H2 BIOLOGY

CORE SYLLABUS II

TOPICS COVERED:

1. GBV I
2. GBV II
3. PHOTOSYNTHESIS
4. CELLULAR RESPIRATION
5. DIVERSITY AND EVOLUTION
6. CELL SIGNALING
7. NERVOUS SYSTEM

(a) Degree of freedom (df)

Calculate the number of degrees of freedom using the following formula:

df = n – 1
where n is the number of phenotypic classes

First, determine how many phenotypic classes there are in the investigation being carried out. If there are 2 phenotypic classes, the degree of freedom (df) is 1.

- The degree of freedom measures the number of classes of data (in this case, phenotypic classes) that are independent of each other. The degree of freedom measures the spread of the data and is always one less than the number of classes of data.
- In the case of 2 phenotypic classes where the total number of offspring is known, when the number in any one phenotypic class has been determined, the number in the second class is fixed. Hence, one is subtracted from the number of phenotypic classes.

(b) Level of significance (α)

State the level of significance:

- There are two critical theoretical values (cut-off points) of $\alpha = 0.05$ and $\alpha = 0.01$, against which χ^2_{calc} is usually compared to decide whether or not to reject the null hypothesis.
- **For Biology, unless stated otherwise, we take the level of significance to be 0.05.**

(c) Critical chi-square value (χ^2 crit)

From the χ^2 probability table on page 23, obtain the critical theoretical χ^2 value (χ^2 crit), stating it as $\chi^2_{crit\ df\ =\ \_\_\_\_,\ \alpha=\_\_\_\_} = \_\_\_\_\_$.

5. Write a conclusion.

If χ^2 calc > χ^2 crit,

- the probability that chance alone is the reason for the difference of the observed from the expected results/ratio is **less than 5 %.**
- The deviation is **significant.**
- Hence, **reject H_0 in favour of H_A.**

OR

If χ^2 calc < χ^2 crit,

- the probability that chance alone is the reason for the difference of the observed results and the expected results/ ratio is **more than 5 %.**
- The deviation is **not significant.**
- Hence, **do not reject H_0.**

LIGHT HARVESTING STAGE

The plant uses a mixture of pigments – chlorophyll, to capture light energy

Excitation of chlorophyll by light:

When a molecule of chlorophyll absorbs light, it becomes excited and this energy is used to boost electrons to a higher energy level

An excited electron is unstable and returns to its ground state in two main ways:

1. **By transferring the energy –** directly to a neighboring pigment molecule through resonance energy transfer (occurs in light harvesting stage)
2. **By transferring the high-energy electron –** to another nearby molecule, an electron acceptor, and then returning back to its original state by taking up a low-energy electron from another molecule, an electron donor (occurs in light dependent stage)

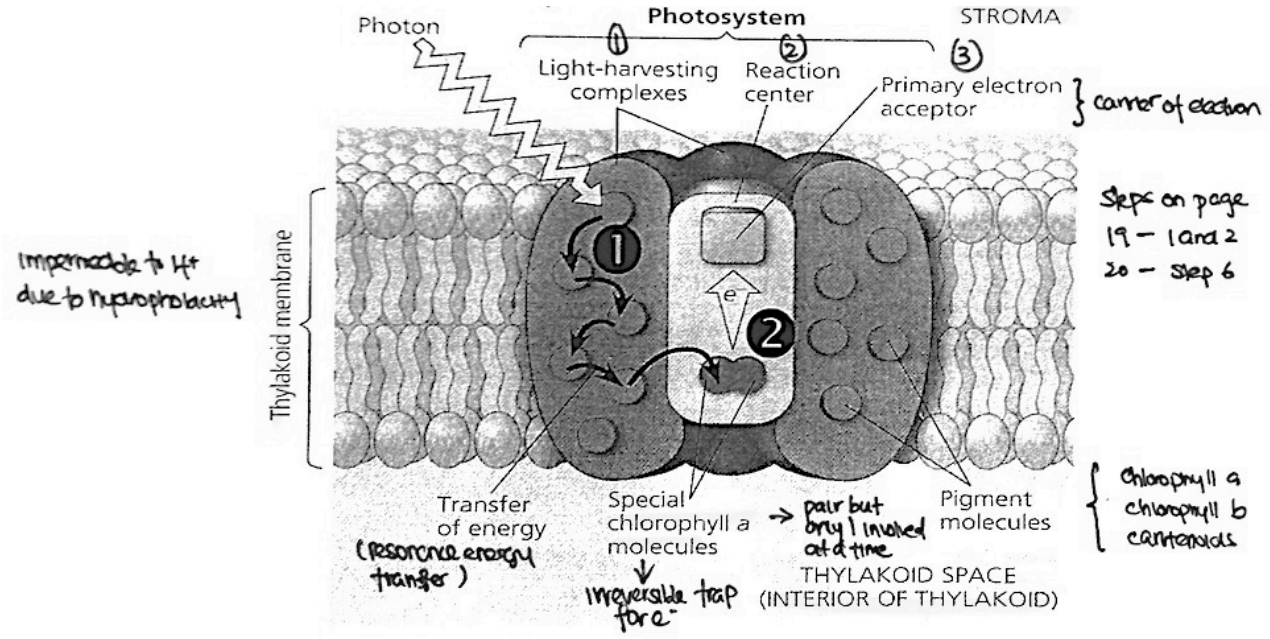
Usually water serves as a weak electron donor – when it is oxidized, it will release oxygen along with two protons

