St Ninian's High School

Biology Department

Higher Biology

Unit 1: Metabolism and Survival

Revision Notes

Name: _____

Learning Outcomes

Key Area 1:	Metabolic Pathways & their control
Key Area 2:	Cellular Respiration
Key Area 3:	Oxygen Delivery & Thermoregulation
Key Area 4:	Surviving and avoiding adverse conditions
Key Area 5:	Microbe Growth in a laboratory
Key Area 6:	Genetic control of microbes

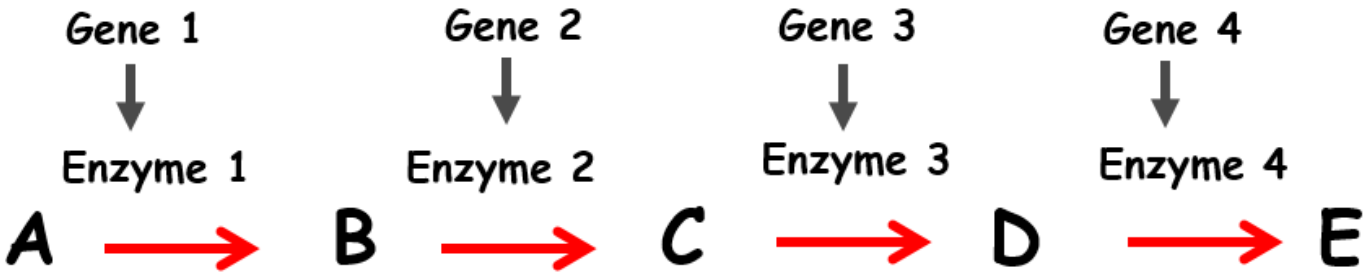
Unit 1 Metabolic Pathways, Enzymes & Respiration Revision

Metabolism

Sum of all integrated and controlled metabolic pathways within a cell.

Metabolic Pathways

Metabolic pathways have 3 types of steps: reversible, irreversible steps and alternative routes.



Each step in a metabolic pathway requires a specific enzyme produced by a specific gene.

Enzymes often act in groups in metabolic pathways or as multi-enzyme complexes.

Mutation on a metabolic pathway

A gene mutation leads to an non functional enzyme affecting the concentration of most substances in the pathway.

Rules

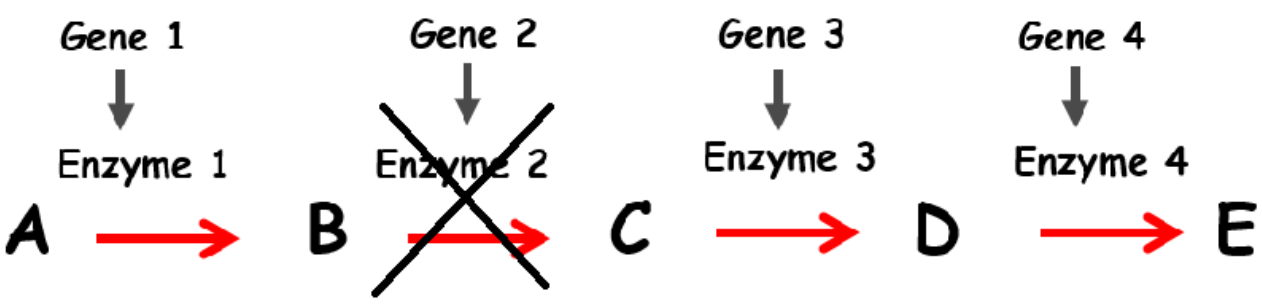
1. The molecule directly before the mutation increases.

2. ALL substance directly after the mutation decreases

3. Molecules indirectly before the specific enzyme remain constant

Worked Example

Enzyme 2 non functional due to gene mutation in gene 2



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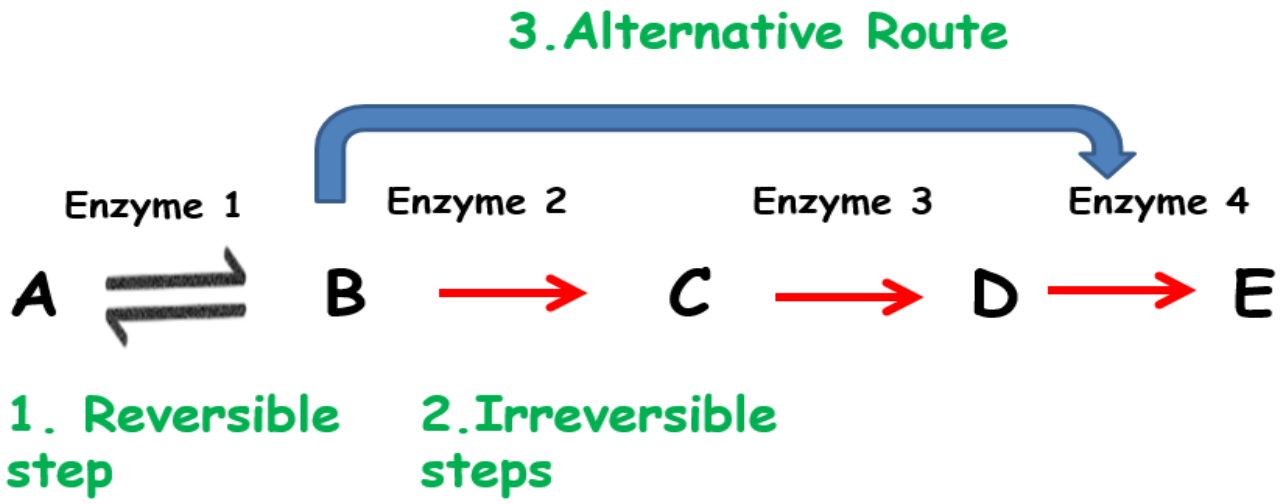
Metabolism and Enzymes

