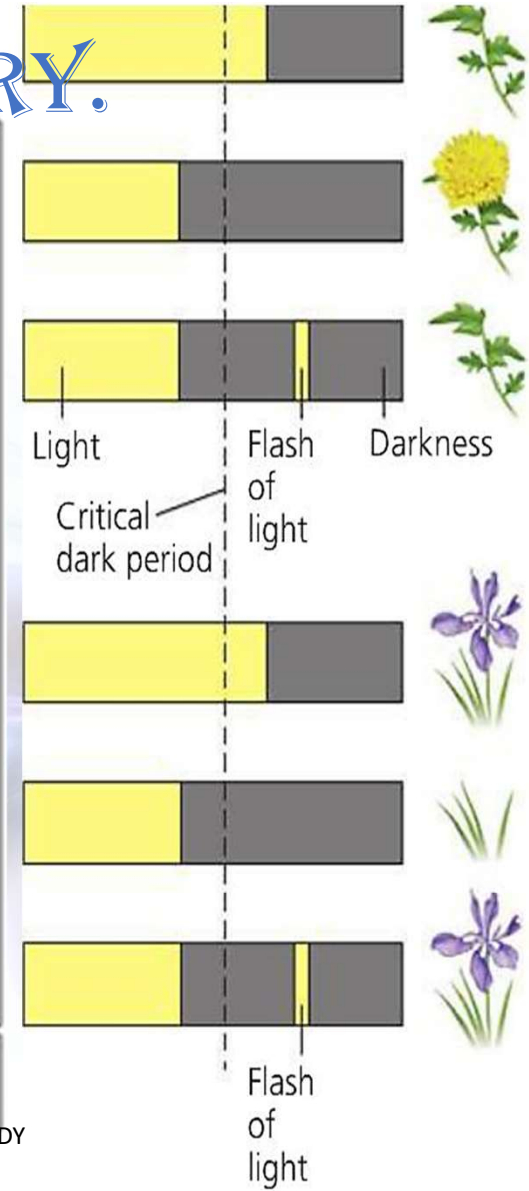
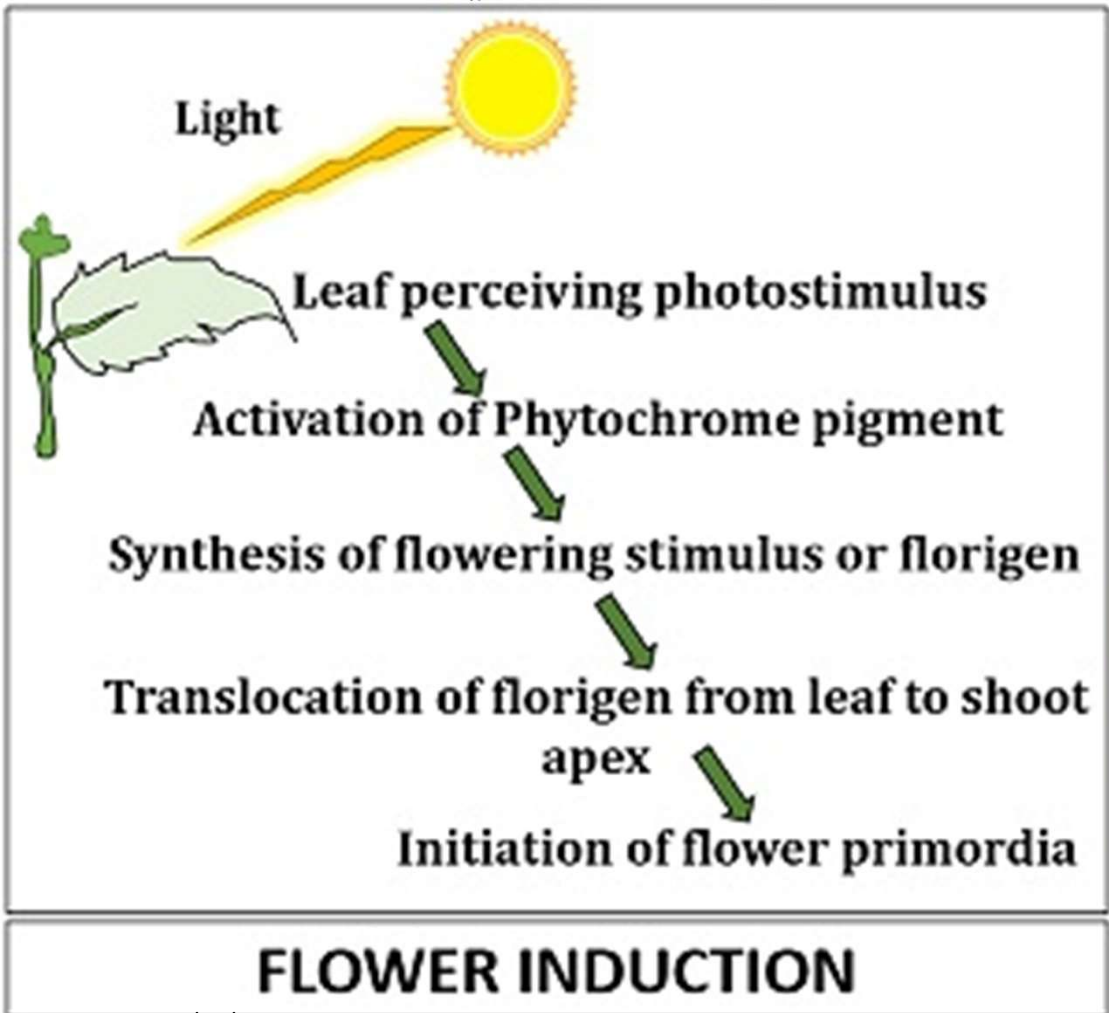
- *During the day*, there is *more P_{fr} than P_r* because *sunlight has a higher proportion of red light* than far-red light hence P_r is *rapidly converted to P_{fr}* . During the darkness of night, P_{fr} is *gradually converted back to P_r* .



- Therefore the relative amounts of the two forms of phytochrome could indicate day length.
- The *balance between the two forms of phytochrome controls flowering* in short-day and long-day plants.
- A build-up of P_{fr} could *stimulate flowering* in *long-day plants*, whereas in short-day plants, P_{fr} could *inhibit flowering*.
- Phytochromes involved in detection of the photoperiod are *found in the leaves*.

- When a short-day or long-day plant is exposed to *normal daily routines of light and darkness*.
- *Phytochrome red (P_r) absorbs red light* and it is *rapidly converted to phytochrome far red (P_{fr})* during *day* or *light* hours. P_{fr} is also *converted slowly back* into P_r when exposed to far-red light or when in darkness during *night hours*.
- Phytochrome far red (P_{fr}) *is the active form* and its *low concentration in the leaves of short-day* plants *lead to production of Florigen hormone* which then *carried in the vascular system(phloem)* to the *flower buds*.
- Florigen *induces the terminal* and *auxiliary buds* to develop *into flowers*.
- In long-day plants, high levels of P_{fr} or low levels of P_r may stimulate florigen secretion, whereas in short-day plants, florigen may be secreted when P_{fr} levels are low or when P_r levels are high. However, *until florigen has been isolated, these suggestions remain highly speculative.*

PHOTOPERIODISM SUMMARY.




(a) Short-day (long-night) plant. Flowers when night exceeds a critical dark period. A flash of light interrupting the dark period prevents flowering.

(b) Long-day (short-night) plant. Flowers only if the night is shorter than a critical dark period. A brief flash of light artificially interrupts a long dark period, thereby inducing flowering.

STRUCTURE OF A NERVOUS TISSUE.

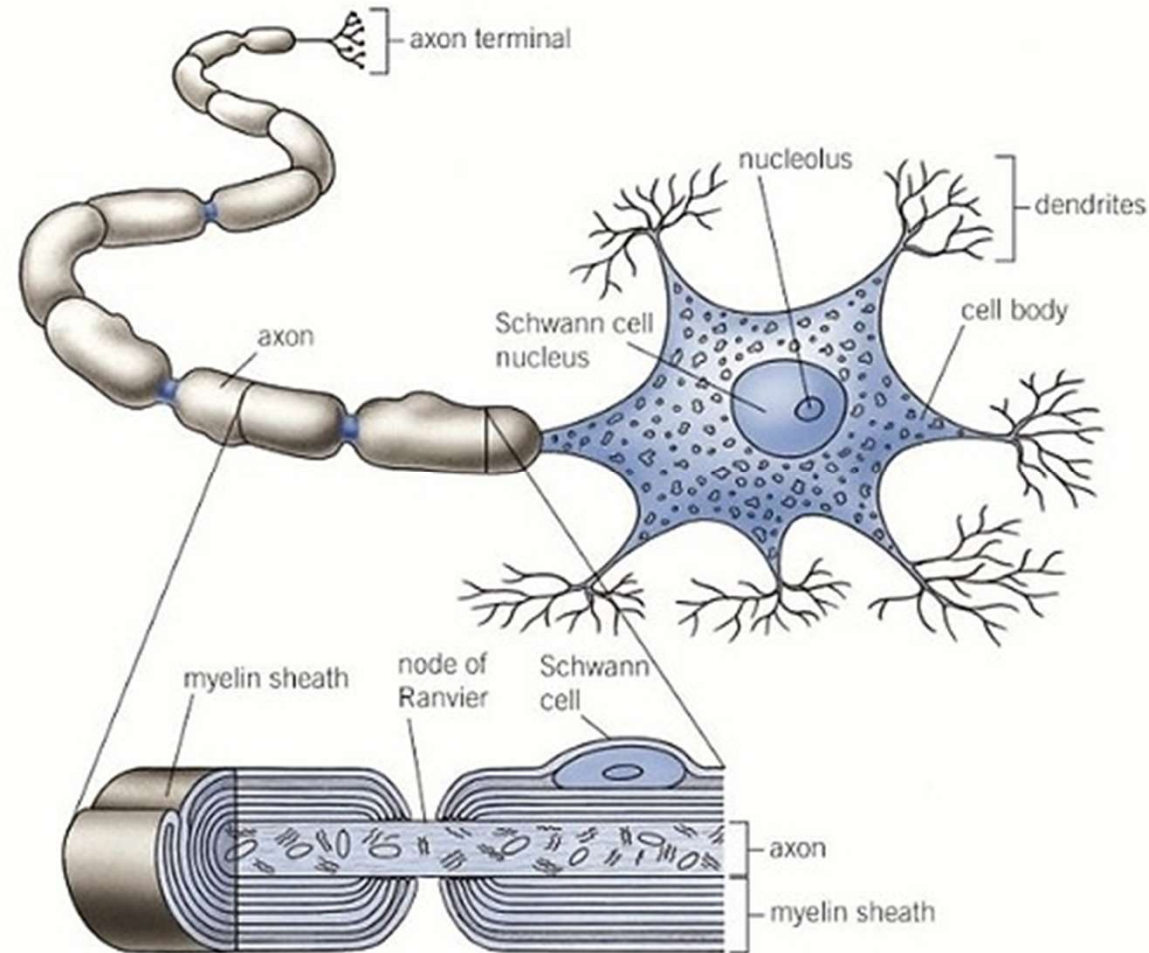
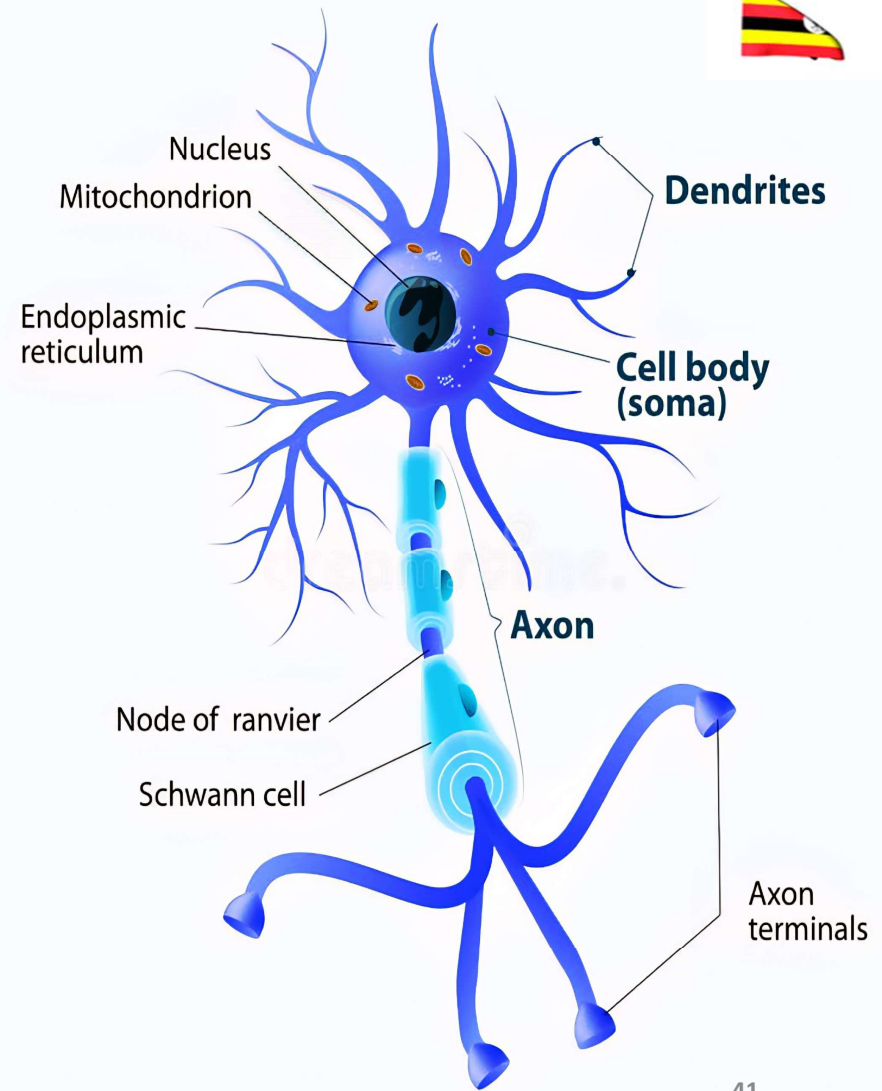


- Nervous tissue comprises closely packed *nerve cells* or *neurones* with *little intercellular space*. The neurones are bound together by connective tissue.

Structure of a nerve cell (neurone)

- All neurones *have a cell body* containing a *nucleus*. This *cell body has a number of processes/ extensions* called *dendrites* which transmit impulses to the cell body. Impulses *leave via the axon* which may be several meters in length.
- Some axons are *covered by a fatty myelin sheath produced by Schwann cells*. The *space between adjacent Schwann cells lacks myelin* forming gaps called *Nodes of Ranvier*. These occur every 1-3mm in humans. Neurones which are myelinated transmit impulses faster than neurons without myelin sheath.
- *Nerve fibres may be bundled together* and *wrapped in connective tissue* to form nerves. Nerves may be sensory, comprising *sensory neurones*, effector (motor), comprising *effector (motor) neurones*, or mixed, with both types present.

STRUCTURE OF A NERVE.

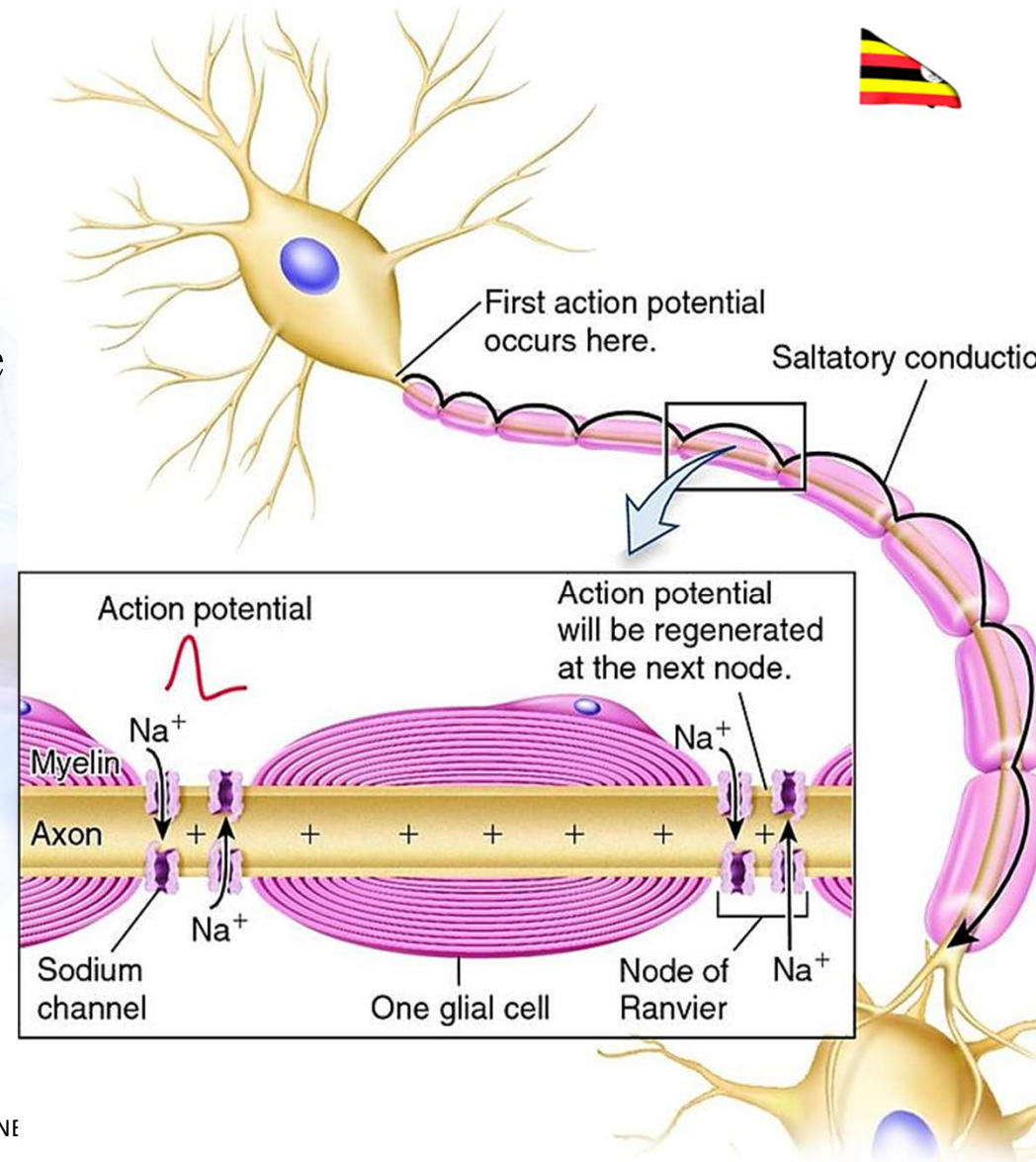


NOTE.

- On neurons, a specialized cell called ***Schwann cell*** wraps its self around the nerve axon to form numerous ***concentric layers of myelin sheath***. The sheath consists of **70% lipid** and **30% protein** in the usual bilipid structure.
- It provides ***insulation*** preventing ionic exchange, ***facilitating the leaping of an impulse*** from ***one node of Ranvier to another***, allowing faster conduction of electrical signals(impulses).
- The axon is the functional unit of a nerve cell. It exhibits 2 states ie the ***resting potential*** and ***action potential***.

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FUNCTIONS OF THE PARTS OF A NEURONE

- ❑ **Cell body:** This consists of a **nucleus** surrounded by a mass of cytoplasm. The ***nucleus controls all activities of the neuron.***
- ❑ **Axon:** ***Transmits impulses over long distances in the body.*** Each axon is filled with cytoplasm called axoplasm.
- ❑ **Myelin sheath:** This is a fatty material that covers the axon. The myelin sheath is secreted by cells called Schwann cells. The myelin sheath ***insulates the axon*** and ***speeds up the transmission of impulses.***
- ❑ **Dendrites:** These are hair-like structures surrounding the cell body. ***They conduct incoming signals from one nerve cell to another.***
- ❑ **Node of Ranvier:** This is the space on the axon between two adjacent myelin sheaths. ***It speeds up nervous transmission.***



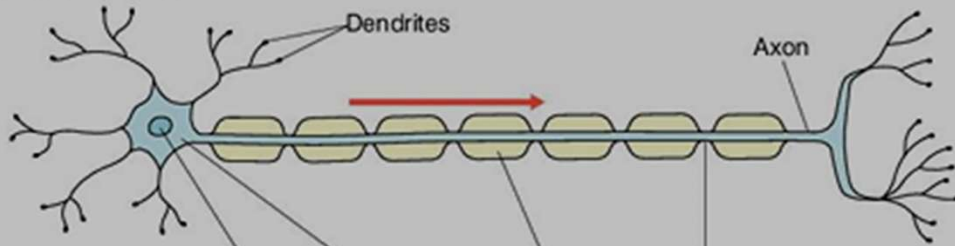
ADAPTATIONS OF NEURONS.

- Neurons' have *long axons* to *increase the distance over* which electric signals are transmitted in the body.
- Nerve cells have *numerous dendrites* which *increase area for receiving electrical signals from receptors and distribution of impulses* to effectors allowing faster response to stimuli.
- Some nerves are *myelinated* hence *facilitating faster transmission of impulses* by providing insulation to ionic exchange *encouraging leaping of action potentials* between nodes of Ranvier.
- Nerves contain *numerous mitochondria* in the axon terminals which generate *large amounts of ATP used for active pumping of ions* for maintaining the resting potential.
- It has *many ribosomes and Golgi body* for *synthesis of much neuro transmitter substance* that is used for faster transmitting of impulse across the synapse
- The axon terminals contain synaptic knobs with *numerous vesicles* that *store much neurotransmitters*, allowing faster impulse transmission from one nerve to another.
- They have a large nucleus in the cell body for effective control of neuro transmitter substance synthesis required for impulse transmission. *Research for more.*

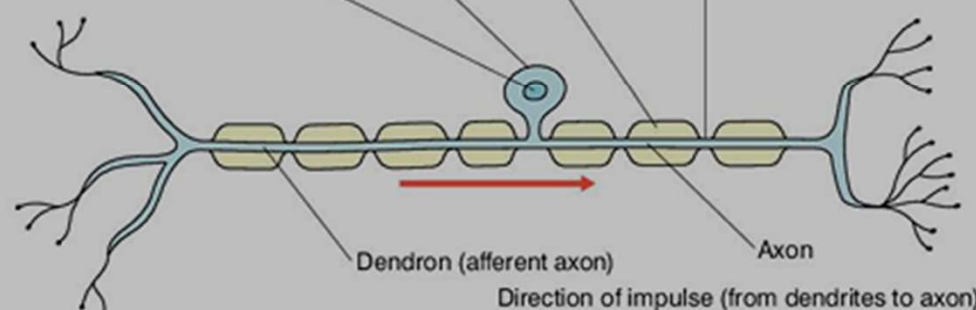
- **Sensory neurones** transmit nerve impulses from a receptor to a relay or motor neurone. They have one afferent dendron that brings the impulse towards the cell body and one axon that carries it away from the cell body.
- **Relay neurones (intermediate neurones)** transmit impulses between neurones, e.g. from sensory to motor neurones. They have numerous short processes (extensions).
- **Motor neurones (effector neurones)** transmit nerve impulses from a relay or sensory neurone to an effector such as a gland or a muscle. They have a long axon and many short dendrites.

The three different types of neurone are illustrated in Figure 4.

MOTOR NEURONE



SENSORY NEURONE



Direction of impulse (from dendrites to axon)

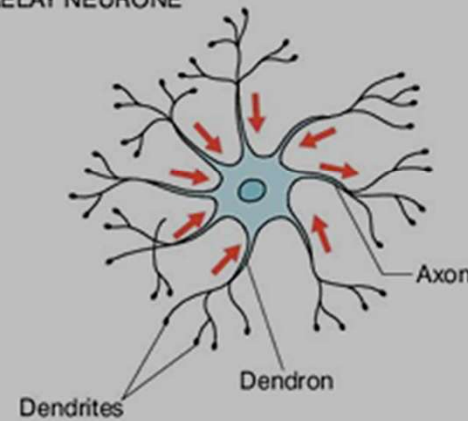
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Figure 4 Types of neurone

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Figure 2 Scanning electron micrograph of neurone with cell body at its centre and dendrites radiating from it

RELAY NEURONE



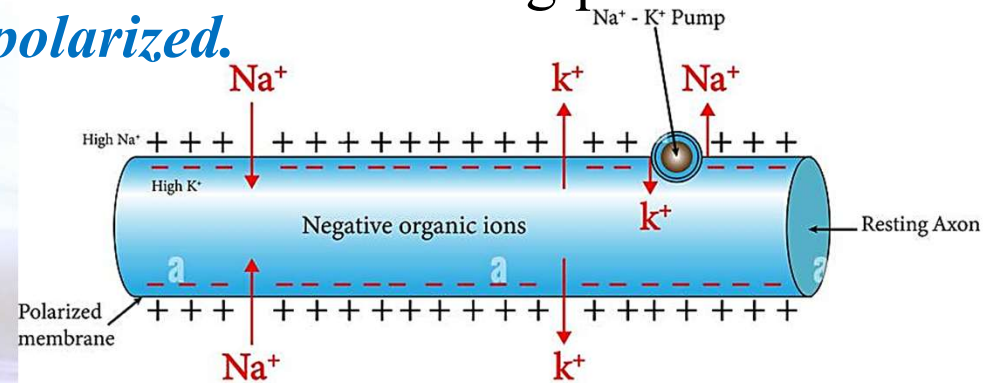
Self study

Read about the structure of different neurones



RESTING POTENTIAL.

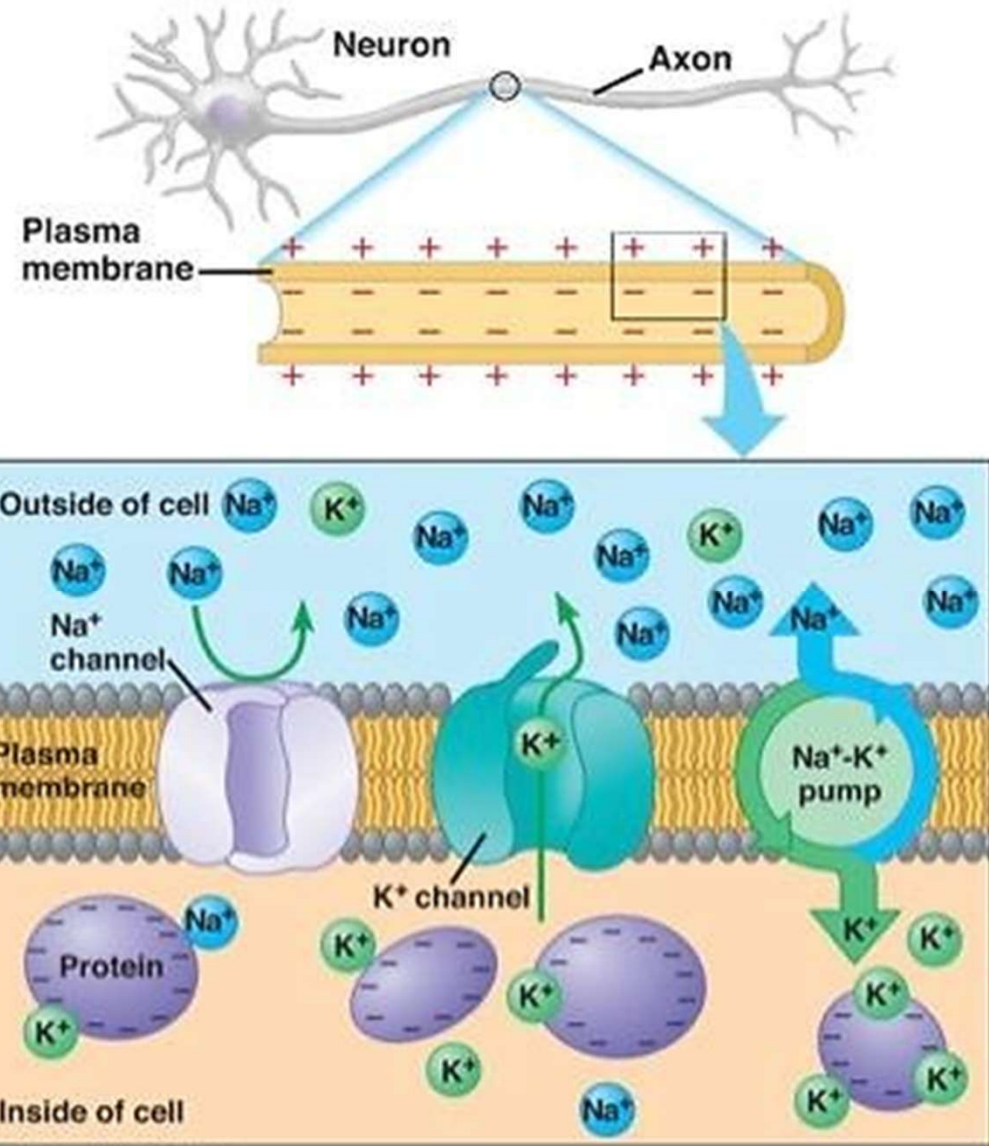
- In normal state, the membrane of a neuron is **negatively charged internally** with respect to the outside because of **an unequal distribution of charged ions**. The potential difference varies depending on the neuron but **lies in the range 50-90 mV**, most usually **around -70 mV**. This is known as the resting potential and in this condition the membrane is said to **be polarized**.