Photosystems: Present in the thylakoid membranes

Photosynthetic pigments are arranged into photosystems, and they catalyze the conversion of light energy captured by excited chlorophyll molecules to useful forms.

A photosystem has three closely linked components

1. **Light harvesting complexes**
   - Light is collected by the 200-300 pigment molecules bound to light-harvesting protein complexes in thylakoid membrane
   - They absorb light and transfer the light energy to the reaction center
2. **Reaction center**
   - Contains a pair of special chlorophyll a molecules (only one excited at a time)
   - Act as an irreversible trap for energy as its excited electron is immediately passed to an adjacent chain of electron acceptors in the same multi-protein complex
3. **Primary electron acceptor**
   - Found in reaction center, involved in electron transfer (ETC)



FACTORS AFFECTING PHOTOSYNTHESIS

The rate of photosynthesis is affected by many factors – which determines the yield of material produced by the plant

The principle of limiting factors states that

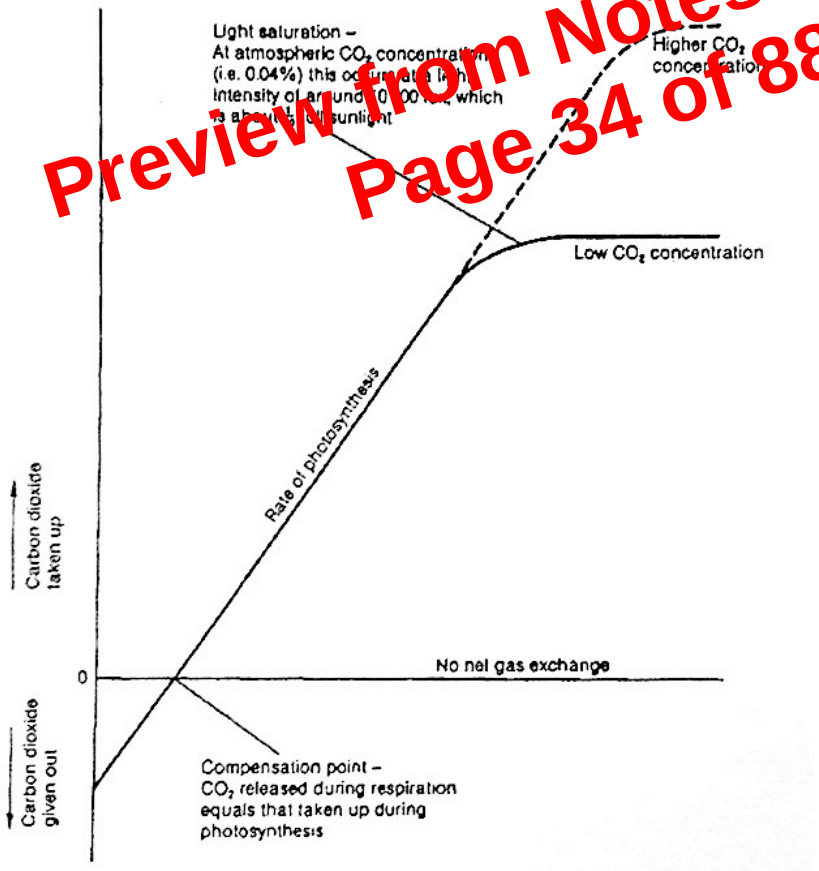
- The rate of a biochemical process, which consists of a series of reactions, is limited by the slowest reaction in the series
- When it is affected by several factors, its rate is limited by the factor that is nearest its minimum value – it directly affects the biochemical process if its quantity is changed