Three Steps in a metabolic Pathway

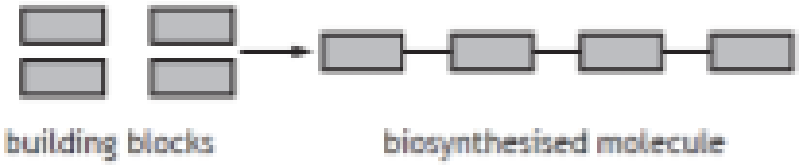
1. Reversible (2 way arrow allowing forward and back ward reaction)
2. Irreversible (1 way conversion)
3. Alternative route (skips certain steps but produces same molecule regardless)

Types of metabolic reactions



1. Catabolic reactions break larger molecules into smaller ones RELEASING energy.

Example Glycogen/starch → glucose Protein → amino acids



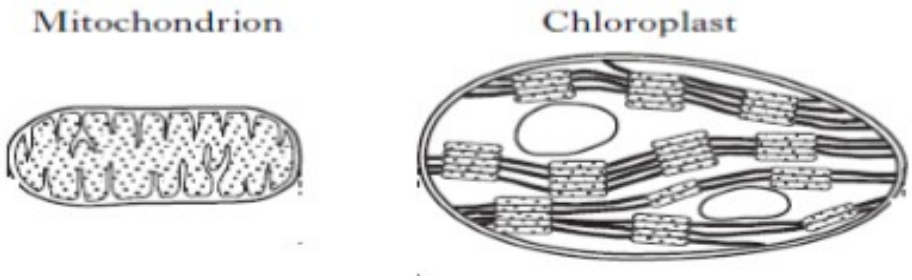
2. Anabolic reactions involve the BIOSYNTHESIS of larger molecules into smaller ones REQUIRING energy to undertake this process.

Example ADP + Pi → ATP amino acids → polypeptides (proteins)

Metabolism and Enzymes

Compartmentalised Membranes

Membranes form surfaces and compartments for a specific metabolic pathway e.g. respiration or photosynthesis



Mitochondria	Chloroplasts
Site of aerobic respiration	site of photosynthesis

Advantage of Compartmentalised Membrane

The **high surface area to volume ratio** of small compartments allows

1. High concentrations e.g. oxygen in mitochondria speeding up the rate of aerobic respiration
2. High reaction rates.

Structure of Membrane

Fluid mosaic model of membrane due to

1. phospholipid bilayer creating movement (fluid)
2. 3 types of protein randomly placed in membrane

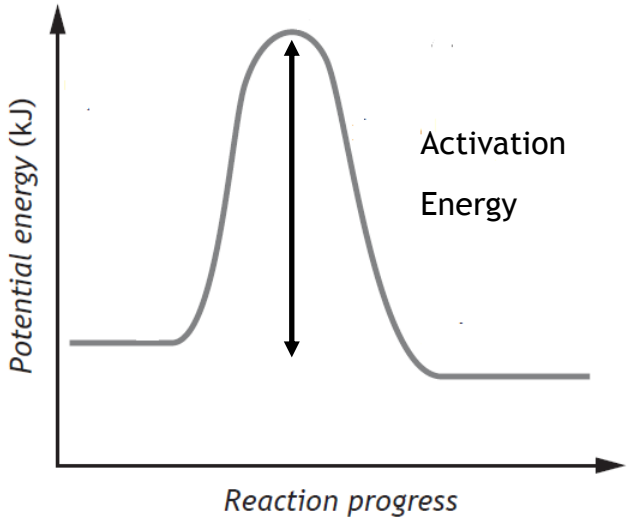
Three types of proteins

1. **Protein pumps (active transport)**
2. **Protein pores (diffusion)**
3. **Enzymes (ATP Synthase in electron transport chain**

Enzymes

Activation Energy

Enzymes speed up reactions as they **lower the activation energy** required to form products .



What is Activation Energy?

The energy required to BREAK chemical bonds in the reactants to allow products to be made.

Induced Fit model

After the substrate has bound to the active site the ACTIVE site changes shape to better fit the substrate.

Affinity for Active site

Substrate—**high affinity** for active site

Product—**low affinity** for active site

The **active site** ensures the **correct orientation of substrate** (ensures it enters the active site the correct way round)