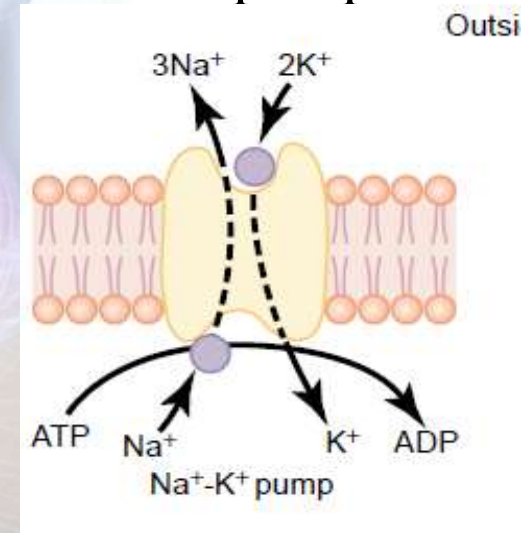
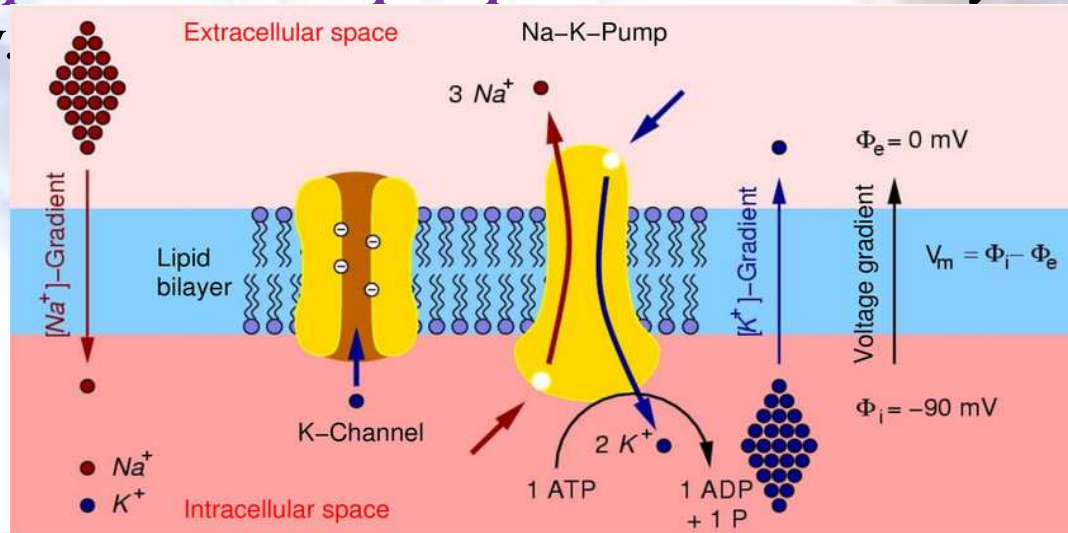
- The resting potential is the result of the distribution of four ions: potassium (K^+), sodium (Na^+), chloride (Cl^-) and organic anions (COO^-) however the distribution of chloride ions and other ions is **ignored since it does not play a vital role in the process**. On the **outside**, Na^+ , Cl^- and Ca^{2+} are present in higher concentrations than inside the cell. By contrast, **the inside** of the axon has a higher concentration of K^+ and COO^-

NOTE.

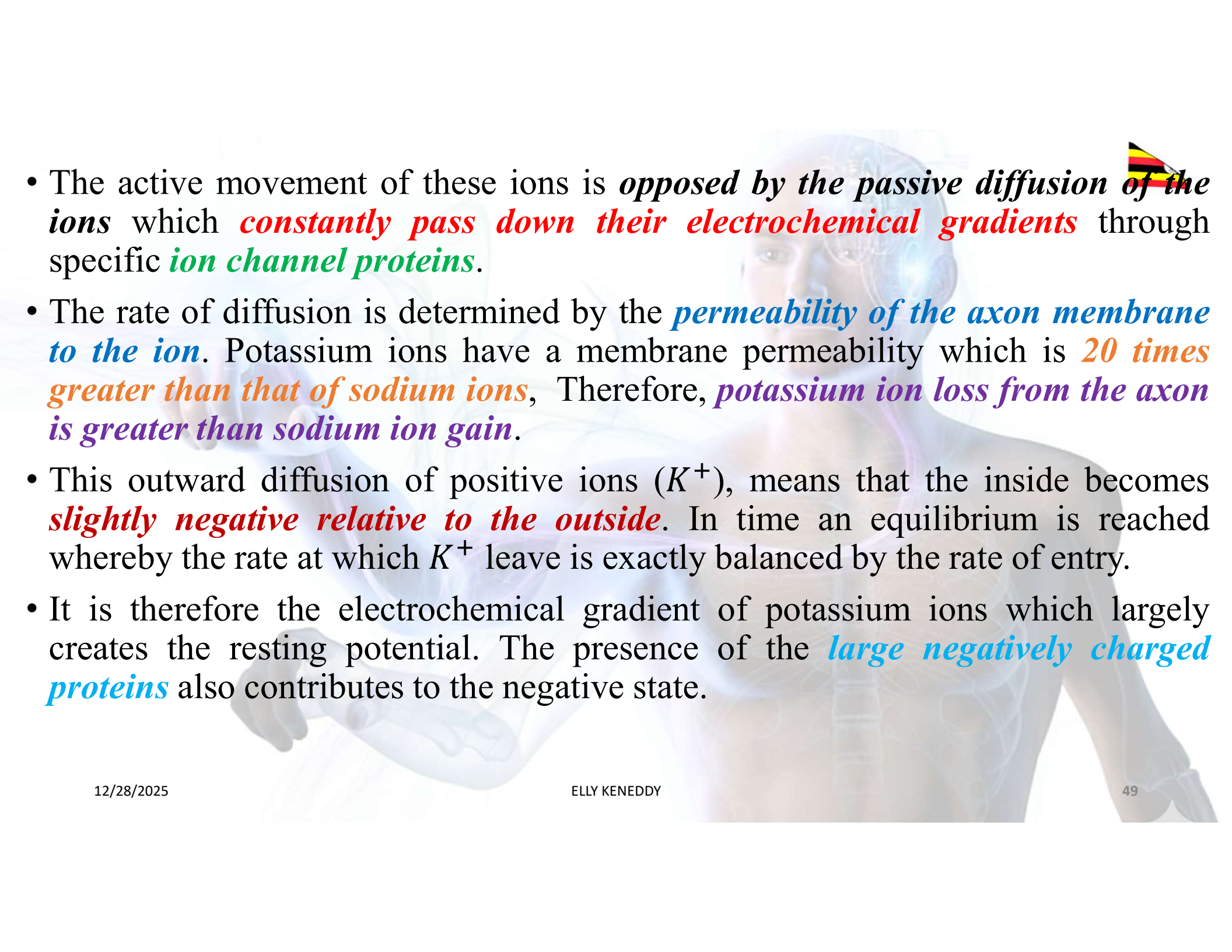
- This unequal distribution of ions results from a combination of *active transport* and *diffusion of sodium and potassium ions* across the cell membrane, and the *inability of large organic anions to pass out of the cell*



- The resting potential is maintained by the **active transport of ions against their electrochemical gradients** by **sodium/potassium (Na^+ / K^+) pumps**. These are carrier proteins **located in the cell surface membrane of the axon**. They are driven by energy supplied by **ATP**. **3 sodium ions are actively pumped out** of the axon and **2 potassium are pumped into** the axon by the Na^+ / K^+ pump simultaneously.



- Although both Na^+ / K^+ are **both positively charged**, the **outward movement of sodium ions is greater** than inward movement of potassium ions creating a chemical gradient.

- 
- The active movement of these ions is *opposed by the passive diffusion of the ions* which *constantly pass down their electrochemical gradients* through specific *ion channel proteins*.
 - The rate of diffusion is determined by the *permeability of the axon membrane to the ion*. Potassium ions have a membrane permeability which is *20 times greater than that of sodium ions*, Therefore, *potassium ion loss from the axon is greater than sodium ion gain*.
 - This outward diffusion of positive ions (K^+), means that the inside becomes *slightly negative relative to the outside*. In time an equilibrium is reached whereby the rate at which K^+ leave is exactly balanced by the rate of entry.
 - It is therefore the electrochemical gradient of potassium ions which largely creates the resting potential. The presence of the *large negatively charged proteins* also contributes to the negative state.

ACTION POTENTIAL.



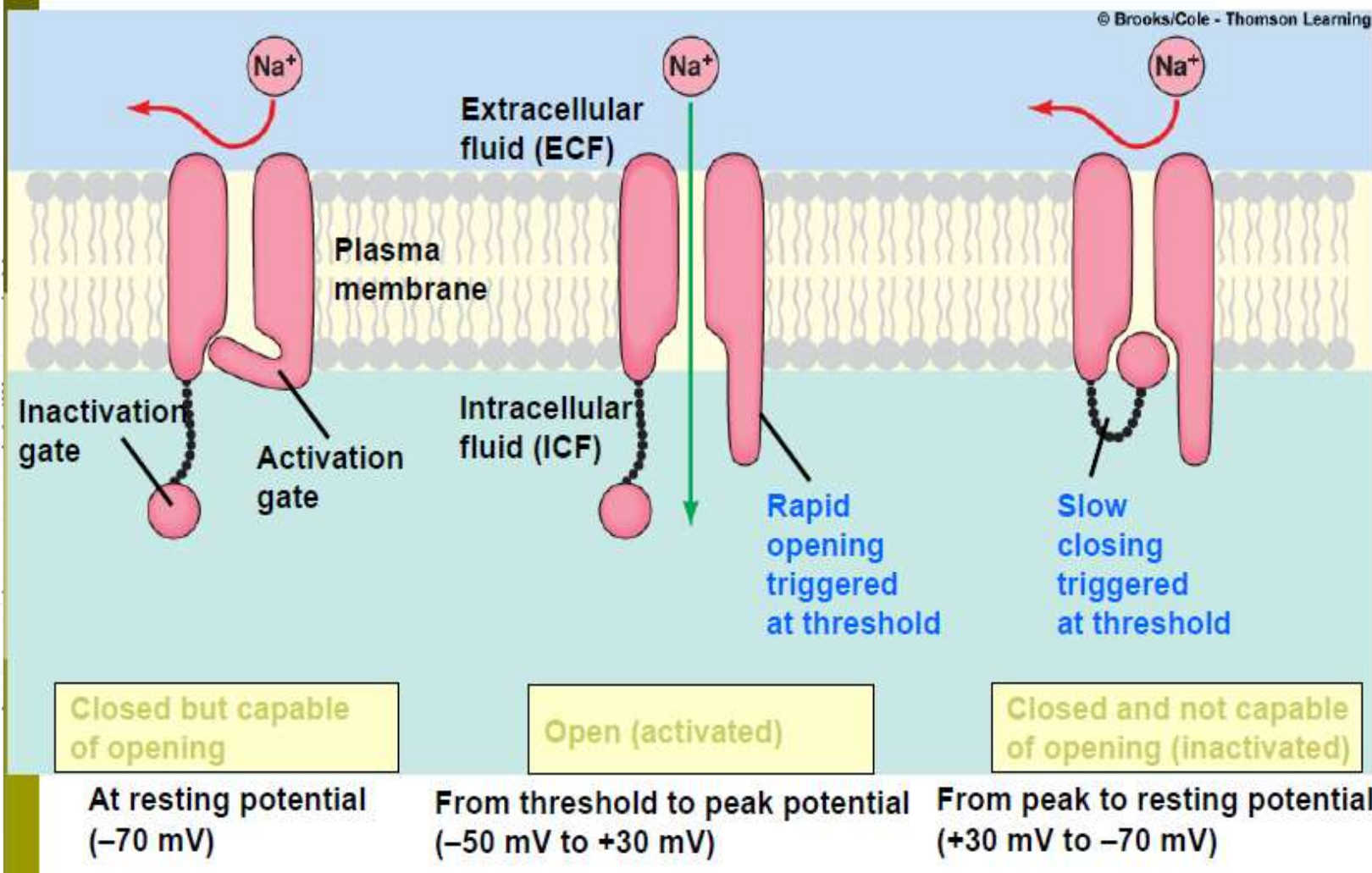
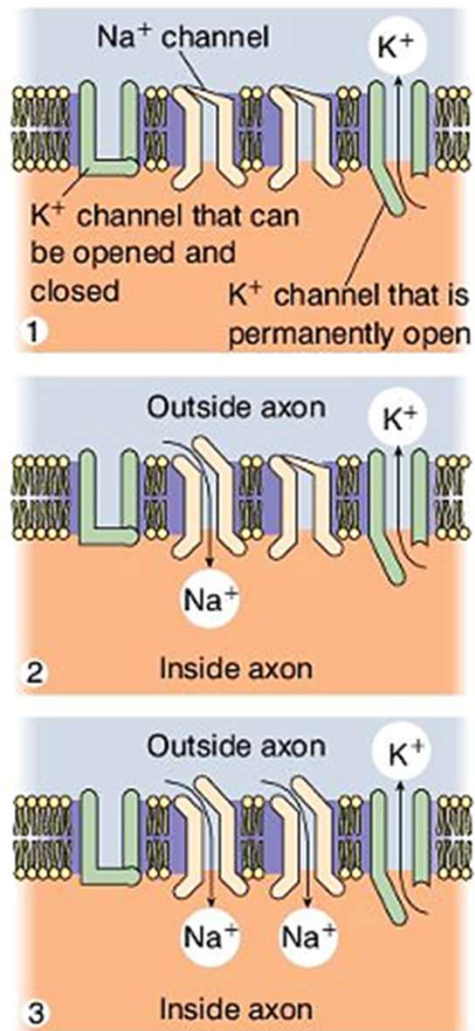
- By **appropriate stimulation**, the charge on a neuron can be reversed. As a result, the **negative charge inside the membrane of -70mV changes to a positive charge of around $+40\text{ mV}$.**
- This is known as the **action potential** and in this condition the membrane is said to be **depolarized**. Within about 2ms (two thousandths of a second) the same portion of the membrane returns to resting potential (-70 mV inside).
- This is known as **repolarization**. Provided the stimulus exceeds a certain value, called the **threshold value**, an action potential results. Above the threshold value the **size of the action potential remains constant**, regardless of the size of the stimulus
- This is generated by a change in the sodium ion channel. This channel and some of the potassium ion channels, are known as **gated channels**, meaning they can be **opened** or **closed with polypeptide chains** called gates.

- When the *gate is closed*, the *membrane is not very permeable to the ion* that normally passes through the gate. *Opening the gate increases permeability.*
- Regulation is achieved mainly by the sodium gate which is closed in the resting cell. This helps to explain why the membrane is normally 20 times more permeable to potassium.
- An action potential is *generated by a sudden and brief opening of the sodium gates* however *Potassium gated channels remain closed*. This happens in response to a stimulus which brings about a *slight depolarization*, or *loss of negative charge inside* the axon membrane.
- Opening the gates *increases the permeability of the axon membrane to sodium ions* which *enter the axon by diffusion* because *there is a high concentration outside the neuron* which has been maintained by the sodium potassium pump.
- The influx of sodium ions depolarizes the membrane and this depolarization in turn *increases the membrane's permeability to sodium, leading to greater influx of Na^+* and *further depolarization.*

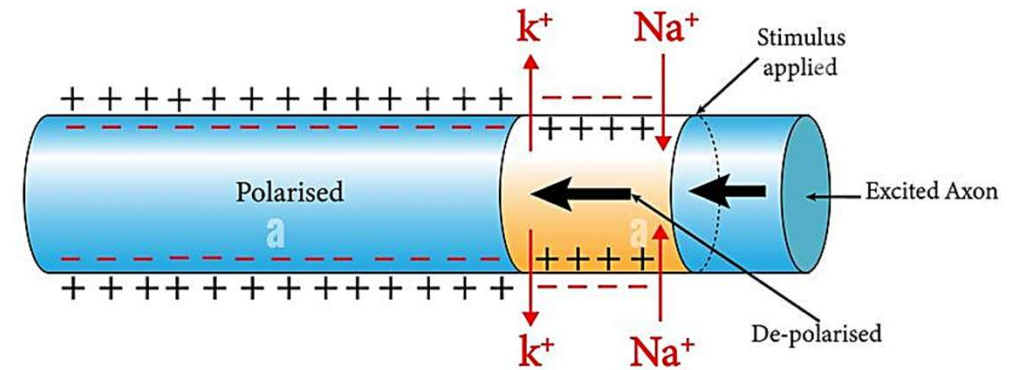
Voltage-Gated Sodium Channel



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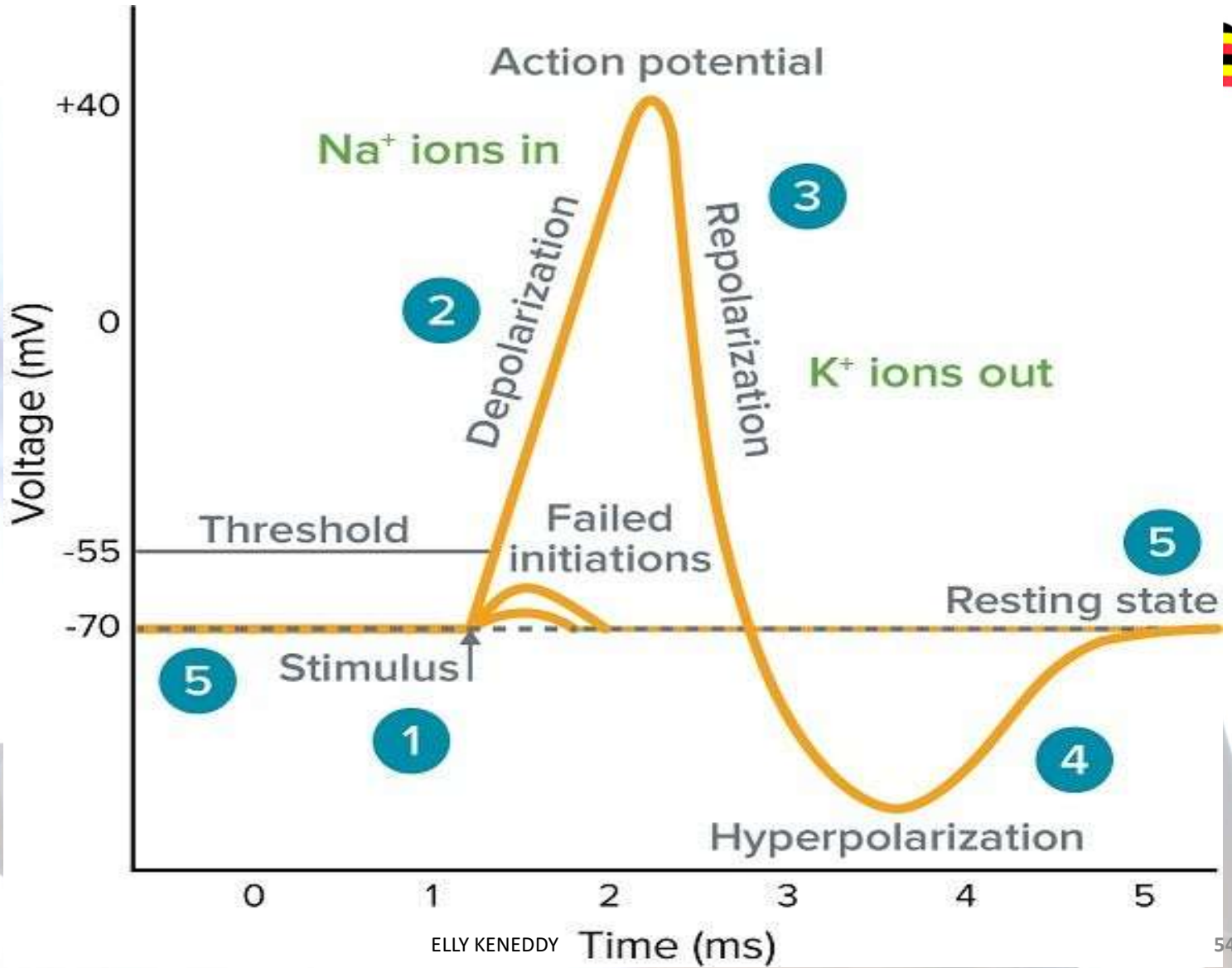


- At first, the negative *resting potential is cancelled out*, at which point the membrane is *completely depolarized*, then it makes the *potential difference across the membrane becomes more positive* until when *threshold is reached and an action potential* is generated.

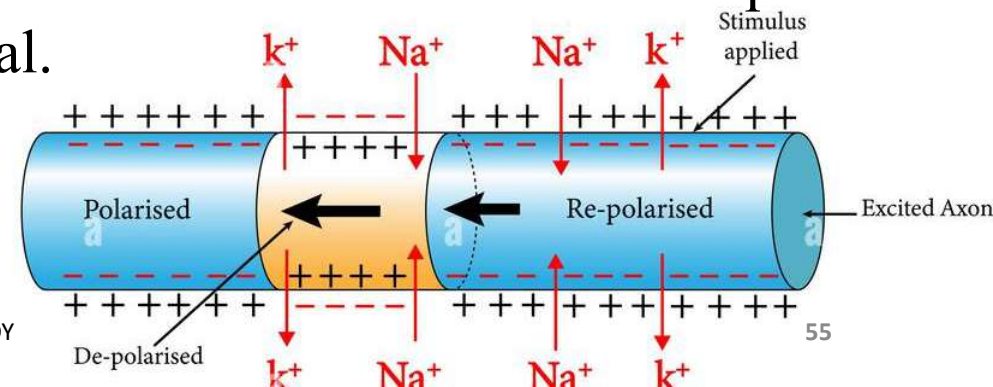


Note.

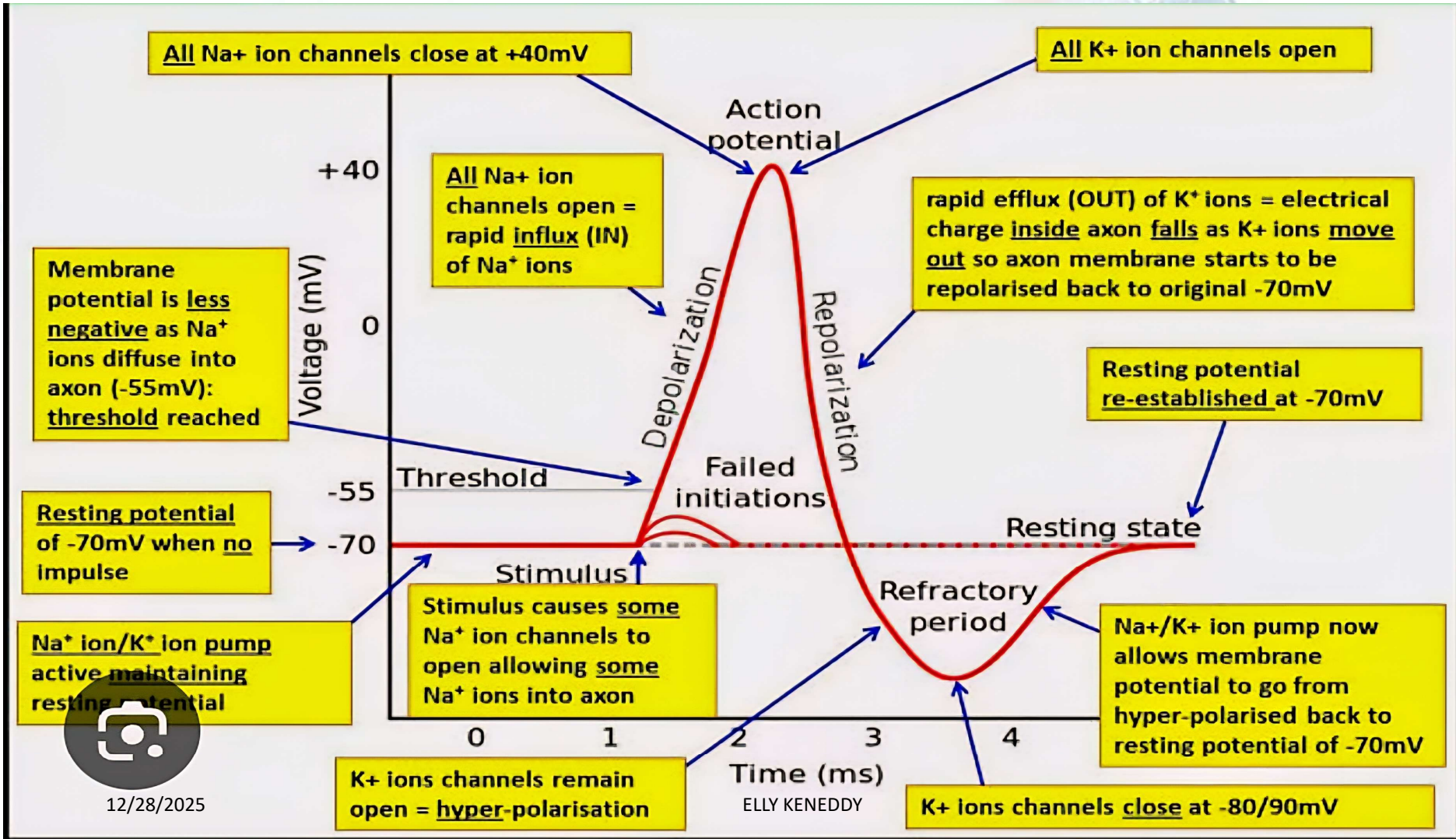
- Sodium gates are sensitive to depolarization, the greater the depolarization, the more gates open. This allows more sodium into the cell, causing greater depolarization.
- The two processes therefore reinforce each other. This is called a positive feedback loop. It causes an explosive acceleration within in the rate of entry of sodium.