Light intensity:

At low light intensity, rate of photosynthesis increases linearly with increasing light intensity until it reaches light saturation point

- Gradually rate of increase falls off as other factors become limiting
- Illumination on a clear summer's day is 100,000 lux, but light saturation point is 10,000 lux – thus light intensity is usually not a limiting factor
- Very high light intensity may damage the chlorophyll and decrease rate of photosynthesis
- The compensation point is point where rate of photosynthesis is equal to the rate of respiration – there is no net gaseous exchange

Below compensation point, rate of P < rate of R: CO_2 is evolved and O_2 is taken in
Above compensation point, rate of P > rate of R: CO_2 is taken in and O_2 is evolved



Process of glycolysis

Step 1 to 5: Energy-investment phase

Steps 1 to 3: Activation of glucose

- Conversion (and hence activation) of unphosphorylated glucose to a phosphorylated fructose 1,6-bisphosphate
- Involves hydrolysis of 2 ATPs to provide phosphate groups and energy
- Step 3 – rate limiting step of glycolysis involving the enzyme phosphofructokinase

Step 4 to 5: Cleavage / Lysis

- Cleavage of fructose 1,6-bisphosphate to two 3-carbon sugars (glyceraldehyde-3-phosphate / G3P)

Steps 6 to 10: Energy-payoff phase

Step 6: Reduction of NAD (Dehydrogenation)

- Each G3P is oxidized and NAD is reduced to NADH, with 2 NADH per glucose molecule
- 1 NADH supplies 2 energized electrons to drive most ATP production by oxidative phosphorylation

Steps 7 and 10: Substrate-level phosphorylation

- Substrate-level phosphorylation of ADP occurs at steps 7 and 10, coupled to the dephosphorylation of an organic substrate
- Produces 4 ATP per glucose molecule
- Results in overall net gain of 2 ATPs per glucose molecule

Importance of glycolysis

1. It is the only catabolic reaction that can be completed in the absence of oxygen
2. Supplies cells with essential biosynthetic precursors

- Liver carries out glycolysis to provide precursors for molecules it synthesizes (fats)
- Glycolysis associated with supplying initial steps of fat biosynthesis with substrate, rather than acting as a source of ATP
- For microorganisms, both energy and necessary biosynthetic precursors are obtained from glycolysis

Regulation of glycolysis

Phosphofructokinase is an allosteric enzyme inhibited by ATP and stimulated by AMP

- As ATP accumulates, inhibition of enzyme slows down glycolysis
- Enzyme becomes active as cellular work converts ATP to ADP (and AMP) faster than ATP being regenerated
- It is also sensitive to citrate, first product of Krebs Cycle – if citrate accumulates in mitochondria, some passes into cytosol and inhibits phosphofructokinase
- Thus it helps to synchronize rates of glycolysis and Krebs Cycle

MUTATIONS

It is a permanent change in the nucleotide sequence of an organism's DNA; it immediately brings about changes in the gene pool of a population by substituting one allele for another

Thus random mutations with pre-existing genes are a source of new alleles that are new heritable variations

- Mutation can obviously change the allele frequency in the gene pool of a population
- Mutations are slow, random and rare

GENE FLOW

It is the movement of genes / alleles from one population to another through migration of fertile individuals to another and breeding in that new population

A population may therefore gain or lose alleles by gene flow, but it reduces differences between populations that have accumulated as a result of natural selection or genetic drift

Example: Copper tolerance in grass plants

Demonstrates gene flow opposing natural selection

- Concentration of metals ions in soil is relatively high, thus we expect resistant allele to grow on soil with heavy metals ions to occur with 100% frequency on mine sites and 0% elsewhere
- However this thus not occur due to prevailing winds blowing pollen containing non-tolerant alleles onto mine site and tolerant alleles beyond the site's borders

GENETIC DRIFT

It is the random change of allele frequencies as a result of chance alone, differing from generation to generation in a small gene pool, resulting in less genetic variation within the small population

Effects of genetic drift:

1. Significant in small populations – chance events alter allele frequencies substantially only in small populations
2. Causes random change of allele frequencies
3. Can lead to loss of genetic variation within populations and creates genetic divergence between populations – might eliminate alleles from a population and can thus influence how effectively a population adapts to a change in the environment
4. Can cause harmful alleles to become fixed

Founder effect:

Occurs when one or few individuals colonize a habitat isolated from their place of origin or new to that species

Example 1: Amish population in the US / Example 2: Finches on the Galapagos Island

About 200 members of the Amish religion migrated from Switzerland to Pennsylvania between 1720 and 1770

- Discovered they had an allele frequency for Ellis-van Creveld syndrome of about 0.07 compared to less than 0.001 in the general population
- One couple who immigrated in 1744 carried the allele and inbreeding passed the allele along to their descendants
- Also, by chance the Ellis-van Creveld had more children than the average Amish, further increasing the allele frequency by genetic drift

Bottleneck effect:
Occurs when natural disasters, diseases, or predators (by chance) kill large numbers of individuals, resulting in drastic short-term reductions of a population size

Alleles may be under-represented, over-represented or even eliminated
- Portion of its original diversity is permanently lost
- Leads to reduction and restriction in genetic variability

Example: Greater prairie chicken

Millions of greater prairie chicken used to live on the prairies of Illinois
- These prairies were converted to farmland and caused the number of chickens to plummet such that by 1993, only two populations remained (fewer than 50 birds)
- Also had low levels of genetic variation and less than 50% of their eggs hatched
- Hence this suggest that genetic drift during the bottleneck led to a loss of genetic variation and increase in frequency of harmful alleles
- 1993 Illinois greater prairie chicken population had lost nine alleles present in the museum specimen

NON-RANDOM MATING / ARTIFICIAL SELECTION
Non-random selective breeding is a process where changes in allele and genotype frequencies are determined by deliberate human actions – man exerts a directional selection

Artificial is a fast and rapid process
- Alleles favored by humans increase in frequency at the expense of less favorable alleles
- There are two kinds of artificial selection: inbreeding and outbreeding

Inbreeding:
Involves breeding of closely related individuals – most extreme form is self-fertilization
- Increases proportion of individuals that are homozygous at many gene loci
- Tends to maintain desirable characteristics and allows production of crop with uniformity in characteristics
- However, genetic diversity may be reduced to an extent where every individual has identical alleles for every gene (complete homozygosity) and cause reduced fertility and lowered disease resistance

Outbreeding:
Involves breeding between members of genetically distant populations – forming hybrids
- These hybrids often have characters which are superior to that of either parents, phenomenon known as hybrid vigor / heterosis

Example: Domestication of brassica

Artificial selection by humans has produced six separate vegetables from this single species: *Brassica oleracea*
- Kale, Brussels sprouts, Cabbage, Broccoli, Kohlrabi, Wild mustard

Example: Domestication of breeds of dogs

Many dogs also descended from the Gray Wolf

SPECIATION

Defined as the evolution / origin of species. Evolution occurs when the inherited characteristics of a population or of a species change over a period of time

Speciation must involve: disruption of gene flow, accumulation of RIMS and genetic diversity

Process of speciation:

Four stages characterize most processes of speciation

(1) Single population

- Ancestral species is a single reproductive community and all members of the species actually or potentially interbreed and are reproductively / genetically isolated from other species

(2) Barrier develops

- Subgroups of ancestral species become divided and separated from each other by a barrier – causing them to be geographically isolated
- Other types of barriers can also divide a species into separate, ecologically isolated populations that live in the same area
- Members can still interbreed if brought together
- Due to external barrier isolating the populations, gene flow between the geographically isolated population is interrupted

(3) Differentiation due to different selection pressures

- Now divided, each population experiences a slightly different environment that delivers different selective pressures causing different characters to be successful in each location
- Through successive generations, accumulation of character leads to genetic distinctiveness of each separate population
- Due to mechanisms of natural selection and change in gene pool, each population becomes more adapted to its own environment and thus differentiation has occurred

(4) Barrier disappears

- Barrier now disappears and different populations come into contact
- However they are reproductively isolated / genetically incompatible and can no longer produce viable, fertile offspring
- There must be accumulation of sufficient reproductive isolating mechanisms (RIMs), adaptations and genetic diversity for a new species to be formed

Allopatric speciation:

Refers to formation of a new species as a result of geographical isolation and subsequent natural selection and / or genetic drift (likely to occur if population is small)