Metabolism and Enzymes

Factors affecting Enzyme activity

1. pH
2. Temperature
3. Substrate concentration
4. Product concentration

Substrate Concentration

1. Low substrate concentration Low enzyme activity

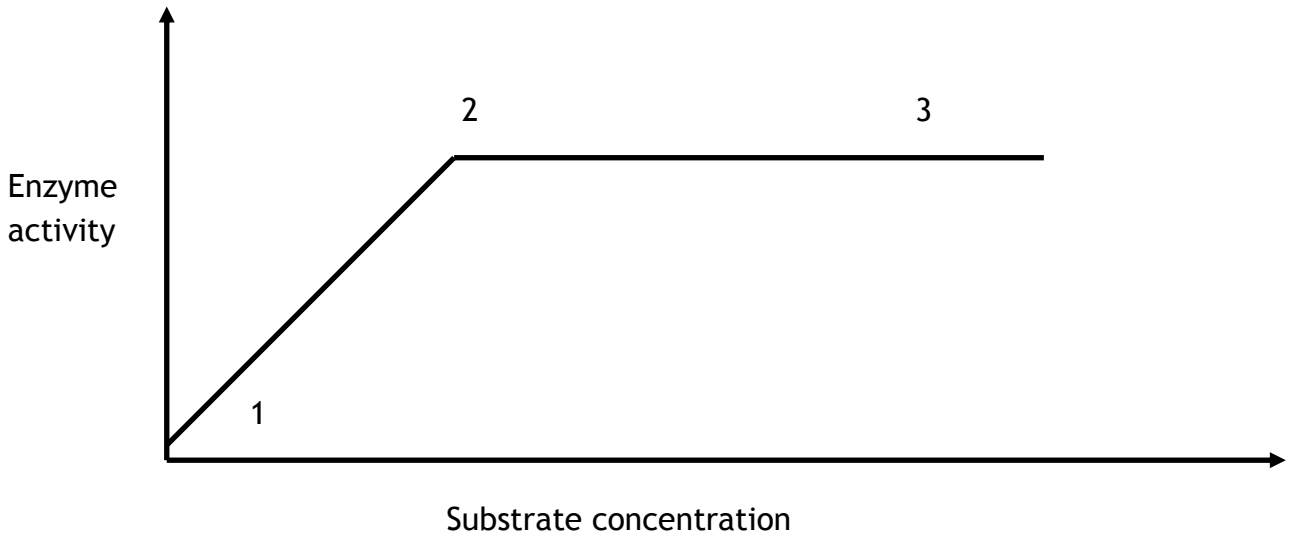
There are not enough substrate molecules to fill all the active sites

2. High substrate concentration Higher enzyme activity

There are now enough substrates to fill all the active sites

3. Very High substrate concentrations No further increase in enzyme activity

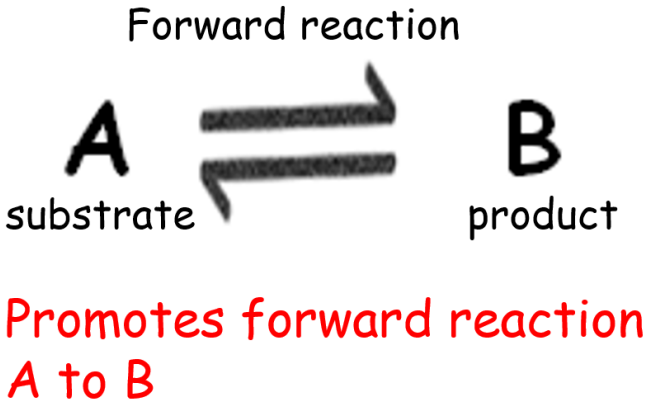
Enzyme working at maximum and all active sites are filled by substrates. No further increase in reaction.



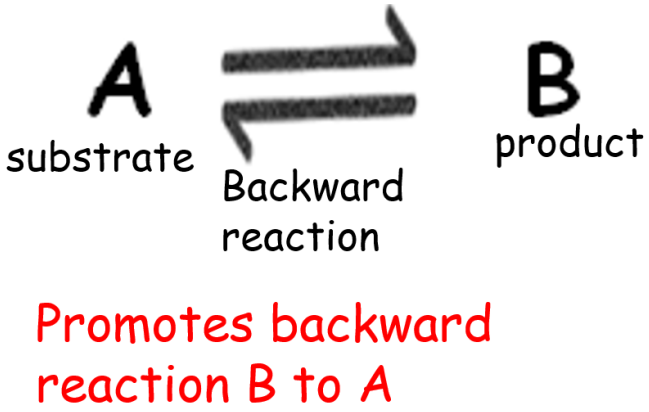
Metabolism and Enzymes

Substrate & Product Concentration on reversible reactions

High substrate concentrations (A) promote forward reactions i.e. conversion to products (B).



High product concentrations (B) promote the backward reaction i.e. conversion back to substrate (A).



Inhibitors

All inhibitors reduce enzyme activity compared to a control.

Increasing the concentration of an inhibitor always LOWERS enzyme activity.

3 types of enzyme inhibitors

1. **Competitive Inhibitors**
2. **Non competitive Inhibitors**
3. **Feedback Inhibition (end product inhibition)**

Metabolism and Enzymes

Competitive Inhibitors

Bind at active site and prevent substrate from binding.

Competitive inhibitor molecule resembles substrate.

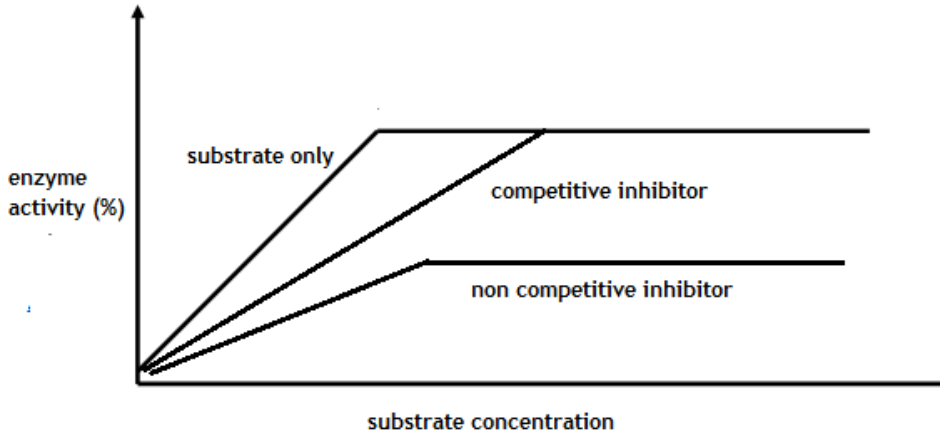
Inhibition reversed with <u>increasing substrate concentration</u>

Non competitive Inhibitors

Bind AWAY from active site and change shape of active site preventing substrate from binding.

Action irreversible—no effect of adding increased substrate.