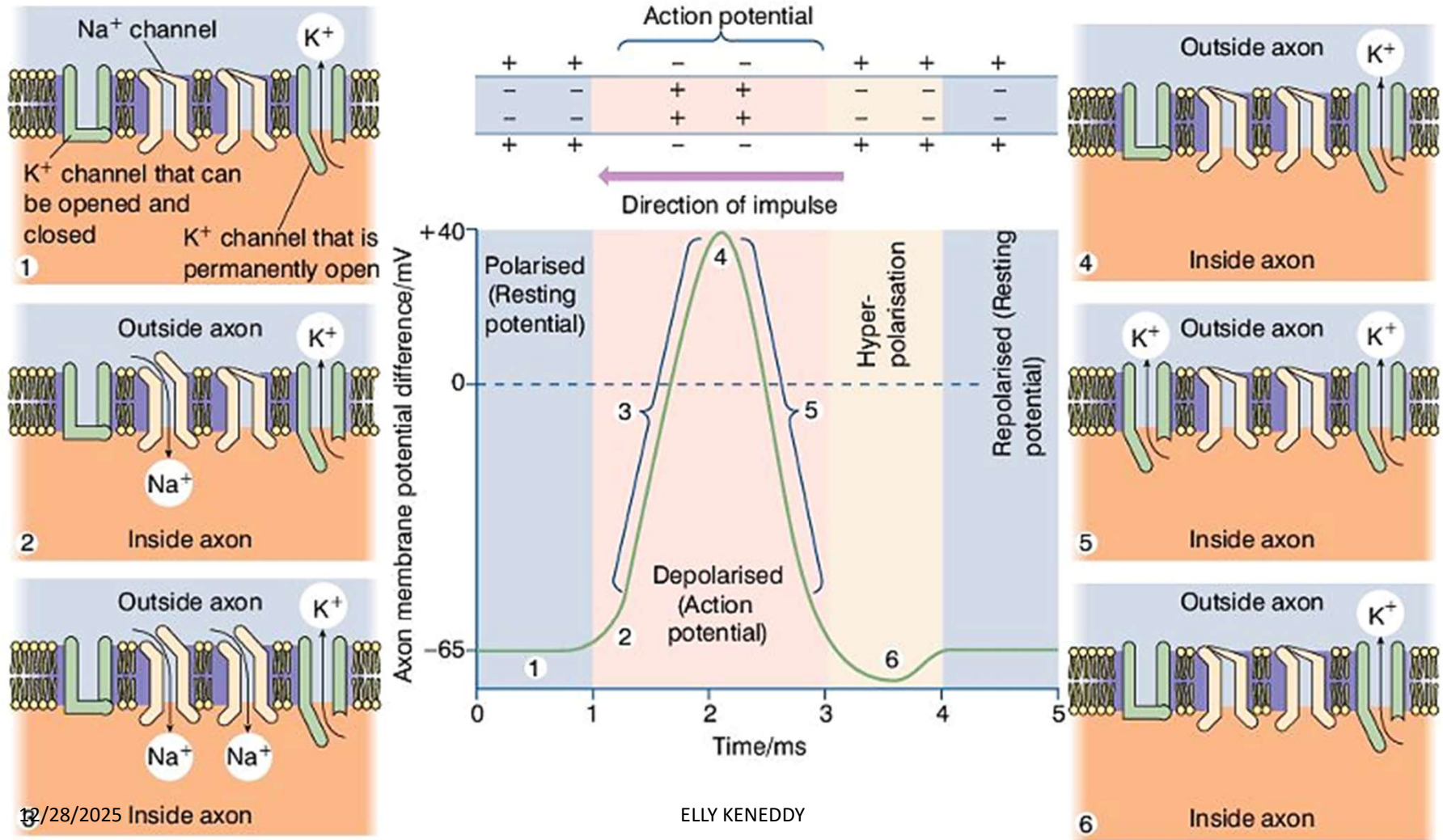
- *At the peak of the action potential*, the **sodium gates start to close again**. **Sodium permeability therefore declines**. The sodium-potassium pump continues to work during this time, so it **gradually begins to restore the original resting potential**. This repolarization is shown by the falling phase of the action potential 'Peak' and results in the membrane potential returning to its original level.
- There is a *slight overshoot into a more negative potential* than all the original resting potential. This is called **hyperpolarization**. It is due to the *slight delay in closing the potassium gates compared with the sodium gates*.
- As potassium ions continue to return to the inside of the axon their positive charge restores the normal resting potential.



SUMMARY.



GRAPHICAL REPRESENTATION.



12/28/2025 Inside axon

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action potential, and in this condition the membrane is said to be **depolarised**. This depolarisation involves the **voltage-gated** channels. The sequence of events is described below and the numbers relate to the stages shown in Figure 2.

1. At resting potential some potassium ion channels (leak channels) are open but the potassium voltage-gated and sodium voltage-gated channels are closed.
2. As a result of the stimulus some voltage-gated sodium channels in the axon membrane open and therefore sodium ions diffuse in through the channels along their electrochemical gradient. Being positively charged, they begin the reversal in the potential difference across the membrane and the membrane depolarises. Voltage-gated potassium channels remain closed.
3. As sodium ions enter, so more voltage-gated sodium channels open, causing an even greater influx of sodium ions. This is an example of positive feedback (Topic 14.1). An action potential will only occur if the membrane depolarises enough to allow the remaining voltage-gated sodium channels to open. This is known as the threshold potential (approximately -5 to -15 mV less negative than the resting potential).
4. Once the action potential of around $+40$ mV has been established (depolarisation has occurred), the voltage

gates on sodium channels close (so further influx of sodium is prevented) and the voltage gates on the potassium channels begin to open.

5. With some voltage-gated potassium channels now open this causes the other voltage-gated channels to open and more potassium ions diffuse out, causing repolarisation of the axon membrane.
6. The outward movement of these potassium ions and the slight delay in the closing of the gates causes the temporary overshoot of the electrical gradient, with the inside of the axon being more negative (relative to the outside) than usual. This is called **hyperpolarisation**. The gates on the potassium channels now close and the activities of the sodium–potassium (cation) pumps cause sodium ions to be pumped out and potassium ions in, once again. The axon membrane returns to a resting potential and the axon is said to be **repolarised**.

The terms **action** potential and **resting** potential can be misleading, because the movement of sodium ions inwards during the action potential is purely due to diffusion – a passive process – and the resting potential is maintained by active transport – an active process. The term action potential simply means that the axon membrane is transmitting a nerve impulse, whereas resting potential means that it is not.

REFRACTORY PERIOD



- Following an action potential, the ***outward movement of potassium ions*** quickly ***restores the resting potential***. However, for about 1ms after an action potential the ***inward movement of sodium is prevented***. This means that a further action potential cannot be generated for at least 1ms. This is called the ***refractory period***.
- The refractory period is important for two reasons:
 - It means the action potential can only be propagated in the region which is not refractory, i.e. in a forward direction. The ***action potential is thus prevented from spreading out in both directions*** until it occupies the whole neurone.
 - By the end of the refractory period the action potential has passed further down the nerve. ***A second action potential will thus be separated from the first one by the refractory period***, which therefore sets an upper limit to the frequency of impulses along a neurone.

REFRACTORY PERIOD

- **The absolute refractory period** lasts around 1ms and during this period *no new impulses can be propagated however intense the stimulus*.
- Where the stimulus is at the threshold value, the *resting potential of the axon must be restored first* before a new action potential can be formed.
- **The relative refractory period** lasts around 5ms and during this period *new impulses can be propagated only if the stimulus is more intense than the normal threshold level*.

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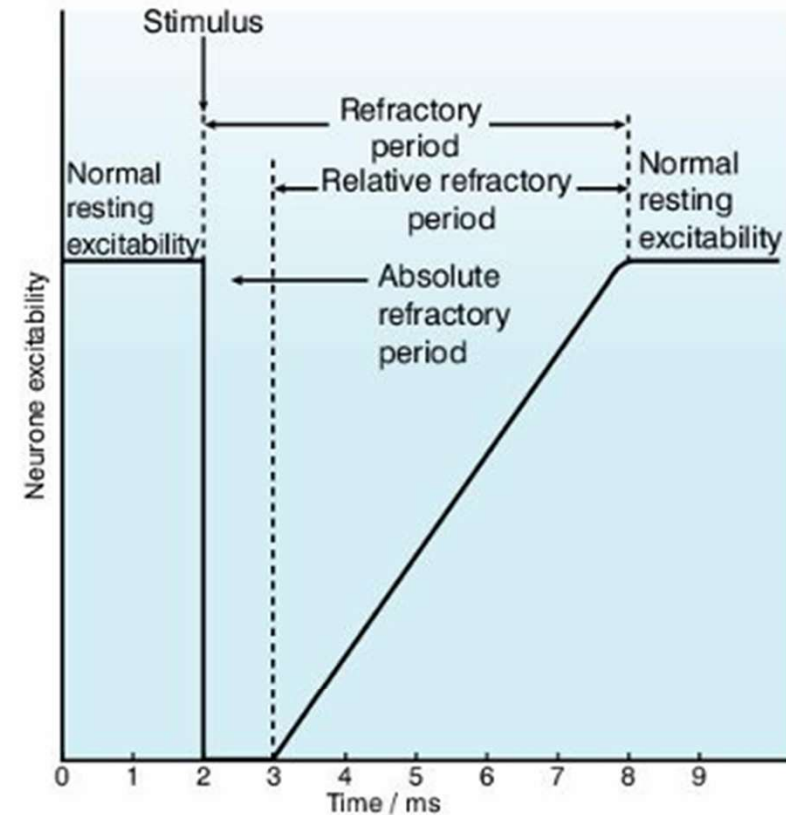


Figure 1 Graph illustrating neurone excitability before and after a nerve impulse

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IMPULSE TRANSMISSION UNDER VARYING STIMULATIONS



- A nerve impulse is a wave of depolarization that moves along the surface of a nerve cell. Action potentials are propagated, that is *self generated*, along the axon *by the effect of sodium ions entering the axon*.
- Action potentials are capable, in theory, of *being transmitted over an infinite distance*, that is, *they do not lose strength*. The reason for this is that the *production of an action potential at each point* along the axon is *a self-generating event* resulting from a change in the local concentration of ions.

Note.

- In both unmyelinated and myelinated nerve fibers, a nerve impulse is an *all-or-none event*. A neuron will not transmit an impulse unless given a stimulus of a certain strength. Once this *threshold level of stimulation is reached*, *an action potential will be set up*.

ALL-OR-NOTHING LAW

- It does not make any difference of *how far beyond the threshold level the stimulus is, the action potential is either set up, if the stimulus reaches the threshold, or it is not, if it does not.*
- Increasing the stimulus above the threshold *does not cause a larger action potential* because all nerve impulses in a particular neurone *have the same amplitude.*

The law states that: Provided the stimulus exceeds the threshold value, an action potential results. Above the threshold value the size of the action potential remains constant, regardless of the size of the stimulus.

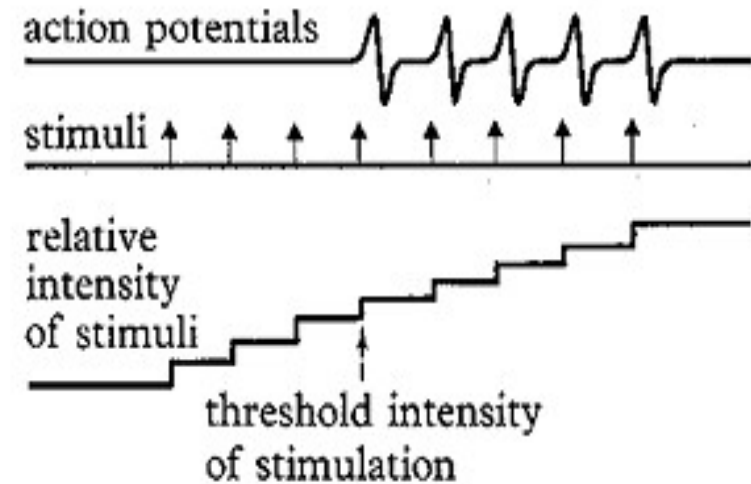


Figure 18.6 The all-or-nothing law. One end of an axon is stimulated with eight electrical shocks of gradually increasing intensity and action potentials are recorded from the other end. The results indicate that a stimulus either evokes a full response or no response at all.

CODING FOR STIMULUS INTENSITY.



- It has also been shown that the speed at which the impulse is transmitted is ***not affected by the strength of the stimulus.***
- ***So how does the body distinguish between weak and strong stimuli?***
- The answer lies with the ***frequency of the action potentials*** (the number in a given time).
- The ***stronger the stimulus***, within limits, the ***greater the frequency of action potentials set up*** there fore, Frequency is proportional to intensity. This is known as the ***frequency code.***
- Impulses at the frequency of ***10 per nerve fibre per second*** keep the biceps muscle in tone (in a state of ***partial concentration ready for action***). About 50 impulses per fibre per second are needed for steady contraction.
- Most nerve fibres can conduct impulses in the region of 10—100 per second, although some can conduct as many as 500 per second in natural situations.

FACTORS AFFECTING IMPULSE TRANSMISSION SPEED.

Axon diameter/ cross sectional area.

- The *greater the axon diameter*, the *faster the speed of transmission*. This is because there is *greater area of the membrane over which ionic exchange can take place* facilitating faster generation of action potentials. Myelin sheath stops ion leakage; therefore, *large diameter is only important for unmyelinated neurons.*

Temperature.

- Homoiotherms with a *high constant body temperature have faster impulse transmission* than poikilotherms which have fluctuating body temperature. This is because a high constant body temperature *facilitates faster diffusion of ions into the axon* required *for impulse propagation leading to faster impulse transmission.*



The myelin sheath.

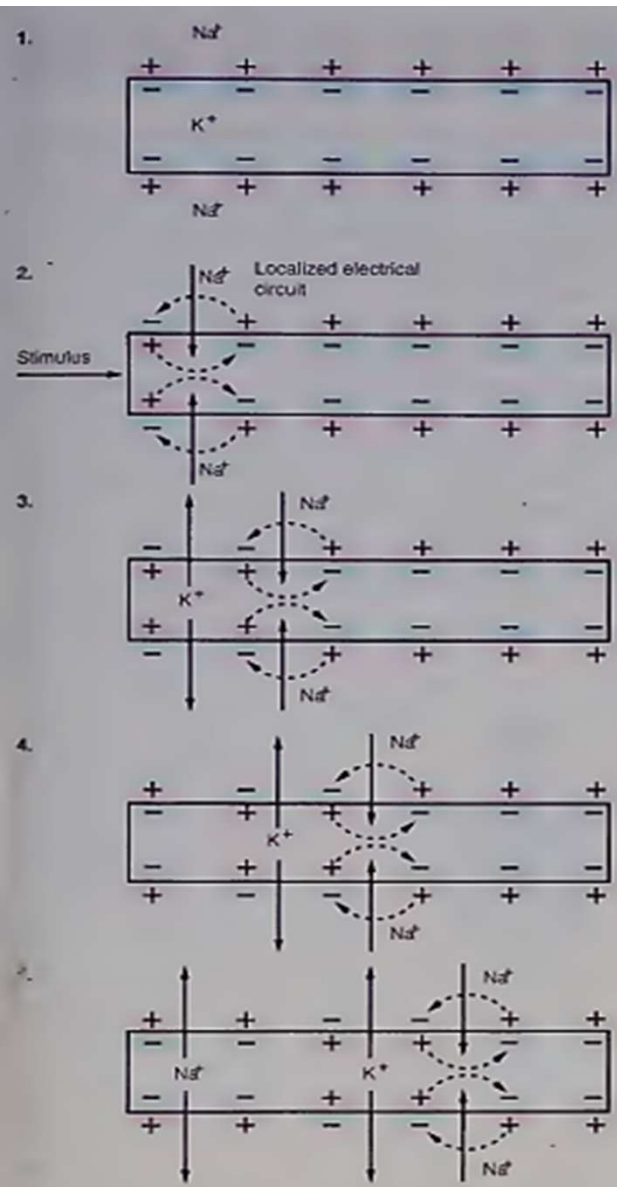
- Myelinated neurons *conduct impulses faster than non-myelinated ones.*
- The myelin sheath, which is produced by the Schwann cells, is not continuous along the axon, but is absent at points called nodes of Ranvier which arise every millimeter or so along the neurone's length.
- As the fatty myelin *acts as an electrical insulator*, an *action potential cannot form in the part of the axon covered with myelin.* It can, however, *form at the nodes.*
- The action potentials therefore *jump(leap) from node to node* (saltatory conduction), *increasing the speed with which they are transmitted.*
- Saltatory conduction allows nerve impulses to be transmitted very quickly. It is also highly efficient because *relatively few ions cross the membranes at the nodes, so active transport is minimized.* (for restoring resting potential)



MULTIPLE SCLEROSIS

- Multiple sclerosis (MS) is a major neurological disease that results in the gradual *deterioration of the myelin sheath* (demyelination) around neurons of the brain and spinal cord.
- In demyelinated regions, hardened scars or plaques (scleroses) replace the sheath. These scars *interfere with the transmission of nerve impulses*, slowing them down and *causing a gradual loss of motor activity*. The symptoms, including *loss of coordination, blurred vision* and *weakness*.
- The precise *cause of MS is unknown*, but evidence strongly suggests that *proteins within the myelin sheath are attacked by certain enzymes* or *by cells* from the body's own immune system.
- One theory suggests that MS *appears in people who were infected by the measles virus during childhood*. According to the theory, the *virus lies dormant in the myelin sheath* until it *emerges later in life, coated with protein from myelin*. The *immune system attacks the virus and the myelin proteins, destroying the myelin sheath*.

Impulse transmission along un-myelinated axon.



1. At resting potential there is a high concentration of sodium ions outside and a high concentration of potassium ions inside the neurone.
2. When the neurone is stimulated sodium ions rush into the axon along a concentration gradient causing depolarization of the membrane.
3. Localized electrical circuits are established which cause further influx of sodium ions and so, progression of the impulse. Behind the impulse, potassium ions begin to leave the axon along a concentration gradient.
4. As the impulse progresses, the outflux of potassium ions causes the neurone to become repolarized behind the impulse.
5. After the impulse has passed and the neurone is repolarized, sodium is once again actively expelled in order to increase the external concentration and so allow the passage of another impulse.

THE SYNAPSE.

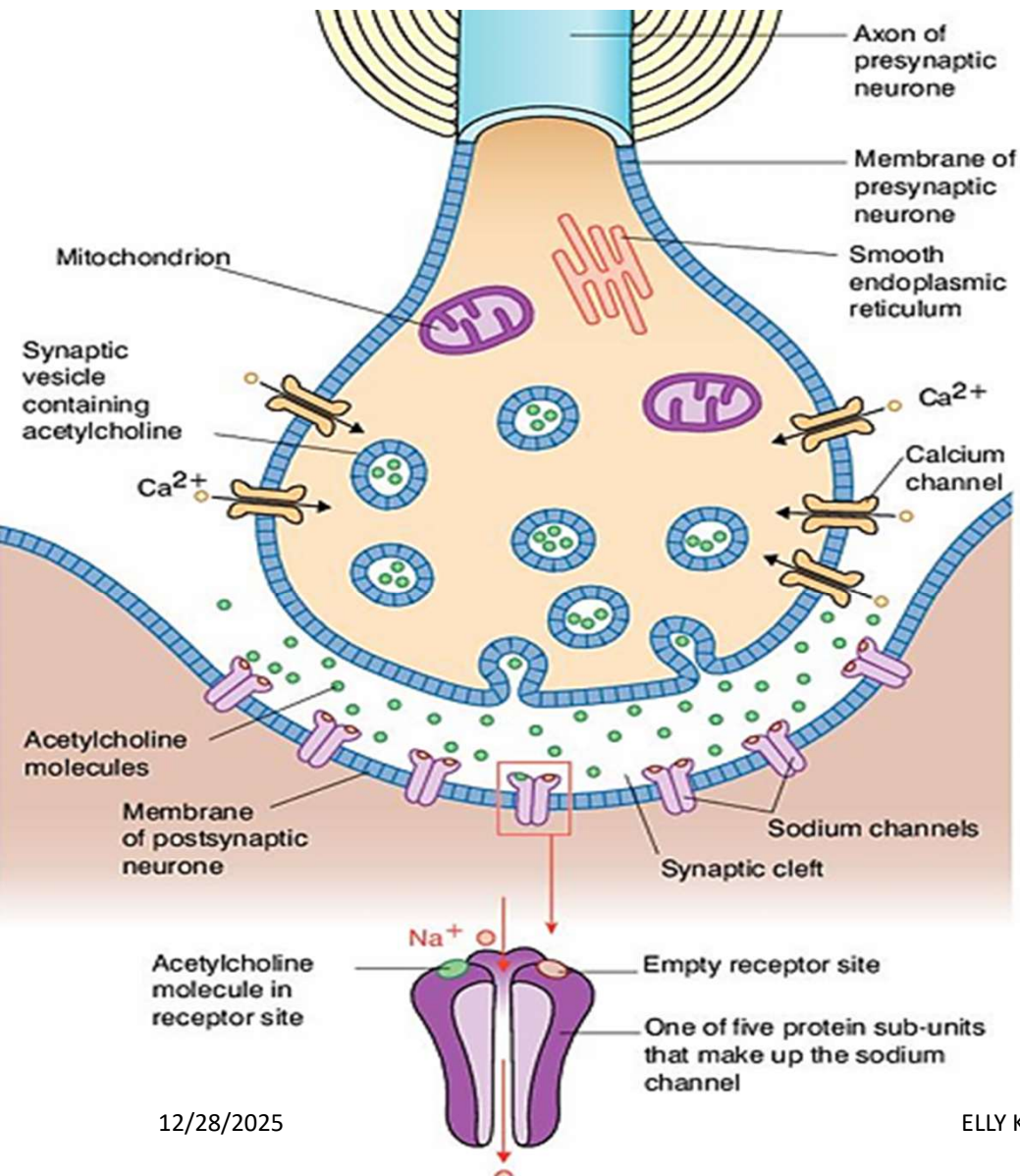


- The nerve cells are *not in direct contact with each other*. They join at synapses. A synapse is the *point where the axon of one neurone clasps or joins the dendrite or cell body of another*. The gap between the two is around 20 nm in width.
- The synapse must in some way *pass information across itself from one neurone to the next*. This is achieved in the vast majority of synapses by *chemical transmission*, although at some synapses the *transmission is electrical*.
- Chemicals which transmit messages across the synapse are called *neurotransmitter substances*.
- The two main ones in the peripheral nervous system are *acetylcholine* and *noradrenaline*, although others include *dopamine* and *serotonin*.
- Neurones *using acetylcholine* as a neurotransmitter are termed *cholinergic* neurones whereas those *using noradrenaline* are called *adrenergic neurones*.

STRUCTURE OF THE SYNAPSE

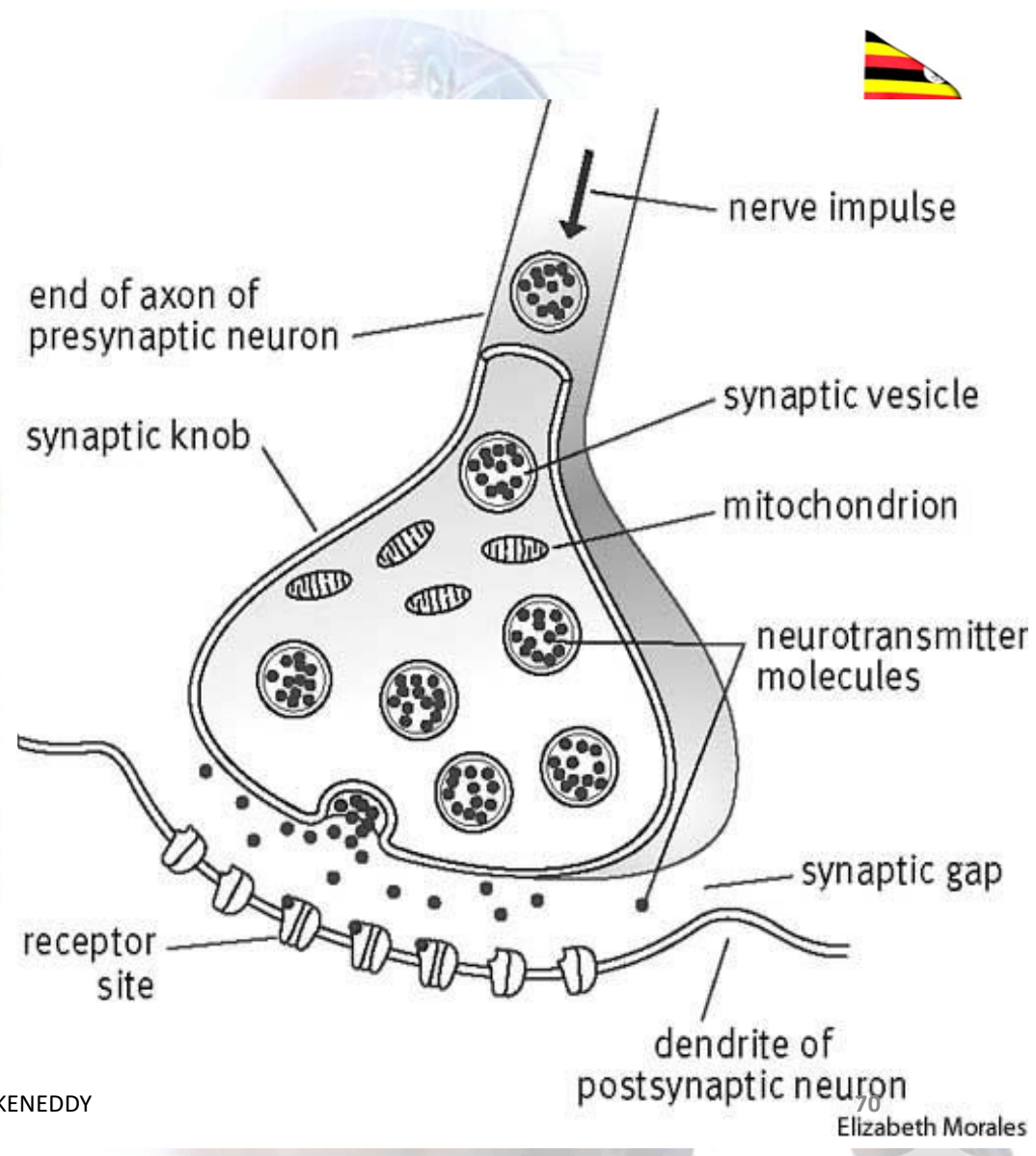


- At the synapse the *nerve axon is expanded* to form *a bulbous ending* called the *axon terminal* or *synaptic knob*. The cytoplasm of the synaptic knob contains *numerous mitochondria*, *microfilaments* and structures called *synaptic vesicles*.
- The vesicles *contain a neurotransmitter substance* such as *acetylcholine* or *noradrenaline*.
- The neurone immediately before the synapse is known as the presynaptic neurone and is bounded by the *presynaptic membrane*.
- The neurone after the synapse is the postsynaptic neurone and is bounded by the *postsynaptic membrane*.
- Between the two *is a narrow gap, 20 nm wide*, called the *synaptic cleft*.
- The postsynaptic membrane possesses a number of large protein molecules known as *receptor molecules*.



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Elizabeth Morales

UNDERSTANDING CHECK.

- *Explain the significance of warmups before physical activity and the use of cold packs in first aid.*

- **Hint**: warm ups increase muscle and tendon elasticity, increases blood flow, increases heat generation increasing body temperature. Cold ice packs decrease the temperature of the injured area

- **Note**. Explain using the hint above in relation to impulse transmission and muscle contraction.