Example 1: White-tailed antelope squirrel

Geographical isolation at the Grand Canyon where there is the North and South Rim

- Founder effect occurs at the North Rim
- Over a long period of time, natural selection resulted in adaptation and changes to genotype and allele frequencies of the gene pool of *A. leucurus*
- Accumulation of sufficient reproductive isolating mechanisms (RIMs) and genetic diversity
- If individuals cannot produce viable, fertile offspring, then speciation has occurred

Example 2: Darwin's finches on Galapagos Islands (Also for adaptive radiation)

There were different, though apparently related, species of finches on the different islands of the Galapagos Islands – each species had a beak adapted to the particular food source

- One of the islands was colonized by a small population of finches from South America
- Natural selection resulted in adaptations to local conditions on the island and reproductive isolating mechanisms (RIMs)
- Geographical isolation permitted additional speciation
- Later a few of these species reached neighboring islands and after diverging, a new species re-colonized the island
- **Selection pressure –** types, availability and competition for food

Sympatric speciation:

A new species evolves within the same geographical region as the parental species or geographically overlapping populations

Polyploidy

Instances in which organisms possess more than two of the haploid chromosome set. There are two kinds of polyploidy: **autopolyploidy** and **allopolyploidy**

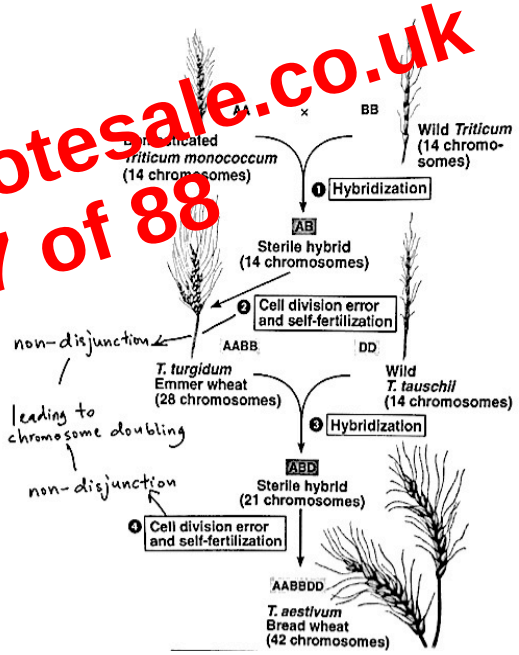
Autopolyploidy (same species)

- Chromosome doubling during non-disjunction
- Could give rise to a tetraploid plant, where flowers produced would have diploid gametes through meiosis
- If self-fertilization occurs, it develops into plants producing fertile tetraploid offspring
- Thus the formation of a tetraploid (4n) plant is an instantaneous speciation event

Allopolyploidy (different species)

- Haploid gametes from two different species combine, resulting hybrid normally sterile
- Hybrid may produce asexually
- Subsequent errors in cell division may produce chromosome duplications resulting in diploid set of chromosomes
- A fertile polyploid species is now formed
- Allopolyploids are reproductively isolated from both parents

Example: Bread wheat



Signal reception:
Refers to the target cell's detection of an extracellular signal molecule.

Ligand-receptor interaction is highly specific where the ligand (signal molecule) binds to a specific structurally complementary site on the target cell receptor to form a ligand receptor complex

- Causes receptor protein to undergo conformation change resulting in activation

There are two kinds of signal receptor proteins: (A) Intracellular receptors and (B) Extracellular / Cell surface / Membrane receptors

Signal transduction:
Process by which a target cell converts an extracellular signal into an intracellular signal that results in specific cellular response

Formation of activated ligand-receptor complex changes conformation of receptor protein, initiating process of transduction – can sometimes occur in a single step (intracellular receptors)

- Multistep transduction pathway with relay molecules operating in sequence
- Act by altering the conformation and activating / inhibiting the protein immediately downstream
- Conformation change brought about by phosphorylation, causes phosphorylation cascade

Transduction may also involve non-protein molecules that function as second messengers to relay signal from cell surface to cell interior

Cellular response:
Response may occur either in the cytoplasm (cytoplasmic response) or the nucleus (nuclear response)

- Cytoplasmic response involves changes in cell metabolism (regulation of enzyme activity)
- Nuclear response involves changes in gene expression (regulation of gene activity)