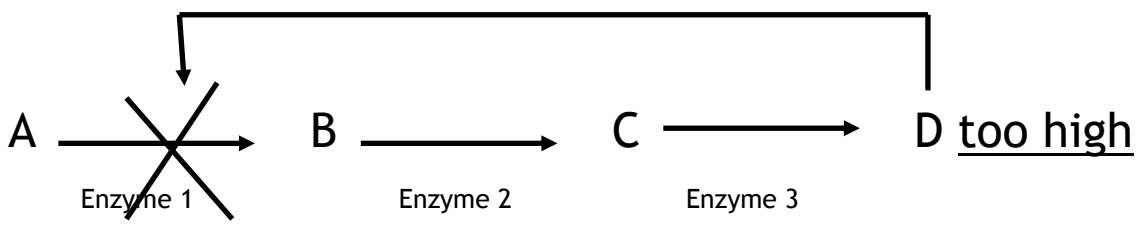
Enzyme Inhibitor Graph



Feedback Inhibition

When the end product concentration is too high it binds to the <u>FIRST ENZYME</u> in the pathway and stops it working to reduce its own concentration.

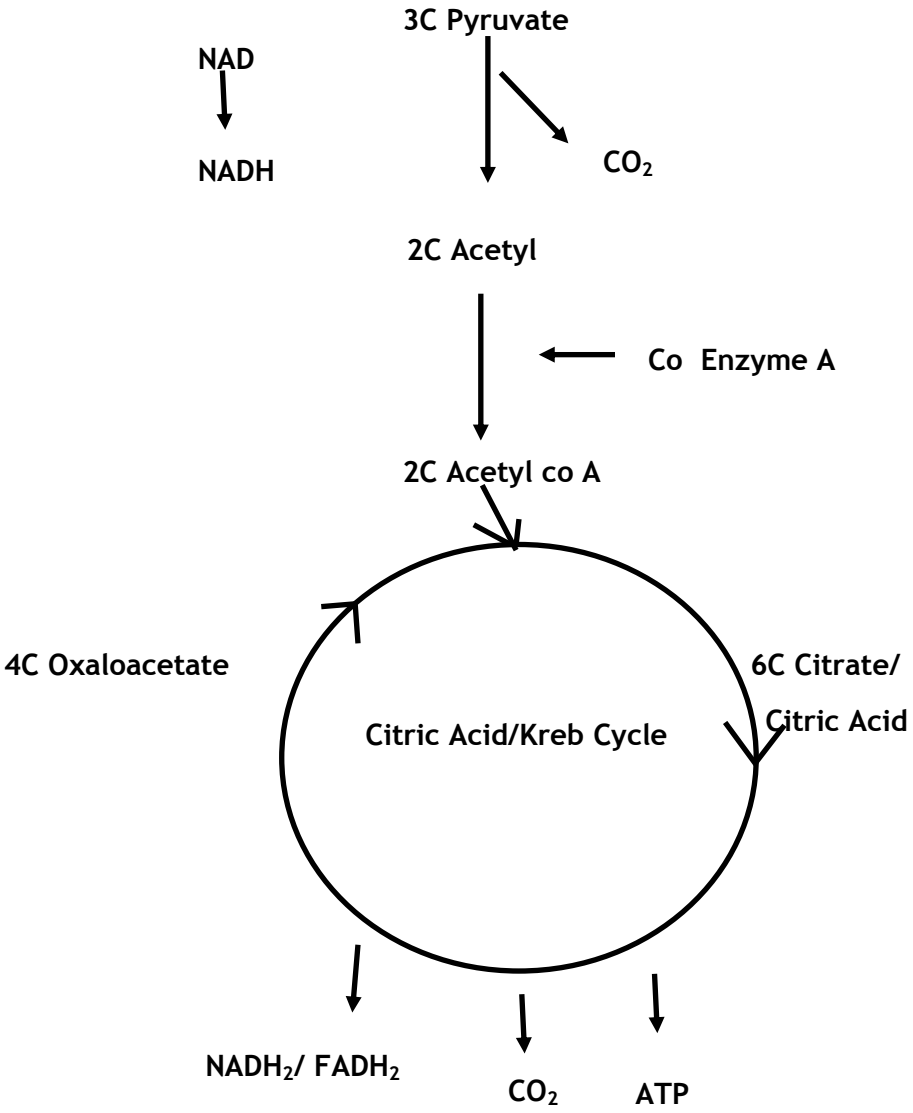
This is a form of negative feedback.



Respiration

Aerobic Stage of Respiration

Process **requires oxygen** to proceed beyond pyruvate and is enzyme controlled by enzymes called dehydrogenases



Summary of steps

3C pyruvate in presence of oxygen is converted into 2 C acetyl with carbon dioxide being released and NAD forming NADH.

2C Acetyl joins with Co A to form Acetyl Co A

Citric Acid Cycle

Citric acid cycle is enzyme controlled by dehydrogenases.

4C Oxaloacetate joins with Acetyl Co A to form 6C citric acid

The regeneration of oxaloacetate from citric acid releases some ATP, carbon dioxide and the co enzymes NAD and FAD to form $NADH_2$ and $FADH_2$

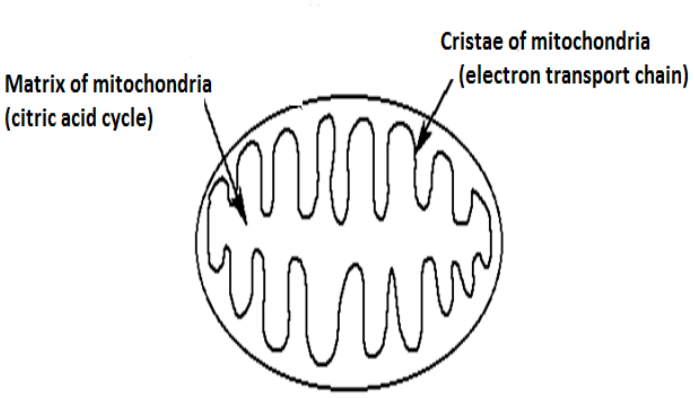
Respiration

Stages of respiration

1. Glycolysis (cytoplasm)

2. Citric Acid/Kreb Cycle
   (matrix of mitochondria)

3. Electron Transport Chain
   (cristae/inner mitochondria membrane)



The **majority of the ATP** is produced during the **electron transport chain** although glycolysis and Kreb Cycle do contribute to the total **38 ATP** made per glucose molecule.