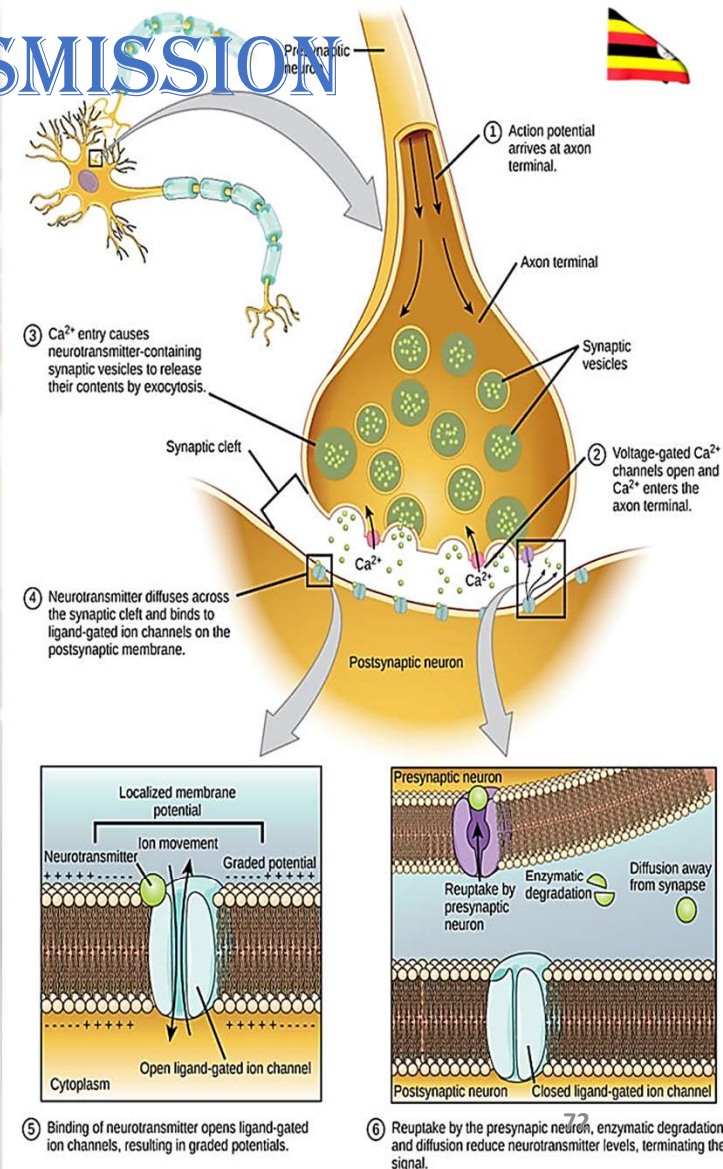


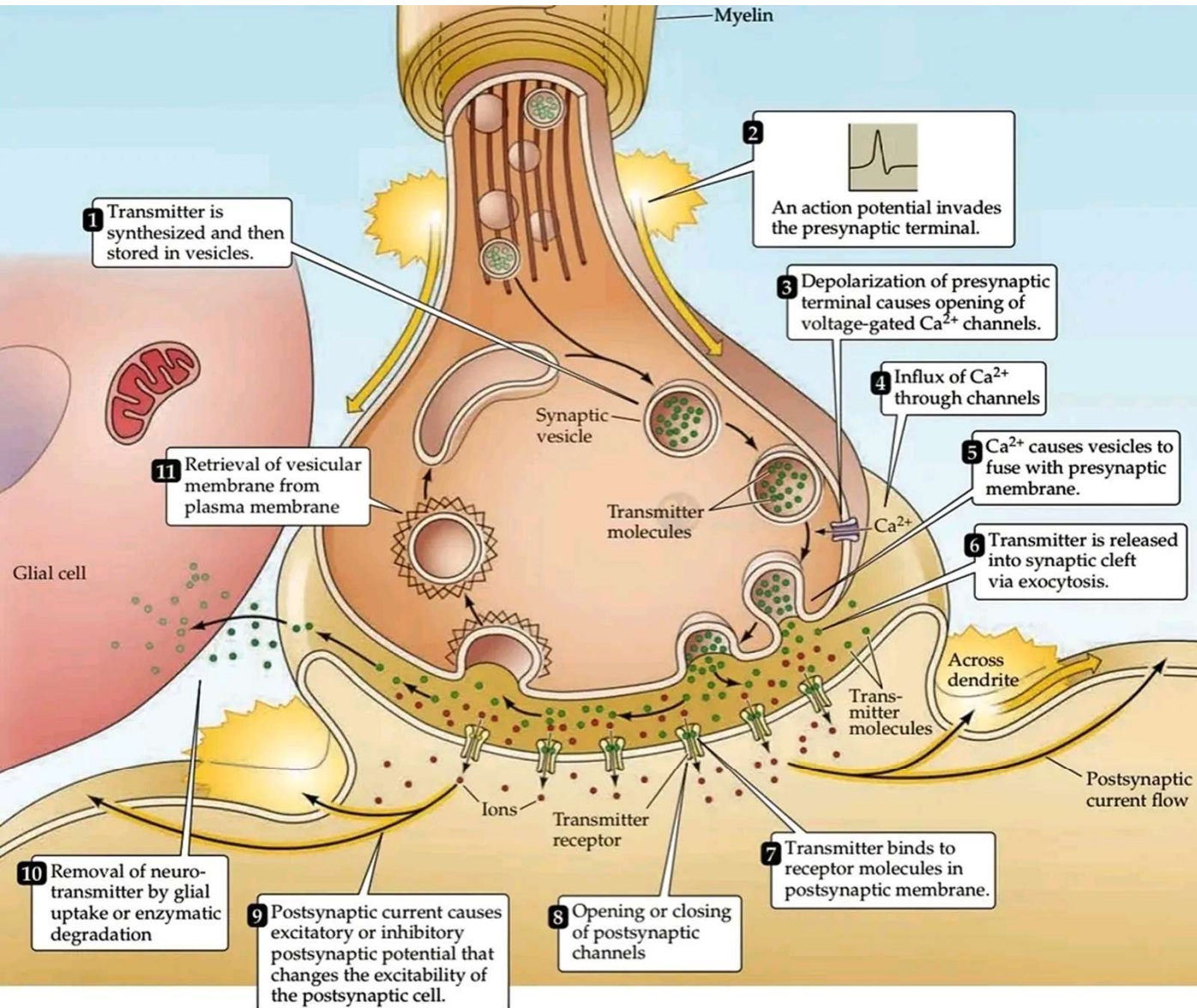
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MECHANISM OF SYNAPTIC TRANSMISSION


- In the following mechanism neuro-transmitter **acetylcholine will be used**. Acetylcholine is synthesized within the presynaptic knob and **stored in synaptic vesicles**.
- The **arrival of nerve impulses** at the synaptic knob **depolarizes the presynaptic membrane**, causing **calcium channels to open**, increasing the permeability of the membrane to calcium ions. Calcium ions **diffuse into the presynaptic knob**.
- Calcium ions in the synaptic **knob cause synaptic vesicles to migrate** and **fuse with the presynaptic membrane**, releasing their contents into the **synaptic cleft by exocytosis**.
- The vesicles then return to the cytoplasm where they are refilled with transmitter substance.





- 1 Action potential arrives at axon terminal
- 2 Voltage-gated Ca^{2+} channels open
- 3 Ca^{2+} enters the presynaptic neuron
- 4 Ca^{2+} signals to neurotransmitter vesicles
- 5 Vesicles move to the membrane and dock
- 6 Neurotransmitters released via exocytosis
- 7 Neurotransmitters bind to receptors
- 8 Signal initiated in postsynaptic cell

Graded potential

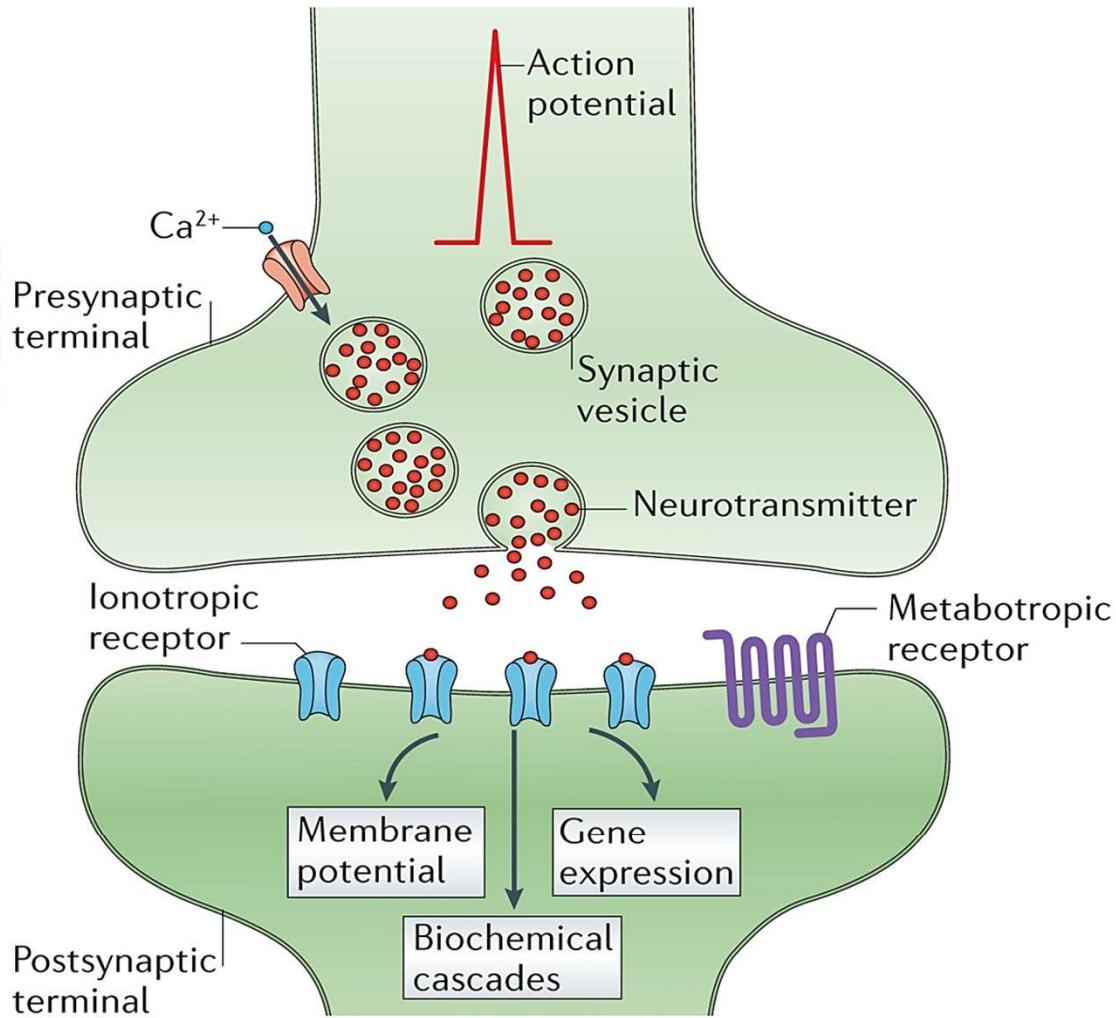
- Acetylcholine *diffuses across the synaptic cleft*, creating a delay of ~~about~~  about 0.5ms, and *attaches to a specific receptor site* (a process known as *receptor activation*) on the postsynaptic membrane that recognizes the molecular structure of the acetylcholine molecule .
- The arrival of the acetylcholine *causes a change in shape of the receptor site* which *results in sodium ion channels opening up in the postsynaptic membrane.*
- Entry of sodium ions through the postsynaptic membrane *causes depolarization of the membrane.* This *excites the cell, leading to generation of an action potential when the threshold is attained.*
- Having produced a change in the permeability of the postsynaptic membrane, the *acetylcholine is immediately removed from the synaptic cleft*, by the *enzyme acetylcholinesterase (AChE)*, also called *cholinesterase.*
- The enzyme is situated on the postsynaptic membrane and *hydrolyses the acetylcholine to choline.* The choline is reabsorbed into the synaptic knob to be *recycled into acetylcholine by synthetic pathways in the vesicle*

MECHANISM OF IMPULSE TRANSMISSION IN ELECTRICAL SYNAPSES.

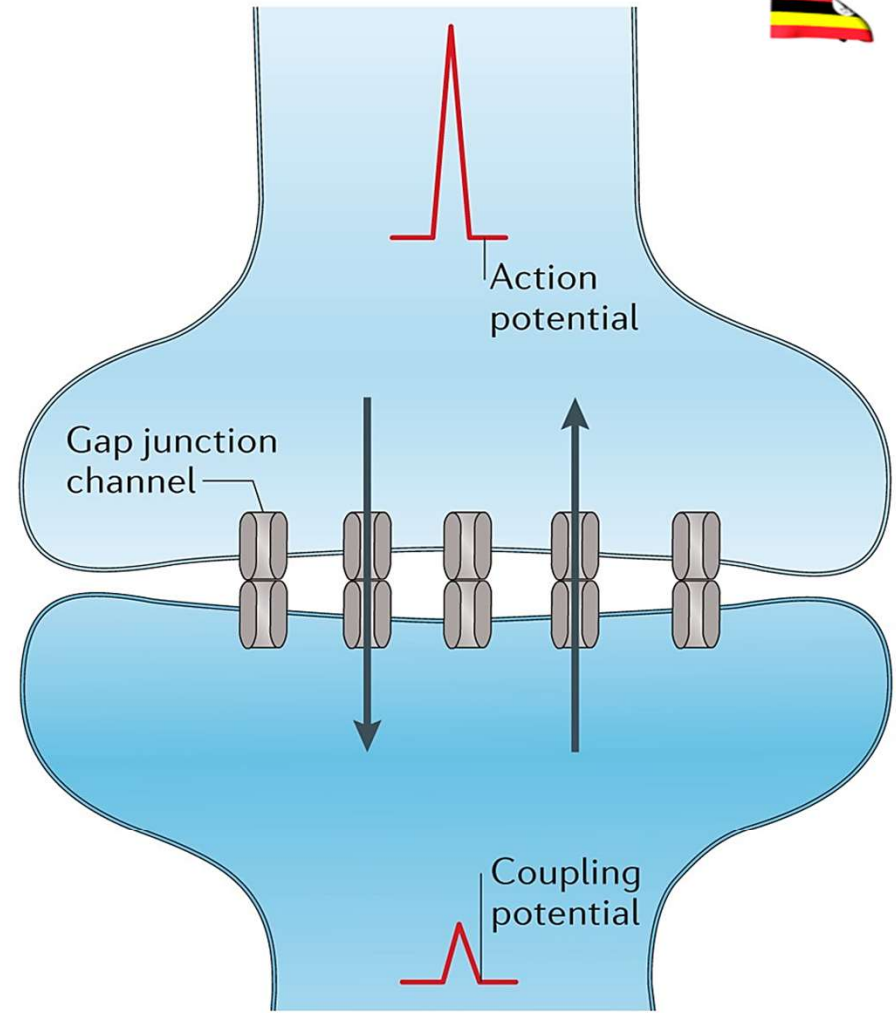


- In an electrical synapse, the *presynaptic* and *postsynaptic membranes* are *close together*, *with pores made of protein linking the cytoplasm of the two cells*. This *enables electrical signals to jump relatively unchanged* from *the presynaptic cell* to the *postsynaptic cell*.
- Transmission is very fast because there is *no intervening chemical*, therefore electrical synapses are *found where responses have to be very quick*. Electrical synapses are found in pathways that control the escape responses of some animals.
- In mammals, they occur in nerve pathways which control rapid eye movements; they are also common in the heart.

a Chemical synapse



b Electrical synapse



EXCITATORY SYNAPSES



- Excitatory synapses *use acetylcholine as the neurotransmitter.*
- When an action potential reaches the presynaptic membrane, it *depolarizes the membrane.* This depolarization *triggers the opening of calcium ion channels* in the presynaptic membrane.
- *Calcium ions diffuse into the presynaptic knob*, causing the presynaptic vesicles containing acetylcholine to *migrate and fuse with the presynaptic membrane.* The acetylcholine is *released into the synaptic cleft by exocytosis* and *diffuses across the synapse.* Then it *binds to specific protein receptor molecules on the postsynaptic membrane*, a process known as receptor activation.
- Receptor activation *causes sodium ion channels to open*, making the membrane more permeable and *producing a graded potential.* If enough acetylcholine is released, *the graded potential may become large enough to generate an action potential.*

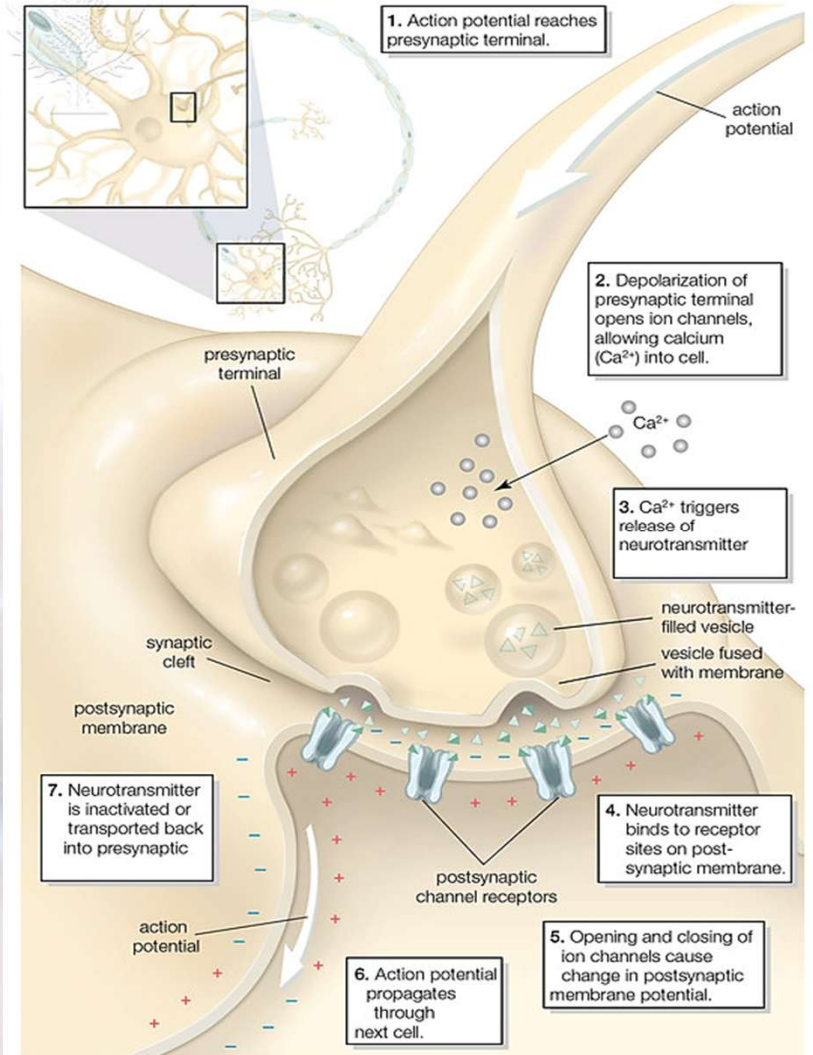
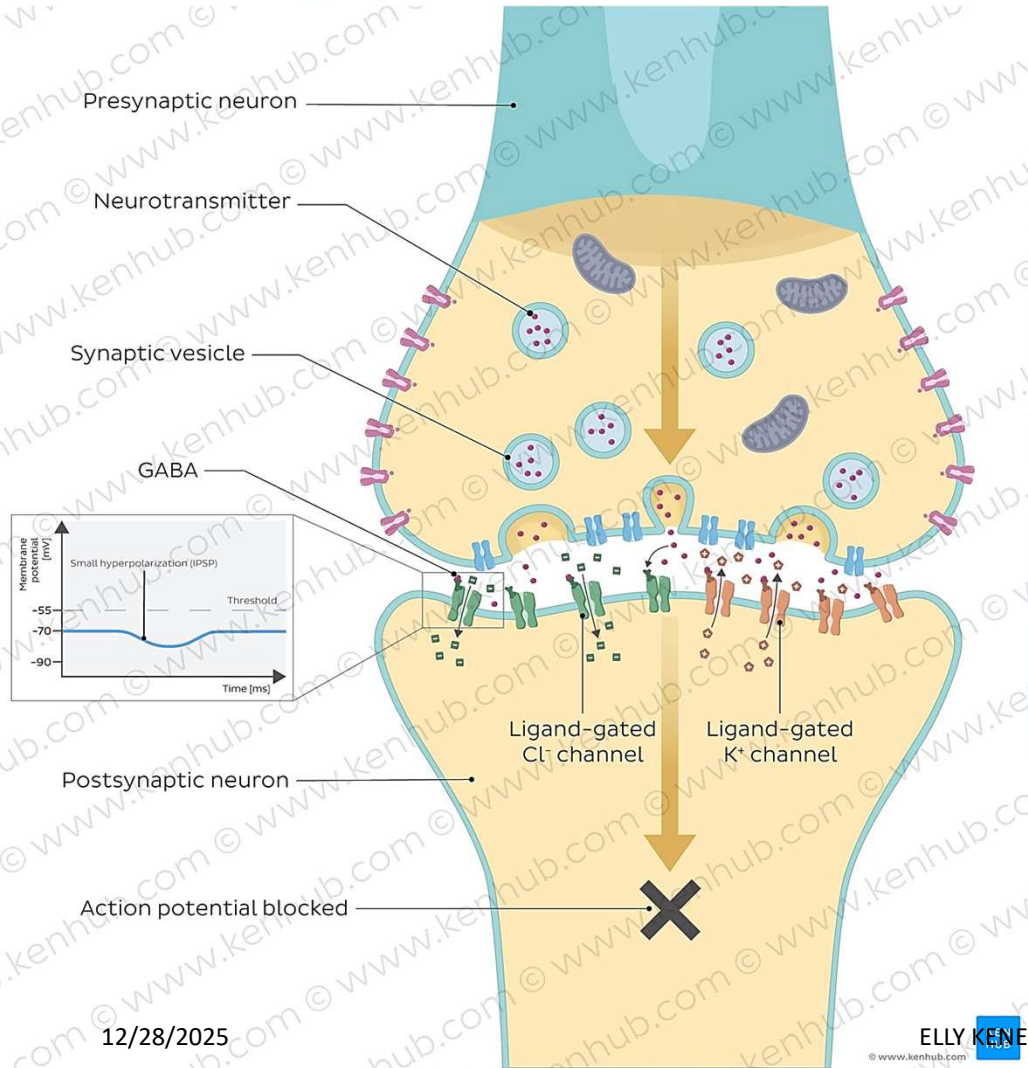
INHIBITORY SYNAPSES



- When an action potential reaches the presynaptic membrane, it *depolarizes the membrane*. This depolarization *triggers the opening of calcium ion channels* in the presynaptic membrane.
- *Calcium ions diffuse into the presynaptic knob*, causing the presynaptic vesicles containing acetylcholine to *migrate and fuse with the presynaptic membrane*. The acetylcholine is *released into the synaptic cleft by exocytosis* and *diffuses across the synapse*. Then it *binds to specific protein receptor molecules on the postsynaptic membrane*, a process known as receptor activation.
- Receptor activation by inhibitory neurotransmitters *causes other effects on postsynaptic membranes*.
- Usually, it *opens chloride ion channels* which *makes the postsynaptic membrane more negative than normal* (it becomes *hyperpolarized*) and less likely to depolarize *sufficiently to generate an action potential*.



INHIBITORY VS EXCITATORY SYNAPSE



12/28/2025

ELLY KENNEDY

SIGNIFICANCE OF SYNAPSES.



- **Pass impulses in one direction only** : As the neurotransmitter *substance can only be released from one side of a synapse*, and *location of receptor sites is only at the post synaptic membrane*, ensures that nerve impulses only pass in one direction along a given pathway.
- **Adaptation and fatigue**: The amount of transmitter substance released by a synapse *steadily falls off in response to constant stimulation* until the *supply of transmitter substance is exhausted* because the *rate of release of neurotransmitter exceeding the rate at which it can be reformed* and the synapse is described as *fatigued*. Further passage of information along this pathway is not possible until after a period of recovery. The significance of fatigue is that it *prevents damage of the effector through over stimulation*.
- Synapses are involved in memory and learning.



- **Integration, convergence** and **spatial summation**. A postsynaptic neurone *may receive impulses from a large number of excitatory and inhibitory presynaptic neurones* known as *convergence*, and the postsynaptic neurone is *able to summate the stimuli from all the presynaptic neurones*.
- This spatial summation *enables the synapse to act as a centre for the integration of stimuli* from a variety of sources and the *production of a coordinated response*.
- **Discrimination** and **temporal summation**. Temporal summation at synapses *enables weak background stimuli to be filtered out* before they reach the brain. Only changes in the intensity of stimuli are significant to the stimulate the nervous system. These increase the frequency of stimuli and pass across the synapse to cause a response.

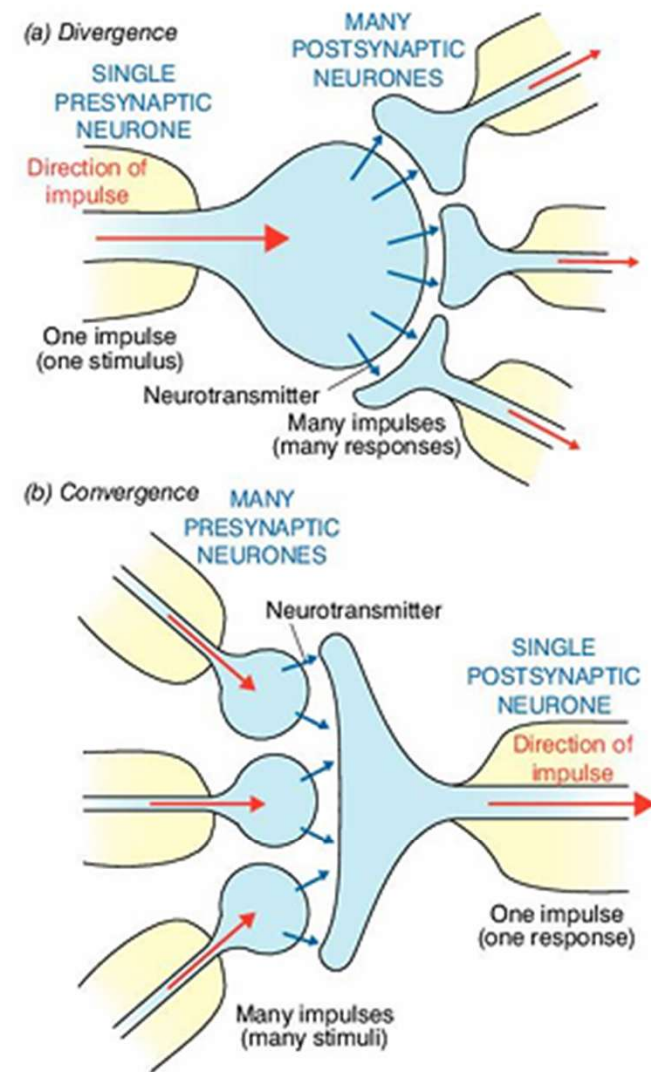
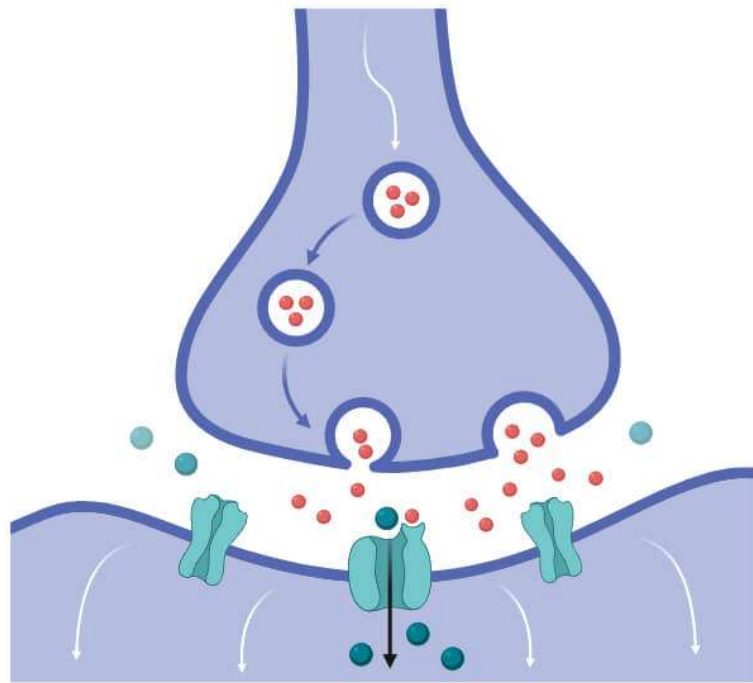