INTRACELLULAR RECEPTOR SIGNALING
Signal molecules can do this because they are either hydrophobic or small enough to diffuse across the hydrophobic core of the cell membrane

- E.g. steroid hormones, thyroid hormones (hydrophobic) and nitric oxide (small)

Types of intracellular receptors:

Gene regulators
Serves as transcription factors when activated by signal molecules, like steroid hormone receptors

1. Steroid hormone diffuses across plasma membrane into target cell

Signal Reception:
2. Steroid hormone binds to specific intracellular receptor protein in the cytoplasm, activating it

Signal Transduction:
3. Activated hormone-receptor complex enters the nucleus and binds to hormone response elements of a specific gene

Cellular Response:
4. Bound protein stimulates the transcription of the gene into mRNA

Ion-channel receptors:
They are membrane receptors that allow specific ions to pass through when the receptor changes conformation

When a signal molecule binds as a ligand to the receptor protein, a region of it acts as a "gate" to open or close, allowing or blocking the flow of specific ions through a channel / pore

- It is important in the functioning of nervous system, especially in the formation and transmission of nervous impulses
- Such as receptors for neurotransmitters in synaptic signaling

Signal Reception:
1. Ligand binds to a specific site on the receptor protein, triggering conformational change and causing the gate to open

Signal Transduction:
2. Allows or blocks respectively the flow of specific ions through a channel / pore
3. This results in a temporary change in the membrane potential, affecting activity of other membrane proteins or cytoplasmic enzymes

Cellular Response:
4. Altered activity of membrane / cytosolic proteins triggers a cellular response

5. When ligand dissociates from the receptor, the gate closes or opens again

ADVANTAGES AND SIGNIFANCE OF CELL SIGNALING

Advantages and significance of multistep pathways:

1. Signal amplification – allows for possibility of amplifying a signal, and the result can be a large number of activated molecules – hence a small number of extracellular signal molecules can produce a large cellular response

2. Provides more opportunities for coordination and regulation

3. Contribute to specificity of the response – the same signal molecule can lead to a variety of cellular responses via specific combination of signaling/relay proteins present in each cell

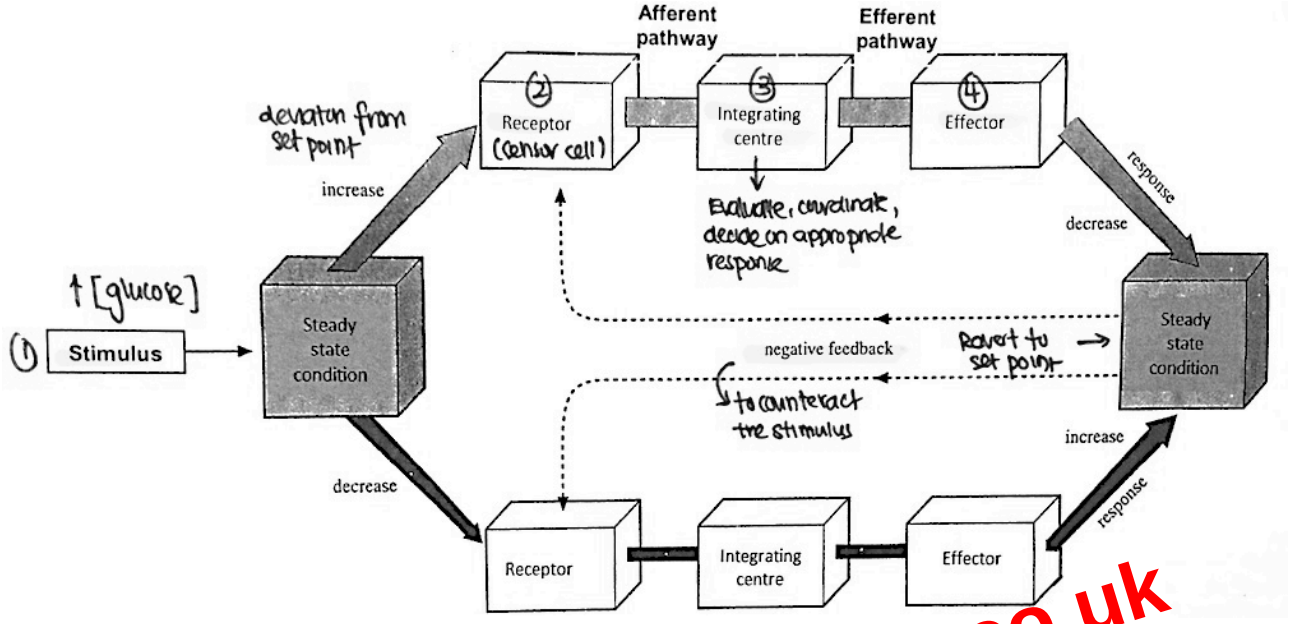
Signal amplification:
It is the process of enhancing the signal strength as the signal is relayed through a transduction pathway