Glycolysis

Location—cytoplasm Process does not require oxygen

Glucose

↓

intermediates

↓

3C Pyruvate

NAD

↓

NADH

1. Energy Investment Stage

2 ATP IN to

<u>phosphorylate intermediates</u>

2. Energy Payoff stage

4 ATP produced after 2ATP in so

Net gain of 2 ATP

Respiration

Role of dehydrogenase

Removes hydrogen and high energy electrons from substances and passes this to coenzyme NAD to form NADH.

Found in glycolysis and Kreb Cycle.

Role of Co enzymes

Accept hydrogen ions and high energy electrons and pass to electron transport chain.

There are two co enzymes NAD and FAD,

1. NAD found in glycolysis and Kreb Cycle
2. FAD only found in Kreb Cycle

Fermentation

In absence of oxygen **fermentation pathways** occur in cytoplasm

Animal cell e.g. muscle	Plant/Yeast cells
6C Glucose	**6C Glucose**
↓	↓
3C Pyruvate	**3C Pyruvate**
↓ ↑	↓
3C Lactate	**2C alcohol + CO_2**
Reversible fermentation	Irrreversible fermentation

Fermentation in **animals cells is reversible**. Once oxygen is present(repaying the oxygen debt) lactate is broken down into pyruvate which can now be made into acetyl etc.

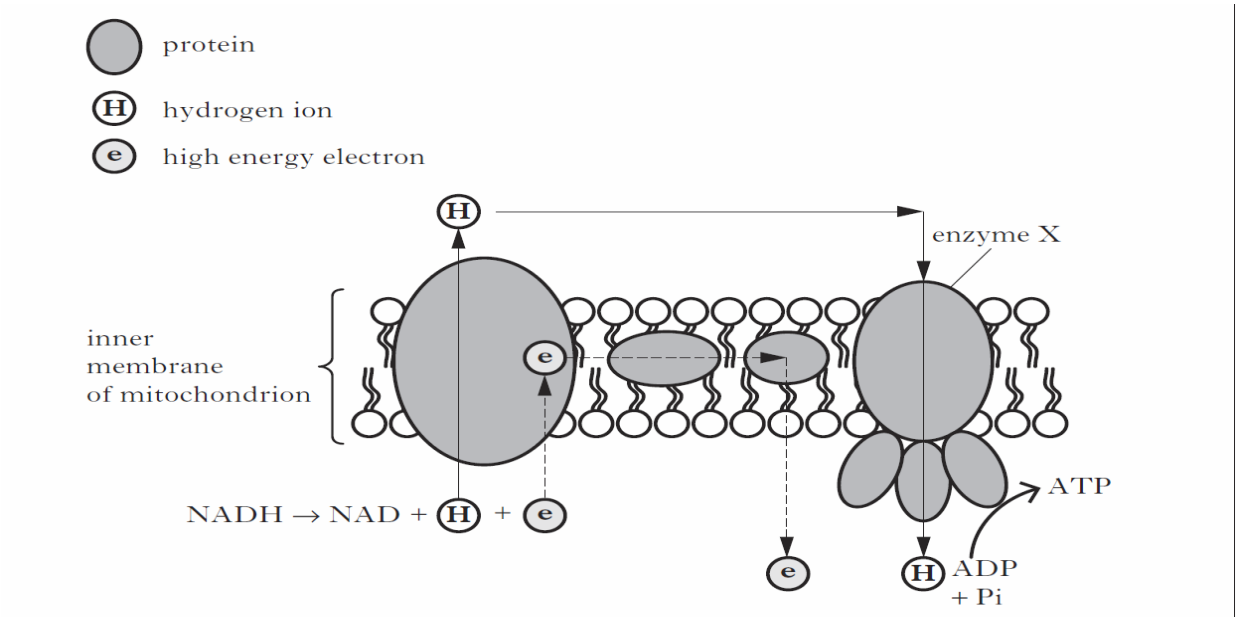
Fermentation in **yeast/plants is irreversible** due to loss of CO_2 and builds up and kills plant.

Electron Transport Chain

Electron Transport Chain

The electron transport is a collection of **membrane proteins** in the **inner mitochondrial membrane.**

Location—Cristae/ Inner membrane of Mitochondria



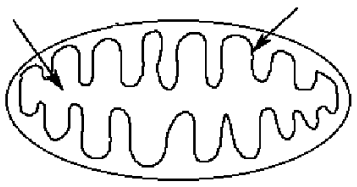
Summary of Process

1. The co enzyme NADH or FADH releases high energy electrons and hydrogen ions.
2. High energy electrons pass along the electron transport chain and release energy
3. This energy release by electrons pumps H ions across the membrane by active transport
4. H diffuses back across ATP synthase causing it to rotate to make ATP from ADP + Pi.
5. Oxygen is the final hydrogen and electron acceptor forming water.
6. The most ATP is produced during this stage.

High/Low Cristae

Lots of cristae are needed for active cells need lots of ATP

e.g. muscle/brain/sperm cells.



More folds/cristae mean more electrons pass down chain/more H is released & more ATP is produced by ATP synthase.