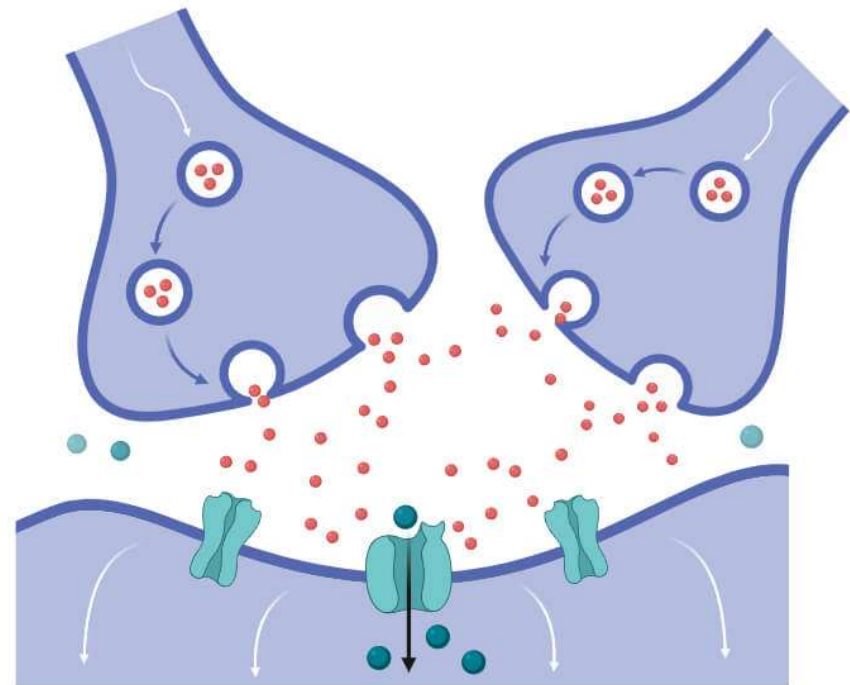
Figure 3 Divergence and convergence at synapses



Neural Integration: Temporal and Spatial Summation



Temporal summation



Spatial summation

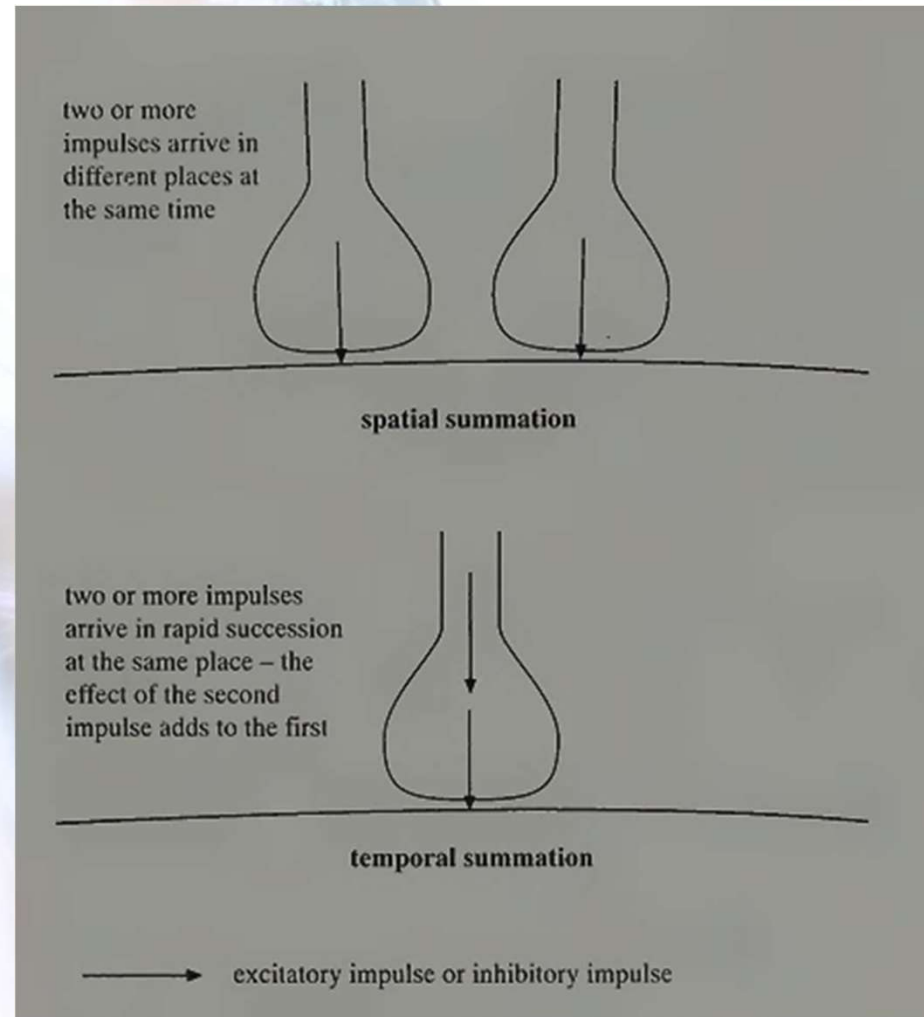
Spatial: where a number of *different presynaptic neurons release enough neuro transmitter substance simultaneously* to trigger a new action potential. 

Temporal: where a *single presynaptic neuron release enough neuro transmitter substance many times over short period* to trigger a new action potential.

- **Amplification**: *Sufficient acetylcholine is released at a neuromuscular junction by each nerve impulse to excite the postsynaptic membrane to produce a response in the muscle fiber.* Thus, nerve impulses arriving at the neuromuscular junction, *however weak, are adequate to produce a response from the effector*, thereby increasing the sensitivity of the system.
- **Facilitation**. This occurs at leaving some the synapses and involves each stimulus leaving the synapse and more responsive to the next stimulus. The sensitivity of the synapse has therefore been increased, and subsequent - weaker stimuli may cause a response. Facilitation is *not temporal summation. in that it is a chemically controlled response of the postsynaptic membrane* and *not an electrical summation of postsynaptic membrane potentials.*

- **Filter out low-level stimuli:**

- Background stimuli at a constantly low level, e.g. the drone of machinery, produce a low frequency of impulses and **so cause the release of only small amounts of neurotransmitter at the synapse**. This is **insufficient to create a new impulse in the postsynaptic neurone** and **so these impulses are carried no further** than the synapse. Such **low-level stimuli are of little importance** and the absence of a response to them is rarely, if ever, harmful.
- Any change in the level of the stimulus will be responded to in the usual way.



BEHAVIOUR OF THE IMPULSE UNDER INFLUENCE OF LOCAL ANESTHETICS.

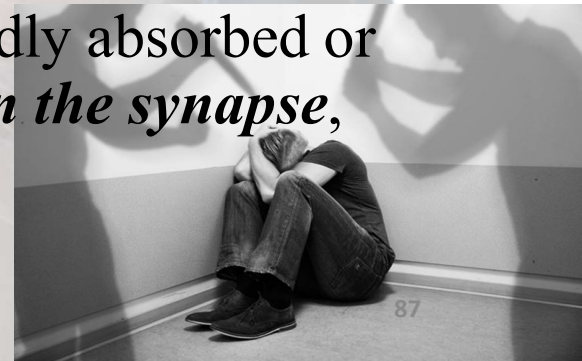
- Although *acetylcholine* and *noradrenaline* are the main neurotransmitters outside the brain. There are many different neurotransmitters responsible for information exchange across synapses, *more than 50 natural neurotransmitters have been isolated from the brain*, all associated with their own particular nervous pathways.
- In addition, *many other chemicals affect synapses*. These may affect the brain, and therefore behaviour, or other parts of the body such as the neuromuscular junction.
- Most of the psychoactive drugs available in society today, such as *ecstasy*, *cannabis* and *cocaine*, cause their effects by *interfering with the synaptic transmission of one of these messengers*.
- Those drugs which *amplify the process of synaptic transmission* are called *excitatory* or *agonistic drugs*, while those which *inhibit synaptic transmission* are known as *inhibitory* or *antagonistic drugs*.




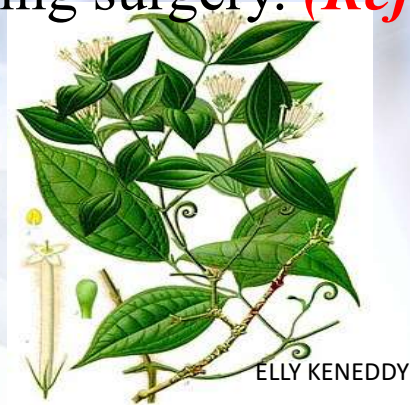
- Narcotics such as **heroin** and **morphine** *mimic the actions of the neurotransmitters* known as **endorphins**, through binding to their specific receptors and blocking sensations of pain. They reduce pain, influence emotion and are involved with certain types of mental illness..
- Nicotine similarly *mimics natural transmitter Acetylcholine (ACh)* on certain receptors . The receptors concerned are called **nicotinic receptors** and are found in the membranes of postsynaptic cells. Nicotine causes strong **sympathetic vasoconstriction in abdominal organs such as the gut**, and **in the limbs**, but at the time **parasympathetic effects occur, such as increased gastrointestinal activity** and **sometimes slowing of the heart**. Nicotinic receptors are also found at neuromuscular junctions. If **nicotine is applied directly to the junction it makes the muscle contract**, mimicking acetylcholine.
- Caffeine is **a stimulant, although a relatively weak one**. It is thought to **cause dopamine release stimulates reward pathways**. The presence of **caffeine in the body raises cell metabolism, leading to the release of more neurotransmitters**.



- Amphetamines *cause increased release of noradrenaline* by *interfering with storage mechanisms*. This *leads to excessive activation of neurones and extra information is transmitted around the brain*. A user will feel highly aroused but may also suffer damage to organs including the heart.
- Some drugs affect the body by interacting with natural neurotransmitters. The *benzodiazepine tranquillizers*, such as *Valium*, *increase the effect of the inhibitory transmitter GABA in the brain*, resulting in *less transfer of information between neurones*.
- In contrast *phencyclidine*, the active ingredient in magic mushrooms, *interacts with excitatory transmitters in the brain* and *inappropriate information is passed between neurones, leading to hallucinations*.
- It is important to remember that neurotransmitters are rapidly absorbed or broken down. *Cocaine causes noradrenaline to 'linger' in the synapse*, producing effects similar to those from amphetamines.



- ***Curare*** specifically blocks nicotinic receptors of acetylcholine. It therefore  has opposite effects to acetylcholine and nicotine at these receptors. The effects of ***curare are particularly noticeable at neuromuscular junctions*** where it ***prevents muscle contraction, causing rapid paralysis throughout the body.***
- The ***victim dies as a result of being unable to breathe.*** (Artificial respiration can save a victim if applied until the effect of the drug wears off.) This ***accounts for its use as a poison to tip arrows by some South American tribes when hunting:*** it prevents wounded animals escaping into thick undergrowth. Curare and related drugs can be ***used as a muscle relaxant on patients during surgical operations,*** which makes operating easier for the surgeon. Breathing is maintained artificially during surgery. ***(Refer to BS for more details)***





SENSORY RECEPTORS.



Elly Kenny

SENSORY RECEPTORS.



- The coordinated activity of an organism relies upon a continuous *input of information from the internal and external environments*. Information leading to a *change in activity or behaviour* of the animals is called *stimulus*. The *specialized region of the body detecting the stimulus* is known as a *sensory receptor*.
- The simplest and most primitive type of receptor consists of a *single sensory neurone which is capable of detecting the stimulus* and giving *rise to a nerve impulse* passing to the central nervous system e.g. *skin mechano-receptors*.
- More complex receptors, known as *sense cells*, consist of *modified epithelial cells able to detect stimuli*. These form synaptic connections with their sensory neurones which transmit impulses to the CNS, for example *mammalian taste buds*.
- The most complex receptors are *sense organs* such as the eye and ear. These are composed of a *large number of sense cells, sensory neurones and associated accessory structures*.
- The most essential role of receptors is *converting the stimulus into an impulse*.

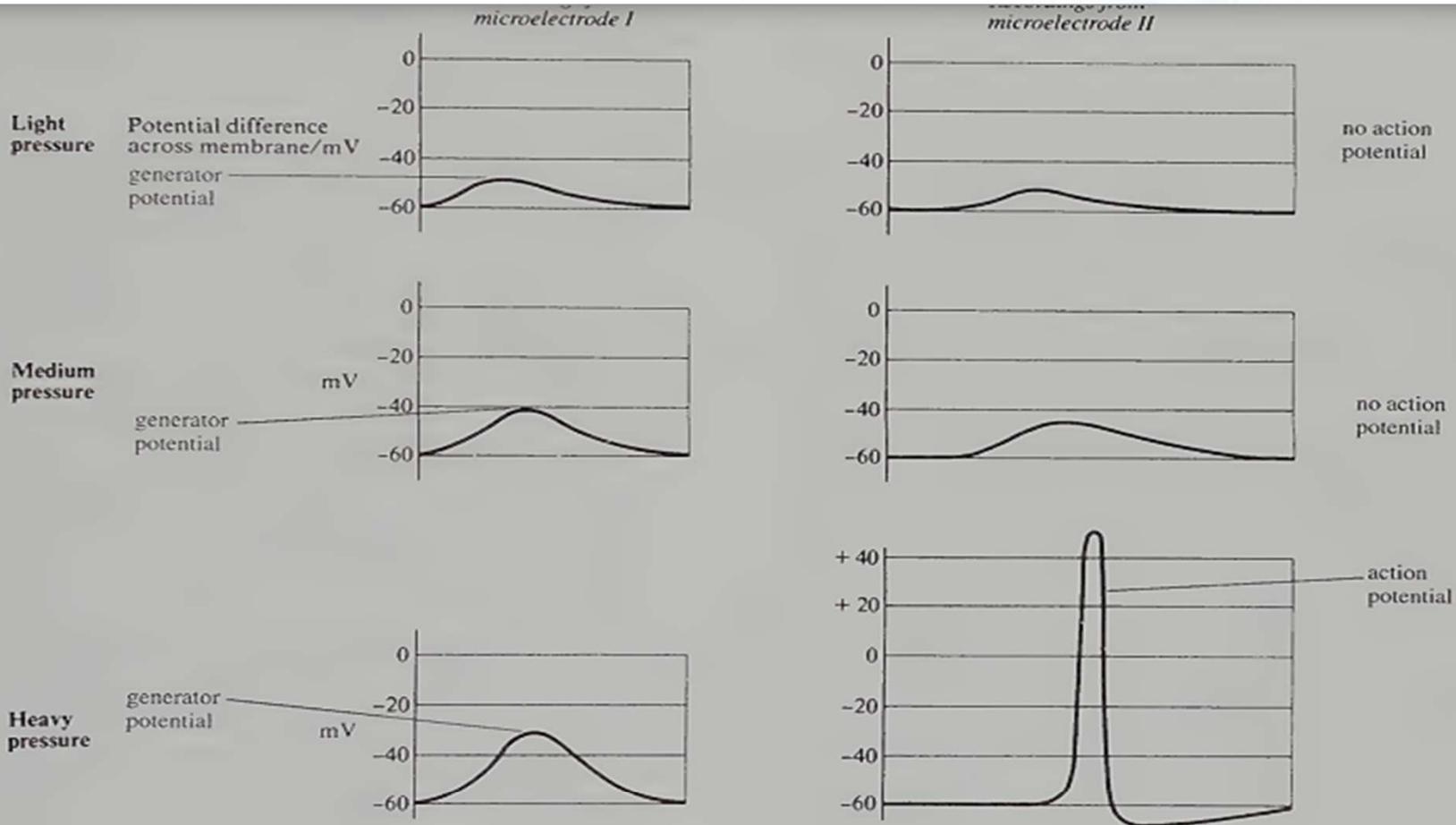


Fig 17.30 The electrical activity recorded by two microelectrodes and inserted into (I) the axon within a Pacinian corpuscle and (II) the axon of the sensory neurone leaving the corpuscle. As the pressure on the fine glass rod (the stimulus) is increased, the size of the generator potential increases and at a certain threshold triggers an action potential in the sensory neurone. 12/28/2025

CLASSIFICATION OF SENSORY RECEPTORS



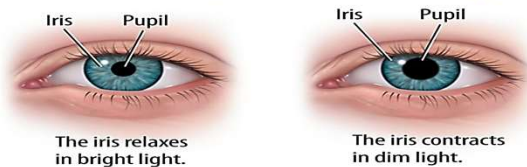
Receptors are commonly *classified according to the type of stimulus energy they detect*. The main types are:

- **Mechanoreceptors** which detect *changes in mechanical energy*, such as *movements, pressures, tensions, gravity, and sound waves*
- **Chemoreceptors** which detect *chemical stimuli*, for example, through *taste, PH and smell*
- **Thermoreceptors** which detect *temperature changes eg receptors in the skin sensitive to warmth and cold.*
- **Electroreceptors** which *detect electrical fields*
- **Photoreceptors** respond to *particular wavelengths of light*. i.e found in the eyes

NOTE.

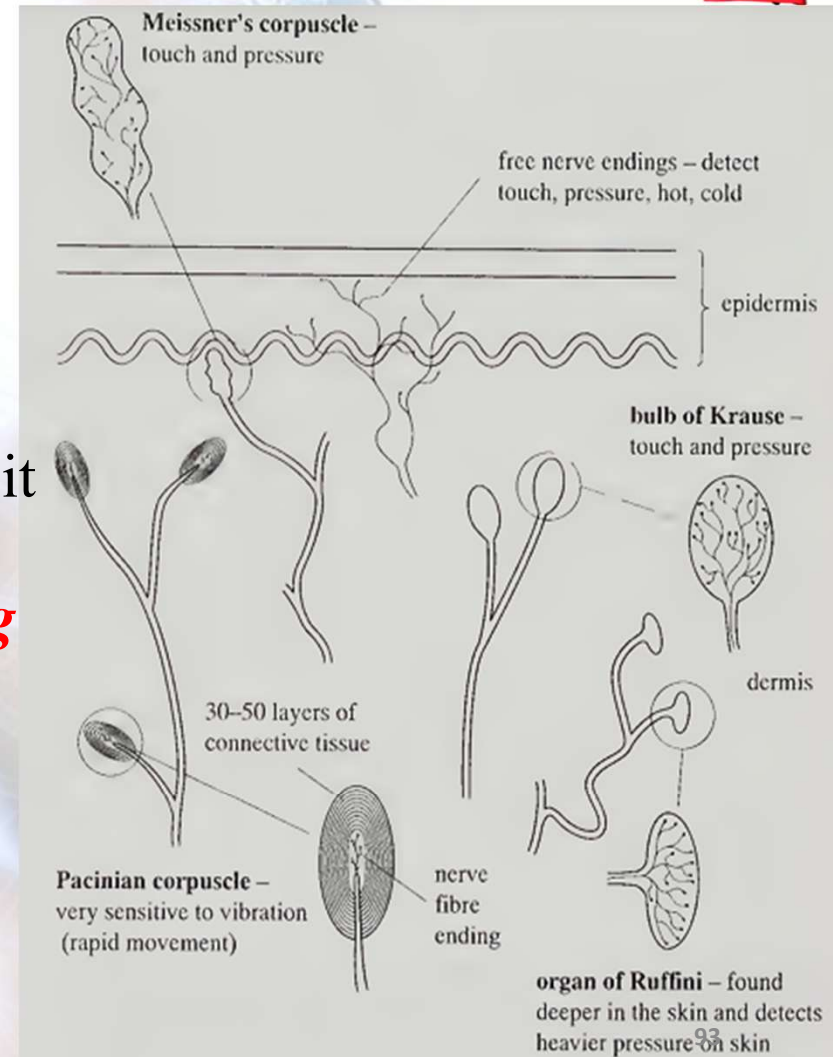
- Receptors can *also be classified according to their structure*. Simple receptors, known as *primary receptors*. located in the skin, tendons, joints, and muscles.

- **Primary receptors** consist of a *single neurone*, *one end of which is sensitive to a particular type of stimulus* E.g. Pacinian corpuscles are *mechanoreceptors* located in the skin.
- **A secondary receptor** is more complex. It *consists of a modified epithelial cell* which is sensitive to a particular type of stimulus.
- The *cell senses changes and passes this information on to a neurone* which transmits it as nerve impulses.
- **Sense organs** are *complex-stimulus-gathering structures* consisting of *grouped sensory receptors*.
- In many sense organs, several receptors make *synaptic connections with a single receptor neurone*.



ELLY KENNEDY

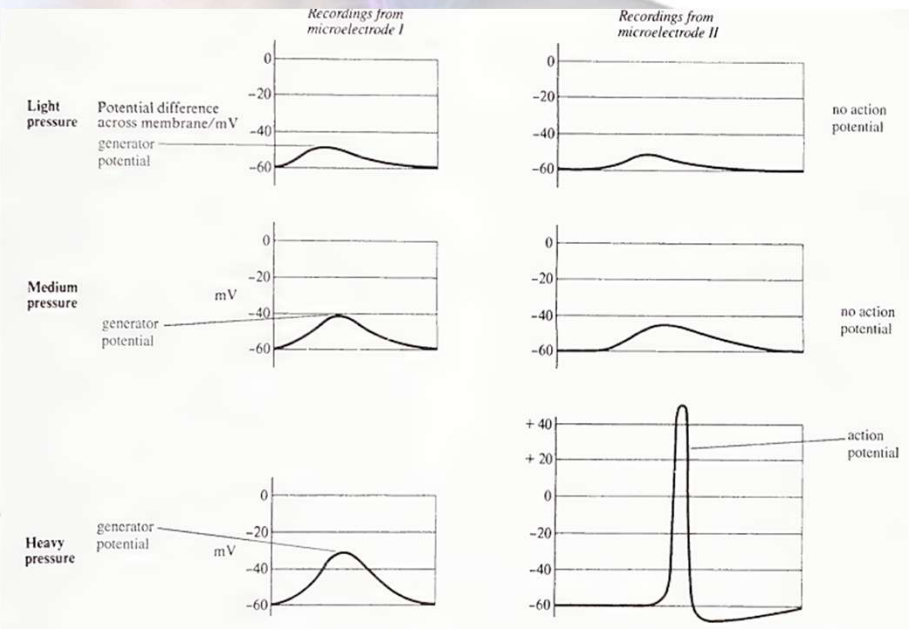
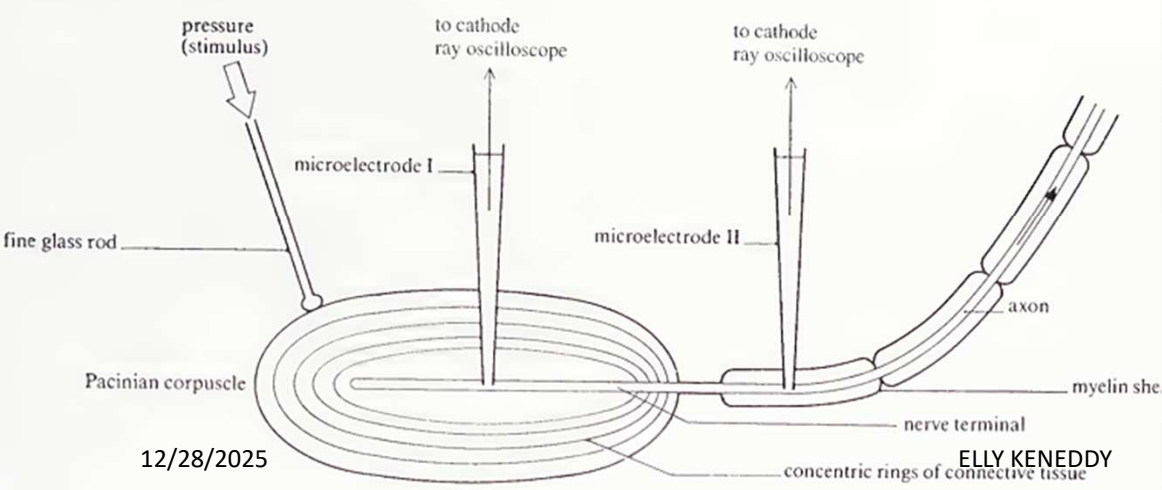
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HOW A RECEPTOR CELL WORKS.



- On stimulation, the **sensitive part of the receptor cell** called **generator region** develops a **generator potential**. The generator potential is caused by **depolarization of the membrane** surrounding this part of the cell **due to exchange of ions as in impulse transmission**.
- **The magnitude of the generator potential is proportional to the intensity of the stimulus**. If the generator potential reaches the **threshold**, **an action potential is generated in the nerve fiber**.



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PROPERTIES OF SENSORY RECEPTORS.



Excitability and receptor potential

- Some sense organs, such as stretch receptors in muscle, are composed of **many sense cells which have a range of thresholds**. If a cell has a **low threshold it responds to a weak stimulus**.
- As the strength of the stimulus increases the cell **can respond by producing an increasing number of impulses** in the sensory neurone leaving the cell. However, **at a given point saturation occurs**, and the frequency of impulses in the neurone cannot be increased.
- **A further increase in intensity of stimulus** will then **excite sense cells with higher thresholds**, and these too will produce a frequency of nerve impulses which is proportional to the intensity of the stimulus. In this way the range of the receptor is extended.



Adaptation

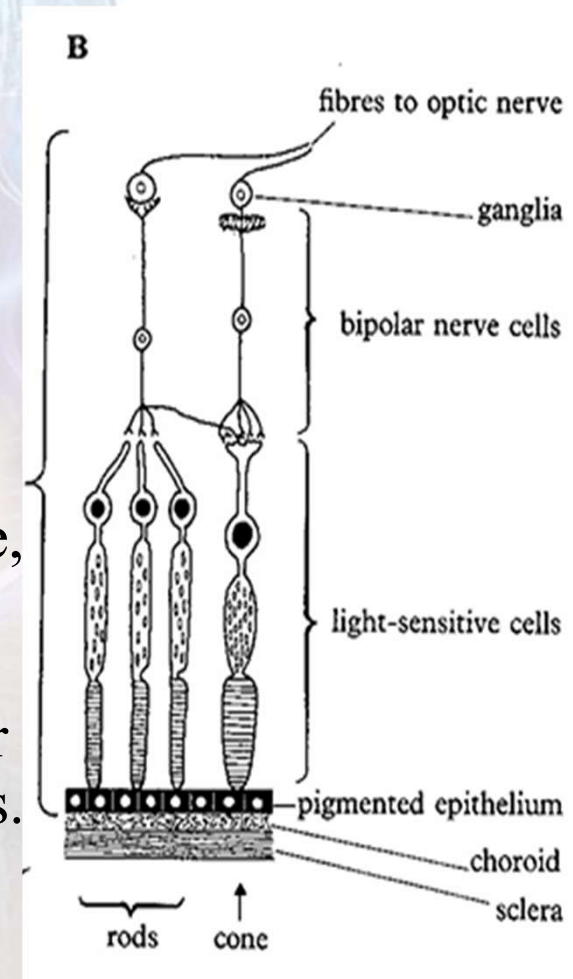
- Most sensory receptors initially **respond to a strong constant stimulus by producing a high frequency of impulses in the neurone**. The **frequency of these impulses gradually declines** and this reduction in response, with time, called **adaptation**. There are two types, rapidly and slowly adapting receptors
- **Rapidly adapting receptors (phasic receptors)**: respond to changes in stimulus level by producing a high frequency of impulses at the
- **Slowly adapting receptors (tonic receptors)**: register a constant stimulus with a slowly decreasing frequency of impulses.

Specificity

- Each type of receptor is **highly sensitive to one particular stimulus** e.g. photoreceptors in the eyes are most sensitive to light, chemoreceptors in the tongue sensitive to chemicals, etc. they are **only stimulated if a particular stimulus adequate to initiate a response is** provided.

Convergence and summation

- **A high degree of sensitivity is achieved** in many sense organs by an **arrangement of sense cells and sensory neurones** known as **convergence**. **Several sense cells are connected to (converge on) a single sensory neurone**. These cells are characteristically small, are found in large numbers and are extremely sensitive to stimuli.
- Whilst the effect of a stimulus on a single one of these cells would not produce a response in the sensory neurone, the **combined effect of the simultaneous stimulation of several cells is cumulative stimulatory effect** produced in the sensory neurone is known as summation and is similar in function to the summative effect described for synapses.
- This in a **cumulative stimulatory effect produced** in a sensory neurone is called **summation**.