There are three key features of signal amplification
- At each catalytic step in the cascade, number of activated products is much greater than the preceding step
- Small number of extracellular molecules is sufficient to elicit a cellular response
- Response at the target cell is large, as large number of activated molecules are produced

Amplification effect is possible for two reasons
- Presence of multiple steps in the transduction pathway (signal reception and cellular response)
- Persistence of proteins in the active form long enough to process many molecules of substrate

Homeostasis control system:
Control of a reaction lies outside the organ (effector) that carries out the response

Reflex means any long distance pathway that uses the nervous system or endocrine system, or both, to receive input about a change, integrate the information, and react



Efficiency of a control system can be judged by
- Extent of deviation from the set point
- Speed with which the set point is restored after a change has occurred

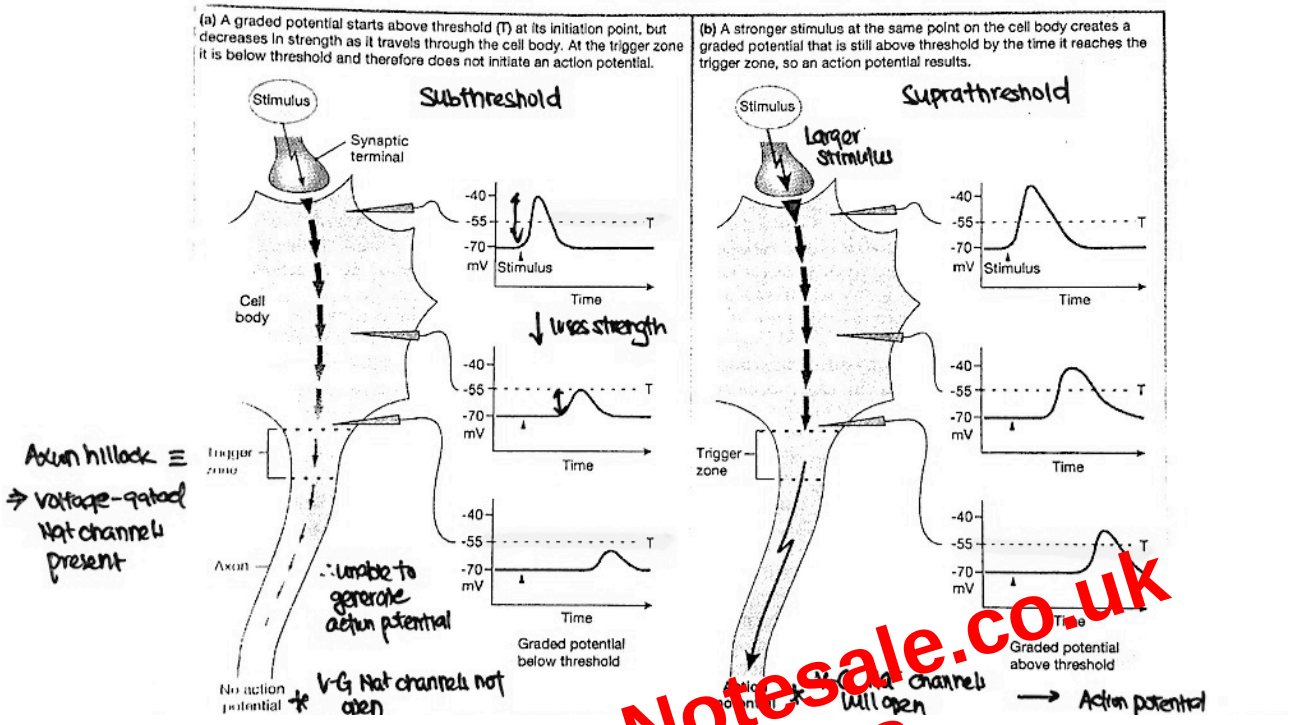
Component	Function
Set point	Steady state range of values at which the system operates
Stimulus	Fluctuations in the normal condition or variable above or below the set point
Receptor (sensor)	Signals the extent of deviation from the set point
Integrating center	Determines the set point Evaluates and coordinates incoming signals from receptors, compare it to the set point, determines appropriate responses to restore the set point
Effector	Responds to commands from the integrating center by eliciting the appropriate responses
Feedback mechanism	Informs the integrating center which then acts on the stimulus of any change as a result of the response elicited by the effector