Respiration

ATP

ATP Synthase

ADP + Pi ⟶ ATP

This is an anabolic reaction and REQUIRES energy released from respiration to make ATP by the enzyme ATP synthase

ATP ⟶ ADP + Pi

This is a catabolic reaction and releases energy for other cellular reactions/processes such as

1. Active transport
2. DNA replication Or Protein synthesis (any other anabolic reaction)
3. Mitosis

ATP transfers energy produced in catabolic reactions (respiration to anabolic reactions such as protein synthesis which require energy.

Alternative Respiratory Substrates

Glucose is the main respiratory substrate but other substrates can be used when glucose is not available.

1. Fat broken down into intermediates of **Glycolysis and Kreb/Citric Acid Cycle**
2. Proteins broken down into intermediates of **Glycolysis and Kreb/Citric Acid Cycle**
3. Carbohydrates (starch and glycogen) broken down into glucose **for glycolysis ONLY**

Metabolic Rate & Circulatory Systems

Measurement of metabolic rate

1. oxygen consumption (respirometer)
2. carbon dioxide production (respirometer)
3. heat production

Relative Metabolic Rates

Birds and mammals	highest metabolic rates
Amphibians and reptiles	lower metabolic rates
Fish	lowest metabolic rate

Animals with higher metabolic rates require more efficient oxygen delivered to cells to generate more ATP via the design of their circulatory system and lungs.

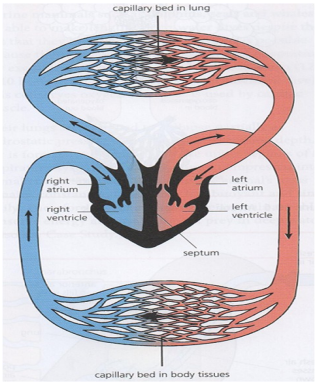
Birds and mammals

Double complete circulatory system

2 hearts and 2 ventricles

Prevents mixing of oxygenated and deoxygenated blood

More efficient oxygen delivered to cells for respiration



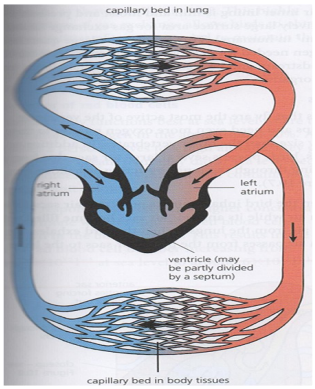
Amphibians and Reptiles

Double incomplete circulatory system

2 atria and 1 ventricle

Allows mixing of oxygenated and deoxygenated blood

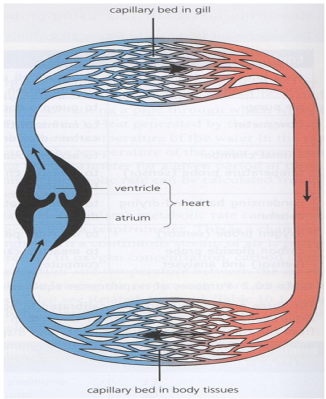
Less oxygen delivered to cells for respiration



Fish

Single circulatory system

1 atria and 1 ventricle



Lung systems& Metabolic Rate

Amphibians Respiratory System

Most basic respiratory system

Normal gas exchange is via skin and mouth

The respiratory system is simply 2 air sacs and trachea (no bronchi and bronchioles)

Mammals and Reptiles Respiratory system

More efficient respiratory system for gas exchange

Contain trachea, bronci, bronchioles and alveoli

Birds Respiratory System

Highest metabolic rate requires even more efficient respiratory system

1. **One directional airflow** through posterior and anterior air sac.
   More efficient than 2 way system in birds and reptiles

2. **Contain parabronchi** which are tiny tubes that increase efficiency of gas exchange.
   Preferable over alveoli which are dead end.

Low Oxygen Niche and Maximal Oxygen Uptake

Physiological adaptations for low oxygen niches.

1. high altitude

   Produce more red blood cells per ml of blood.

2. deep diving mammals

   Partially deflate lungs OR lower heart rate to save energy (less oxygen required)

Maximal Oxygen Uptake

Measure of **CV fitness** in humans.

The higher the maximal oxygen uptake, the fitter the individual.

As individuals are of different masses it is important to ensure that data is per kg per minute to ensure valid comparisons.

Units—**ml/min/kg**

Terrestrial Body Size and Oxygen Concentration

As oxygen concentration has increased, terrestrial body size has increased.

Terrestrial body size is limited as larger organisms would require high metabolic rates and oxygen demands above 20% oxygen in air.

Temperature Regulation in Regulators

Homeostasis Definition

Maintenance of the internal environment within tolerable limits despite changes to the external environment.

Any change away from optimum detected by the hypothalamus (temperature monitoring centre) which communicates with the effector skin organ via **nerve impulses to produce corrective responses.**

Negative feedback

Corrective responses return system back to normal via negative feedback.

Importantly the corrective responses then turn OFF.

Too hot: make individual cooler

Four corrective responses

1. **Sweating increases**
   To increase evaporation of WATER to cool down body
2. **Vasodilation of blood vessels (arterioles)**
   Increased blood flow
   Increased heat loss by radiation
3. **Hair erector muscles relax**
   Hairs lie flat
   No need to trap a layer of insulating air
4. **Metabolic rate decreases**
   No need to generate heat energy.