Spontaneous activity

- Some receptors *produce nerve impulses in sensory neurones in the absence of stimulation*. This has two important advantages.
- Firstly, it *increases the sensitivity of the receptor* by enabling it to make a response to a stimulus that would normally be too small to produce a response in the sensory neurone. Any *slight change in the intensity of the stimulus will now add to the existing potential* in the receptor and *produce a change in the frequency of impulses along the sensory neurone*.
- Secondly the direction of the *change in stimulus can be registered* by this system as an increase or decrease in the frequency of the response in the sensory neurone. For example, infra-red receptors in pits in the face of the rattlesnake, which act as direction finders in locating prey and predators.



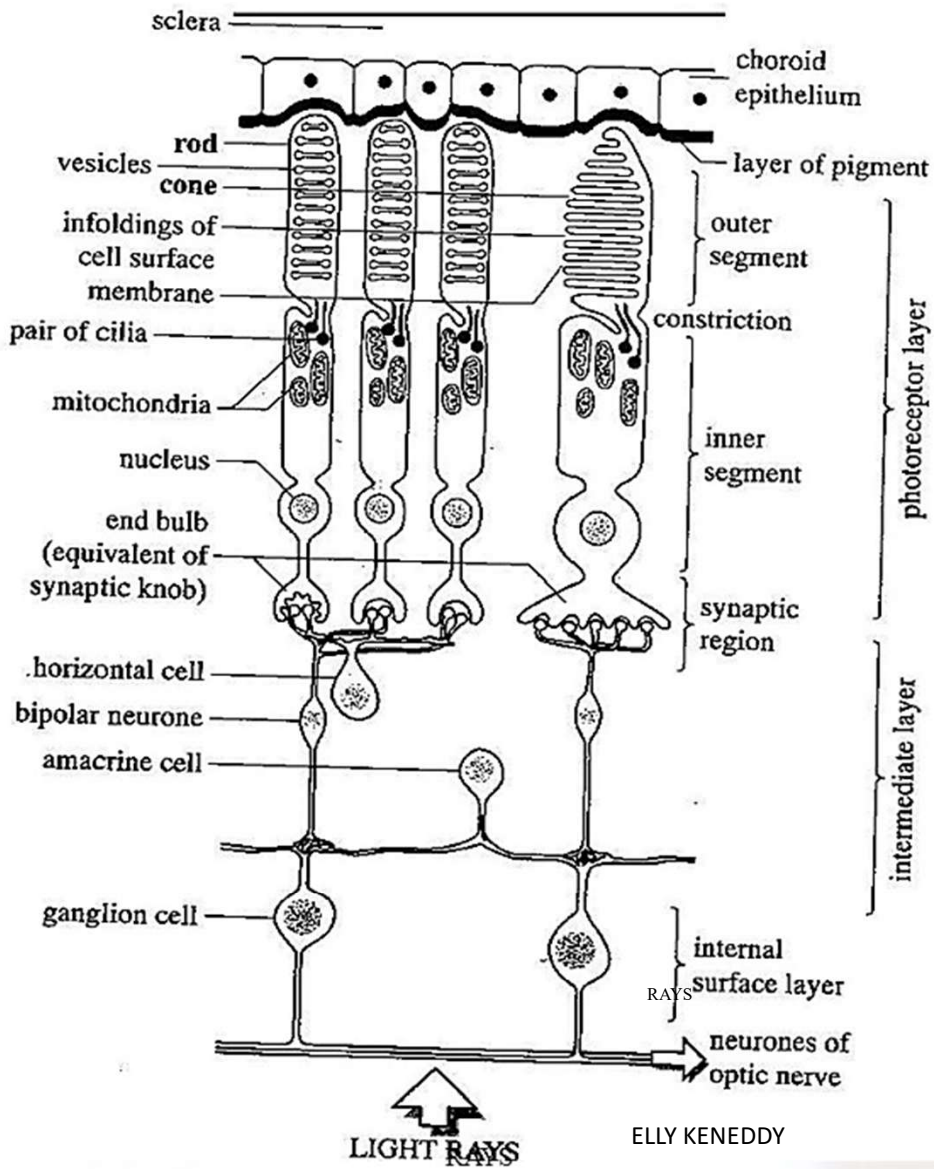
THE HUMAN EYE.

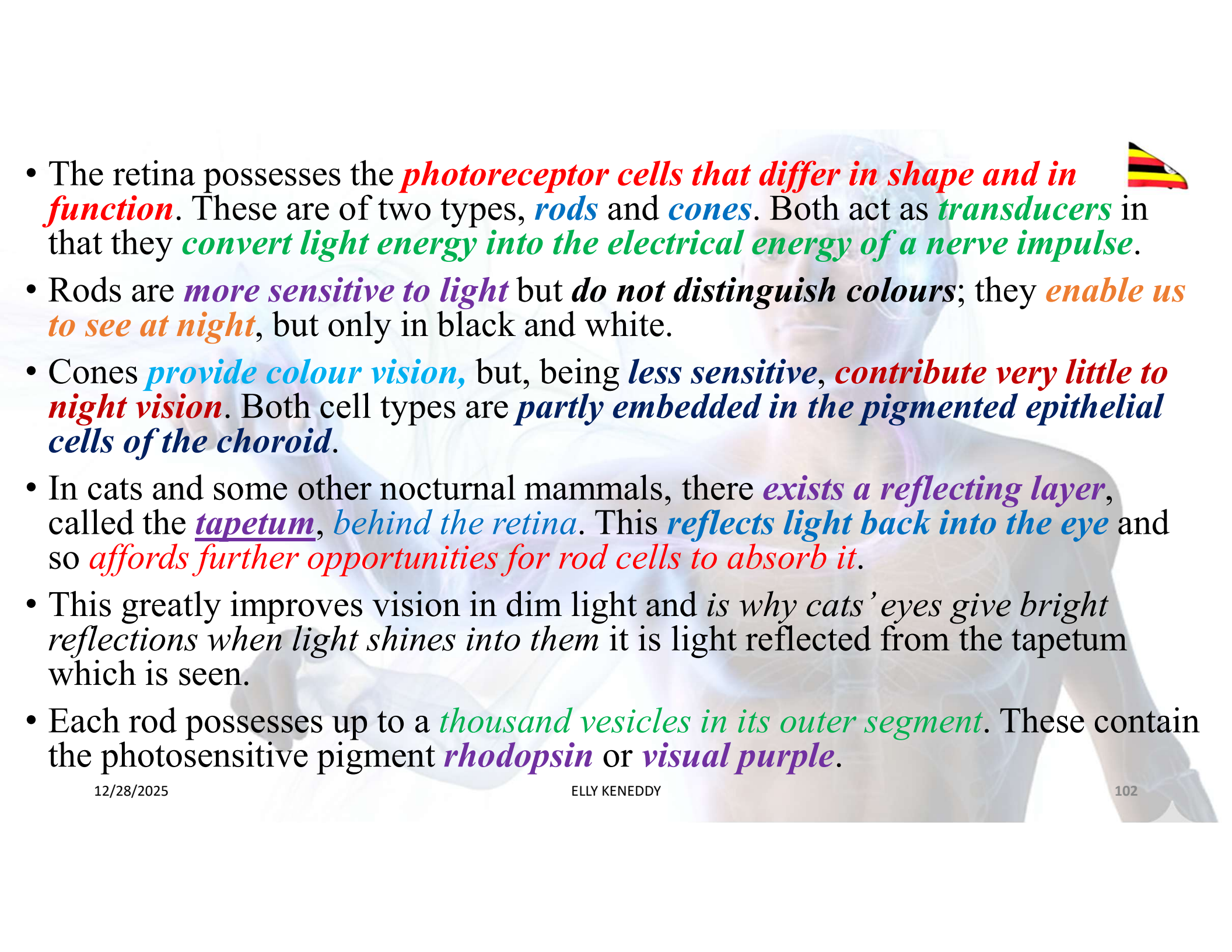
- The eye is a *sense organ which receives light of various wavelengths* reflected from objects at varying distances, the visual field, *and converts it into electrical impulses*. *Optic nerves transmit these impulses to the brain* where an image of *remarkable precision is perceived*.
- The wavelengths of the visible spectrum *carry sufficient energy in each quantum of radiation to produce a photochemical response* in the sense cells of the eye.
- Most of the eye is composed of *'accessory structures' concerned with bringing light to the photoreceptor cells* which are *situated in the innermost layer of the eye, the retina*.
- The eye is composed of three concentric layers: the sclera (sclerotic coat) and cornea; the choroid, ciliary body, lens and iris; and the retina


STRUCTURE OF THE RETINA.



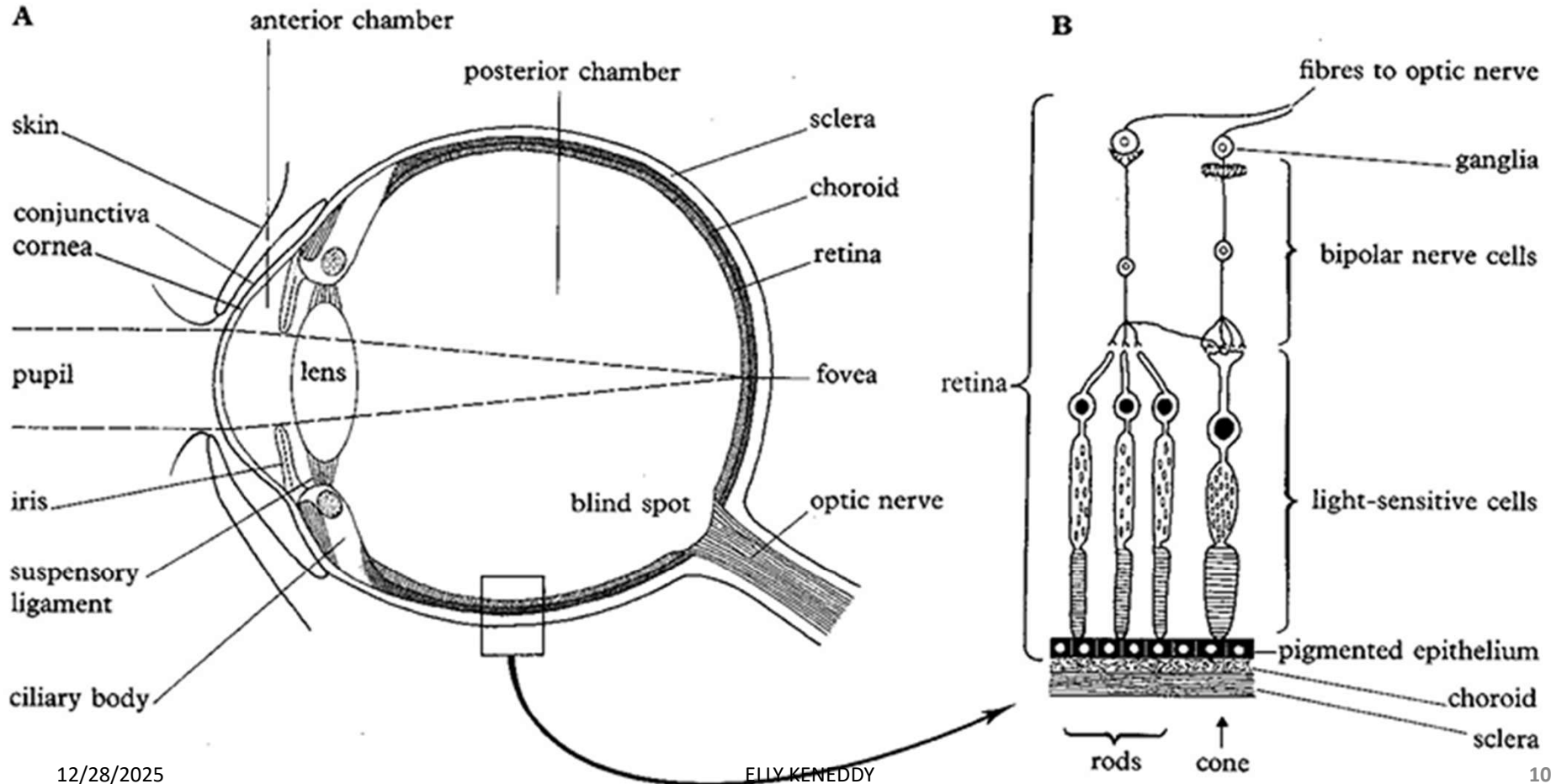
- The retina is composed of *three layers of cells each containing a characteristic type of cell.*
- First there is the *photoreceptor layer (outermost layer)* containing the *photosensitive cells*, the *rods* and *cones*, *partially embedded in the pigmented epithelial cells of the choroid.*
- The *photoreceptor cells of the retina face towards* the choroid layer.
- Next is the *intermediate layer* containing *bipolar neurones with synapses connecting the photoreceptor layer* to the cells of the third layer. Cells called *horizontal* and *amacrine cells* found in this layer *enable lateral inhibition to occur .*
- The *third layer* is the internal surface layer containing *ganglion cells with dendrites* in contact with bipolar neurones and axons of the optic nerve.



- 
- The retina possesses the *photoreceptor cells that differ in shape and in function*. These are of two types, *rods* and *cones*. Both act as *transducers* in that they *convert light energy into the electrical energy of a nerve impulse*.
 - Rods are *more sensitive to light* but *do not distinguish colours*; they *enable us to see at night*, but only in black and white.
 - Cones *provide colour vision*, but, being *less sensitive*, *contribute very little to night vision*. Both cell types are *partly embedded in the pigmented epithelial cells of the choroid*.
 - In cats and some other nocturnal mammals, there *exists a reflecting layer*, called the *tapetum*, *behind the retina*. This *reflects light back into the eye* and so *affords further opportunities for rod cells to absorb it*.
 - This greatly improves vision in dim light and *is why cats' eyes give bright reflections when light shines into them* it is light reflected from the tapetum which is seen.
 - Each rod possesses up to a *thousand vesicles in its outer segment*. These contain the photosensitive pigment *rhodopsin* or *visual purple*.

- Rhodopsin is made up of the protein opsin and a *derivative of vitamin A*, retinal. Retinal normally *exists in its cis isomer form*, but light *causes it to become converted to its trans isomer form*. 
- This change *initiates reactions which lead to the splitting of rhodopsin* into *opsin* and *retinal* a process known as bleaching.
- This splitting in turn *leads to the creation of a generator potential* in the rod cell which, *if sufficiently large, generates an action potential along the neurones* leading from the cell to the brain.
- Cones are so-called because outer segments are essentially cone-shaped. These have *fewer membranous vesicles* which are formed by repeated infoldings of the outer membrane. They are *thought to work on the same principle as rods*. However, there are *three types of cone*, each containing a *different form of the pigment iodopsin* which *breaks down only in bright light*. The three pigments together are sensitive over the visible spectrum, but *one is most sensitive to blue light, one to green light* and *the other to red light*.

STRUCTURE OF THE EYE AND PHOTSENSITIVE CELLS



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COMPARISON OF CONES AND RODS



Rods

- Outer segment is rod-shaped
- Occur in greater numbers in the retina being 20 times more common than cones
- Distributed more or less evenly over the retina
- None found at the fovea centralis
- Give poor visual acuity because many rods share a single neurone connection to the brain
- Sensitive to low-intensity light, therefore mostly used for night vision
- Do not discriminate between light of different wavelengths, i.e. not sensitive to colour
- Contain the visual pigment rhodopsin which has a single form

Cones

- Outer segment is cone-shaped
- Fewer are found in the retina being one-twentieth as common as rods
- Much more concentrated in and around the fovea centralis
- Greatest concentration occurs at the fovea centralis
- Give good visual acuity because each cone has its own neurone connection to the brain
- Sensitive to high-intensity light, therefore mostly used for day vision
- Discriminate between light of different wavelengths, i.e. sensitive to colour
- Contain the visual pigment iodopsin which occurs in three forms

DISTRIBUTION OF CONES AND RODS.



- Over most of the retina, the *rods and cones are buried under a layer of blood vessels and nerve fibres* which lead into the optic nerve. The relative numbers of rods and cones in the retina *varies among different animals*, correlating to some degree with the *extent to which an animal is active at night*.
- The distribution of rods and cones varies across the human retina. Overall, the *human retina contains about 125 million rods* and about *6 million cones*. However, a small depression in the retina opposite the lens, *the fovea, consists only of cones* because it is *the centre of the visual field*.
- This means that light falling on the fovea *produces a clear well-defined visual image in colour*. There is only a thin layer of nerve fibres here, and no capillaries.
- When a person wants to examine the details of an object, the *eyes move automatically so that light from the object falls on the fovea*.

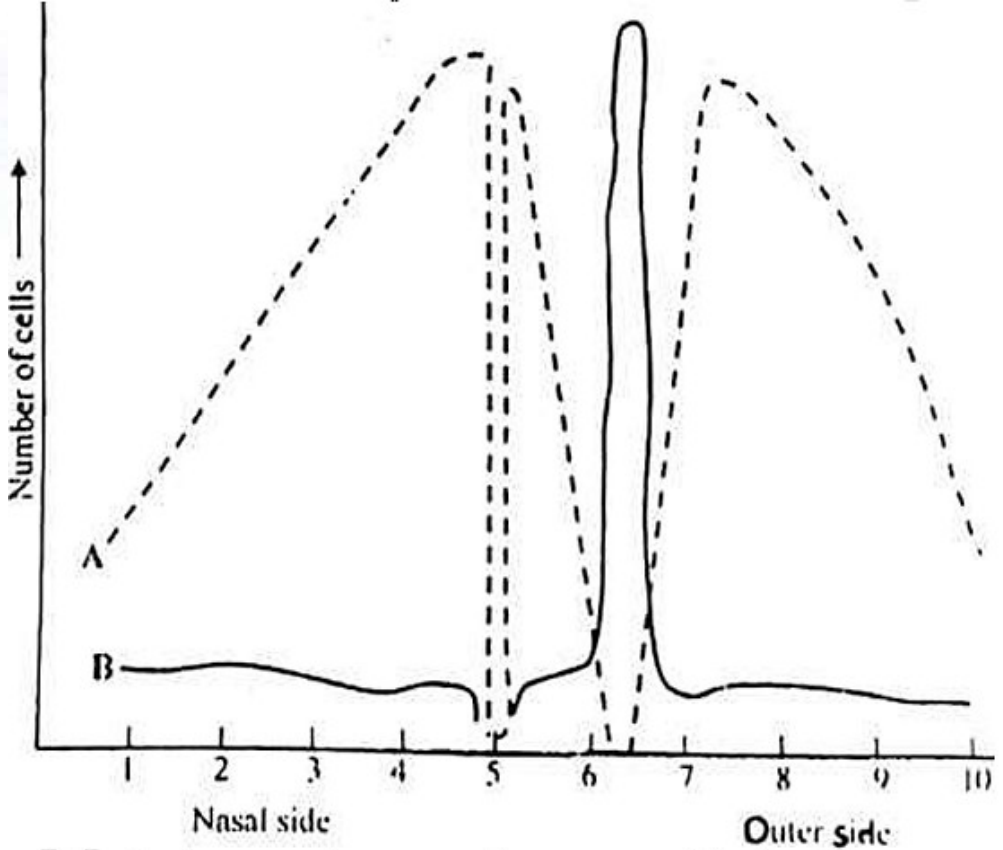
CONT.....



- Sensory information from rods and cones *passes to the brain via the optic nerve*, a bundle of hundreds of thousands of nerve fibres.
- The *point of exit of the optic nerve and blood vessels from the eye* is called the **blind spot** because it is *devoid of photoreceptors* and *insensitive to light*.
- The fovea, the centre of the visual field, *has no rods*, but has a very high density of cones about 150,000 cones per square millimeter.
- The *ratio of rods to cones increases with distance from the fovea*, with the *peripheral regions having only rods*. In day light, you achieve your sharpest vision by looking directly at an object, such light shines on the tightly packed cones in your fovea.
- At night, *looking directly at a dimly lit object is ineffective*, since the *rods-the more sensitive light receptors are found outside the fovea*. Thus, for example, you see a dim star best by focusing on a point just to one side of it.



• The graph below shows the number of receptor cells (type A and B) in arbitrary units in the human retina along a long a horizontal line from the nasal side of the eye to the outer side



a) From the graph, describe the distribution of both types of receptor cells in the retina. (07 marks)

b) Explain the significance of the distribution of the two types of receptor cells in the retina as shown in the graph. (08 marks)



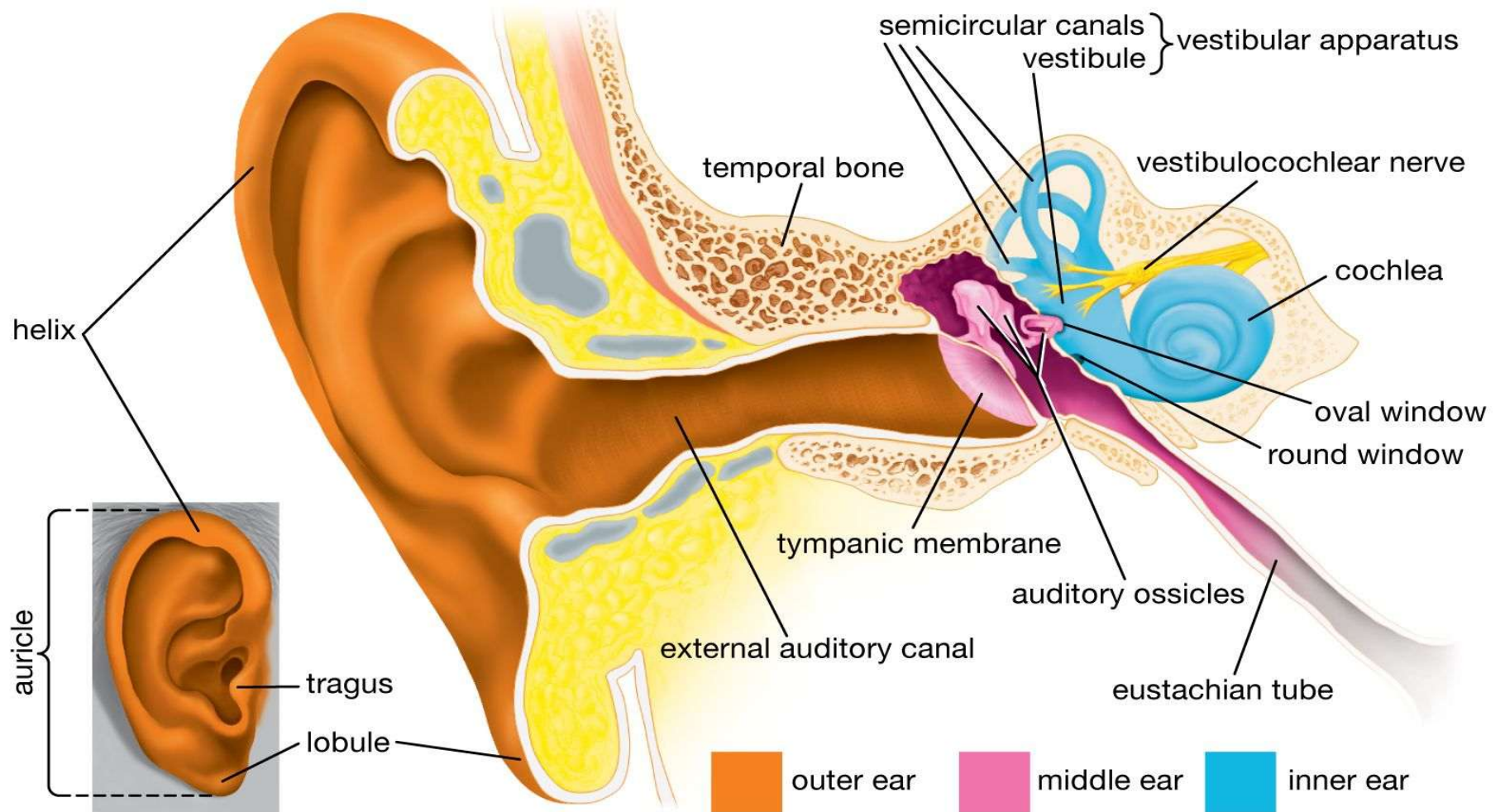
THE HUMAN EAR & ITS ROLE IN BODY BALANCING. 🇪🇺

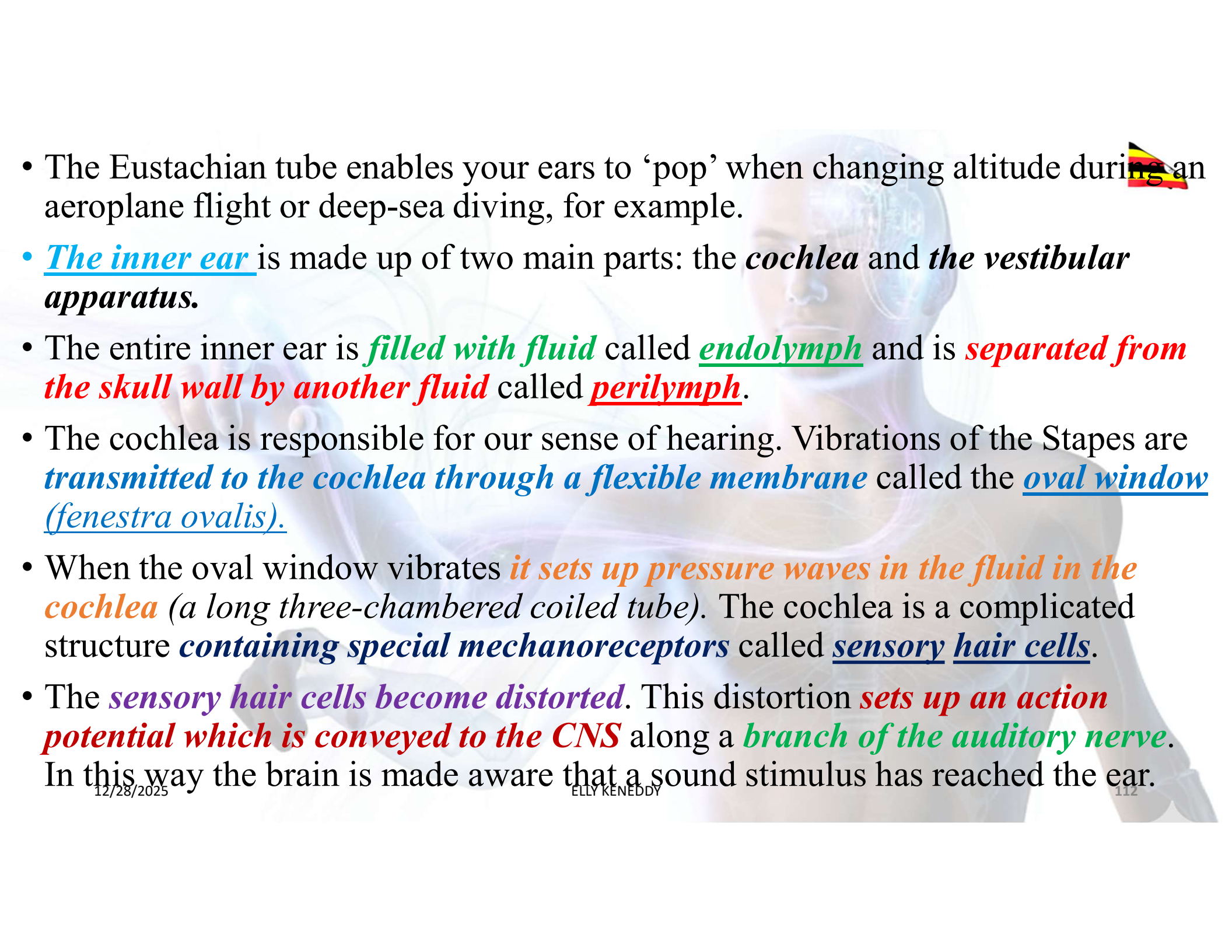
- The human ear is a complex sensory organ that *enables us to hear sounds, detect body movements*, and *maintain balance*.
- Sound is the sensation we feel *when structures in the ear are acted upon by pressure waves* (vibrations) in the air within a limited frequency range.
- The ear has three main parts: *an air-filled outer ear*, an *air-filled middle ear*, and *a fluid-filled inner ear*.
- *The outer ear* consists of a flap (called the *pinna* or auricle) which *funnels sound waves from the air into a canal* called the auditory canal or ear canal.
- Some people share the ability of other mammals such as dogs and cats to move the pinna towards sources of sound, but in most people the pinna is fixed.