Feedback mechanisms:
Feedback requires action of the system to be related to a set point. Any deviation from the set point activates the control system to trigger responses to return the condition to its optimum level

Two types of feedback
1. Negative feedback – counteracts the stimulus so that the entire control mechanism shuts down
2. Positive feedback – reinforcing the stimulus to allow the reaction to proceed at a faster rate

Fate of the graded potential is determined when it reaches the trigger zone (axon hillock)

- Graded potential below threshold potential of -55mV to -50mV (subthreshold) is not strong enough to trigger an action potential
- Graded potential above threshold potential (suprathreshold) triggers an action potential. The stronger the stimulus, the more frequently action potentials are generated

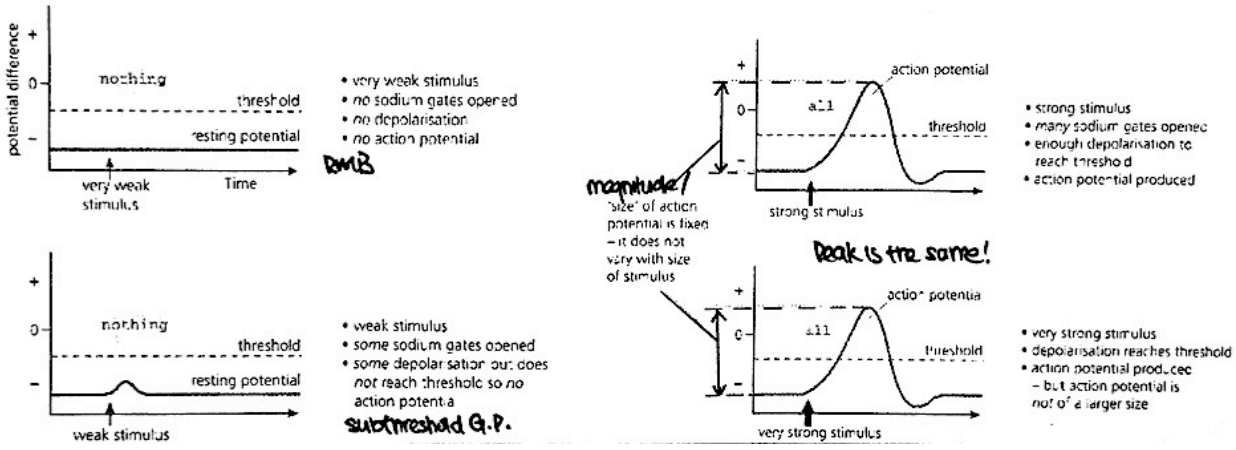


Action potential:

It is a brief, rapid and large change in membrane potential during which the potential reverses, so the inside of the excitable neuron transiently becomes more positive than the outside

The action potential is propagated in a non-decremental fashion and are known as all-or-none phenomena

- Occur as maximal depolarization if stimulus reaches the threshold
- Amplitude does not vary with stimulus strength
- Do not occur at all if the stimulus is below the threshold



COMPARISON BETWEEN NERVOUS AND ENDOCRINE SYSTEM

Basis	Endocrine system	Nervous system
Complexity	Less structurally complex	More structurally complex; can integrate vast amounts of information and stimulate wide variety of responses
Nature of transmission	Information transmitted as chemical substances (hormones)	Information transmitted as nerve impulse which is electrical in nature Across a synapse, information transmitted by chemical substances (neurotransmitters)
Mode of transmission	By circulatory system via blood	By the nervous system via neurons / nerve cells
Rate of transmission	Sow transmission and slow-acting (except for adrenaline)	Rapid transmission and response (in milliseconds)
Duration of effect	Often long-term changes / effects	Short-term effects
Types of responses	Response may be very wide spread, and a single hormone may act on target organs far from each other	Response often very localized
Specificity of pathway	Not specific (blood circulation around body) but target is specific	Pathway is specific (through neurons / nerve cells)

~ END ~