Too Cold: make individual hotter

Four corrective responses

1. **Shivering increases**
   Generate heat by muscle contraction
2. **Vasoconstriction of blood vessels**
   Decreased blood flow
   Decreased heat loss by radiation
3. **Hair erector muscles contract**
   Hairs stand up
   Layer of insulating air trapped
4. **Metabolic rate increases**
   To generate heat energy

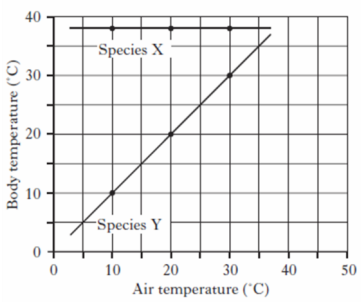
<u>Importance of regulating body temperature in mammals</u>

1. To keep enzymes at their optimum temperature
2. To maintain high diffusion rates

Conformers & Regulators

External abiotic factors

1. pH
2. Salinity
3. Temperature



Regulators (species X on graph)

Internal environment is held constant despite changes to external environment

High metabolic costs

Metabolism regulates internal environment which costs a lot of energy

Wider ecological niche

Use physiological adaptations through homeostasis to regulate internal environment which costs a lot of energy

Conformers (species Y on graph)

Internal environment (metabolism) varies with external environment

Low metabolic costs

External abiotic factors influence internal environment

Narrow ecological niche

Use behavioural adaptations such as moving in and out of sun to slightly control internal environment/ metabolism

Surviving and Avoiding Adverse Conditions

Surviving Adverse Conditions

Sometimes conditions vary beyond tolerable limits

Organisms survive by **reducing metabolic rate (dormancy**) when conditions would make normal metabolic activity too high.

Dormancy is visible through lower heart rate, breathing and body temperature.

This **saves energy** for the organism involved.

Three types of dormancy

1. Hibernation

Reduced metabolic rate when **temperatures are too low** to allow normal metabolic activity.

Example—dormouse hibernating through winter by dropping breathing rate and heart rate until the spring when food is plentiful.

2. Aestivation

Reduced metabolic rate during **droughts**/very high temperatures

Example—crocodile burrow into mud to find shelter from heat and reduce breathing rate and heart rate until conditions are cooler.

3. Daily torpor

This is when metabolic rate is reduced every day to save energy in organisms with **high metabolic** rates.

Humming bird has a heart rate of 1200 beats per minute which is only sustainable due to

torpor periods each day to **save energy**.

Surviving and Avoiding Adverse Conditions

Extremophiles

Live in conditions other organisms find lethal .

Thermophiles

Locations

1. hot springs
2. Volcanoes
3. Sea Bed Vent

Importantly thermophiles' enzymes are adapted so they do not denature at high temperatures. These heat tolerant DNA polymerases are used in PCR to amplify DNA.

Sea Bed Vent Bacteria

Some bacteria generate ATP by removing high energy electrons from inorganic molecules such as Hydrogen sulfide.

Avoiding Adverse conditions

Avoid Adverse conditions Strategy

Animals avoid adverse conditions by **Migration**.

Migration **avoids metabolic adversity by relocating** to more favourable conditions.

Disadvantage of Migration

Costs energy to relocate

Vertebrate Example

Salmon migrate from fresh water to sea water to breed and then migrate back again.

Invertebrate Example

Monarch Butterfly migrates from Canada to Mexico to find more favourable conditions in

Tracking Migration

1. Mark and recapture
2. Electronic tags
3. GPS satellite tracking

Migration: Innate & learned components

1. Innate—instinct & inflexible causing all birds to migrate at winter.

2. Learned component—flexible and gained by previous migration experiences such as direction of travel/where to stop flying etc.

Microbe Growth in Fermenter

Substances added to a fermenter

1. **Energy source** (chemical or light)
2. **Raw materials** from simple chemical compounds for biosynthesis.

   a)Simple raw materials made by microbe e.g. Amino Acids for protein synthesis

   b) Complex raw materials need to be added to growth media e.g beef extract, vitamins OR fatty acids.

3. **Enzyme inhibitors, precursors or inducers** may also be added to the fermenter if the desired product is an intermediate metabolite.

Fermenter Conditions

1. Sterility to prevent contamination by bacteria

   This is to prevent diseases spreading OR other microbes using up culture nutrients.

   HOW? Steam and filters

2. Temperature to keep enzymes at optimum

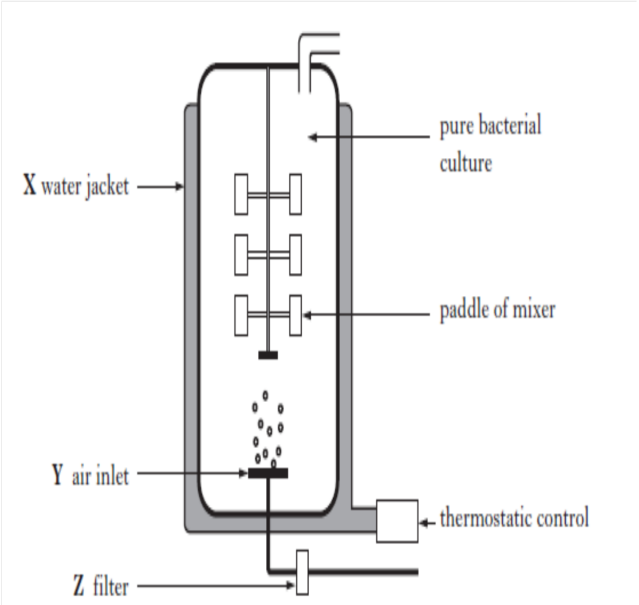
   HOW? Water jacket and thermostat

3. Oxygen concentration for aerobic respiration

   HOW? Air inlet and paddles for aeration

4. pH to keep enzymes at optimum

   HOW? Use of buffers



Stages of Microbe Growth

Viable cell count	Total Cell Count
Living cells	Living and dead cells included

Phases of Viable Cell Microbe growth

1. **lag** (no cell growth)

   Enzymes are being induced

2. **Log/Exponential** (rapid growth)

   Plentiful nutrients so mean generation time is rapid

   Logarithmic scales are required due to rapid exponential growth to fit on graph paper.