- The *sound waves travel down the auditory canal to its inner end* where they *hit a tough membrane* called the *ear drum* or *tympanum*.
- On being hit by the sound waves, the *ear drum vibrates and transmits its vibrations to three ossicles* (small bones) in the middle ear: the hammer (malleus), the anvil (incus), and the stirrup (stapes). The ossicles form a lever system transferring vibrations from the ear drum to the inner ear.
- The *ossicles reduce the amplitude of the vibrations* but *amplify the pressure they produce more than 20 times*. Two small muscles attach the ossicles to the skull.
- During high intensity sounds, these make the ossicles stiffer and less sensitive to sound waves, protecting receptor cells (hair cells) in the inner ear from over-stimulation.
- A tube called the *Eustachian tube* connects the middle ear to the back of the throat. This *allows air to pass in and out of the middle ear to equalize pressure on either side of the tympanum* during swallowing.

PARTS OF AN EAR.



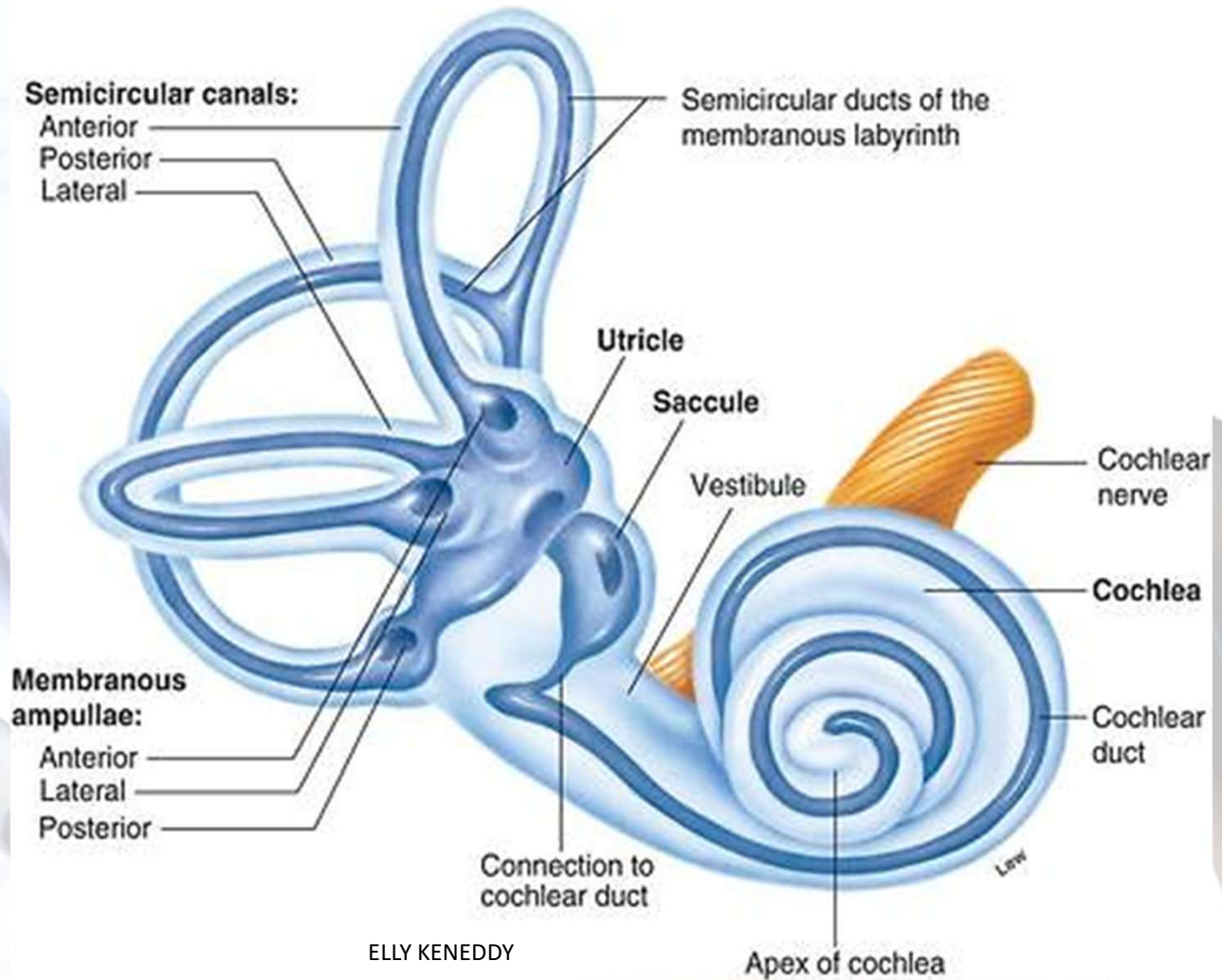
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- The Eustachian tube enables your ears to ‘pop’ when changing altitude during an aeroplane flight or deep-sea diving, for example.
 - The inner ear is made up of two main parts: the *cochlea* and *the vestibular apparatus*.
 - The entire inner ear is *filled with fluid* called endolymph and is *separated from the skull wall by another fluid* called perilymph.
 - The cochlea is responsible for our sense of hearing. Vibrations of the Stapes are *transmitted to the cochlea through a flexible membrane* called the oval window (fenestra ovalis).
 - When the oval window vibrates *it sets up pressure waves in the fluid in the cochlea* (a long three-chambered coiled tube). The cochlea is a complicated structure *containing special mechanoreceptors* called sensory hair cells.
 - The *sensory hair cells become distorted*. This distortion *sets up an action potential which is conveyed to the CNS* along a *branch of the auditory nerve*. In this way the brain is made aware that a sound stimulus has reached the ear.

DISCOVER.(HEARING PROCESS)



- The median canal contains endolymph. The basilar membrane separates the median and tympanic canals and supports sensory hair cells that can be brought in contact with tectorial membrane above. This unit consisting the tectorial membrane, sensory cells and basilar membrane, is called the organ of Corti and is the region where transduction of sound waves into electrical impulses occurs.
- Sound waves transmitted from the ear tube to the oval window produce vibrations in the perilymph of the vestibular canal and these are transmitted via Reissner's membrane to the endolymph in the median canal.
- From there they are transferred to the basilar membrane and the perilymph in the tympanic canal, and are finally dissipated into the air of the middle ear as vibration of the round window.
- The precise mechanism of transduction of pressure waves into nerve impulses is not known but is believed to involve relative movement of the basilar and tectorial membranes. Vibrations of the basilar membrane, induced by pressure waves, push the sensory hairs against the tectorial membrane and force the two membranes to slide past each other.
- The distortion produced in the sensory hairs due to the shearing forces causes a depolarization of the sensory cells, the production of generator potentials and the initiation of action potentials in auditory nerve axons.

THE VESTIBULAR APPARATUS AND THE SENSE OF BALANCE



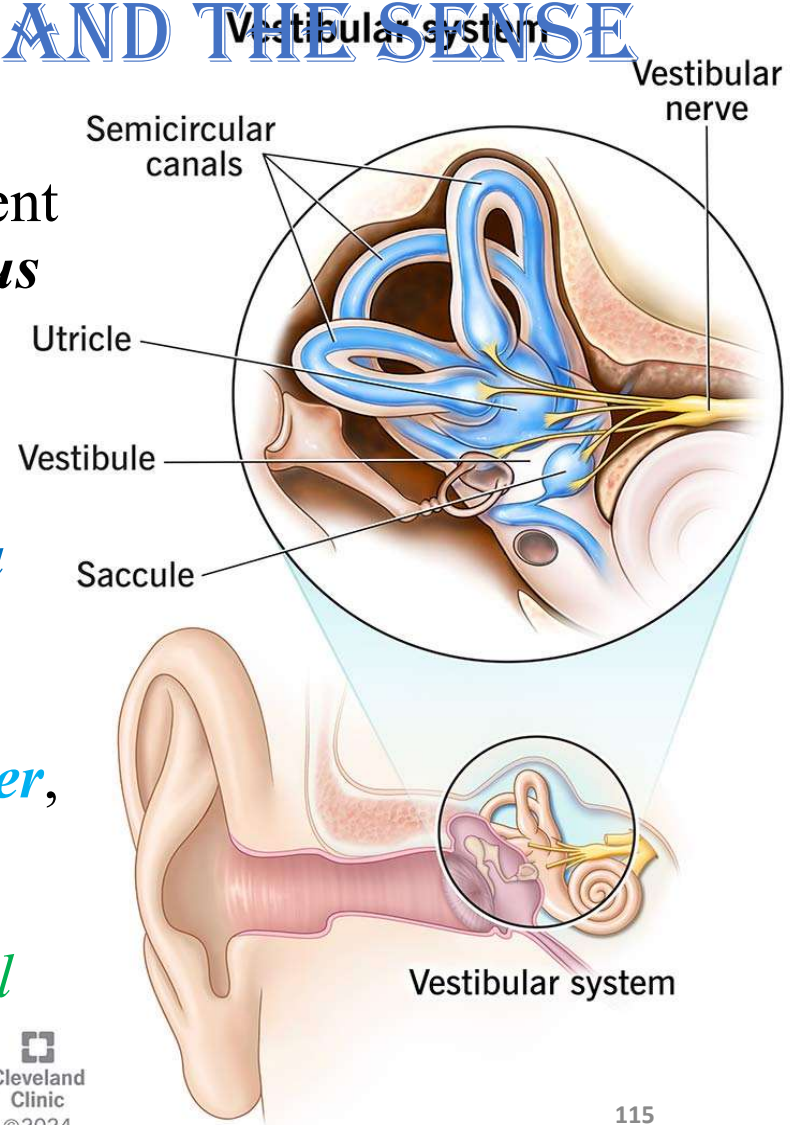
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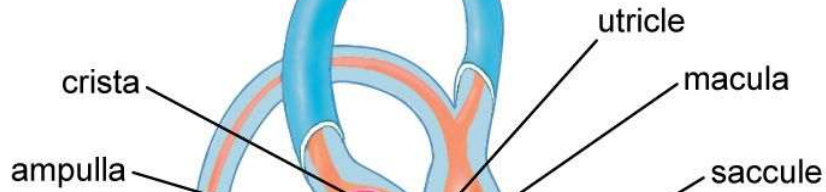
THE VESTIBULAR APPARATUS AND THE SENSE OF BALANCE

- Vital information relating to position and movement of the head is provided by the *vestibular apparatus* of the ear, the *utricle*, *saccul*e and *semicircular canals*..
- Each semi-circular canal terminates in a swelling known as the *ampulla*, which contains the *cupula* (*dome-shaped, gelatinous structure*).
- The cupula is *in contact with sensory hairs*. The canals are *filled with fluid* and are *three in number*, *arranged in three planes*; *vertical canals detect movement in upward direction*, *horizontal canals detect backward and forward motion* while *lateral canals detect sidewise movements of the head*.

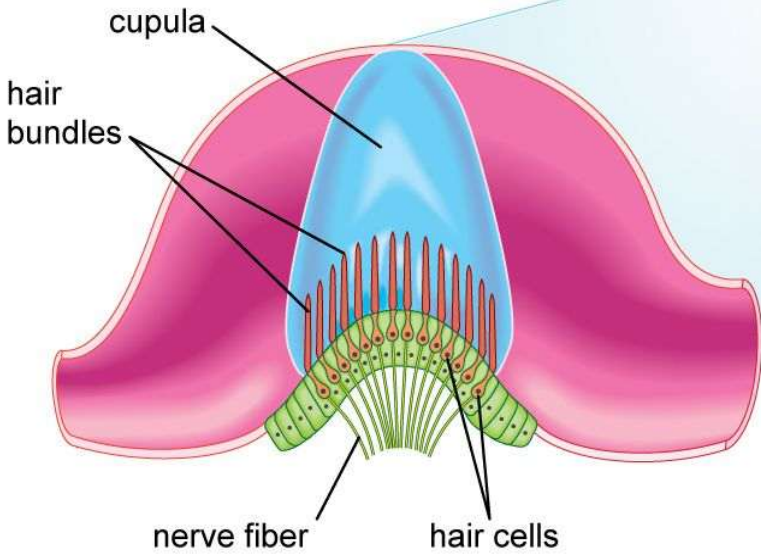




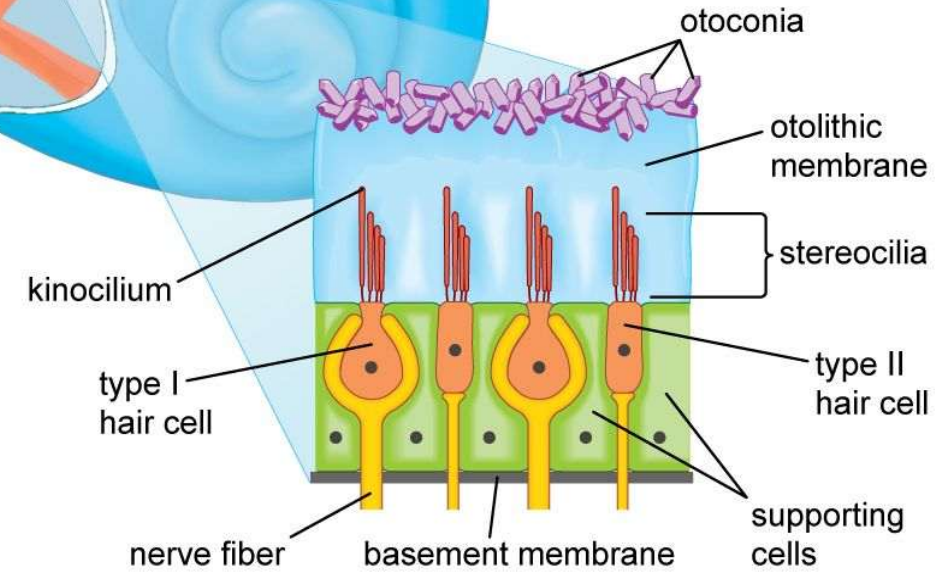
vestibular system



enlargement of crista



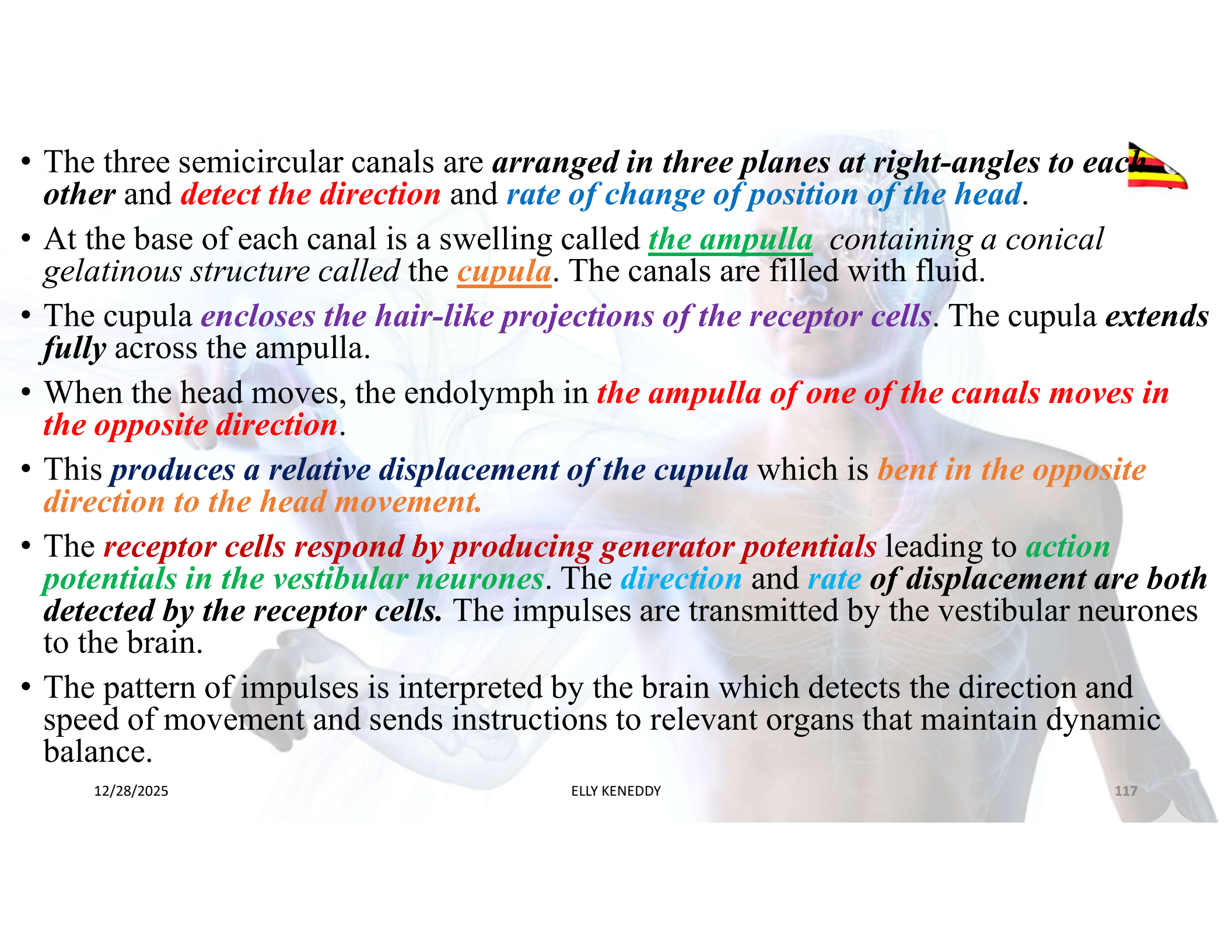
enlargement of macula



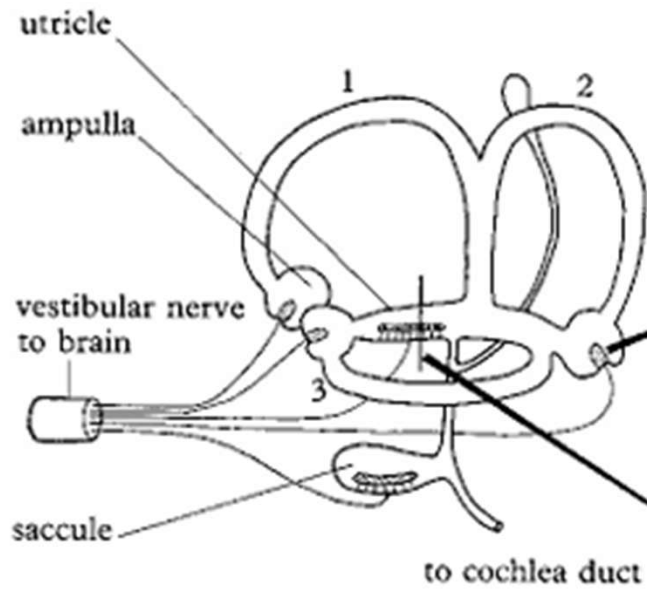
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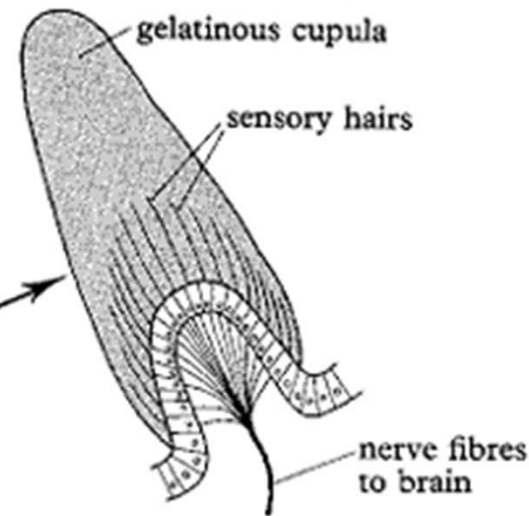
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- The three semicircular canals are *arranged in three planes at right-angles to each other* and *detect the direction* and *rate of change of position of the head*.
 - At the base of each canal is a swelling called *the ampulla* containing a conical gelatinous structure called the *cupula*. The canals are filled with fluid.
 - The cupula *encloses the hair-like projections of the receptor cells*. The cupula *extends fully* across the ampulla.
 - When the head moves, the endolymph in *the ampulla of one of the canals moves in the opposite direction*.
 - This *produces a relative displacement of the cupula* which is *bent in the opposite direction to the head movement*.
 - The *receptor cells respond by producing generator potentials* leading to *action potentials in the vestibular neurones*. The *direction* and *rate of displacement are both detected by the receptor cells*. The impulses are transmitted by the vestibular neurones to the brain.
 - The pattern of impulses is interpreted by the brain which detects the direction and speed of movement and sends instructions to relevant organs that maintain dynamic balance.

A Membranous labyrinth inside vestibular apparatus

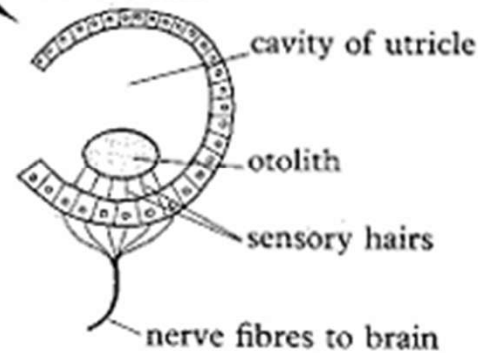


Semicircular canals numbered 1, 2 and 3.

B Ampulla organ (crista)



C Utricle organ (macula) in section



Sudden movement of head causes deflection of cupula which exerts mechanical strain on the sensory hairs.



Relative density of otolith is greater than its surroundings so it either presses down on, or pulls, the sensory hairs, depending on the position of the head in relation to gravity.

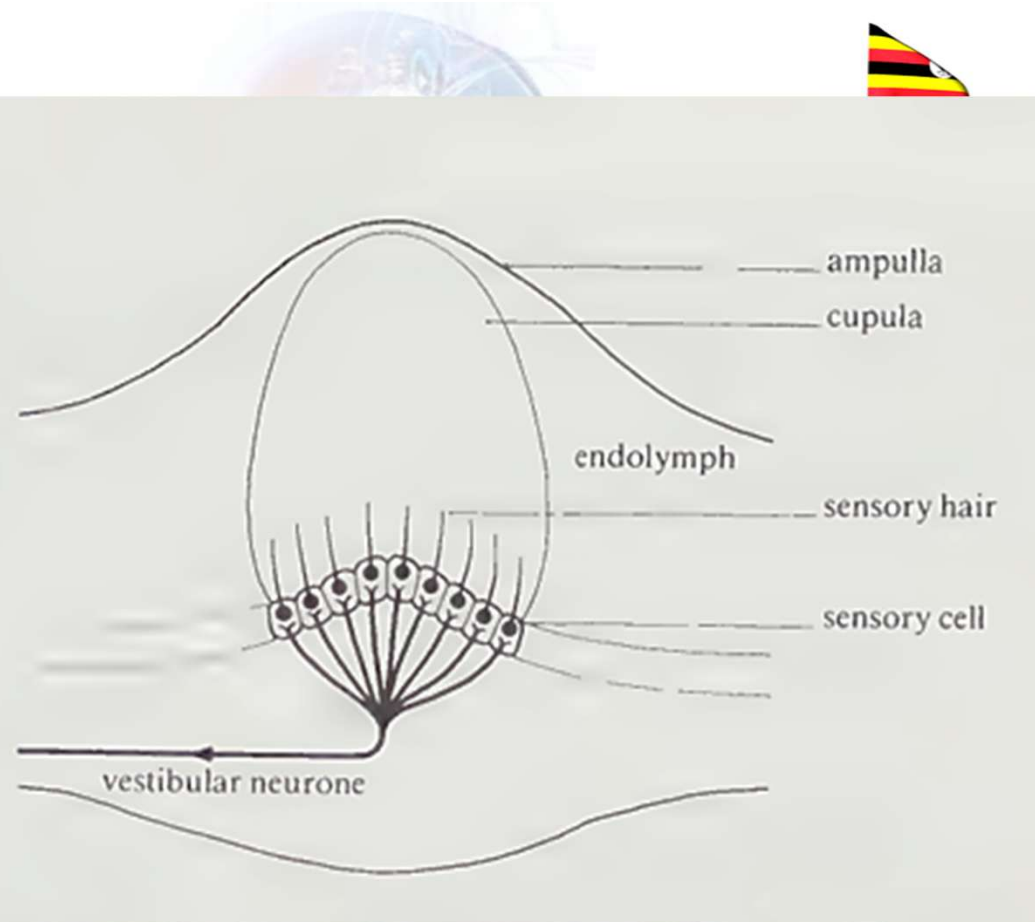
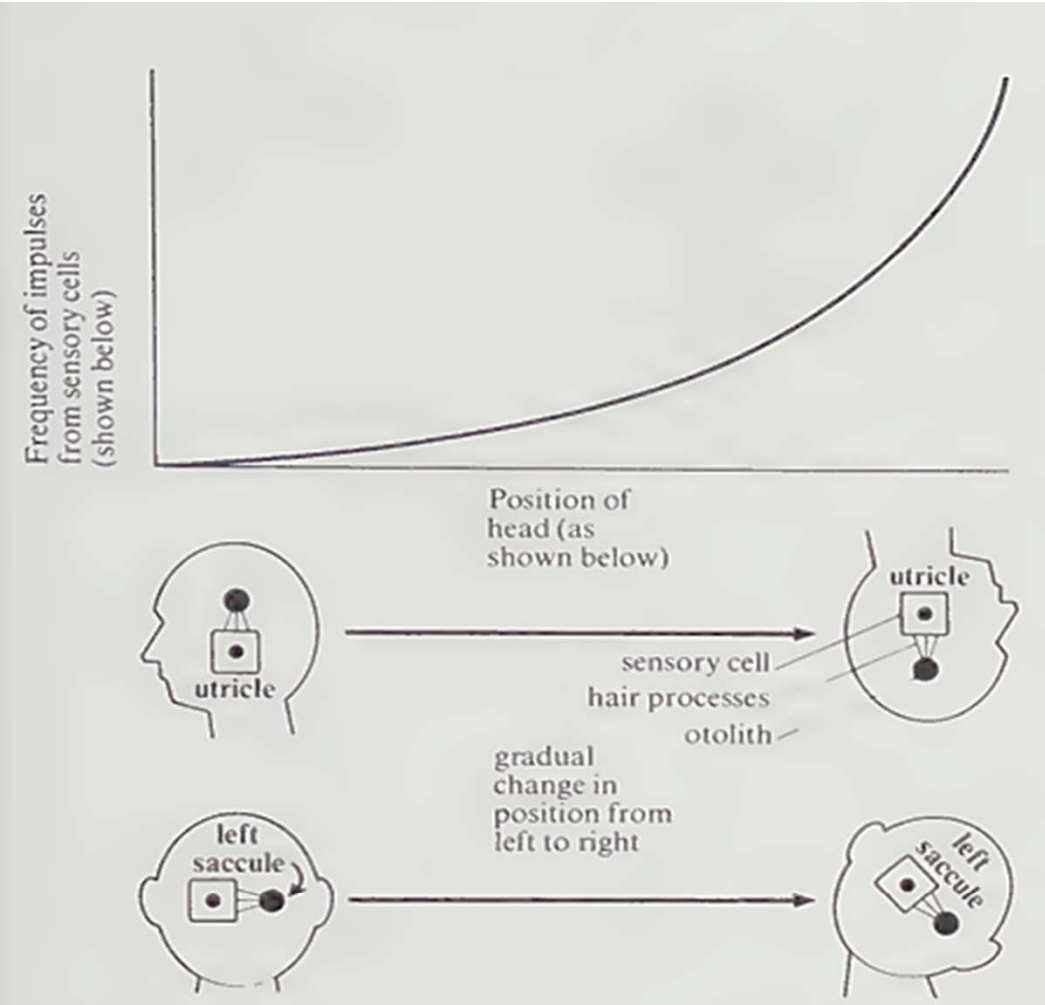


Fig 17.44 Graph showing the effect of head position on the activity of receptor cells of the utricle and saccule.

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- ***Utriculus and sacculus***

- Movement of the head results in *deflection of the hairs and production of a generator potential in the hair cells.*
- Regions of the walls of the utricle and saccule, called *maculae*, contain *receptor cells which have their hair-like processes* embedded in a *gelatinous mass* that *contains granules of calcium carbonate*. This mass is called an *otoconium*.
- *Otoconia respond to the pull of gravity* acting at right-angles to the Earth's surface and are mainly *responsible for detecting the direction of movement the of the head with respect to gravity.*
- The *utricle responds to vertical movements* of the head and *otoconia produce maximum stimulation when pulling the receptor hairs downwards*, such as when the body is upside down

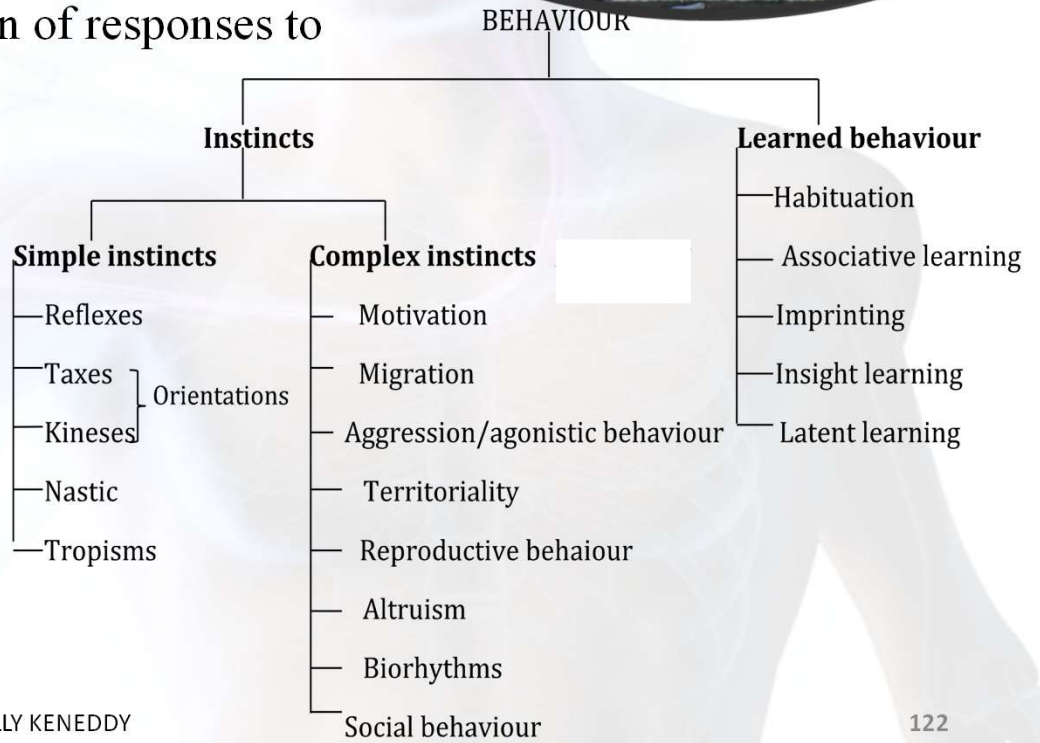


- The *sacculle responds to lateral (sideways) movement of the head*. The *hair cells of the sacculle are horizontal when the head is upright*.
- *Tilting of the head to the left* produces a *differential response from left and right sacculles*.
- The *left receives increased stimulation as the pull downwards on the hairs* whereas the right receives decreased stimulation.
- The *different influences of the pull of gravity result in a pattern of impulses to the cerebellum in brain*.
- The *impulses are interpreted thus providing information about the position of the head* and *accordingly sends instructions to relevant muscles to restore balance*.
- When the head is upright, the otolith is positioned on top of the sensory cells and no stimulation occurs.

BEHAVIOUR.

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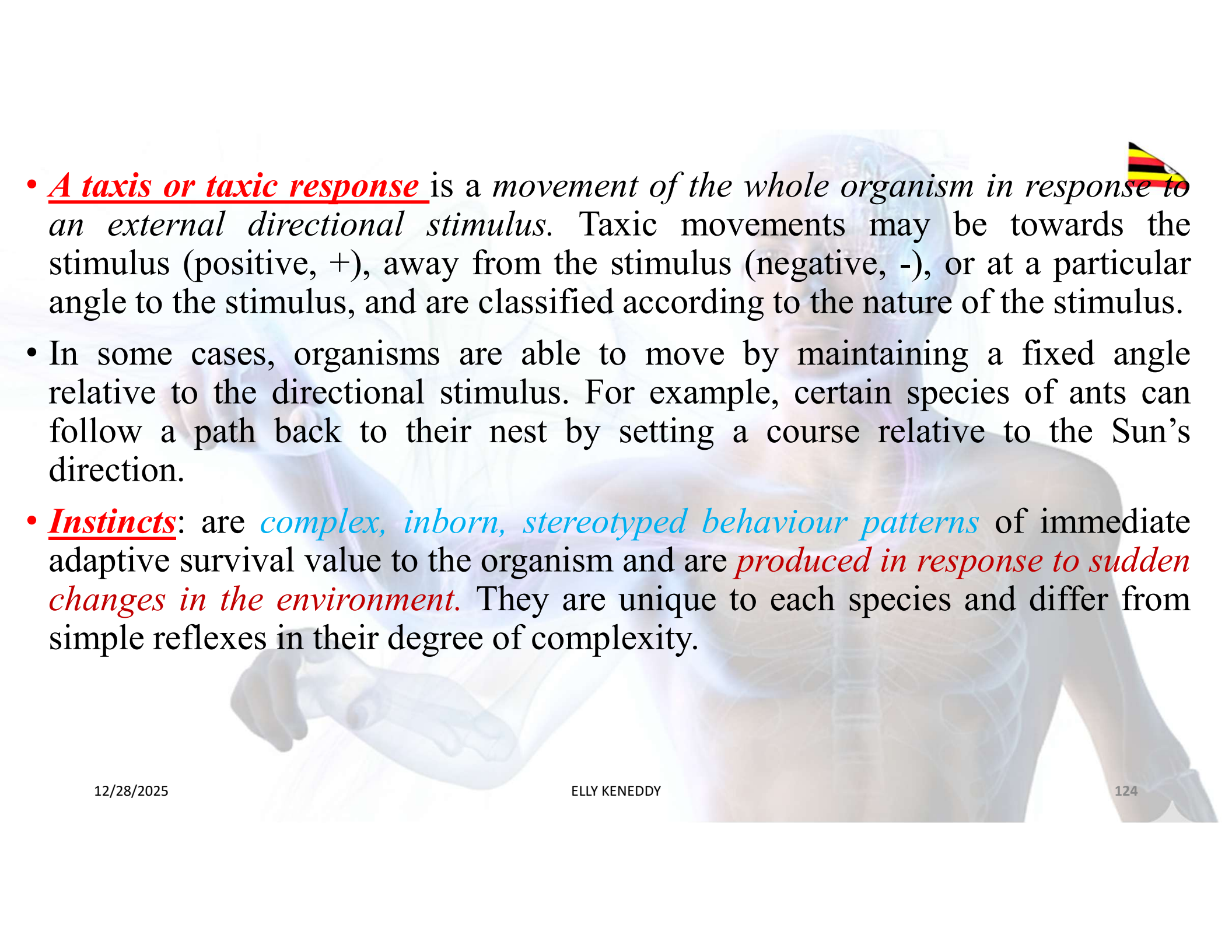
Behaviour: Is an outward expressive pattern of responses to stimuli in an organism.



INNATE/INSTINCT BEHAVIOUR.



- Innate or instinctive behaviour is *inherited and is highly specific*. It is normally an *inborn pattern of behaviour which cannot be altered*.
- In practice almost all instincts can be modified to some degree in response to experiences. However, innate behaviour is relatively inflexible when compared to learning.
- Much instinctive behaviour is highly complex and consists of a chain of actions, the completion of each stage in the chain acting as the stimulus for the commencement of the next stage.
- Innate behaviour patterns include orientations (*taxes* and *kineses*), *simple reflexes* and *instincts*. The latter are extremely complex and include biological rhythms, *territorial altruism behaviour*, *courtship*, *mating*, *aggression*, *hierarchies* and *social organization*. All plant behaviour is innate.

- 
- **A taxis or taxic response** is a movement of the whole organism in response to an external directional stimulus. Taxic movements may be towards the stimulus (positive, +), away from the stimulus (negative, -), or at a particular angle to the stimulus, and are classified according to the nature of the stimulus.
 - In some cases, organisms are able to move by maintaining a fixed angle relative to the directional stimulus. For example, certain species of ants can follow a path back to their nest by setting a course relative to the Sun's direction.
 - **Instincts**: are *complex, inborn, stereotyped behaviour patterns* of immediate adaptive survival value to the organism and are *produced in response to sudden changes in the environment*. They are unique to each species and differ from simple reflexes in their degree of complexity.

- **A kinetic response** is a *non-directional movement response* in which the rate of movement is *related to the intensity of the stimulus and not the direction* of the stimulus.
- For example, the direction of movement of the tentacles of Hydra in search of food is random and slow, but if saliva, glutathione or water fleas are placed close to the Hydra the rate of movement of the tentacles increases.
- There are two main types: *orthokinesis*, which involves *changes in speed of movement*; and *klinokinesis*, which involves *changes in the rate of turning*
- **A simple reflex** is an *involuntary stereotyped response of part of an organism to a given stimulus*. It is determined by the presence of an *inherited pattern of neurones forming spinal and cranial reflex arcs*. In terms of behaviour, simple spinal reflexes are either **flexion responses**, *involving withdrawal of a limb from a painful stimulus* **or** *stretch responses involving change of posture and balance*. This behaviour shows *fixed patterns of coordinated movements* called **fixed action patterns**

CHARACTERISTICS OF INNATE BEHAVIOUR

- It is inherited and not acquired, although some modifications may result from experience.
- It is similar among all members of a species and there are no individual differences other than those between males and females of the species.
- It is unintelligent and often accompanied by no appreciation of the purposes it serves.
- It often comprises a chain of reflexes. Completion of each link in the chain provides the stimulus for the commencement of the next link.
- Don't require prior experience
- Are automatic

COMPLEX INSTINCT BEHAVIOURS



- **Migration**; more complex innate behaviour; that *involves movement of a population/part of population; from one area to another* and *their return to original area/habitat after some time*.
- Migration range from short distance migration like up and down a single mountain to long distances across continents or oceans.
- E.g Salmon fish; spawn in fresh water streams in western Europe but return to the sea for normal life only seasonally to breed,
- Many species of birds live doves are known to migrate between the north pole in Europe and south pole in south Africa/southern America to escape unfavourable winter seasons.



TERRITORIALITY/TERRITORIAL BEHAVIOUR

- Is innate behaviour where organism or group of *organisms acquire; demarcate; protect/guard an area out of intruders*. A territory is *an area(avenue) of the habitat which is occupied by an individual/group of individuals and defended from other individuals of the same species*.
- It occurs in *all classes of invertebrates* and *some cats* like cheaters, lions, true cats etc.
- The major purpose of keeping a territory is *for breeding purposes*; to defend the territory *from predators/intruders*.
- Animals don't keep the territory by physical fighting or other form of aggressive behaviour but they use passive methods like; defecating around the territory, urinating around it, making special sounds.
- *Read reproductive behaviour also.*



SIGNIFICANCE OF INSTINCT BEHAVIOUR.

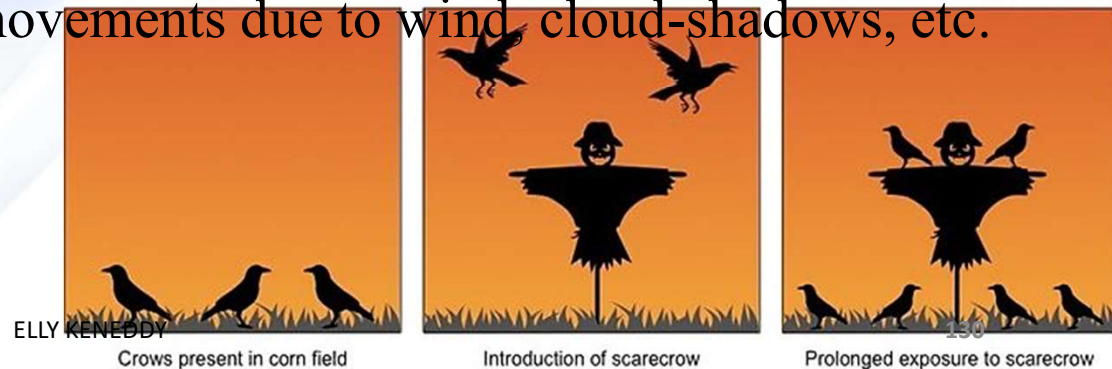


- Migration ensures finding better food suppliers provides better chances of finding good breeding places/sites thus animals that have migrated breed successfully
- Migration enables animals to avoid adverse unfavourable environmental conditions.
- Territoriality reduces losses of animals(organisms) to predation by defending the territory against predators;/intruders.
- Territoriality guarantees food supply, shelter and adequate space to offsprings, old and the mates; by keeping off all other animals that would feed on their food and reducing intraspecific competition
- Reduces/prevents spreading of diseases/epidemics; due to reduced contact with other organisms.
- Permits improved defense of nest and young ones; due to protection of breeding area & offsprings;

LEARNED BEHAVIOUR



- Learned behaviour is ***behaviour which is acquired and modified in response to experience***. It takes time to refine and so is of greatest benefit to animals with ***relatively long-life spans***. The chief advantage of learning over innate behaviour is its adaptability; ***learned behaviour can be modified to meet changing circumstances***.
- The simplest form of learned behaviour is **habituation**. Habituation is learning in which ***repeated exposure to a stimulus results in decreased responsiveness*** because it's followed by neither reward nor punishment.
- Continuous repetition of a stimulus not associated with reward or punishment extinguishes any response to the stimulus, e.g. birds learn to ignore a scarecrow.
- Important in development of behaviour in young animals helping to understand neutral elements in the environment, such as movements due to wind, cloud-shadows, etc.



- **Associative learning** involves the *association of two or more stimuli*. One form of associative learning is the conditioned reflex exemplified by the classic experiments performed on dogs by the Russian physiologist I. P. Pavlov:

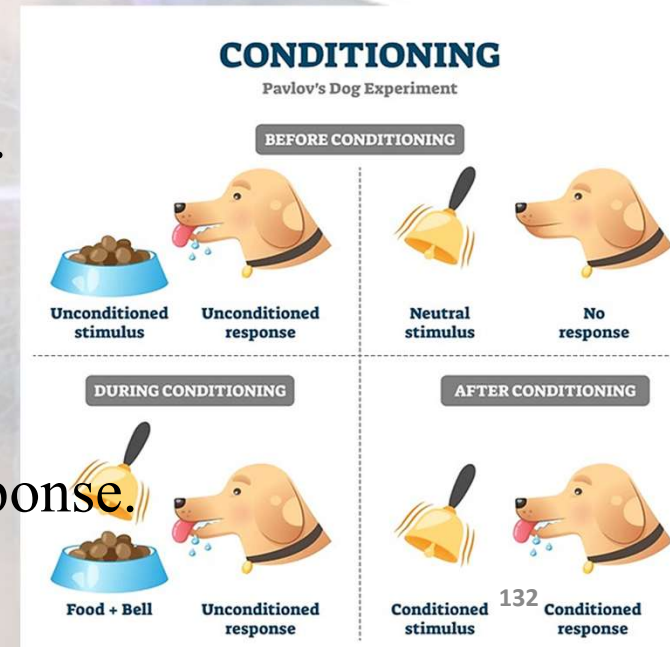
Experiment.

1. He allowed dogs to hear the ticking of a metronome and observed no change in the quantity of saliva produced.
2. He presented the dogs with the taste of powdered meat and measured the quantity of saliva produced.
3. He presented the powdered meat and the noise of the metronome simultaneously on five or six occasions.
4. He presented the noise of a ticking metronome only and observed that the dogs salivated in response to it whereas previously they had not done so (Stage 1).
5. Repetition of Stage 4 leads to a reduction in the quantity of saliva produced until the stimulus fails to produce any response.

- This association of one stimulus with another is the *basis upon which birds reject certain caterpillars*. If a caterpillar is *distasteful*, it is in its interests to advertise itself by being brightly patterned. This is known as *aposematic colouration* (*apo = away, sema = sign*; therefore ‘*keep away sign*’). *Having associated a particular pattern with the unpleasant memory of eating such a caterpillar*, the *bird ignores it as a potential source of food*. This often *leads to mimicry by otherwise edible insects*, which thereby avoid being eaten.

The features of a conditioned reflex are

- ✓ It is the association of two stimuli presented together.
- ✓ It is a temporary condition.
- ✓ The response is involuntary.
- ✓ It is reinforced by repetition.
- ✓ Removal at the cerebral cortex causes loss of the response.





• Second form of associative learning is **operant conditioning** (*trial and error learning*). This form of learning, studied by Skinner, differs from the conditioned reflex in the way it *becomes established*. Animals learn by trial and error.

• If mistakes are followed by an unpleasant stimulus while correct responses are followed by a pleasant one, the animal learns a particular pattern of behaviour. The **features of operant learning are:**

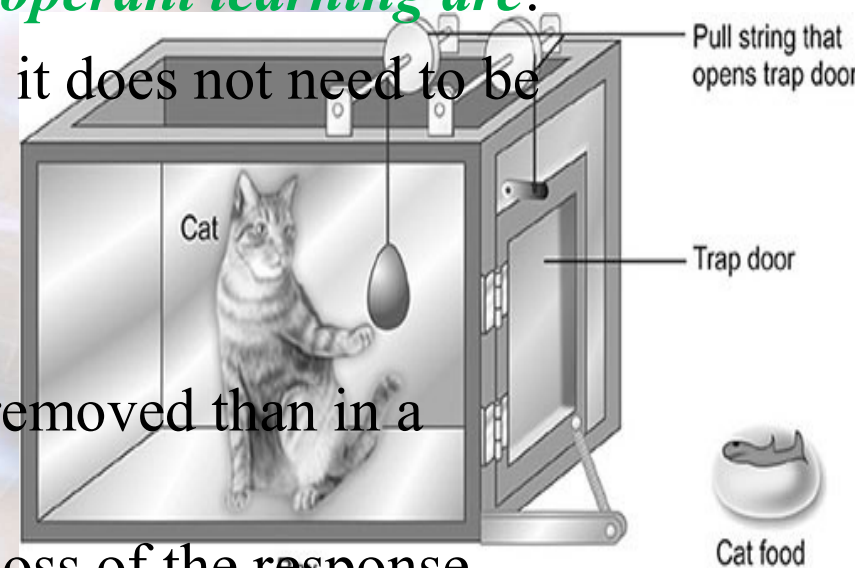
✓ The associative stimulus follows the action, i.e. it does not need to be simultaneous with it.

✓ Repetition improves the response.

✓ The action is involuntary.

✓ While temporary, the association is less easily removed than in a conditioned reflex.

✓ Removal of the cerebral cortex does not cause loss of the response.



Theory of Insightful learning



Figure 22.21 Insight learning? The ball has to be aimed at the grapes which, if hit, roll down the slope for the chimpanzee to eat. (F. A. E. Hall, Zoological Society of London)



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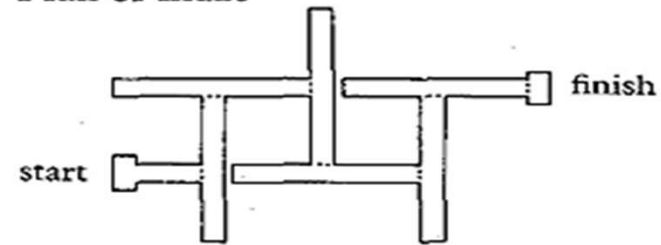
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EXPLORATORY/LATENT LEARNING

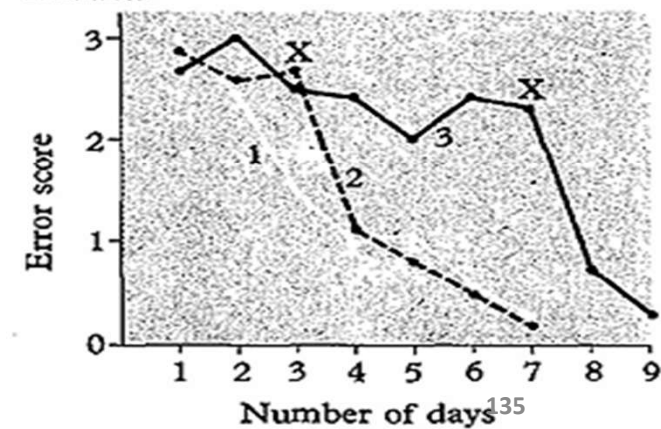
- Not all behavioral activities are apparently directed to satisfying a need or obtaining a reward (i.e. appetitive behaviour).
- *Animals explore new surroundings and learn information which may be useful* at a later stage (hence latent) and mean the difference between life and death.
- For example, in mice, knowledge of the immediate environment of its burrow may help it escape from a predator.
- At the time of acquiring this knowledge it had no apparent value.

Figure 22.20 Exploratory learning in rats. Group 1 were given a reward (food) at the end of each run. Groups 2 and 3 were given no reward until the third and seventh days respectively (the points marked X in the graph), after which they were rewarded each time. Notice the slow learning prior to X, and the very rapid reduction in errors immediately after X. This is attributable to previous exploratory learning. (After Blodgett)

Plan of maze



Results





- **Latent learning** arises when an *animal stores information while exploring its environment*, and *uses it at some later time*.
- A rat placed in a maze with no reward as a stimulus will *later complete the maze, when a reward is present, more rapidly* than a rat which has never been in the maze. It involves internal mental process (*mental reasoning*) or *intelligence*.
- The highest form of learning is **insight or intelligent behaviour**. In this, animals seem to solve problems by internal mental processes. Problem- solving usually involves cognition, which includes *conscious thinking, self-awareness, judgement*.
- It also involves the *recall of previous experiences* and *their adaptation to help solve a new problem*. The rapidity with which a solution is achieved *excludes any possibility of trial and error*.
- Kohler showed that *chimpanzees will acquire bananas fixed to the roof of their cage by piling up boxes upon which they climb to reach them*.
- In the same way *sticks may be joined together to form a long pole* which is *used to obtain bananas which are out of reach outside the cage*.

Operant learning / trial and error

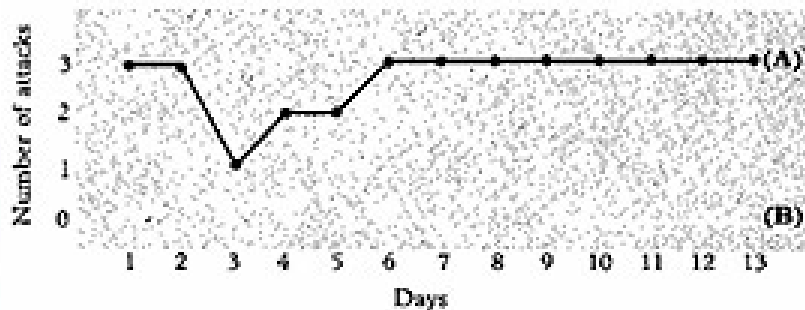


Figure 22.18 . Trial and error learning by an octopus. In the upper diagram an untrained octopus is seen leaving its shelter and advancing towards the crab at the other end of its tank. If it attacks the crab with white square it is given an electric shock (note the electrodes sticking out of the white square). If it attacks a crab alone it is allowed to take it back to its shelter and eat it. Six trials are carried out each day, three with crab only, and three with crab plus white square. The results are shown in the lower diagram: after a few days the octopus learns to attack the crab alone (Graph A), but *not* to attack the crab with white square (Graph B). (Based on *Boycott and Young*)

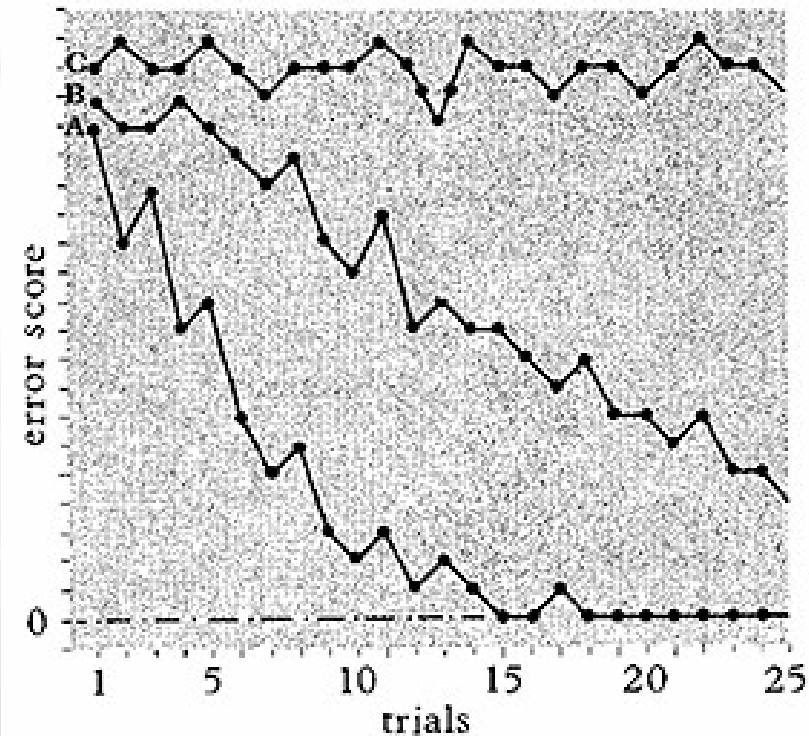
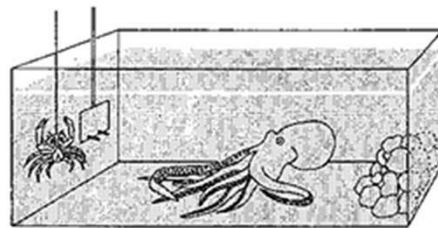



Figure 22.17 The kind of results obtained in learning experiments. Animal A learns quickly; B moderately quickly; C fails to learn at all.

- ***Imprinting*** is a simple but specialized form of learning. Unlike other forms of learning, *imprinted behaviour is fixed and not easily adapted*. 
- Newly hatched geese will ***follow the first thing they see***. ***Ordinarily this would be their mother*** and the significance of this behaviour is therefore obvious.
- However, as shown by the Austrian behaviourist, Konrad Lorenz, they will follow humans or other objects should these be seen first. This principle is often used in training circus animals.
- If a trainer becomes imprinted in an animal's mind, it becomes much easier to train.



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SIGNIFICANCE OF LEARNED BEHAVIOUR



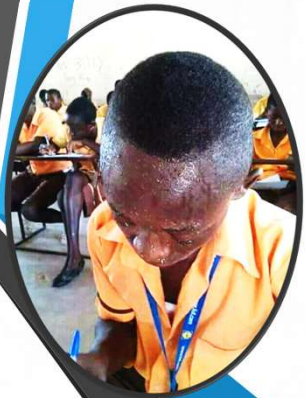
- Habituation avoids wasting time and energy on harmless stimuli.
- Insight learning saves time and energy which is used for important activities like feeding; courtship, mating, parenting, protection, acquiring territory.
- Habituation prevents over stimulation and damaging of receptors and effectors.
- Is important in wild animals e.g. predators learn to associate unpalatable animals with certain marking or colouration and thus avoid eating them.
- Imprinting enables offsprings to acquire essential skills possessed by the parents e.g. learning to fly in birds to locate food and escape predation.
- Imprinting creates strong bond between the offspring and parents thus protection from predators and parental care.
- Insight learning ensures survival of an organism by avoiding adverse, dangerous conditions through solving problems at first sight/immediately.



ALWAYS AIM FOR EXCELLENCE

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