3. **Stationary**

   Nutrients running out and toxic metabolites start to be produced

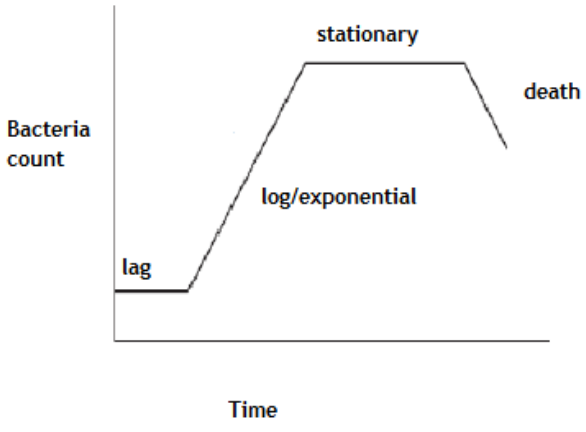
   Birth rate is equivalent to death rate

   Secondary metabolites are produced such as antibiotics are produced to outcompete other bacteria

4. **Death phase**

   Toxic metabolites accumulate and kill microbe

   The prove that cells are viable is that a death phase can occur.



Primary and Secondary Metabolism

1. Primary metabolism—rapid growth of microbe during lag and exponential

2. Secondary metabolism can confer an ecological advantage by producing substances not associated with growth such as antibiotics during **stationary phase**.

Recombinant DNA technology

Improving Wild strains of microorganisms

1. **mutagenesis**

   Deliberately mutating bacteria by exposing wild microbes to UV light, Xrays or mustard gas.

2. **selective breeding**

   Reproducing fungi sexually to produce new phenotypes

   horizontal gene transfer in bacteria to produce new strains by transferring plasmids

3. **Recombinant DNA technology**

   plant/animal genes transferred to microbes to make desired animal/plant protein.

Two key enzymes in Recombinant DNA technology

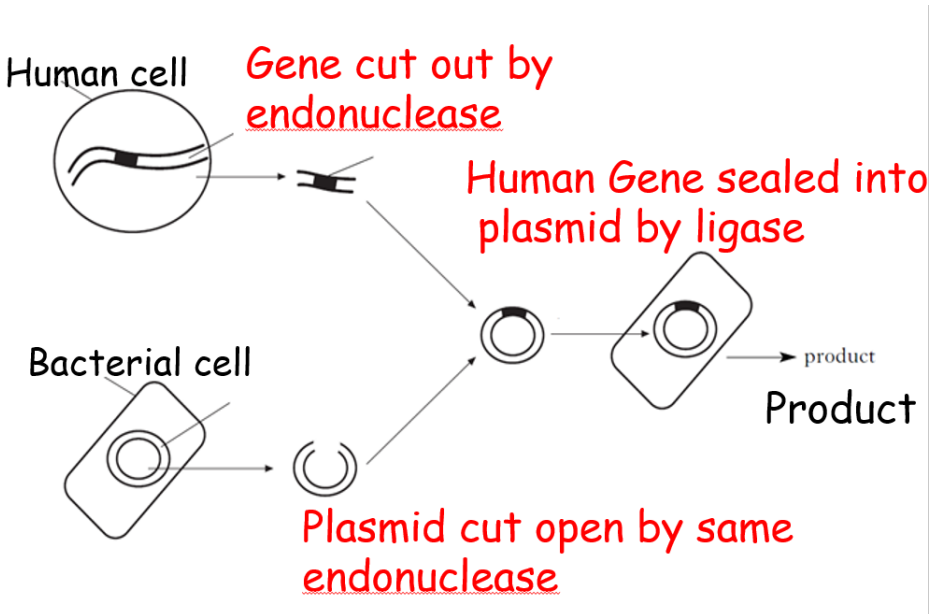
1. Endonuclease

   Same endonuclease cuts open the plasmid and cuts gene out of chromosome

   Leaving COMPLEMENTARY sticky ends.

2. Ligase

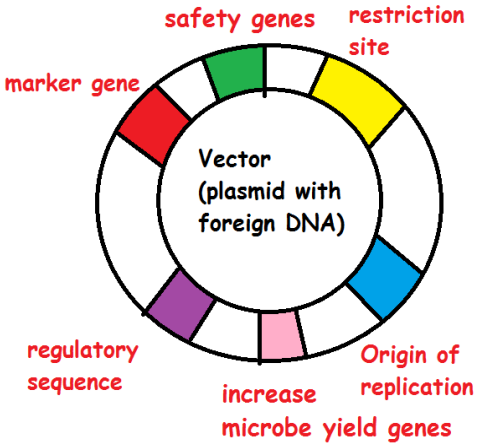
   Seals genes into plasmid.



Genes on Vector

Genes on Vectors

1. Antibiotic resistance (marker gene)
2. Regulatory sequence
3. Restriction site
4. ORI sequence
5. Safety genes
6. Genes to increase microbe yield



Antibiotic Resistance

Expose bacteria to antibiotics and only transformed bacteria survive.

Restriction Site

Endonuclease cuts plasmid open and cuts gene out of chromosome.

ORI sequence

Self replicating/future copying of plasmid.

Safety genes

Prevent microbes growing in external environment

Regulatory sequences

Controls gene expression (which genes are turned ON or OFF).

Genes which increase yield

Microbe yield can be increased by introducing genes which remove inhibitory effect/amplify metabolic steps

Bacteria vs Yeast Plasmids

In bacteria the protein may lack post translational modifications/cannot fold properly

Yeast vectors avoid this problem and are more successful in recombinant DNA technology

Ethical Issues

1. Genetically engineered bacteria released into external environment & pass on antibiotic resistance.
2. Genetically engineered bacteria could be used as biological weapons.